DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 293

UNDERGROUND WATER RESOURCES OF IOWA

BY

W. H. NORTON, W. S. HENDRIXSON, H. E. SIMPSON,
O. E. MEINZER, AND OTHERS

PREPARED IN COOPERATION WITH THE
IOWA GEOLOGICAL SURVEY

WASHINGTON
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UNDERGROUND WATER RESOURCES OF IOWA.

By W. H. Norton and others.

INTRODUCTION.

By W. H. Norton.

SCOPE OF THE WORK.

The investigation of the underground water resources of Iowa was planned and carried out along three lines. The artesian waters of the State were studied by W. H. Norton, the waters of the drift and country rock by H. E. Simpson, O. E. Meinzer, and a number of assistants, and the chemical and industrial qualities of all ground waters by W. S. Hendrixson. Three reports were therefore submitted for publication. It was later decided, however, to publish these in a single volume. In the editorial recasting thus made needful the three reports have been combined, so that several chapters are now composed of excerpts taken from the work of two or more writers, but throughout the volume each writer is responsible for all statements respecting his allotted field of investigation. In each of the county reports data as to the artesian wells of the district and forecasts of artesian conditions for towns not now supplied with deep wells have been inserted from the report of the senior author.

The line of demarcation between artesian waters and waters of the drift and of the country rock—that is, the rock which outcrops at the surface or immediately underlies the drift—though not everywhere exact, is fairly definite and was placed where it would best subserve the uses of the public. The artesian waters of the State, except some of minor importance, rise from a few related formations of early Paleozoic age. These formations underlie practically the entire State and form a well-defined artesian system. The water beds or aquifers of this system are as a rule readily distinguished from those of the country rock as well as from those of the drift, but in one or two of the northeastern counties of the State the artesian aquifers approach the surface and might be included in the country rock.

In the investigation of the waters of the drift and of the country rock, the county was made the areal unit, and each county in the

State was visited and studied. The officials of each town were asked to contribute the facts as to the municipal water supply. From the well drillers were procured data of great value as to the type of wells in common use, their depth in different localities, the materials they passed through, and the sources from which they drew their waters. As an average of less than a week could be given to each of the 99 counties of the State, the investigation was necessarily far more cursory than could have been wished. Fortunately the Iowa Geological Survey had nearly completed its areal work with the county as the unit, and thus a large amount of material was at hand relating to the geologic conditions which control the distribution of ground water, the topography of the State, and the structure and composition of the country rock, and of the Quaternary deposits (ground moraines of successive ice invasions with their outwash sands and gravels and interbedded deposits of interglacial epochs). All this material, both published and unpublished, was generously placed at the disposal of the writers by the late Dr. Samuel Calvin, director of the Iowa Geological Survey, and it has been very freely drawn upon in each of the county reports.

OBJECT OF THE INVESTIGATION.

The need of the scientific investigation of artesian waters is obvious to all. Many of these deep zones of flow lie far below the surface and below the sources that supply the common wells. The local well driller can not be expected to know either the quantity or the quality of artesian waters or the depth at which they can be reached. Town councils in considering municipal supply often send committees to the nearest towns which have deep wells to obtain such facts as may throw light upon the local problem. Information thus gathered may be useful or it may be misleading; it is always insufficient and inconclusive. There is needed the skillful interpretation of data collected from a wide area, a knowledge of the geologic structure and acquaintance with the distribution and movements of deep waters. For house wells in towns and for common farm wells, the knowledge of local conditions held by the well drillers of the district is ordinarily sufficient. Yet even here a scientific knowledge of general as well as local conditions often makes it possible to suggest new and better sources of ground water or new and better methods of utilizing those already in use.

The object of the investigation whose results are here presented is to furnish to each community so far as possible deductions made from the entire body of facts obtainable, showing whether artesian water can be found at that locality, at what depths it may be reached, through what formations the drill must pass, what mineral compounds—healthful or harmful—the water is likely to contain, how high it will rise, how large will be its discharge, and how such a supply will compare in cost, purity, permanence, and general availability with that from other sources.

COOPERATION WITH THE IOWA GEOLOGICAL SURVEY.

So far as the investigation concerns artesian waters, it has been carried on jointly by the United States Geological Survey and the Iowa Geological Survey. The State Survey began this investigation at the time of its inception, the work being under the charge of W. H. Norton. The earlier results are published in its annual reports.[1] Since 1896 the Iowa Survey has continued to gather data and to furnish to towns, corporations, and individuals all obtainable information relating to deep wells, together with forecasts of local artesian conditions. The cooperation between the State and national surveys has resulted in a more thorough investigation.

In the present report free use is made of all material gathered under the direction of both surveys. It seems desirable to collect in one report the entire body of data relating to the subject as a basis for the deductions which may be drawn therefrom.

GEOLOGIC INVESTIGATION OF WELLS.

MEANS OF INVESTIGATION.

The distribution and the quality of artesian waters are so intimately connected with geologic conditions that their profitable study must concern itself first with the attitude, the texture, and the composition of the deep rocks from which the waters rise. In a general way much may be inferred as to these features from the character of the formations where they outcrop, for here their thickness may be measured and their various physical characteristics may be observed. The dip or inclination of any terrane gives some clue to the probable depth at which it may be found at a given distance from the outcrop. But in an area so large as Iowa formations that dip below the surface may be expected to thicken or to thin, to pinch out, to be replaced by other formations which may have no outcrop, to change their chemical composition or their texture, and to be affected by upwarps and downwarps which may have no surface expression.

For all these reasons the investigation of the deeper water beds must be based not only on the surface geology of the State but also on all geologic facts obtainable from drill holes as to the strata through which they have passed as indicated by the logs of drillers and the samples of the rock cuttings of the drill. From these data the attempt is made to correlate the strata penetrated by any well

[1] Ann. Rept. Iowa Geol. Survey, vol. 3, 1895, pp. 169-210; vol. 6, 1897, pp. 115-428.

with known terranes outcropping elsewhere and found in other wells, to ascertain the geologic formations to which the strata belong, and thus to construct a geologic section at the locality of the well to the depth of the boring. By connecting the sections of different wells in different parts of the State, cross sections may be had which show the geologic structure of many parts of the area to depths of 2,000 and even of 3,000 feet, and which indicate the depth to which new wells in the area must be sunk to reach the deep-lying water beds. Plates V to XVIII supply examples of such sections in different parts of the State.

AVAILABLE DATA.

The data on which a geologic investigation of deep wells must rest consist of records made and samples of drillings collected when the wells were put down. Necessarily they are largely second hand and are incapable of verification. A report such as this deals with thousands of statements and observations made by many individuals, and the writer can do little except to determine the lithologic character of deep-well drillings, and in drawing inferences from these he must accept the reports of others as to the thickness and location of the strata which they represent. Fortunately, many owners of deep wells and many other citizens realize the scientific and practical value of the facts which can be obtained when a well is being drilled and at that time only, and these persons have placed on record many valuable data as to diameters of the bore and casings, fluctuations of water in the tube, depth, discharge, and head of water horizons, and have obtained both the driller's log and samples of the drillings. In practically every place where such data have been gathered and preserved they have been placed at the service and disposal of the surveys. Unfortunately, of many wells little or nothing, except the existing head, discharge, and quality of the water, is known or can ever be known. In many parts of the State the writer is quite in the dark as to artesian conditions and is unable to make reliable forecasts for towns desiring to sink deep wells, not because no deep wells have ever been drilled within the area, but because when they were put down no record was made of the essential facts.

SAMPLES OF DRILLINGS.

COLLECTION AND STORAGE.

Since the beginning of this investigation a special effort has been made to obtain full sets of samples of the drillings of the deep wells of the State, and it is on these samples that the geologic part of this report is largely based. Where such samples are taken directly from the slush bucket and labeled at once with the exact depth from which they were drawn, they form the most authentic record possible of the strata penetrated. When thus taken, at intervals not exceeding 10 feet, and at every "change" in the strata, they afford a lithologic record and section inferior in value only to an exposure of the edges of the strata in an outcrop. Such reliable data have been obtained from an exceptionally large number of Iowa deep wells.

The value of sets of cuttings from some wells has been impaired by the neglect of precautions which should be obvious. Thus, if the samples are taken only at every "change" of the strata, it is left entirely to the judgment of the workman who empties the contents of the slush bucket to decide whether or not there has there been any change. Several hundred feet of limestone, including two or more geologic formations, may be represented by a single sample. The depth is not always carefully taken, and remeasurements of the well on completion have shown that the driller's estimates of depth placed on samples or in the log were incorrect. If, however, the inaccuracy affects all depths alike little serious error is likely to result.

Some samples of drillings seem to have been labeled from memory after a considerable lapse of time. This fact affords an explanation of the reported occurrence of drift clays 1,000 feet and more below the surface, and perhaps also of the occurrence of several samples of nonmagnesian limestones of Platteville facies below the St. Peter sandstone. Some samples seem to have been scraped up from the ground instead of being taken in some clean receptacle immediately from the sand pump. The cinders which may be included are easily disregarded, but the admixture of chippings from higher levels is serious. In one or two extreme cases it seems probable that at the completion of the well the workmen went over the outwash from the slush bucket, dug up a sample here and there, and labeled it according to their recollection. But even such a record may be of value if nothing better is available.

The samples collected under the direction of the United States Survey were sent to Washington in stout canvas bags provided with labels and were there transferred to wide-mouthed glass bottles with screw aluminum covers. In the collection made earlier for the Iowa State Survey most of the samples were taken directly from the slush bucket, put into empty cigar boxes, labeled, and shipped to the writer at Mount Vernon, where they were transferred to wide-mouthed glass bottles for permanent preservation, each sample being thus kept separate and accessible. Some of the samples presented to the Iowa Survey had been mounted in long glass tubes, in which the chippings of any terrane are supposed to occupy a space proportional to the actual thickness of the terrane. Such a method of mounting has a certain advantage for purposes of exhibition, but its disadvantages are so great that it must be unqualifiedly condemned. The drillings from different strata settle and tend to mix. They can not be taken from the tube for study, and no adequate inspection can be made through the glass. Sooner or later the long tube is sure to be broken and the record of the geologic section is irretrievably lost.

Drillings should not be washed. When the drill is working in a pure limestone washing does little harm, for it removes only the fine flour of the stone, whose quality is fully represented in the larger chippings. But with some marls and shales and with clayey sandstones the removal of the finer material in washing leaves a residue far from representative of the rock. In some sets certain samples had been washed and others not, thus making error possible in the determinations, except where the treatment to which the cuttings had been subjected was indicated on the labels or could be told by inspection.

For all scientific purposes samples should be taken directly from the sand pump at every 5 or 10 feet, at the end of a cleaning out, and at every change of stratum. They should be placed, unwashed, in wide-mouthed bottles or glass jars (1 to 4 ounce bottles are large enough) and plainly and accurately labeled in india ink with the names of the town or other location and of the owner, the date, and the depth from which each was taken.

STUDY OF SAMPLES.

PETROGRAPHIC EXAMINATION.

The drillings were studied petrographically as an aid in identifying, from well to well, the strata from which they came. With some samples a simple inspection was sufficient, but, as a rule, this inspection was supplemented by other tests. Under polarized light in the field of the petrographic microscope the minerals making up the meal or flour of the drillings were generally readily determined and their relative proportion in the rock was roughly indicated by their proportion in the microscopic field. Crystalline silica, flint and chalcedony, gypsum and anhydrite, glauconite, pyrite, and calcite—to mention only common minerals of the sedimentary rocks—were thus distinguished. The microscope was used also in determining the texture of such rocks as oolites, fine-grained sandstones composed of angular quartzose particles, sandstones of grains of crystalline quartz of various degrees of rounding and assortment, and sandstones whose grains have been enlarged by secondarily deposited silica. Limestones were tested with weak cold hydrochloric acid, free effervescence indicating a small percentage or total absence of magnesium carbonate, and a slow and feeble effervescence a high percentage of the same carbonate, unless attributable to siliceous or other impurities. Residues after digestion in strong acid determined the argillaceous and siliceous contents of impure limestones. The relative amount of magnesium carbonate in some limestones was roughly estimated after a solution in hydrochloric acid had been neutralized with ammonium carbonate and treated successively with ammonium oxalate and hydric disodic phosphate. Through the kindness of Dr. Nicholas Knight, professor of chemistry in Cornell College, Iowa, the services of several of his advanced students were placed at the disposal of the writer, and a number of quantitative analyses of samples of terranes of special interest were made in the chemical laboratory of that college.

POSSIBILITIES OF ERROR.

Mention should be made of certain possibilities of error in any determination of the nature and thickness of the rock by means of drillings.

The most serious of these errors is due to fewness of samples. Where, as in some deep wells, samples are taken at regular intervals of 100 feet, little indeed can be determined as to the geological succession. Where samples are taken at irregular or considerable intervals, it may be naturally assumed that each sample represented to the driller a stratum of homogeneous rock and that each sample was taken at the change and thus designates the summit of its own terrane and the base of the terrane above it. This assumption may or may not be correct. Any such sample may possibly be taken midway or at any other point within a terrane instead of at its top, and the assumed thickness of one terrane may be as much too little as that of the next terrane is too great. This source of error is avoided when a sample is labeled not only with its own depth but with the upper and lower limits of the stratum which it is supposed to represent. In the columnar geologic sections of this report the uncertainty attaching to the thickness of a terrane from this cause is indicated by drawing the terrane over the area of uncertainty as a right triangle with apex downward. (See Tipton section, Pl. X, p. 374.)

Another source of possible error lies in the fact that the contents of the slush bucket may not correctly represent the rock in which the drill is working. Along with cuttings from the contiguous rock are fragments of other and higher strata. The vibration of ropes and rods and the lifting and lowering of the drill and other implements may detach pieces of rock from any higher stratum. Caving shales and incoherent sandstones furnish a large admixture of shale and sand to the cuttings at the bottom of the drill hole. Thus black coaly shale from the coal measures (Pennsylvanian) may be recognized in otherwise clean limestone chips of the Mississippian or inferior terranes; the fossiliferous green shale of the Platteville is seen mingled with cuttings in the dolomites of the Prairie du Chien group; and the St. Peter and Jordan sandstones contribute a large arenaceous content to the cuttings of the dolomites below.

Where strata of different character alternate at short intervals the mingling of cuttings makes the determination of the rocks peculiarly difficult. Drillings from Ordovician and Cambrian strata below the St. Peter in many places contain a mixture of rolled quartz grains and chips of dolomite, and it may be a delicate question to decide whether the sand is wholly foreign, having fallen in from water-washed, loose, overlying sandstones, or whether it is more or less native—that is, whether the sample represents either a pure dolomite on the one hand or an arenaceous dolomite or a calciferous sandstone on the other. If it is decided that some of the sand is native to the stratum, it still remains to be discovered whether the sand is disseminated through the dolomite or exists in thin interbedded layers. In some samples an interbedded sand grain or mold of sand in some larger chips of dolomite may decide in favor of dissemination.

In some drillings material fallen from above may be distinguished by its lithologic nature or by the size or shape of its fragments. The dislodged pieces from the sides of the drill hole should as a rule be larger than drill cuttings and of different shape. Fragments of easily worn shales fallen from overlying beds soon assume a rounded form. But in many wells, as, for example, where fragments from above have themselves been cut into chips by the drill, these tests are not decisive and the real nature of the bottom rock must be left in some doubt. To keep distinct the facts observed in the study of well drillings from the inferences drawn by the observer, a complete statement of the composition of the drillings should be given as well as an opinion as to the character of rock which they represent.

CORRELATION OF ROCK FORMATIONS.

The methods in correlation and the degree of certainty to be attained must next be considered. If an unbroken series of drillings from the top to the bottom of the well has been obtained, by what methods can the different rocks thus represented be assigned to known formations?

FOSSILS.

The occurrence of a series of fossils in a given terrane—the sure means employed by the geologist whenever possible in his correlations—is lacking in well records and samples. The drill cuts and crushes the harder rocks to fine meal or powder and the softer to small chips. It is the rarest of good fortune that the drill leaves any fossil unbroken into unidentifiable fragments. The smaller the fossil the greater its chances of escape. The minute tests of the foraminifer Fusulina are sometimes obtained intact in considerable numbers from certain strata in the coal measures. Rocks fallen from higher strata in the drill hole give fragments of considerable size, and when these are fossiliferous and their own horizon can be determined by lithologic identity, they are of the greatest value. Thus the caving green shale of the Platteville is in places highly fossiliferous and its fragments, along with bits of Ordovician brachiopods characteristic of the horizon, are often brought up when the drill is working in the subjacent strata. But such fossils will be a source of the gravest error if it is assumed that they belong to the same formation as that of the cuttings brought up with them from the bottom of the well.

LITHOLOGIC SIMILARITY.

The lithologic method employed by geologists in the field in tracing a terrane from point to point is by no means infallible when applied in studies of deep wells, but it is used when other methods are lacking. Certain terranes exhibit the same well-defined lithologic characteristics over a large part of Iowa and adjacent States. The coaly shale of the Pennsylvanian can hardly be mistaken for the calcareous (mud rock) shale of the Maquoketa, nor can either be confounded with the glauconiferous shales of the Cambrian. The white crystalline encrinital limestone and the cherts and oolites and geodiferous beds of the Mississippian are diagnostic, and the same is true of the arenaceous cherty dolomites of the magnesian Prairie du Chien group. The presence of anhydrite or gypsum in certain beds has been used to correlate rocks in widely separated wells.

The magnesian carbonate content of limestones can be used as a means of correlation, but must be used with care. Thus, so far as known, from the Shakopee dolomite down all limestones throughout the State are thoroughly dolomitized. But above the Shakopee the changes in the magnesian content in the same terrane may be rapid and complete. Thus at Dubuque the Galena is a dolomite, but at Manchester, 40 miles west, a deep-well section finds it wholly of ordinary limestone. Similarly, some of the Devonian limestones of east-central Iowa pass into dolomites in the northern counties.

The lithologic nature of a terrane may be expected to change over so broadly extended an area as the State of Iowa. One formation may thin and disappear and give place to other formations of the same series. Thus the Niagara dolomite of northeastern Iowa apparently gives place to Silurian sandstones or sandy limestone in southeastern Iowa; and gypsiferous beds, perhaps of Salina age, appear in deep wells at stations as far separated as Mount Pleasant, Des Moines, Bedford, and Glenwood. An entire system may disappear; for example, the Silurian in the extreme northeastern parts of the area occupied by the Devonian in Iowa.

Lithologic similarity may only exceptionally be used as the sole means of correlation. It is a belief as mistaken as it is prevalent that a geologist can identify a formation simply by means of the physical characteristics of its rocks. In the study of deep wells this means should be used only with the greatest care and in combination with other and better methods.

ORDER OF SUCCESSION

A third means of correlation is that of order of succession. The terranes of Iowa, for example, do not occur haphazard. They were laid down in a definite order during the long ages of geologic time and for the most part on the floors of ancient seas. The oldest is therefore found at the bottom and the most recent at the top, the strata having suffered no inversive deformation. The application of this method of correlation may be illustrated from the general columnar section of Iowa (Pl. II, p. 60), in which the formations are arranged in order of their succession. It is plain that on the areas of outcrop of the Silurian the first heavy shale which the drill encounters must be the Maquoketa. In the Mississippian area a heavy shale found near the surface may be identified as belonging to the Kinderhook, and the Maquoketa will be reached only after passing through the intervening Devonian and Silurian limestones. In the Pennsylvanian area another and still higher body of shales belonging to the country rock is first penetrated and the Maquoketa becomes the third heavy shale bed in the descending series.

DIP OF STRATA.

A fourth aid in interpreting the drillings is the known dip of the strata. A glance at any of the geologic sections of the State, such as that shown in Plate XI (along the Chicago & North Western Railway from Clinton west), shows a general westward downward slope to all terranes. The second body of shale at Belle Plaine may be recognized as the Maquoketa, not only by lithologic similarity to the limy shales of that formation over its outcrops to the northeast and by its position in the series, but also by the fact that it occurs at about the depth to which the known westerly dip of the strata would carry it from its known position at Cedar Rapids.

Local exceptions to prevailing dips may be expected anywhere. Upwarps and downwarps, sags and swells, thickenings and thinnings may bring any formation nearer to or farther from the surface at a given point than would be expected. Thus at Ames (Pl. XI, p. 382) an upwarp of the entire body of strata brings each formation higher than the position which would have been deduced from the general dip. In southeastern Iowa also the dip of the surface formations is found reversed in the deeper terranes.

DIFFICULTY OF DEMARCATION.

In some deep-well sections insuperable difficulties are found in drawing the boundaries between adjoining terranes. No attempt has been made to discriminate the limestone of the Kinderhook group from the limestones of the Osage group (Burlington and Keokuk) which rest upon it nor the limestones of the upper part of the Maquoketa shale from the Silurian limestones which they underlie. Upper Devonian shales can not be separated with any certainty from the shales of the Kinderhook where the two are in immediate succession. With increasing distance from the outcrops of Devonian and Silurian limestones and with a changing facies in each it becomes in places impossible to draw any sure line between them. It must be understood, therefore, that in the interpretation of the sections the assignment of formations is not offered with the confidence of the field geologist. In many of the sections there may be a close approach to certainty; in others the reference is made from scanty data and on some slight turn of the scale of evidence. Realizing the nature of the data dealt with, the meager, second-hand, and sometimes untrustworthy evidence at hand, the difficulties of interpretation, and the possibilities of error, the writer submits his tentative conclusions in a spirit far removed from any dogmatism.

FORECASTS.

Information is often sought by cities, officials, and representatives of railways and other corporations and by private citizens as to probabilities of an artesian supply in their localities. In response to such requests many forecasts have been made as to the depth at which artesian water may be found, its pressure, quantity, quality, and availability for specific uses. To make this report as helpful as possible, forecasts have been made for all the towns of the State whose population indicates that an artesian supply may be needed, and in which the artesian field has not been already fully exploited. These forecasts will be found in the county descriptions.

In using these forecasts as a basis for estimating the depth to water-bearing strata at any given point, it must be remembered that many of the data on which they rest are scanty, some are conflicting, and others are no doubt erroneous. Estimates as to the depth to water beds necessarily assume uniform degree of dip and uniform thickness of strata over given areas, whereas in fact the strata vary in thickness from place to place and are affected by local upwarps and downwarps that tend to bring them nearer to or farther from the surface than would be computed on the assumption of an unvarying dip. The information given must not be used as if it had the exactness of calculations based on accurate data.

Nevertheless enough is known of the attitude and nature of the deeper rocks of Iowa to permit forecasts that may be of considerable value and perhaps sufficiently close for the purpose for which they are made. The degree of approximation which the data permit is evident by comparing forecasts already made with the facts later disclosed by the drill. Thus at Osage (Pl. VII, p. 272) the St. Peter sandstone was predicted at 700 to 750 feet from the surface and was found at 715 feet; at Charles City (Pl. VII) the same formation was forecast at 800 feet and was found at 780 feet; at Fort Dodge (Pl. VI, p. 258) it was forecast at 1,300 to 1,500 feet and found at 1,408 feet; at Waterloo (Pl. VI) it was forecast at 835 feet and was found at 815 feet; at Bloomfield it was forecast at 1,230 feet and was found either at 1,190 or, more probably, at 1,445 feet, the records of the well being very incomplete. At Mount Pleasant (Pl. XIII, p. 526) the St. Peter sandstone was found within 57 feet of the predicted depth.

How far local deformations, entirely unknown before the drilling of a well, may cause an error in forecast is indicated by the deep well at Ames. No predictions were made, but if it had been assumed that the St. Peter had the same dip west of Cedar Rapids that it is known to have east of that city, the estimates of its depth at Ames would have been 250 feet too low, as the drill disclosed a local upwarp which brought the St. Peter that far above its normal place (Pl. XI, p. 382). At New Hampton (Pl. V, p. 238) the St. Peter was found 150 feet below where it would have been predicted on the assumption of an uniform southward dip from Mason City to Ackley. In southwestern Iowa, where data are very scanty, the base of the Pennsylvanian at Bedford (Pl. XVIII, p. 898) was forecast at 140 feet below sea level. The base of the Pennsylvanian shale was, indeed, found at 82 feet below sea level, but the intervention of a heavy sandstone, which probably should be classed with the Pennsylvanian, brought the base of the latter to 240 feet below sea level (fig. 6, p. 898). The water horizons of the heavy magnesian limestones of this area were predicted to occur not more than 900 feet below sea level, and were found at Bedford at 850 feet below that datum. Contracts for artesian wells should make provision for drilling at specified rates for several hundred feet beyond the supposedly necessary depth.

ACKNOWLEDGMENTS.

The writer is greatly indebted to the courtesy of artesian contractors and drillers who have generously placed at his service the well logs made by their foremen as the work was in progress. Unfortunately the records of one large firm, which has done much work in the State, were destroyed some years ago by fire, and some other firms seem to have preserved few or no data as to the wells which they have drilled. The opinion of the foreman as to the character

of the strata in which the drill is working is always of value, for he has means of inference as to the strata in the "chuck" and in the wear of the drill as well as in the character of the drillings brought up in the slush bucket.

CHEMICAL INVESTIGATION OF WELL WATERS.

By W. S. Hendrixson.

SCOPE OF INVESTIGATION.

In the investigation of the quality of Iowa ground waters the practical aim has been kept in view. No attempt has been made to find exceptional waters containing uncommon mineral matter or common mineral constituents in uncommon proportions. The object has been to determine the inorganic chemical substances in average and representative well waters in many localities from the three sources, the alluvium, the drift, and the stratified rock. Springs of large flows from known formations have also received attention. Wells supplying towns or important industrial establishments have been investigated in preference to those supplying only a single home or farm. Little attention has been given to shallow wells reaching only a short distance into the clay and supplied from it by seepage, or to wells on river banks which evidently obtain their water from the rivers by percolation through a few feet of sand or clay.

The small funds for the work have made it necessary to avoid duplication. One or two wells of about the same depth and casing in a locality have been deemed sufficient to indicate the quality at that place, unless the wells were very deep and reached the extensive aquifers. Wells of the latter type are likely to be of more importance, and as a matter of fact their casings are likely to be of very different lengths and are frequently defective. It was, therefore, considered desirable to secure analyses of several such wells, even if close together, in order to eliminate the accidental to some degree and to draw more nearly accurate conclusions as to what quality of water the main sources of supply might be expected to furnish at that point.

ACKNOWLEDGMENTS.

This report contains about 400 analyses of well waters. Of this number nearly one-half have been made by the writer with some assistance in the chemical laboratory of Grinnell College. About 45 analyses have been taken from Norton.[1] Most of them were made by Prof. J. B. Weems, at that time of the Iowa State College at Ames. The remainder were obtained through the kindness of the chemists

[1] Rept. Iowa Geol. Survey, vol. 6, 1896, pp. 353–407.

of the Iowa railroads, hundreds of pen copies of analyses and blue-print sheets of analyses being sent in. The aid given by these men has been invaluable.

The greatest number of analyses was sent by Mr. George M. Davidson, engineer of tests of the Chicago & North Western Railway, who also contributed a full statement of the plants and processes used by his road in softening the waters along its lines for use in its engines.

Others who have shown the same generous and obliging spirit are Mr. W. D. Wheeler, of the Minneapolis & St. Louis Railroad; Mr. W. H. Chadburn, of the Chicago Great Western Railway; Mr. M. H. Wickhorst, of the Chicago, Burlington & Quincy Railroad; Mr. George N. Prentiss, of the Chicago, Milwaukee & St. Paul Railway; and Mr. F. O. Bunnell, of the Chicago, Rock Island & Pacific Railway.

CHAPTER I.

TOPOGRAPHY AND CLIMATE.

By Howard E. Simpson.

TOPOGRAPHY.

RELIEF.

Iowa has but one primary physiographic form—the prairie plain. Taken as a whole it is a typical prairie State. Here waving grasses once covered the gently rolling uplands and deciduous trees bordered the dark and slowly meandering streams. Now the deep, rich soils, moistened by ample and well-distributed rainfall, offer rich returns for agriculture, and cultivated groves dot the landscape in every direction.

The relief of Iowa is slight. The general surface elevation varies from 494 feet above sea level at Keokuk in the extreme southeast corner to 1,551 feet at Ocheyedan in Osceola County near the northwest corner, a range of slightly more than 1,000 feet. The total range in altitude between the low water of Mississippi River where it leaves the State at Keokuk and the highest mound on the great divide in Osceola County is not exactly known, but it does not exceed 1,200 feet, a slight relief for an area of 55,475 square miles.

Originally Iowa was an old sea floor. The alternating layers of sands, muds, and lime deposits by which it was underlain were slowly cemented and consolidated into sandstones, shales, and limestones and raised by gentle uplift into the great interior plain which slopes southward from the old lands of Canada and the Lake Superior region. Time did not materially disturb the rock layers of this ancient coastal plain except to bevel off their surface and they still dip away slightly to the southwest, with scarcely a fold or fault to break the unity. The surface irregularities are largely the result of long-continued erosion by weather and running water, the effects of which have been greatly modified and almost obliterated over the larger portion of the State by glacial ice.

DRAINAGE.

Though lying entirely within the Mississippi basin, the rivers of the State, when viewed as a whole, are readily separable into two distinct systems, one of which drains to the Mississippi and the other to the Missouri. The divide between these two systems enters the State a few miles east of Spirit Lake and passes southward through the eastern parts of Dickinson and Clay counties, thence through Buena Vista, Sac, Carroll, Guthrie, and Adair counties. Thus far it is a broad, flat, and inconspicuous ridge. The direct extension of this ridge, somewhat better defined than before, continues southward through Union, Ringgold, and Decatur counties to the Missouri State line. The divide, proper, however, turns eastward through Clarke, Lucas, and Monroe counties, and thence goes southward through Appanoose County around the headwaters of Grand and Chariton rivers, which turn southwestward after crossing the State line and flow into Missouri River. The rivers of the Mississippi system have a southeastern trend, those of the Missouri system a southwestern trend consequent upon the original slope of the plain. The direction of the minor streams generally does not depend in any way on the character or structure of the underlying rock.

DRIFTLESS AREA.

All of Iowa, except a narrow strip lying along Mississippi River in the northeast corner of the State and including Allamakee County and the northeastern portions of Winneshiek, Clayton, Dubuque, and Jackson counties, has been overridden by glacial ice. The topography of this strip is in sharp contrast with that of the drift-covered area and must fairly represent the topography of the entire State before the great ice invasion. Weather and running water have had continuous and undisturbed action on nearly horizontal rocks of varying hardness for a long period of time, and the surface has reached the stage of mature dissection.

RELIEF.

Chief among the many interesting topographic features of the driftless area is the valley of the Mississippi. The Mississippi flows from the north through a remarkable steep-sided, rock-walled valley 400 to 500 feet deep and 1 to 3 miles wide, swinging south in great and gentle curves such as could be carved only by an earlier stream of far greater volume. The present Mississippi clearly misfits its valley, flowing through a braided network of shifting channels and leaving in its changes numerous ponds, lakes, and bayous on the broad plain which now forms its valley floor. That the valley has been extensively filled is evident from well borings, which reveal great thicknesses of sand, clay, and gravel; at McGregor, for instance, 187 feet of sediment, evidently of glacial origin, is found above the ancient rock channel. The larger tributaries flow in rock-walled, flat-bottomed valleys 100 to 300 feet beneath abrupt bluffs on either side and 500 to 600 feet beneath the crests of rounded dividing ridges. Near their headwaters they flow through steep-sided rocky gorges, and their tributaries have sharply carved and thoroughly drained uplands. Farther down the walls retreat, the uplands break into rugged ridges, rounded hills, and flat-topped mounds. Here and there, as between Turkey and Mississippi rivers, they terminate in the sharp points crowned with picturesque pinnacles, towers, and long mural escarpments that result from the presence of strong cliff-forming rocks underlain by weaker slope makers.

The main valleys have been cut considerably deeper than their present floors and are aggraded with alluvium, probably Pleistocene in age. Thus the wells at New Albin strike rock at 130 to 140 feet below the surface, or more than 100 feet below the present river levels. Moreover, old terraces, remnants of ancient flood plains, standing as high as 60 feet above the rivers, mark the height of the streams of the region when they ceased aggrading their rock-cut valleys and resumed the task of degradation.

SOILS.

The soil of the area is chiefly residual, resulting from the decay of the country rocks in place. The upland, however, is broadly mantled by loess, a fine, porous clay. Many of the steep slopes characteristic of the region are nearly bare, the loess cover being generally absent. The larger valley floors are commonly filled with water-bearing sands and gravels, overlain by rich soil.

DRAINAGE.

The drainage system of the driftless area is completely developed except for the lakes and other undrained areas on the flood plains. Underground drainage is not uncommon in the area underlain by limestones, this being shown by sink holes, limestone caverns in the uplands, and numerous large springs which rise in the valleys. The topography of the driftless area has a very marked influence on the underground-water conditions. In the deep dissection of the country the many water-bearing beds, such as limestone and sandstone, are cut through in many places by the stream valleys, and the water is permitted to escape as seepage and as springs from numerous joints and fissures or over shale horizons.

The slopes are so numerous and steep that water can not linger on the uplands but is shed rapidly into the streams, affording little opportunity for either evaporation or absorption and giving rise to occasional floods, which cause serious damage to towns like McGregor and Decorah, which are situated in the valleys.

The residual soil is tenacious and relatively impervious, and so absorbs little water. The loess is porous but comparatively thin. The broad, flat uplands away from the valleys are the best retainers of moisture. In them the ground-water level stands high, and shallow wells may be had in many places, though the supply is scanty, for seepage is slow. The ground-water level, as a rule, however, stands low, owing to natural drainage through deep dissection. Rock wells are most common and depths of from 300 feet to 600 feet are not unusual. In the valleys the ground-water level is but slightly below the surface, and the gravels and sands in the filled valleys carry a strong underflow, yielding abundant water at slight depths.

DRIFT AREAS.

GENERAL CHARACTER.

With the exception of the driftless area above described, every portion of the State of Iowa was occupied by an ice sheet at least once during the glacial epoch. The general effect of the ice work was to wear away the more prominent topographic prominences, to fill the valleys, and to spread rock waste over the area. Portions of the State were several times invaded by ice, which left the sheets of till, varying in smoothness and thickness, that combine to form the present mantle of drift—a mantle averaging in thickness from 100 to 200 feet, with a probable maximum of 600 feet in Louisa County.

The topography of this region is young as compared with that of the driftless area, and is generally independent of the geologic structure of the underlying rocks. Only along the margins bordering the driftless area and in the valleys of the larger streams is it influenced by the preglacial topography. The topographic features are chiefly due either to the manner in which the ice laid down its load of waste or to the subsequent action of the agents of erosion.

On the whole, the surface left on the retreat of the glacial ice was a gently undulating plain. Only near the margins of the drift sheets or at places where long pauses were made in the retreat of the ice front were marked irregularities produced. Here belts of hills with alternating depressions were formed by the irregular heaping up of the drift material, producing terminal or recessional moraines having characteristic knob and kettle topography. The material is chiefly till, a mixture of clay, sand, pebbles and bowlders of all kinds, deposited directly by the ice. Associated with this are beds of sand and gravel left by streams of running water and fine clays deposited in quiet waters. Overlying the drift sheets of the earlier ice invasions over more than half the State is a fine porous clay of peculiar vertical cleavage called loess. This formation is of eolian or aqueous origin and can be readily distinguished from the underlying drift by its lack of pebbles and bowlders. It tended to smooth over the slight inequalities of the drift sheets on which it was deposited.

DRIFT SHEETS.

At least five different ice invasions, each of which deposited a sheet of drift, entered Iowa from slightly different directions and at widely separated periods of time during the glacial epoch. The drift of the first invasion, formerly known as the sub-Aftonian or pre-Kansan and more recently named the Nebraskan, was everywhere overridden by later ice sheets and is not known to influence the topography of the State. The deposits of the remaining four invasions, the Kansan, the Illinoian, the Iowan, and the Wisconsin, are represented on the surface by areas of drift differing only slightly in composition but very greatly in age and topographic form.

KANSAN DRIFT.

The oldest drift sheet appearing on the surface in Iowa is the Kansan, which heavily mantles the entire State with the exception of the driftless area already described and is exposed in the southern and western portions over an area equal to half the area of the State. A line connecting Fort Madison, Iowa City, Des Moines, Carroll, and Sibley roughly separates the exposed Kansan area from that to the north and east, which is covered by younger drift sheets.

The evidence offered by unaltered remnants of the old Kansan drift leads to the inference that its surface must have been very gently undulating and have been characterized by the absence of moraines, drumlins, kames, and other hills due to accumulation. The relief of to-day has therefore been developed by the action of weather and running water through long periods of time. So long have these agents of erosion been at work on the Kansan area that they have in most places drained it and reduced it to a high degree of maturity characterized by a heavily rolling topography.

The drainage is so complete that lakes, ponds, and other bodies of standing water are practically unknown except on the flood plains of large streams. The slopes are so steep and the run-off so rapid that little opportunity for absorption or for evaporation is given as compared with the areas of younger drift. On the other hand, the loess cover is so porous as to absorb a slow rainfall very rapidly. The ground water is relatively low, especially on the higher region about the Mississippi-Missouri divide. It is higher, however, than in the maturely dissected region of the driftless area, where slopes are very steep and soils tenacious.

Not all the uplands are so thoroughly dissected. Away from the larger rivers broad flat-topped divides retain many of the surface features of the original drift plain. Long, low swells alternate with shallow swales, through which sharp stream channels have been excavated by storm waters. A few damp sloughs and small patches of marsh grass in gentle depressions indicate that here at least youth lingers in the midst of maturity. In such an upland much of the storm rainfall is absorbed; ground-water level is found close to the surface in the swales; and shallow wells are common, even on the low swells where the houses are located.

Nearer the rivers little of the plain remains and the country is sharply broken into hills and valleys. The slopes, though not so steep as in the driftless area, show frequent outcrops of bedrock, from which springs flow in places and seepage is common. The larger streams occupy broad flat-bottomed valleys and meander over well-developed flood plains. So long have they worked that many of them have discovered preglacial channels in which they are now flowing. In the valleys the ground-water table coincides with the surface of the stream and rises in general toward the valley sides. Shallow dug wells reach water a few feet down; where gravels and sands have been deposited in the valley the underflow is strong and is easily obtained by means of driven wells.

Owing to the steeper slope of the plain in the southwestern portion of the State, west of the Mississippi-Missouri divide, and the short distance of the headwaters from the master stream, a maturity has been attained beyond that of any other drift-covered portion of the State. The rivers flow through deep, broad, nearly parallel valleys, the floors of which are underlain by gravel, sand, and clay. Most striking of these valleys, perhaps, are those of Nishnabotna and Nodaway rivers. The valley floors of these range from 1 to 4 miles in width and are so terraced that only a narrow belt is exposed to frequent flood waters. Throughout these valleys shallow wells furnish an abundance of good water from the sand and gravel layers of the alluvium.

Missouri River, on the western border of Iowa, lies within the area of Kansan drift and meanders through a postglacial valley partly filled with yellow loess. Its broad flood plain, constantly shifting channel, muddy waters, and ever-present snags, are among its most striking characteristics.

ILLINOIAN DRIFT.

In the southeast corner of the State a small area of younger drift overlies the Kansan, extending along Mississippi River from Princeton to Fort Madison in an irregular belt 5 to 20 miles in width. The depositing ice sheet came from the northeast and the drift is known as the Illinoian. The surface of the whole is thickly mantled with loess.

Several important rivers, among which are the Cedar, the Iowa, and the Skunk, have had a marked influence on the topography in the vicinity, excavating deep, wide valleys in the soft drift.

The greater part of the area retains the characteristic features of a young drift plain. Few sloughs remain and the storm waters have washed out well-marked drainage channels, but broad tabular areas of the original plain still persist, forming large, level, floorlike divides. The Mississippi here occupies a narrow channel whose youth is indicated by rock-cut portions at Le Claire, Davenport, and Keokuk.

At its western margin the Illinoian drift sheet thickens into a low morainal ridge, beyond which a broad, flat channel, roughly paralleling the Mississippi from Bellevue to Fort Madison, marks the temporary channel occupied by that river while diverted by the Illinoian ice. In "The Forks" between Cedar and Iowa rivers in Louisa and Muscatine counties lies a level sandy plain, the bed of an extinct glacial lake, whose waters were held between bluffs bordering Iowa River on the west and the ice front on the east. The diverted Mississippi, flowing down from the northeast, was here blocked and ponded until it rose sufficiently to flow away southward over the bluffs through the channel mentioned.

The loess cover of the Illinoian drift readily absorbs water and the general ground-water level stands high except in the broken areas near the larger rivers and at the margins of the drift. In such places the conditions resemble those in the Kansan area.

IOWAN DRIFT.

Over the greater part of the northeast quarter of the State lies the drift left by the Iowan ice sheet. Its borders on the south and east are remarkably sinuous owing to the projection of many long, narrow tongues. It is overlain on the west by the younger Wisconsin drift, the margin of which lies near Clear Lake and Eldora. Its southern margin passes near Grinnell, Belle Plaine, and Iowa City. On the east it is separated from the driftless area by a narrow belt of Kansan drift.

The topography of the region is characteristic of a youthful drift plain. The irregularities left in the drift by the departing ice sheet still remain. The loess, which so fully mantles the older drift sheets in the southern part of the State, is conspicuous by its absence, being found only in irregular patches near the margin. The surface is gently undulating. Low flat swells alternate with swales, on whose broad floors "sloughs," marshy remnants of glacial lakes, give rise to small creeks which follow a sluggish, winding course toward the master streams. In the northeast portion bowlders strew the surface, especially in sags and swales where some of the drift has been removed by erosion. Near the southern margin of the Iowan area the even surface rises into low hills with parallel axes, apparently drumloid in character, but capped with loess. To these hills the name paha has been given. Along the southwestern margin in Tama and Benton counties they become more knobby and much resemble a terminal moraine.

The river valleys are not well developed, as in the area of the Kansan drift, but flow in narrow channels between steep banks of drift and alluvium except where they have found preglacial channels held open during ice invasion.

Natural drainage is not complete in the Iowan drift area, but the process is being rapidly hastened by artificial means. In no other part of the State can man so easily aid nature in this respect. The young stream courses are well marked and, when once the sod in their bottoms has been broken by the plow, they deepen rapidly and form the outlets for extensive systems of tile drainage. The excess of water which would otherwise form ponds and sloughs in the low flat areas is thus readily drained off, yet so slightly is the ground-water level lowered beneath the surface that the normal moisture is retained during dry seasons, a most favorable condition for agriculture.

Throughout the Iowan area the ground-water level stands high. The lack of the porous loess cover probably tends to increase evaporation and run-off, but owing to the flatness of the surface the run-off is slow. Most wells find water within a few feet of the surface, but owing to the imperviousness of the drift many fail to obtain a large supply until they penetrate the bedrock.

WISCONSIN DRIFT.

The youngest of all the drift sheets in Iowa, that deposited during the Wisconsin ice invasion, lies in a broad lobe extending from the north boundary of the State to the city of Des Moines, its western margin being near Sibley, Storm Lake, and Panora, and its eastern near Clear Lake, Iowa Falls, and State Center.

The area presents all the characteristics of early youth. It is an undissected drift plain in which the drainage remains strikingly incomplete, the topography being practically as the ice sheet left it. Low rounded swells separate shallow basins, in which lie numerous sloughs, lakes, ponds, and peat bogs. The smaller streams wander in narrow, crooked valleys and in many places end in undrained basins. The few rivers are simple consequent streams; some occupy shallow channels on the surface of the plain and others have cut deep trenches in the drift, but all lack well-developed systems of tributaries.

A feature of this drift area is the accumulation of well-marked terminal moraines on the eastern and western margins, together with several recessional moraines within the area. On the eastern margin a distinct belt of knobs 50 to 100 feet in height enters the State along the north boundary of Winnebago County and passes southward through Hancock, Cerro Gordo, Franklin, and Hardin counties, dying out in the western part of Marshall County. On the west side another belt, partly terminal and partly recessional, enters Dickinson County and curves southward through Clay, Palo Alto, Buena Vista, Sac, Carroll, and Greene counties and dies out in the northeast corner of Guthrie County. Well-marked recessional moraines are found in northern Boone and adjacent counties and in Webster County.

The Wisconsin drift area is the lake region of Iowa. A few ponds and sloughs occur in the Iowan drift area, and lagoons, cut-offs, and bayous are found on the flood plains of all the larger rivers of the driftless area and of the Kansan drift area, but the only lakes of importance in the State are found in the Wisconsin area and are of glacial origin. They lie chiefly within the heavy morainal belt already described and occupy irregular depressions between the kames. Chief among them are Spirit, Okoboji, Storm, Wall, and Clear lakes. The last named furnishes the water supply for the town of Clear Lake, and several are valuable sources of ice.

The problem of adequate drainage is more difficult in the Wisconsin area than anywhere else in Iowa. The lakes, ponds, and sloughs all indicate a high ground-water level. The absence of the loess leaves the drift without a porous cover and the tenacious quality of the bowlder clay prevents the entrance of much water into the ground. Wells in swales therefore find abundant water, but on the higher portions they must be driven deep, frequently into rock, to get a plentiful supply. The surface waters are so abundant, however, that fewer stock wells are necessary than in other areas.

SUMMARY.

The level character of the prairie plain is such as to favor the ready absorption of rainfall by the soils and to cause the ground water to stand near the surface of the drift or the country rock and to be within easy reach of comparatively shallow wells. The gently rolling character of the topography insures good drainage, thus preventing stagnation of water on the surface, and lowers the ground-water level far enough to permit purification of the downward percolating waters by filtration before they join the great underground system. The topographic conditions, in connection with drift soils such as are found throughout nearly all of the State of Iowa, insure a supply of underground waters at depths which permit most of the inhabitants outside of the large cities to be supplied at very slight cost.

CLIMATE.

GENERAL CONDITIONS.[1]

The climatic conditions of the State of Iowa are, on the whole, favorable to a good and constant supply of underground water. Most important of these conditions are precipitation and temperature, both of which, though liable to marked variations from the normal, are shown, by the abundant annual rewards of agriculture, to be favorable to the storage and conservation of the moisture in the soils and country rock. Nothing approaching a failure of crops either by drowning or drought has been experienced in the history of Iowa—a history which now spans more than three-quarters of a century.

Climatic observations within the present boundaries of Iowa were officially taken by the medical officers of the United States military posts as early as 1820, and widely scattered, though systematic, records were kept with standard instruments under the direction of the War Department and the Smithsonian Institution until 1870, when the Weather Bureau was established. Since 1890 the State government has cooperated with the Weather Bureau through the Iowa Weather and Crop Service.

There exists, therefore, a series of records covering a period of over 90 years, during all of which time much attention has been given to both temperature and rainfall. Though the early records are few and incomplete they are of value in indicating the constancy of the Iowa climate and the error of many who have not carefully studied the conditions in believing that marked changes have taken place. The observed facts make it highly improbable that any important change in the average precipitation of either rain or snow has taken place since the settlement of the region by civilized people.

TEMPERATURE.

The mean annual temperature of the State is 47.5° F. The variation from this figure scarcely ever exceeds 2°; but owing to the location of the State in the interior of the continent, exposed alike to cold waves from the northwest and warm waves from the south, the average annual range of temperature amounts to 136°. The highest temperature recorded is 113° and the lowest is −43°, giving the remarkable range of 156° between the highest and lowest observed temperatures.

[1] Detailed information regarding climatologic conditions in Iowa may be found in the following reports: Sage, J. R., Climate and crops of Iowa: Ann. Rept. Iowa Weather and Crop Service for 1902, appendix. Henry, A. J., Climatology of the United States, U. S. Weather Bureau, Bull. Q, 1906, pp. 626-658.

The mean annual temperature decreases gradually and uniformly from Keokuk, the lowest and most southerly point in the State, to the higher parts of the north-central region.

The table below gives the monthly, seasonal, and annual mean temperatures as recorded at six climatologic stations of the United States Weather Bureau in Iowa and one at Omaha, Nebr. The distribution of these seven stations is such as to represent fairly well all portions of the State. To these are added for comparison the corresponding mean temperatures for the State as a whole.

Monthly, seasonal, and annual mean temperatures (°F.) in Iowa and at Omaha, Nebr.

Station.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Winter.	Spring.	Summer.	Autumn.	Annual.
Charles City	16	14	31	48	60	68	73	71	63	50	32	19	16	46	71	48	45
Dubuque	18	21	33	49	61	70	75	72	64	52	36	25	21	48	72	51	48
Sioux City	20	19	32	50	60	70	74	72	64	52	34	25	21	47	72	50	48
Des Moines	20	23	35	51	61	70	75	73	65	53	37	26	23	49	73	52	49
Davenport	21	24	35	50	61	71	75	73	65	53	38	27	24	49	73	52	50
Omaha, Nebr	21	25	36	52	62	72	76	74	66	54	38	27	24	50	74	53	50
Keokuk	24	28	38	52	63	72	77	75	67	55	39	30	27	51	75	54	52
Iowa	19.3	19.2	34.0	48.5	60.1	68.8	73.4	71.8	63.7	51.9	35.9	23.6	20.7	47.5	71.3	50.5	47.5

The first killing frosts of autumn occur about October 5 and the last of spring about April 25, the time varying about two weeks between the northern and the southern portions. This gives a period of about six months during which frost is liable to occur. The streams are closed by ice for approximately three months and the surface of the ground is sufficiently frozen to prevent ready absorption of rainfall for about four and one-half months.

The relations of temperature to ground water are very complex. They include (1) the immediate and direct relations that govern the amount, rate, and form of the precipitation; (2) those that determine the proportionate parts of the rainfall that evaporate, run off, or are absorbed, as affected by the character of the surface and by its freezing, baking, etc.; and (3) those that govern the direct movements of ground water. The last item is often overlooked, but its importance may be suggested by the fact, determined by experiment, that water at 100° F. percolates twice as rapidly through sand as it does at 50°; both absorption and flow, therefore, vary greatly with the temperature.

PRECIPITATION.

CONTROLLING CONDITIONS.

The moisture which falls in the form of rain or snow over Iowa comes chiefly from the Gulf of Mexico, being drawn in with the southerly winds toward the rotating areas of low pressure technically called cyclones, which move eastward across the continent with the prevailing westerly winds. These cyclonic storms are great in area, moderate in force, and beneficial in effect. They should not be confused with the violent rotating storms properly called tornadoes, which occasionally occur in the middle and eastern parts of the United States, making a very narrow track and extending over a small area. The rainfall is directly cyclonic in winter and indirectly cyclonic in summer, coming chiefly from thunderstorms in the southeastern quadrant of the low-pressure areas. Many of the thunderstorms, which average about 37 annually for each station in the State, are, however, of the convectional type and are therefore local.

GEOGRAPHIC DISTRIBUTION.

The Iowa Weather and Crop Service has divided the State into three sections, northern, central, and southern, each consisting of three tiers of counties, extending across the State from east to west. The average annual precipitation of the northern section is 29.9 inches, of the central section 31.5 inches, and of the southern section 33.6 inches. Each of the sections has been subdivided into three districts more or less closely approximating rectangles and containing from 7 to 15 counties each. The names of these districts together with their average annual precipitation are: Northeast, 32.25 inches; north central, 29.40 inches; northwest, 28.16 inches; east central, 32.61 inches; central, 31.66 inches; west central, 29.36 inches; southeast, 33.65 inches; south central, 32.53 inches; southwest, 32.60 inches. On later pages of this volume, in discussing the geology and the artesian waters by counties, the counties of the west-central district are divided between the northwest and southwest districts; and in discussing the chemical character of the waters (pp. 135–183) the south-central and southwest districts are treated together. (See fig. 2, p. 140.)

The highest average precipitation is found in the southeast district and the lowest in the northwest. The southeast district has an annual average of 5.49 inches more than the northwest district, 1.40 inches more than the northeast district, and 1.05 inches more than the southwest district. From these figures it is readily seen that there is a regularly decreasing gradient from east to west and a slightly steeper one from south to north, the steepest gradient therefore being from southeast to northwest.

The highest annual average at any of the United States Weather Bureau stations is 35.2, at Keokuk, in the extreme southeast corner of the State, and the lowest annual average is 25.8, at Sioux City, near the northwest corner; this confirms the relations above stated and gives a range of 9.5 inches in the mean annual precipitation as recorded at the different Weather Bureau stations within the State.

Grouped in north-south belts, the eastern or Mississippi River belt has an average annual precipitation of 32.50 inches; the middle belt of 31.51 inches; and the western or Missouri River belt of 30.04 inches.

Thus, the variations in the geographic distribution of the precipitation of Iowa are slight; they consist chiefly of a normal decrease to the north with latitude and a decrease to the north and west with increase in distance from and elevation above the chief source of the moisture, the Gulf of Mexico, and with increase in distance from the usual paths of the cyclones.

SEASONAL DISTRIBUTION.

To give a perfect idea of the relation of rainfall to underground waters the records should show not only the amount, but the rate of the fall, the cloudiness, the direction and velocity of the wind, and the condition of the ground surface at the time. Precipitation falling on a moderately dry surface is absorbed more rapidly than that falling on hard-baked ground, and still more rapidly than that falling on a frozen surface, which is scarcely absorbed at all unless it falls as snow. Winter precipitation is therefore of little value as compared with summer precipitation.

Iowa has fairly well defined wet and dry seasons, due to the migration of the wind system with the sun. In spite of the location in the interior and of the great distance from the source of supply the constancy of the prevailing westerly winds and the frequent recurrence of the cyclones produces a seasonal constant of rainfall which, coupled, with the peculiar character of the glacial soil, makes the upper Mississippi Valley a well-watered region. As the supply of ground water, especially that near the surface, depends on the rainfall, the amount of precipitation and its geographic and seasonal distribution are important. The average annual precipitation as shown by official records is about 31.5 inches. The seasonal distribution of the precipitation is shown in the table below, which gives the mean monthly, seasonal, and annual amounts for the several Weather Bureau stations and for Iowa as a whole.

Monthly, seasonal, and annual mean precipitation (inches) in Iowa and at Omaha, Nebr.

Station.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Winter.	Spring.	Summer.	Fall.	Annual.
Charles City	0.9	1.0	1.7	3.0	4.3	4.6	3.6	3.0	3.1	2.1	1.4	1.1	3.0	9.0	11.2	6.6	29.8
Dubuque	1.5	1.4	2.2	3.0	4.3	4.7	4.7	2.9	4.2	2.6	1.9	1.6	4.5	9.5	12.3	8.7	35.0
Sioux City	.5	.6	1.2	2.8	4.1	4.0	3.5	3.1	2.4	1.7	.8	.8	1.9	8.1	10.6	4.9	25.5
Des Moines	1.2	1.1	1.6	2.9	4.8	5.0	3.7	3.5	3.0	2.8	1.5	1.3	3.6	9.3	12.2	7.3	32.4
Davenport	1.6	1.6	2.2	2.7	4.4	4.1	3.7	3.6	3.2	2.4	1.8	1.6	4.8	9.3	11.4	7.4	32.9
Omaha, Nebr	.6	.7	1.4	3.0	4.4	5.2	4.6	3.5	2.9	2.5	1.0	1.0	2.3	8.8	13.3	6.4	30.8
Keokuk	1.8	1.6	2.4	3.2	4.2	4.4	4.2	3.0	3.8	2.7	2.0	1.8	5.4	9.8	11.6	8.5	35.1
Iowa	1.05	1.06	1.92	2.83	4.50	4.52	4.44	3.99	3.41	2.35	1.39	1.19	3.30	9.25	12.95	7.15	32.65

The bulk of the rainfall occurs during the spring and summer months and little of it during the winter months, the approximate percentages being, winter 10 per cent, spring 28 per cent, summer 39 per cent, and autumn 23 per cent. Only a small proportion falls during the period in which the ground is frozen and absorption prevented, and a very large proportion, probably 80 per cent, falls in late spring and summer when absorption is greatest. This natural advantage is greatly increased by the fact that the heaviest rainfall occurs during the seasons for the preparation and the cultivation of the soil, thus very greatly increasing the absorption. This relative increase of precipitation of spring and summer over that of winter becomes more marked as the total rainfall decreases from the Mississippi westward. The summer precipitation at Keokuk is 11.6 inches and that at Sioux City is 10.6, a difference of but 1 inch; whereas the winter precipitation at Keokuk is 5.4 inches and that at Sioux City is 1.9 inches, a difference of 3.5 inches, thus compensating to a large degree for the differences in total rainfall.

A marked effect of the diminution of precipitation during the winter months is noted in the slightness of the snowfall compared with that of the more eastern States. Though snow falls in all parts the State, the annual average fall for 29 years is but 29.2 inches, less than one-tenth of the precipitation. The effect of geographic differences in precipitation on the underground-water supply is thus very slight.

VARIATIONS.

The table below shows that the precipitation for the entire State is subject to marked variations from year to year. Since 1890 the lowest average for the whole State for a single year was 21.9 inches in 1894 and the highest 43.8 inches in 1902. Between these extremes there has been marked variability, but the tendency to one extreme is frequently followed by a tendency to the other, as illustrated in the dry year of 1901 and the wet year of 1902. The general average has been steadily maintained through all the long period covered by records.

Yearly variations of rainfall in Iowa.

[Inches.]

Year.	Average.	Variation from normal.	Year.	Average.	Variation from normal.
1890	31.28	−0.24	1902	43.82	12.30
1891	32.90	1.38	1903	35.39	3.87
1892	36.58	5.06	1904	28.51	− 3.01
1893	27.59	−3.93	1905	36.56	5.04
1894	21.94	−9.58	1906	31.60	.08
1895	26.77	−4.75	1907	31.61	.09
1896	37.23	5.71	1908	35.26	2.61
1897	26.97	−4.55	1909	40.01	7.36
1898	31.34	− .18	1910	20.03	−12.62
1899	28.68	−2.84	1911	31.57	− 1.28
1900	34.15	2.63			
1901	24.41	− 7.11	Average	31.51	....

Deficiency of summer rainfall sometimes produces partial droughts, the effect of which is marked on the streams, springs, and shallow drift wells, producing scarcity of water for stock and for domestic purposes. Heavy drains are made for stock on the deeper rock wells when streams are low, and as these rock wells are of small bore they are sometimes temporarily exhausted. The texture of the soil and other physical conditions, such as its condition at the beginning of the dry period, determine its ability to store water under the least loss by evaporation. Rather severe general midsummer droughts occur at irregular intervals once or twice in a decade. During all such droughts, however, many small areas have had practically normal precipitation, and the amount has generally been ample in most parts of the State.

The most severe drought on record is that of 1894–95, which may be ascribed to slight precipitation and high temperatures for two successive seasons. The precipitation for July, 1894, was only 0.63 inch, about 15 per cent of normal, and for August was 1.58, about 44 per cent of normal. The departure from the annual precipitation during the year was −9.5 inches. The extreme in the other direction in recent years occurred in 1902, when the precipitation reached 43.82 inches for the year, 12.3 inches above the normal.

SUMMARY.

The information for a satisfactory discussion of evaporation, humidity, wind velocity, and other minor factors in the meteorologic control of ground-water supply is insufficient, but enough data are available in regard to the two chief controlling factors, temperature and rainfall, to show that Iowa, though possessing the variable characteristics of a continental climate, also possesses the requisite meteorologic conditions for a moderately abundant supply of underground water.

CHAPTER II.

GEOLOGY.

By W. H. Norton and Howard E. Simpson.

GENERAL CONDITIONS.

The rocks exposed in Iowa belong to four great divisions separated from each other by pronounced unconformities. (See Pl. I, in pocket.)

The oldest division belongs to the Algonkian system and is represented by the Sioux quartzite. This quartzite outcrops over only a small area in the northwest corner of the State but occurs more widely below other formations, and is also found at the surface over considerable areas in Minnesota and South Dakota.

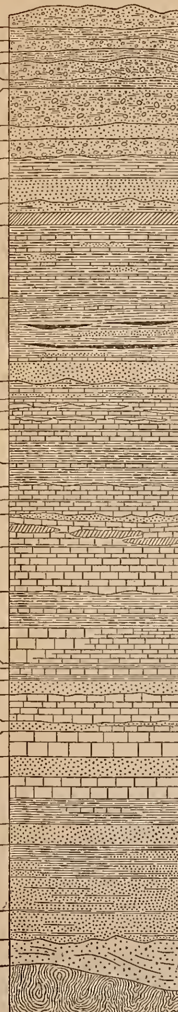
The second division is represented by rocks of the Cambrian, Ordovician, Silurian, Devonian, and Carboniferous systems, and includes a basal series of clastic beds that may be of Algonkian age. This great assemblage of sediments rests on an uneven floor composed of Sioux quartzite and older crystalline rocks. It consists of beds of sandstone, shale, and limestone, many times repeated in varying order. Where these beds come to the surface they have been carefully studied, and the order of their succession has been determined. (See Pl. II.) They are for the most part apparently conformable with one another, but important erosional unconformities occur at the base of the Devonian system and between the Mississippian, Pennsylvanian, and Permian series of the Carboniferous system. The oldest exposed rocks of this division are of Cambrian age and outcrop in the northeastern part of the State. The strata dip in general toward the southwest, and in this direction the younger formations become successively the surface rocks. The boundary lines between the formations, at the surface or immediately below the drift, follow in general the strike of the rocks, and, hence, are approximately parallel and cross the State with a northwest-southeast trend. (See Pl. I.) Where the principal unconformities occur, however, the boundaries depart from this parallel arrangement.

The third great rock division of Iowa is represented by Upper Cretaceous sandstones, shales, and limestones, which lap over the

ERA	SYSTEM	SERIES	TER OF STRATA
Cenozoic	Quaternary with patches of Tertiary at base	Pleistocene	
			Tertiary age are present at the base of the Quaternary
Meso-zoic	Cretaceous	Upper Cretaceous	
Paleozoic	Carboniferous	Permian (?)	
		Pennsylvanian	
			oal
		Mississippian	
			sandstones
	Devonian	Upper Devonian	
		Middle Devonian	
	Silurian		ite marls, sandstones
	Ordovician		
	Cambrian		
Proterozoic	Algonkian (?)		
	Algonkian	Huronian	
	Archean		

[a] As used in this report includes at top

[b] Includes upper part of Warsaw limest

ERA	SYSTEM	SERIES	GROUP	FORMATION	COLUMNAR SECTION	CHARACTER OF STRATA
Cenozoic	Quaternary with patches of Tertiary at base	Pleistocene		Wisconsin drift		Stony clay, kame, and outwash gravels
				Loess, soil bed, etc. (Peorian interglacial stage)		Soil bed, loess, etc.
				Iowan drift		Stony clay
				Soil, etc. (Sangamon interglacial stage)		Soil and vegetal accumulations
				Illinoian drift		Stony clay
				Buchanan gravel; soil, etc. (Yarmouth interglacial stage)		Soil, gravel, sand, and vegetal accumulations
				Kansan drift		Stony clay and outwash gravels
				Gravel, sand, peat, etc. (Aftonian interglacial stage)		Gravel and sand, soil, peat, and forest beds
				Sub-Aftonian drift		Stony clay
						In places stiff, plastic, and impervious clays of Tertiary age are present at the base of the Quaternary
Mesozoic	Cretaceous	Upper Cretaceous	Colorado			Shales, limestones, chalk
				Dakota sandstone		Sandstones, friable
Paleozoic	Carboniferous	Permian (?)				Red shales and sandstones
						Gypsum
		Pennsylvanian	Missouri			Shales, limestones, some sandstones, and coal
			Des Moines			Shales, some sandstones and limestones, and coal
		Mississippian		"St. Louis limestone"[b]		Limestones, sandstones, shales
			Osage[a]	Keokuk limestone		Limestones, cherts, geodiferous shales
				Burlington limestone		
			Kinderhook			Shales, magnesian and oolitic limestones, and sandstones
	Devonian	Upper Devonian		Lime Creek shale, Sweetland Creek shale, and State quarry limestone		Shales and limestone
		Middle Devonian		Cedar Valley limestone		Limestones
				Wapsipinicon limestone		Limestones and some shales
	Silurian			Salina (?) formation		Dolomites and limestones, gypsum and anhydrite marls, sandstones
				Niagara dolomite		Dolomites
	Ordovician			Maquoketa shale		Shales with some limestones
				Galena dolomite		Dolomites and limestones
				Decorah shale		Green shale
				Platteville limestone		Limestones and shales
				St. Peter sandstone		Sandstone, white rounded grains
			Prairie du Chien	Shakopee dolomite		Dolomite, often arenaceous
				New Richmond sandstone		Sandstone
				Oneota dolomite		Dolomite
	Cambrian			Jordan sandstone		Sandstone
				St. Lawrence formation		Dolomites, marls, shales
				Dresbach sandstone		Sandstone
				Undifferentiated Cambrian		Sandstones, marls, shales
Proterozoic	Algonkian (?)			Red clastic series		Red sandstones
	Algonkian	Huronian		Sioux quartzite		Quartzite
	Archean			Gneiss and schist		Gneiss and schist

[a] As used in this report includes at top the lower part of the Warsaw limestone

[b] Includes upper part of Warsaw limestone

GENERAL COLUMNAR SECTION

older formations, and cover much of the northwest and west-central parts of the State.

The fourth great division includes the drift sheets and associated subaerial, interglacial, and postglacial deposits of the Pleistocene series. These deposits were spread over nearly all of the State except the northeast corner, and in most localities they still cover the older rocks. The distribution of the different Pleistocene formations is shown in Plate III (in pocket).

The rock structure is shown in detail in the geologic sections, Plates V to XVIII, inclusive. The location of these sections is indicated in figure 1.

PRE-CAMBRIAN ROCKS.

ARCHEAN SYSTEM.

Foliated rocks—schists and possibly gneisses—have been found in several deep wells in the northwestern part of Iowa. At Sioux City they were reached at a depth of 1,260 feet (135 feet below sea level), and continued to the bottom of the drill hole, which is 2,000 feet in depth. At Le Mars a rock called by Todd "a gneiss (?)," consisting of orthoclase, quartz, and muscovite, occurs at 215 feet above sea level, and crystalline foliated rocks, either gneisses or schists, continued for 500 feet to the bottom of the boring.

ALGONKIAN SYSTEM.

SIOUX QUARTZITE.

The Sioux quartzite (popularly but erroneously called "Sioux Falls granite") outcrops over a very small area in the northwest corner of the State. This familiar building stone of our large cities is an intensely hard, pink, vitreous rock, consisting of rolled sandstone grains cemented mainly with secondary interstitial quartz. Quartzite, presumably of the same age, occurs in the Baraboo region of southwestern Wisconsin. At Lansing, Iowa, the "granite" noted in a driller's log at 71 feet above sea level may well be quartzite, here sunk nearly 1,500 feet below its elevation at Baraboo, 75 miles east. "Granite" reported at Mason City and Emmetsburg is not confirmed by drillings of any crystalline rock in the sample preserved. At Cedar Rapids an intensely hard, siliceous rock of reddish color was struck at 1,417 feet below sea level and penetrated for a distance of 75 feet; but at Tipton, in an adjacent county, a well drilled to 1,886 feet below sea level failed to discover quartzite or any other crystalline rock. At Burlington the reported occurrence of "quartzite (?) and slate" at the bottom of the Crapo Park well, 2,430 feet deep (1,745 feet below sea level), is not fully confirmed by the drillings, as the reddish siliceous chips show no signs of fracture across grain and cement, and the "slate," though an indurated shale, is accompanied with chips of sandstone of Cambrian type. In the not far distant deep

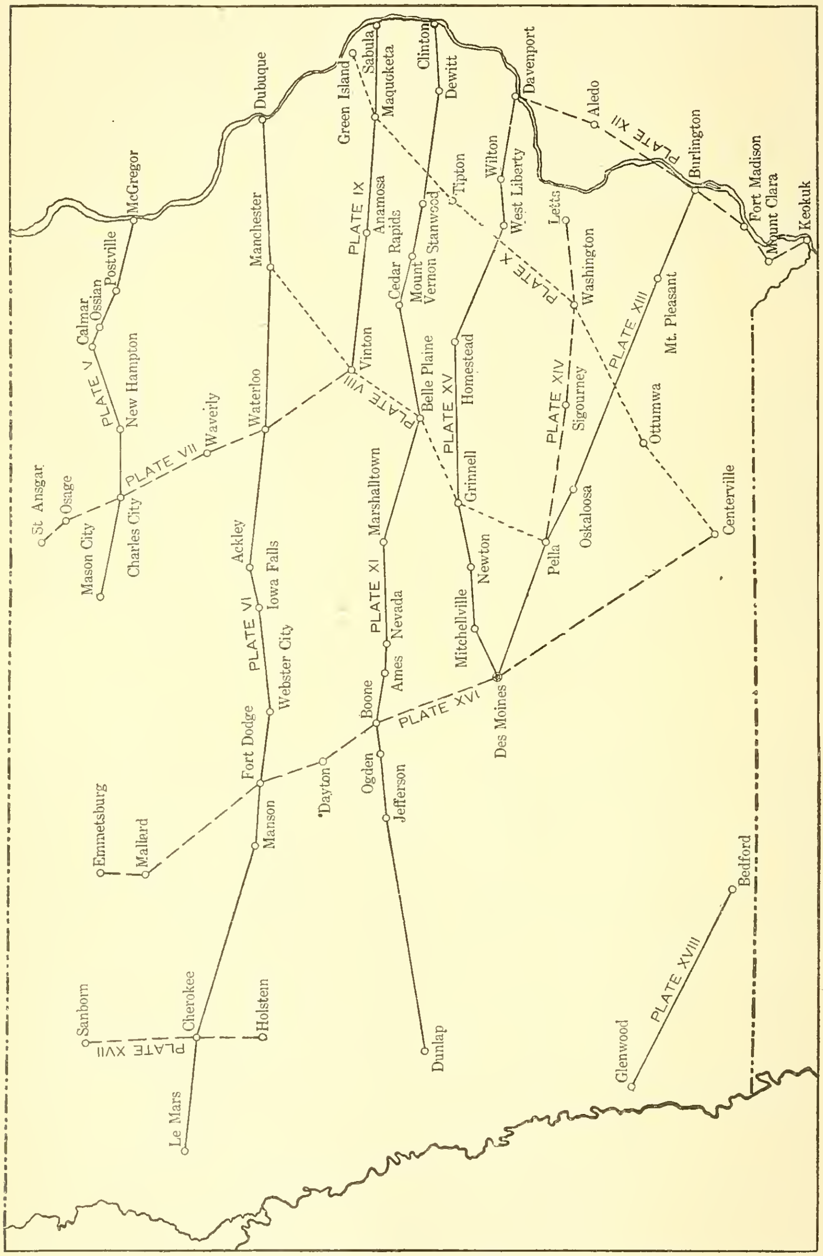


FIGURE 1.—Index map showing the location of geologic sections shown in Plates V–XVIII, inclusive.

well at Aledo, Ill., no crystalline rock was found, although a depth of 3,000 feet was attained.

ALGONKIAN (?) SYSTEM.

RED CLASTIC SERIES.

Certain deep wells of Iowa reach red sandstones beneath Cambrian terranes. Like the red sandstones of the deep wells of Minnesota, the red sandstones of Iowa seem to be dry, and they may be of Algonkian age. At Tipton the drill reached these red rocks at 1,435 feet below sea level, or about the level at which quartzite occurs at Cedar Rapids, and penetrated them for 431 feet to the bottom of the drill hole.

SANDSTONES WITH INTRUSIVE SHEETS.

The deep well at Hull, in northwestern Iowa, encountered, at 755 feet from the surface (678 feet above sea level), the first of six beds of quartz porphyry intercalated between saccharoidal sandstones, the entire series reaching to a depth of 1,228 feet from the surface (205 feet above sea level).

In the absence of any physical or lithologic characteristics determining the age of the sandstones, they have been regarded as probably of Algonkian age, on account of the known igneous intrusions of the same nature in the Keweenawan, the dikes of ancient lava in the Sioux quartzite, and the absence of volcanism in Paleozoic strata of the upper Mississippi Valley.[1]

CAMBRIAN SYSTEM.

OCCURRENCE AND SUBDIVISIONS.

The Cambrian rocks of Iowa were laid down upon an old sea floor which is now exposed far to the north in Minnesota and Wisconsin. They probably underlie the entire State, but rise to the surface only in the deep valleys of the extreme northeast corner. The younger formations overlie the older in the order of their deposition and become the country rock to the south and west in successive roughly parallel bands, each in turn dipping gradually to the southwest and passing underneath the next younger. The formations of the two oldest sedimentary systems represented, the Cambrian and the Ordovician, follow one another in rapid succession and the narrow bands of their outcrop roughly parallel one another in intricate patterns.

The Cambrian, a system of massive sandstone formations several hundred feet thick, is an excellent water carrier. At Lansing it was found to have a thickness of 1,000 feet. The Cambrian outcrops or lies immediately below the drift only in the valleys of Mississippi River and its immediate tributaries from the northern boundary of the State to McGregor in Clayton County, in the valley of the Oneota

[1] Ann. Rept. Iowa Geol. Survey, vol. 1, 1893, pp. 165-169; vol. 6, 1897, pp. 112, 180, 199.

and its immediate tributaries in Allamakee County, and over an area of less than a square mile in Winneshiek County. It outcrops in all of these valleys only along the base of the high bluffs, where it has been exposed by the deep carving of ancient streams.

The Cambrian rocks of Iowa consist of certain undifferentiated sandstones, marls, and shales, at the base, above which lie the formations known, from the bottom up, as the Dresbach sandstone, the St. Lawrence formation, and the Jordan sandstone.

DRESBACH SANDSTONE AND UNDERLYING CAMBRIAN STRATA.

DEFINITION.

In the senior writer's early investigations of Iowa deep wells the term "Basal sandstone" was used tentatively to include all Cambrian deposits below the base of the St. Lawrence formation, since no term used by either the Minnesota or the Wisconsin surveys seemed sufficiently inclusive, the term Dresbach being employed by the Minnesota geologists to designate only the upper formation of the series of strata in question. Since that time the term Dresbach has been by some writers used loosely to include all the underlying Cambrian strata, but it is used in this report in the restricted sense, that is, for the sandstone exposed at Dresbach, that being the definition adopted by the United States Geological Survey. The Dresbach sandstone, which in the type region is a white, incoherent fine-grained sandstone, is of Upper Cambrian age, whereas the underlying shales and sandstones are believed by geologists of the United States Geological Survey to belong to the Middle Cambrian.

DISTRIBUTION.

Sandstones referred by Calvin to the Dresbach outcrop in Iowa, along the base of the Mississippi bluffs in Allamakee County from Lansing north to the State line.

It is quite possible, however, that these strata belong to the St. Lawrence formation, and if this is true the Dresbach sandstone nowhere comes to the surface within the limits of the State.

At Dubuque (Pl. VI, p. 258) the Dresbach and underlying Cambrian strata were cut by the drill to a depth of 1,100 feet, the base of the Cambrian not being reached. To the west these strata seem to thin. In east-central Iowa their total thickness is 360 feet at Cedar Rapids (Pl. XI, p. 382), and 463 feet at Tipton (Pl. X, p. 374), not including the red clastic series (Algonkian?) already mentioned. In northwestern Iowa the Dresbach and underlying Cambrian strata probably thin rapidly, as they rise on the western side of the median trough that traverses the State. In central Iowa, at Des Moines and

Boone (Pl. XVI, p. 672), it is difficult to draw the line separating the Dresbach sandstone from the overlying St. Lawrence formation.

LITHOLOGIC CHARACTER.

The Dresbach and the subjacent Cambrian strata include thick beds of sandstone of rolled grains of moderate coarseness, ranging in color from white to yellow and buff. These saccharoidal sandstones are pervious, especially in northeastern Iowa. Close-textured beds also occur whose pore spaces have been filled with limy cements. Sandstones are found whose angular grains of quartz are so minute and so closely packed that the rock must be well-nigh impermeable, and with these may be ranged marls, whose fine siliceous grains were mingled with mud and lime as they were laid on the sea floor. These marls and impure sandstones contain many dark-green, round, subtranslucent grains of glauconite. Limestones are unknown. No order of succession has been made out for the beds. In several wells, as those at Dubuque, Manchester, Anamosa, and Tipton (Pls. VI, IX, X), the upper sandstone (Dresbach sandstone) rests on marls or arenaceous limy shales, which are in turn succeeded by heavy basal sandstones.

ST. LAWRENCE FORMATION.

DISTRIBUTION.

On the Dresbach sandstone rests a heavy body of dolomite and shale, known as the St. Lawrence formation, which outcrops as calcareous and sandy shales in the bluffs of the Mississippi in the northeastern county of the State. In eastern and north-central Iowa the limits of the formation are usually well drawn in deep-well sections, and its dual nature, dolomitic above and argillaceous below, is clearly seen. To the southwest the limits of the formation become difficult to trace, as the sandstones, both above and below, become more dolomitic or more clayey. At McGregor (Pl. V, p. 258) the formation consists of a few feet of arenaceous dolomite, left uneroded in the bottom of the preglacial channel of the Mississippi, and by 113 feet of green shale immediately subjacent. At Waverly (Pl. VII, p. 272) and Sumner the upper dolomitic beds are respectively 150 and 170 feet thick and the shales and marls beneath reach the surprising thickness of more than 300 feet. In each of these places sandy beds occur near the middle of the shales, and if the upper limit of the Dresbach were drawn at the summit of these sands the thickness of the shales left to the St. Lawrence would accord with the thickness reported in other deep-well sections. At Charles City the formation was penetrated for probably 330 feet. (See Pl. V.) Owing to a gap in the record, the upper limit is not certainly known.

At Dubuque an imperfect record allows less than 200 feet for this formation. At Manchester it reaches a total of 242 feet. (See Pl. VI.) Southwest of Dubuque the massive basal shales and arenaceous marls fail to maintain themselves. At Anamosa (Pl. IX, p. 354) the formation consists (from above down) of 145 feet of dolomite, 55 feet of shale, and 40 feet of dolomite. At Tipton (Pl. X) the St. Lawrence embraces 120 feet of dolomite resting on 100 feet of marls. At Boone (Pl. XI) the St. Lawrence is made, with much uncertainty, to include 285 feet of glauconiferous shales and marls and close-grained sandstones reaching nearly to the bottom of the well. At Des Moines (Pl. XIII p. 526) about 300 feet of similar strata, lying immediately below the Prairie du Chien, may be assigned to the St. Lawrence with much hesitation.

LITHOLOGIC CHARACTER.

The upper dolomitic member of the St. Lawrence is in places more or less arenaceous and commonly contains a good deal of finely divided angular quartzose material. Glauconite is present in many localities. The shales of the lower member are commonly somewhat calcareous and siliceous. The rocks, designated "marls," for want of a better term, consist of lime, silica, and clay and give rise to drillings of concreted gray, greenish, bluish, brown, or pink powder. The friability of the concreted mass indicates roughly the relative proportions of clay and sand, and the reaction with hydrochloric acid shows a large amount of lime and magnesian carbonates to be present in many places. The quartzose constituent is in the form of fine rounded grains and still more commonly of impalpably angular particles of crystalline quartz. Noncalcareous, plastic, pink, red, or green shales also occur, and in some places these are hard and fissile.

For these marls the characterization of Winchell of outcrops in Minnesota would seem applicable: "Greenish and shaly and yet not a shale; calcareous and not a limestone; magnesian but not a dolomite; finely siliceous but not a sandstone."[1]

JORDAN SANDSTONE.

DISTRIBUTION.

The St. Lawrence formation is overlain by a sandstone called the Jordan, from the name of a town in Minnesota at which it outcrops. In Iowa it comes to the surface only in Allamakee, Winneshiek, and Clayton counties in the valleys of the Mississippi and its tributaries. In these outcrops it has two phases—a hard sandstone, whose grains are embedded in a dolomitic matrix, as at Lansing, and a soft stone,

[1] Winchell, N. H., Geol. and Nat. Hist. Survey Minnesota, vol. 1, 1884, p. 255.

so destitute of limy cement that it can be readily excavated with pick and shovel, as at McGregor.

West of McGregor, as far at least as Charles City (Pl. V), it forms a well-defined bed about 75 feet thick, and to the southwest, at Waverly (Pl. VII) and Sumner, it is still thicker, reaching 110 feet or more. At Manchester (Pl. VI) it occurs as 86 feet of clean quartz sand, including 4 feet of highly arenaceous and calcareous shale. At Waterloo (Pl. VI) it attains a thickness of nearly 50 feet. At Anamosa (Pl. IX) it reaches nearly 100 feet, including calciferous sandstones, both above and below the main body of pure quartzose sandstone. At Monticello the drill penetrated it for 59 feet. At Cedar Rapids (Pl. XI) the data are very meager; but a distinct water-bearing sandstone, nearly 50 feet thick, is indicated at this horizon, with closer-textured sandstones in juxtaposition both above and below. At Ackley (Pl. VI) it is represented by calciferous sandstones. A gap occurs here of 100 feet, from which no drillings were saved.

In central Iowa either the limestones intervening between the St. Peter and the Jordan greatly increase in thickness, or the Jordan becomes indistinguishable in the rapidly changing assemblages of sandstones, dolomites, and shales which in this area pass downward from the Shakopee dolomite. If the former be true the Jordan is encountered at Ames (Pl. XI) 600 feet below the St. Peter in a well-marked sandstone, 100 feet thick, composed of clean quartz in well-rolled grains. At Boone (Pl. XI), however, this horizon is held by sandstones, close textured and for the most part calciferous. At Des Moines (Pl. XIII) no attempt has been made to divide the Cambrian into the formations seen farther east. In southeast Iowa few deep wells reach the Jordan. At Burlington (Pl. XIII) the Jordan, if it is present, lies within a space of 300 feet from which no drillings were obtained; above this space the strata are clearly Prairie du Chien, and below it they are different beds of the St. Lawrence or Dresbach facies. At Centerville (Pl. X) the magnesian series extends downward from the St. Peter for more than 700 feet, without reaching any heavy sandstone comparable to the Jordan nor any glauconiferous shales or marls of the St. Lawrence type.

LITHOLOGIC CHARACTER.

Typically the Jordan is a loose-textured sandstone consisting of rolled grains of clean quartz sand, white or light gray in color. In many places the grains are about as well sorted and as perfectly rounded and ground by abrasion as are the quartz spherules of the St. Peter. In certain beds, however, dolomitic grains appear among the drillings, indicating either a calcareous matrix or thin interbedded layers of dolomite. The driller recognizes the Jordan by these characteristics and by its place as the first heavy sandstone below the St. Peter, from which it is separated by an interval of not less than 300 feet.

ORDOVICIAN SYSTEM.

PRAIRIE DU CHIEN GROUP.

Prairie du Chien group is a term introduced into geologic literature in 1906 to designate the strata formerly called "Lower Magnesian limestone." This group is divided, from the bottom up, into Oneota dolomite, New Richmond sandstone, and Shakopee dolomite. The New Richmond, however, is in many places ill defined or absent.

DISTRIBUTION.

The Prairie du Chien is a distinct cliff maker, and since it is both underlain and overlain by weak sandstones it rises in bold escarpments and castellated walls along Mississippi River and all of its tributaries from the northern boundary of the State nearly to Guttenberg. Owing also to its resistant quality it is distinctly an upland group of strata, and forms much of the country rock of Allamakee and northeastern Winneshiek counties. In the bold cliffs in which the Prairie du Chien outcrops at Prairie du Chien, Wis., opposite McGregor, and to the north along the Mississippi and its tributaries, it has nowhere been found to measure more than 250 feet. In well sections, however, it appears as not less than 300 feet in thickness. In northeastern Iowa, where the dolomites are well demarked by the St. Peter and the Jordan sandstones, the Prairie du Chien varies in thickness between 300 and 400 feet. To the west in northern Iowa it maintains a thickness of 300 feet at Mason City (Pl. V) and of 375 feet at Ackley (Pl. VI). At Fort Dodge (Pl. VI) 300 feet may with certainty be assigned to this terrane. In central Iowa it seems to thicken and appears to reach 600 feet at Ames (Pl. XI) and nearly as much at Boone (Pl. XI); at Des Moines (Pl. XIII) it is probably 400 feet thick, although its base there can not be accurately determined. In southeastern Iowa, at Burlington (Pl. XIII), it can hardly measure less than 500 feet. At Centerville (Pl. X) more or less arenaceous dolomites of Prairie du Chien facies were still present when the drill had been driven 700 feet below the base of the St. Peter, and neither clean sandstones nor glauconiferous shales were found to indicate that the Cambrian had been reached. South and west of Des Moines no wells have penetrated to this horizon.

LITHOLOGIC CHARACTER.

In all parts of Iowa, unless it be in the extreme northwest, wherever the drill has reached the horizon of the Prairie du Chien it has not failed to find it with the lithologic characteristics of its outcrop quite unchanged. Everywhere it is completely and perfectly dolomitized. Drillings are mostly in the form of gray or light-buff sparkling dolomitic sand. So hard is the rock that chips of any size are rarely preserved. When such are found they show a characteristic porous or vesicular texture. Heavy beds of dolomite occur which are quite free of arenaceous material, but with them are always to be found sandy dolomites and thin interbedded dolomites and sandstones. When a complete series of drillings is at hand the Prairie du Chien commonly exhibits a rapid alternation of beds differing in their arenaceous content, and sections based on a few widely separated samples can not be reckoned reliable in detail. Quartz sand, native in part but no doubt also in part fallen from the St. Peter, is so common in drillings from strata at this horizon that the rock is designated "sand and lime" in many drillers' logs. Chert is another invariable constituent of the Prairie du Chien. Usually white in color, it is not accompanied by the bluish translucent chalcedony characteristic of the geode beds of the Mississippian. In places a siliceous oolite is found, both in outcrops and in drillings; in the latter it is recognized by the white, round grains of chert broken from their matrix and showing concentric structure on fractured surfaces.

The sand grains of the Prairie du Chien are generally rounded, of clear quartz similar in facies to the St. Peter and Jordan sandstones. The New Richmond sandstone, however, in many places displays, both in outcrops and in well drillings, grains which under the microscope show pyramidal secondary enlargements of crystalline silica in optical continuity with the original grains. These crystal facets give a distinctive sparkle to the sand in mass.

Along with these typical features of the Prairie du Chien are others that are local and exceptional. Such are marly beds, which yield drillings of whitish-gray or pink powder that effervesces freely in strong hydrochloric acid, leaving a clayey and minutely quartzose residue. Thin beds of green or red shales occur in some places. Especially worthy of note is a sandy shale found in places as the upper part of the Shakopee dolomite immediately underlying the St. Peter sandstone; at Boone (Pl. XI) this shale is 10 feet thick and at Anamosa 40 feet (Pl. IX, p. 354). The Shakopee is distinctly argillaceous at Belle Plaine. At Holstein a red caving shale occurs 20 feet below the bottom of the St. Peter; and at Sanborn, according to the driller's log, shale and sand extend for 200 feet below this level. (See Pl. XVII, p. 824.)

A wholly exceptional facies is that shown in a drill hole sunk for oil near Maquoketa (Pl. X), the driller's log of which states that for 241 feet below the St. Peter there extends a brick-red argillaceous sandstone, of fine rounded grains, including seams of red shale. As only one sample was supplied for the entire 241 feet, it was the writer's first impression that the drilling might have been colored by particles resulting from the continuous caving in of a comparatively thin bed of red shale situated near the top of the Shakopee. But the log was made out with unusual care by the foreman in charge of the work, and an inspection of the discharge from the sand pump, made after the work was nearly done, showed so large an amount of the red sandstone as to give much support to the statement of the log. If the unconformity believed by some geologists to exist between the Shakopee and the St. Peter is found in eastern Iowa, the sandstone in question may be a continental deposit in a small trough or basin, covered on subsidence by the St. Peter sandstone. So unlike is it to any other body of rock belonging to the St. Peter or the Shakopee in Iowa that the writer has not classed it with either terrane.

The presence of rocks of reddish color underneath the St. Peter is reported in a number of wells in Minnesota and Illinois, though never to such a thickness as at Maquoketa. Thus in Minnesota the deep well at East Minneapolis shows 102 feet of red limestone at this horizon,[1] and the well at the West Hotel[1] a dolomitic limestone 82 feet thick, reddish in color at top. In Illinois a red marl immediately subjacent to the St. Peter is reported as 32 feet thick at Lake Bluff,[2] 45 feet thick at Winnetka,[2] and 40 feet thick at Joliet.[3] At the paper mill at Moline "red marl and limestone" 316 feet thick is reported at this horizon, and at the East Moline well the St. Peter is underlain by 105 feet of limestone resting on 35 feet of red marl.[4]

If the red argillaceous sandstone at Maquoketa be not a continental deposit, it must be placed with the Shakopee.

ST. PETER SANDSTONE.

DISTRIBUTION.

The St. Peter sandstone, which overlies the Prairie du Chien group, is one of the most remarkable water-bearing formations of the State. Owing to its slight resistance to weathering and erosion it outcrops only in a narrow, sinuous belt about the outer margin of the Prairie du Chien. In the valley of Mississippi River it is seen in the sides of the bluffs as far south as Dubuque, and in the valley of Oneota River and its tributaries it extends a short distance into Winneshiek County. Its chief exposures are, however, in Allamakee County. It consists of a bed of sandstone, normally white but in many places stained with iron oxides, which reaches a thickness of 70 to 100 feet. The thickness of the formation, as disclosed

[1] Hall, C. W., Bull. Minnesota Acad. Nat. Sci., vol. 3, 1889, p. 139.
[2] Stone, Leander, Bull. Chicago Acad. Sci., vol. 1, 1886, p. 96.
[3] Leverett, Frank, Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, p. 799.
[4] Udden, J. A., idem, p. 848.

by the deep wells of Iowa, differs widely, though not so widely as in Wisconsin, where, owing to the irregular surface of the Shakopee, on which the St. Peter was laid, it ranges in thickness from 200 feet in troughs to an exceedingly thin layer on crests of the underlying dolomites. In the Iowa wells the maximum reported thickness is 110 feet at Emmetsburg (Pl. XVI, p. 872) and the minimum 15 feet at Pella (Pl. XIV, p. 548).

The St. Peter probably underlies the entire State, except the extreme northwestern part. In the southwestern part it has not yet been reached, but its recognition at Lincoln, Nebr.,[1] and at different places in Missouri makes its presence there not improbable.[2]

The St. Peter reaches its highest elevation in Allamakee County, where it lies not far from 1,200 feet above sea level. It sinks continuously to the southwest, and at Des Moines, where last found in deep drilling (Pl. XVI), it lies at 1,114 feet below sea level, or more than 2,300 feet below its elevation in the northeast corner of the State. In northern Iowa it dips both from the east and from the west toward the median line of the great syncline of the Paleozoic strata, and in southeastern Iowa it rises in the Ordovician dome, so that it stands higher at Burlington and Keokuk than at Davenport and Mount Pleasant. The formation is so important, being the first of the great series of water-bearing beds which constitute the aquifers of the Iowa artesian system, and it is so easily recognized by the driller and the layman, that its elevation above sea level is presented on the map (Pl. I, in pocket).

LITHOLOGIC CHARACTER.

In its outcrops the St. Peter is a massive homogeneous bed of sand, so loosely cemented that it is readily excavated with the spade. Hand specimens of any size are difficult to obtain. No traces of lamination or oblique stratification appear, and the few ill-defined bedding planes are 10 to 15 feet apart.

The individual grains are exceptionally uniform in size. They are of clear quartz, worn no doubt from the crystalline grains of acidic igneous rocks and representing the survival of the hardest. In this respect they differ from the varicolored grains of the Dakota sandstone and the sand beds of the drift. They are also remarkable for the perfection of their rounding. The smoothness of these spherules and their "millet seed" appearance suggest that they had suffered long attrition under the winds of ancient deserts before they were deposited in the sea. Their shape distinguishes them from the subangular sands of the coal measures and from the faceted grains of

[1] Sixth Bienn. Rept. Nebraska Commissioners Public Lands and Buildings, 1888, pp. 59–84.

[2] The St. Peter sandstone has been found recently at Nebraska City, Nebr., at 2,783 feet below the surface.

the New Richmond, as well as from those Cambrian sandstones that are composed of minute angular particles of quartz.

The transition from the St. Peter, either to the beds above it or to those below, is not everywhere abrupt. Arenaceous shales may intervene between it and the Shakopee dolomite, and still more commonly the Shakopee seems to include thin beds of sandstone. These sandy beds were noted in the field by McGee, and led him to classify the Shakopee as a part of the St. Peter.[1] To recognize such sand beds in the drillings of deep wells is far more difficult, but probably the considerable amount of quartz sand in many wells, mingled with dolomitic chips from the Shakopee, comes from intercalated sandstone beds rather than from above or from sand disseminated throughout the limestone. At Boone and Sabula the St. Peter apparently includes intercalated beds of sandy shale. The St. Peter is also in places overlain by transitional sandy shales and limestones, the deposition of which in some areas inaugurated the Platteville epoch. At Des Moines a brown arenaceous dolomite, 30 feet thick, is parted from the St. Peter by a hard green shale 10 feet thick. (See Pl. XIII, p. 526.) At Washington (Pl. X) the St. Peter is overlain by a thin bed of sandy shale. At Charles City (Pl. V) a stratum, 70 feet thick, of fine-grained argillaceous sandstone rests on St. Peter of normal facies. At Mason City (Pl. V) a yellow, highly arenaceous dolomite 20 feet thick, and at Belle Plaine (Pl. VIII) a thin bed of arenaceous limestone occupy this horizon. At Postville (Pl. V) the St. Peter was apparently encountered at 755 feet above sea level; but, after passing through 14 feet of this sandstone, the drill entered limestone of Platteville facies, in which it continued to 689 feet above sea level, when it reached an arenaceous, nondolomitic limestone, which continued 13 feet to the bottom of the boring. If studied in the field, it is probable that some of these arenaceous transition beds would be classed with the St. Peter, but for the purposes of this investigation it has seemed better to place them with the superjacent or subjacent formations.

ROCKS BETWEEN THE ST. PETER SANDSTONE AND THE MAQUOKETA SHALE.

SUBDIVISIONS.

Upon the St. Peter sandstone rests a series of limestones, shales, and dolomites which extends upward to the base of the Maquoketa shale. The upper dolomitized beds of this series have long been known as the Galena dolomite, while the lower limestone and shales have usually been termed the "Trenton." In the report of the

[1] McGee, W J, Pleistocene history of northeastern Iowa: Eleventh Ann. Rept. U. S. Geol. Survey, pt. 1, 1891, p. 332.

senior author on the artesian wells of Iowa [1] the entire series was treated as a single formation, called the "Galena-Trenton," whose strata were shown to be affected by dolomitization to varying depths at different places. Since the publication of this report an intermediate formation, the Decorah shale, has been discriminated. The calcareous beds which overlie the Decorah shale are now known as the Galena dolomite, and the limestones and shales which intervene between the Decorah shale and the St. Peter sandstone are termed the Platteville limestone. These formations rise to the surface in northeastern Iowa in a very broken and irregular area, which extends from the northwestern part of Winneshiek County as far south as Bellevue in Jackson County.

PLATTEVILLE LIMESTONE AND DECORAH SHALE.

In well sections the Platteville is singularly persistent. It embraces a shale bed immediately overlying the St. Peter—the Glenwood shale of the Iowa State Survey—and an overlying body of limestone. Few well sections in Iowa reach the horizon of the St. Peter without finding either this basal shale of the Platteville or the higher Decorah shale, although in many wells the three divisions can not be made out.

The shales of the Platteville limestone and the Decorah shale are typically rather harder, darker, and a brighter green than the Maquoketa shale. Even where no record or sample of them is preserved, characteristic chips, evidently fallen from above, are sometimes brought up from lower levels. At Manchester (Pl. VI) both the Decorah shale and the basal shale of the Platteville were found, the Decorah being 5 feet thick and carrying *Orthis perveta* Conrad, *Strophomena trentonensis* W. and S., and several Bryozoa. A body of typical earthy blue-gray Platteville limestone, 72 feet thick, here intervenes between the two beds of shale, the lower one of which is only 7 feet thick. In northern Iowa, at Hampton, the basal shale of the Platteville is 40 feet thick; at Charles City (Pl. V) 70 feet of arenaceous shales are overlain by 90 feet of more typical shale; at Waverly (Pl. VII), Sumner, Maquoketa (Pl. X), and Clinton (Pl. XI), the Platteville limestone and the Decorah shale are well exhibited, their total thickness in the last two places measuring about 100 feet, including the shale at the base of the Platteville. In northwestern Iowa the basal shale of the Platteville reaches 50 feet at Sanborn (Pl. XVII), 95 feet at Emmetsburg (Pl. XVI), 110 feet at Mallard (Pl. XVI), and somewhat less than 50 feet at Cherokee and Holstein (Pl. XVII). At Des Moines the basal shale member of the Platteville is also present, and the Platteville and the Decorah have a combined thickness of 50 feet (Pl. XVI), but the limestone of the Platteville is exceptional in that

[1] Rept. Iowa Geol. Survey, vol. 6, 1897, pp. 145 ff.

it is dolomitic. In southeastern Iowa the Platteville reaches a thickness of 90 feet at Pella and of 100 feet at Burlington. (See Pl. XIII.)

The Decorah shale extends to the extreme southwest corner of the State; for in the deep boring at Nebraska City, Nebr., it was found at a depth of 2,754 feet, and its identification by stratigraphic and lithologic characteristics was amply confirmed by Ulrich's determination of the distinctive fossils *Stictopora angularis* and *Dalmanella subæquata* var. *minneapolis* (?).

In a number of places the Platteville limestone includes a brown bituminous shale from which the drill chips fragments that readily give forth long flames when ignited. This is the case at the Platteville outcrops near Dubuque. In southeastern Iowa this bituminous shale occurs at Pella, Letts, Washington, and Burlington. Its presence is of special interest, for it is from this horizon that the natural gas and petroleum of some large fields in other States rise to be stored in the reservoirs of overlying rocks. The presence of bituminous shale or other bituminous rock as a source is but one of the conditions for the accumulation of these illuminants in paying quantities. As no oil or gas has been found in the wells which reach the Platteville, even where the formation is bituminous, it is evident that some of the other equally necessary conditions do not exist in Iowa in any area yet explored.

The limestone of the Platteville is typically compact, blue or gray, more or less argillaceous, and in many places fossiliferous; under the drill it is broken to rather large flaky chips of earthy luster. The magnesian content is not sufficient to prevent brisk effervescence in cold dilute hydrochloric acid.

In places the Decorah shale is lacking or unreported, and here no definite boundary can be drawn between the Platteville limestone and the overlying Galena dolomite.

GALENA DOLOMITE.

The Decorah shale is overlain by a heavy body of limestone or dolomite, known as the Galena dolomite, which extends upward to the base of the Maquoketa shale. In its outcrops in Dubuque County, where it is a marked cliff maker along the bluffs of Mississippi River and its tributaries, the Galena is known as the lead-bearing rock, and is a rough, vesicular buff cherty and crystalline dolomite. More or less of the formation is completely dolomitized in other counties of its outcrop in northeastern Iowa, but dolomitization is by no means universal. In well sections the formation varies, at the same horizons, from a rather soft nonmagnesian limestone similar to the Platteville to a crystalline dolomite entirely similar to those of its outcrops near Dubuque. Thus in passing from Dubuque 40 miles west to Manchester the Galena changes from a homogeneous body of heavily bedded dolomite fronting the Mississippi in a wall 250 feet high to a series of thin-bedded earthy blue and gray limestones. Dolomite is absent also at Waterloo and Waverly. Where only a part of the formation is dolomitized, as at Sumner, Charles City, and Hampton, it is generally the upper portion. Dolomitic beds are present at Anamosa, Monticello, Clinton, Cedar Rapids, Tipton, Boone, and Fort Dodge. West of Des Moines River only dolomites occur in the samples of the drillings of this terrane. In central Iowa the formation is wholly dolomitic and in southeastern Iowa either the entire formation or the great bulk of it is either dolomitized or is crystalline and strongly magnesian.

THICKNESS OF THE PLATTEVILLE, DECORAH, AND GALENA FORMATIONS.

In northeastern Iowa the Galena, Decorah, and Platteville formations have a combined thickness ranging from 300 to 350 feet. At Vinton their combined thickness is 401 feet and at Waverly it is 420 feet. In northern Iowa these formations persist far to the west. At Charles City (Pl. V) they together measure 380 feet, at Mason City (Pl. V) 405 feet, at Mallard (Pl. XVI) 375 feet, and at Emmetsburg (Pl. XVI) hardly less than 300 feet. At Osage (Pl. VII) they appear to be about 500 feet thick, but the apparent increase is probably caused by including dolomitic portions of the Maquoketa. At Holstein magnesian limestones at this horizon aggregate 500 feet in thickness, and at Cherokee they measure 300 feet. (See Pl. XVII.) In the extreme northwestern part of Iowa the formations appear to thin and may feather out. At Sanborn (Pl. XVII) the driller's log places a bed 50 feet thick of "shale with streaks of rock" immediately above the St. Peter, and this bed may represent the entire thickness of the three formations, Galena, Decorah, and Platteville. In central Iowa the combined thickness probably attains its maximum, measuring 410 feet at Boone and 508 feet at Des Moines. (See Pl. XVI.) In southeastern Iowa it thins markedly. At Pella the beds measure 350 feet, at Burlington 273 feet, and at Mount Pleasant 256 feet. (See Pl. XIII.)

MAQUOKETA SHALE.

DISTRIBUTION.

The heavy bed of dark bluish-gray clay shale overlying the Galena dolomite is known as the Maquoketa shale. It forms a thin surface cover over the Galena in a broad but broken belt across Winneshiek and Clayton counties, and it outcrops here and there along Mississippi River and its tributaries as far south as Clinton. It disintegrates so rapidly as to allow the massive overlying Niagara limestone to form a bold mural escarpment extending along the entire length of Turkey

River on the western side—an escarpment that clearly marks not only the south and west limits of the Maquoketa as country rock but also fixes the western boundary of formations of the Cambrian and Ordovician rocks.

The Maquoketa varies greatly along its narrow outcrop from Clinton northwest to the Minnesota line. To the southeast it is a heavy body of shale. Thickening to the northwest, it comes to include an upper shale 125 feet thick, a medial bed of cherty magnesian limestone in places 50 feet thick, and lower beds of shales and shaly limestones which may locally attain a thickness of 100 feet; in well sections this triple division, which was perhaps first observed in this investigation, is well demarked. Again, in many wells the formation may appear as a single undivided body of shale, as in its outcrops in Jackson and Clinton counties. The tripartite division obtains in northeastern Iowa and extends west at least as far as Ackley. Thus at Sumner the upper Maquoketa measures 80 feet, the middle 70 feet, and the lower 50 feet. At Manchester (Pl. VI) the median bed is represented by a thin bed of limestone situated about 50 feet from the bottom of the terrane. At Waterloo (Pl. VI) the upper beds are 160 feet thick, the middle 75 feet, and the lower 30 feet. At Charles City (Pl. V) the middle Maquoketa is 30 feet thick, and at Ackley 21 feet (Pl. VI). At Hampton the main body of shale is as usual the upper Maquoketa, and below it are ranged alternately two beds of limestone and two of shale, each about 20 feet thick. At Fort Dodge also beds of limestone occur at several horizons within the supposed limits of the formation. Southward from northeastern Iowa the Maquoketa appears as an undivided body of shale, as might have been expected from the disappearance of its median limestones along its southern outcrops.

LITHOLOGIC CHARACTER.

The shales of the Maquoketa are both softer and paler than the Cambrian shales, and they lack the arenaceous content found in many places in the latter. Their bluish rather than greenish tint helps to distinguish them from the Decorah shale. They are not arenaceous, as are some of the Mississippian shales, and the absence of carbon and the presence of lime serve to distinguish them from many of the Pennsylvanian shales. They resemble most nearly the shales of the Kinderhook group (lower Mississippian). Drillers know them by the forcible and not inappropriate term of "mud-rock" shales, since they appear in the slush bucket as a blue mud. Drillings are preserved in hard molded masses of concreted clay, gritless but calcareous and magnesian. In places the Maquoketa is highly pyritiferous. It includes in some areas bituminous brown shales. These are found near the base of the formation in the wells at Monticello, Tipton, and Anamosa, and in the drill hole near Maquoketa sunk for oil. This drill hole was sunk because a show of oil was found on the surface of a spring, or sink-hole pool, near the site where the well was afterwards drilled, and if this crude petroleum was derived from any subterranean source it probably came from the Maquoketa shale. At Grinnell (Pl. XV, p. 670) bituminous shales 20 feet thick occur 70 feet below the assigned top of this formation.

SILURIAN SYSTEM.

NIAGARA DOLOMITE.

DISTRIBUTION.

Among the best water-bearing rocks of eastern Iowa must be ranked the Niagara dolomite, the only formation of Silurian age that outcrops in the State. Beginning at the prominent Niagara escarpment which borders Turkey River along its entire course, filling the great eastern bend of Mississippi River to Davenport, and lying east of a slightly irregular line drawn from West Union to Muscatine stretches the area over which this limestone outcrops or wherein it lies immediately below the drift.

LITHOLOGIC CHARACTER.

Except at one or two localities the Niagara is completely dolomitized. Chert is not uncommon, especially in the lower beds. Minor differences in color and texture characteristic of the subdivisions of the Niagara can seldom be discriminated in well drillings. Lithologically, the Niagara of wells situated near its outcrops and for some distance west is a light-buff, gray, or bluish dolomite, commonly subcrystalline and vesicular. Under the drill it may be crushed to sparkling sand and drillers may therefore report it in well logs as "sand rock."

Field surveys have shown that the Silurian pinches out in northern Iowa until the Devonian overlaps upon the Maquoketa shale, and the same condition is found in wells. The formation at the Tipton outcrop is 325 feet thick, but at Waterloo it has thinned to 107 feet and at Waverly to 50 feet. (See Pl. VII.) At Osage (Pl. VII) but 150 feet seems to be left for the combined thickness of both Silurian and Devonian. At Hampton but 80 feet can be allowed for the Niagara. At Charles City (Pl. V) the Silurian may reach 180 feet, but as the rocks assigned to this horizon are not lithologically characteristic the estimate may be a good deal too large and may include some rocks properly belonging either to the Maquoketa or to the Devonian.

West of its area of outcrop the Silurian suffers lithologic changes which make its boundaries in many places difficult to determine. Thus, at Charles City (Pl. V) it is supposed to include a considerable amount of more or less argillaceous limestones that can hardly be assigned to the Maquoketa, because they would increase its thickness beyond probable measures. West of Cedar Rapids, along the line of the Chicago & North Western Railway, the Niagara facies is retained at Belle Plaine, where the formation measures 345 feet. (See Pl. XI.) At Marshalltown the Silurian is diminished to about 300 feet and includes brown magnesian limestones and nonmagnesian cherty limestones; several samples show more or less gypsum. At Ames and Boone the Silurian includes dolomites, thin shales, and more or less magnesian sandstones and limestones, the upper limit being drawn with great uncertainty, chiefly on stratigraphic evidence. At Ackley the Niagara comprises about 180 feet of dolomite, but at Fort Dodge, farther west, the strata have so changed lithologically that the summit of the Silurian is very uncertain. (See Pl. VI, p. 258.)

In southeastern Iowa the Silurian includes a calciferous sandstone, which at Washington is reported to be 100 feet thick. At Des Moines (Pl. XVI) arenaceous beds occur near the base of the terrane; at Centerville they are 50 feet thick and are composed of fine grains of clear quartz, moderately well rounded and sorted, many grains showing secondary enlargements whose facets give a peculiar sparkle to the drillings. Beneath this sandstone lies 60 feet of sandy limestone. At Ottumwa a sandy limestone is reported at about this horizon.

SALINA (?) FORMATION.

LITHOLOGIC CHARACTER.

West and south of its outcrops the Silurian comprises an assemblage of limestones and in places red, ferruginous gypsiferous marls and beds of anhydrite, which seem best tentatively referred to the Salina, although this terrane has not been positively identified west of the Great Lakes. Gypsum and anhydrite are uncommon in the rocks of Iowa. Isolated crystals of selenite are present in some of the shales, and beds of gypsum occur in the Permian deposits of Webster County and in the "St. Louis" strata of Appanoose County. Both of these horizons are too high to be correlated with the gypsum deposits found in the deep wells. Apart from these two horizons drillings from Iowa wells have shown gypsum or anhydrite only at the horizon attributed for good stratigraphic reasons to the Silurian. In this system, however, these minerals are in places too conspicuous to escape notice. Bits of white gypsum or of the harder anhydrite are readily noted among the limestone chips. The whole content of the slush bucket may be a whitish mud concreting to tough masses quite unlike marls of similar color. Under the microscope many specimens show a field largely occupied with broken crystals of gypsum or anhydrite, whose identity is recognized unmistakably by their brilliant colors under polarized light and by their distinctive cleavages. Chemical tests confirm these observations.

DISTRIBUTION.

These deposits are assuredly Silurian at Marshalltown, where the Niagara outcrop is but 75 miles to the east. In central and southern Iowa the presence of the Kinderhook above these beds and of the Maquoketa shale below them limits their horizon to either the Devonian or the Silurian. It is most unlikely that they can belong to both, and between the two the choice is not difficult. The absence of such beds from the Devonian elsewhere, their common presence in the Salina of the eastern United States, and other stratigraphic reasons leave little doubt that the beds in question belong to the Silurian and are of Salina age. The presence of a bed of gypsum may therefore be used as a means of correlation. At Des Moines, for example, where 588 feet of limestone lies between the base of the Kinderhook and the summit of the Maquoketa, the presence of gypsum 80 feet from the top and of well-marked beds below leaves not more than 80 feet to the Devonian and more than 500 feet to the Silurian. (See Pl. XV.) On the same assumption, the Silurian at Grinnell is assigned 414 feet, the gypsum beds being confined to the upper 247 feet; at Pella it is assigned 255 feet (Pl. XIII), and at Mount Pleasant, where the anhydrite beds are especially well marked, about 100 feet. The uncommon thickness thus allotted to the Silurian at Des Moines and Grinnell leads to drawing the boundary between the Silurian and Devonian higher at neighboring points, as at Boone and Ames, than might otherwise be done. (See Pl. XI, p. 382.)

If the sub-Mississippian gypsum of central and eastern Iowa is considered Silurian, the horizon of the gypseous beds found in southwestern Iowa below the Carboniferous may also be referred to the Silurian; but the area is so remote from the outcrops of the terranes below the Pennsylvanian, and deep wells are so few, that the geologic sections in the few deep drill holes that pass below the floor of the Pennsylvanian can be made out only with the greatest difficulty. In the well at Glenwood (Pl. XVIII) a 70-foot bed of gypseous limestones and shales was struck at a depth of 1,924 feet. If 262 feet of superjacent dolomites and magnesian limestones and an included bed of sandstone are added, the Silurian will have a probable thickness of 332 feet. At Bedford, 60 miles southeast of Glenwood, beds of gypseous marl and limestone begin at 2,005 feet from the surface and continue to at least 2,350 feet. It is interesting to note that here ferruginous red and pink limestones occur above the gypseous beds, tending to confirm the suggestion that these beds represent the deposits of the arid climate of the Salina epoch. At Council Bluffs magnesian limestones referred to the Silurian and destitute of gypsum form the chief bed.

Though the Silurian as a whole thins out in northeastern Iowa, it thickens toward central Iowa, maintaining a thickness of more than 300 feet to the southwestern border of the State.

In southeastern Iowa the local upwarp of the lower Ordovician strata causes a notable thinning of the Silurian beds toward the dome. Thus the Silurian at Davenport, 345 feet thick, thins to some undetermined part of the 180 feet allotted to the combined Devonian and Silurian at Burlington and to a probable 60 feet at Keokuk. (See Pl. XII.) At Pella the thickness of the combined Silurian and Devonian is 420 feet, at Mount Pleasant it is about half that measure, and at Burlington it is compassed within 180 feet. (See Pl. XIII.) The thickness of the Silurian and Devonian at Centerville is nearly 400 feet (Pl. X); 80 miles east of Centerville, at Fort Madison, it measures only 142 feet (Pl. XII, p. 514).

DEVONIAN SYSTEM.

The Devonian limestones and shales occupy a wedge-shaped area whose wide base lies along the northern boundary of the State from Winnebago County to Howard County. Pointing southeastward and gradually narrowing, it comes to an apex in Scott and Muscatine counties. The Devonian includes rocks formed during three principal epochs. The uppermost formation, the Lime Creek shale, which is of Upper Devonian age, is typically exposed in Cerro Gordo and adjoining counties, where it comprises blue and yellow shale (the Hackberry substage of the Iowa State Survey) 70 feet thick, overlain by dolomite and shale (the Owen substage of the Iowa Survey) exceeding 50 feet in thickness.

In other parts of the State the uppermost Devonian formation is known as the Sweetland Creek shale, and in still other areas it is represented by the State Quarry limestone of the Iowa Survey reports. These three formations have been regarded as more or less contemporaneous. Each rests unconformably upon the Cedar Valley limestone. The medial formation of the Devonian—the Cedar Valley limestone—is of Middle Devonian age, and is the most widely distributed of the three. It comprises an assemblage of limestones varying widely in color and texture and argillaceous content, and in the northern counties includes dolomitic beds, but over most of the area the magnesian content falls far short of that requisite for dolomite. The thickness of the Cedar Valley limestone in Johnson County is estimated at 104 feet by Calvin. The lowest Devonian formation—the Wapsipinicon limestone—is also of Middle Devonian age. It consists of blue and yellow shales, cherty argillaceous limestones, local beds of coal and coaly shales (the Independence shale member), gray lithographic limestones, and breccia beds along with limestone of other types. The lowest beds of the Wapsipinicon are dolomitized and can not always be distinguished in drillings from the Silurian dolomites.

These Devonian formations can be distinguished from each other in some deep wells, but as a rule they can not be separated, and it is with considerable difficulty that even the limits of the Devonian as a whole are drawn. Thus the highest shale of the Devonian may be immediately overlain by shale of the Kinderhook group. Where this occurs and fossils are absent, the discrimination has been found impracticable even in outcrops. Certain shales in a well at Hampton are classified as Devonian rather than Kinderhook, owing to their stratigraphic correspondence with certain heavy shales, apparently Devonian, that outcrop at Sheffield. At Belle Plaine the highest shales of the section are placed with the Devonian only because of the general dip of the strata of the region. (See Pl. XI.) Apparently there is in central Iowa a strong development of the Lime Creek shale, but it can be separated from the Kinderhook only by more or less arbitrary lines, drawn by the accepted areal distribution and the supposed dip of the strata.

In discriminating the dolomitic beds of the Devonian from those of the Silurian, the Silurian beds, except those of northeastern Iowa, are generally considered the more persistent and the heavier. Though the area of outcrop of the Devonian is wide, measuring about 75 miles on the north from east to west, the thickness of the terrane at any point on the area of outcrop is not large. At Waverly (Pl. VII) a well section shows a total thickness of only 70 feet of Devonian rocks, above which the natural outcrops rise some 50 feet higher.

The greatest thickness attributed to the Devonian is at Marshalltown (Pl. XI), Ackley (Pl. VI), and Hampton, where it seems to reach 300 feet. At Grinnell (Pl. XV) it is given as about 200 feet and is largely shaly. At Homestead (Pl. XV) heavy shales below the drift lie at the Devonian horizon, but if there is here a downwarp, the shales may be Kinderhook instead. In southeastern Iowa the Devonian nowhere reaches more than 175 feet in thickness. At Washington (Pl. X) 100 feet can be assigned to it with some certainty. At Letts (Pl. XIV), Mount Pleasant (Pl. XIII), and Burlington the Devonian somewhat exceeds 100 feet, and at Pella and Sigourney (Pl. XIV) it reaches about 170 feet. In several places, however, the rocks ascribed to the Devonian may include more or less of the basal portion of the heavy shales whose main body is unquestionably Kinderhook.

CARBONIFEROUS SYSTEM.

MISSISSIPPIAN SERIES.

OUTCROPS AND SUBDIVISIONS.

Mississippian (lower Carboniferous) rocks outcrop along a belt of varying width extending from Kossuth and Winnebago counties on the north to Mississippi River on the southeast, and along the river from Louisa County to the Missouri State line. The series embraces a wide variety of rocks. With two or three exceptions its formations are not thick, and in well sections lithologic change is comparatively rapid.

The Mississipian of the Iowa State Survey reports, and as used in this report, comprises three major subdivisions which, from the base upward, are known as the Kinderhook group, the Osage group, and the "St. Louis limestone." The Osage group of this report, however, is not exactly the same as the Osage group of the United States Geological Survey, since, for convenience, the former includes at the top the lower part of the Warsaw limestone, the upper part of the Warsaw being included in the overlying "St. Louis limestone," as that formation is defined in this report.

KINDERHOOK GROUP.

The Kinderhook group embraces a median heavy shale with limestones above and below. In central Iowa the upper nonargillaceous beds are strongly developed and furnish the white oolitic and the buff magnesian limestones of Tama, Marshall, Franklin, and Humboldt counties. In most well sections it is quite impossible to discriminate any basal limestones from those of the Devonian, and it is in many places equally impracticable to discriminate the upper limestones of the Kinderhook from the overlying limestones of the Osage group. The main body of shale, however, is one of the best-defined in the State, especially in southeastern Iowa. At Burlington, Mount Clara, and Mount Pleasant it runs from 300 to 370 feet in thickness; at Fort Madison it is 268 feet thick, and at Keokuk about 225 feet. (See Pl. XII, p. 514.) North and west from its outcrops in the extreme southeast of Iowa, the shales thin somewhat. At Ottumwa (Pl. X) they measure 165 feet, at Grinnell (Pl. VIII) 170 feet, at Sigourney (Pl. XIV) 198 feet, at Pella and at Oskaloosa less than 125 feet. (See Pl. XIII.) In central and northern Iowa, as on the uplands of southeastern Iowa, the shales of the Kinderhook generally fail of exposure, as in preglacial time their outcrop formed a belt of weak rock wasting to lower levels than the area of stronger rock adjacent, and during the Pleistocene this trough was deeply filled with drift. The absence of rock exposures along a belt of considerable width bordering the line of the westernmost Devonian outcrops may thus be explained.

In central Iowa the chief beds of the Kinderhook which reach the surface are limestones. The section at Marshalltown (Pl. XI) discloses a thickness of 145 feet for this division of the Kinderhook and of 175 feet of underlying shales. At Ackley (Pl. VI) 207 feet of shale seems to belong to the Kinderhook. At Hampton the 108 feet of shales immediately below the drift falls into two divisions and, according to Williams,[1] the same beds occur at several points in the eastern part of the county, giving rise to a line of springs.

West of a line passing through Marshalltown, Ackley, and Hampton the shales of the Kinderhook greatly diminish in thickness. They are so scant at Ames, Boone, and Fort Dodge that the boundaries of the Kinderhook are drawn with greatest difficulty. At Dayton they are wholly absent so far as the record shows, although it is possible that the well may have failed of reaching them by a few feet. Both at Boone and at Fort Dodge the base of the Kinderhook is arbitrarily drawn at a bed of thin shales lying underneath argillaceous limestones. (See Pl. XVI, p. 672.)

In southwestern Iowa, at Glenwood, shales 134 feet thick occur at the supposed base of the Mississippian, and at Bedford shales 30 feet thick are found at this horizon. (See Pl. XVIII, p. 898.)

OSAGE GROUP.

The rocks of the Osage group immediately overlie the Kinderhook. The basal limestones of the Osage are well known to all drillers in southeastern Iowa as the Burlington limestone. Under the drill they break into flaky chips, many of which are intensely white. Close examination shows that the apparent crystalline structure of many specimens is due to the crystalline cleavages of the broken plates and stem joints of crinoids. In places the stone is made up almost wholly of crinoidal fragments, and where finer cementing material is wanting the rock becomes full of interstices and permeable to water. The lower strata of the Burlington are somewhat thickly bedded with thin partings. Toward the top they include chert and brown siliceous shales. The overlying beds of the Burlington are less massive and in many places parted by shaly layers. These beds pass upward into cherts (the Montrose cherts of the Iowa Geological Survey), which form the top member of the Burlington and which outcrop along the bed of the Mississippi, giving rise by their hardness to the Des Moines Rapids, which extend from Montrose to Keokuk. Hard and resistant to the weather as these cherts are, they present no special difficulty to the experienced driller, for they are brittle, breaking easily under the stroke of the drill, and their angular white chips do not pack. They occur either irregularly bedded in shattered seams or so disposed

[1] Williams, I. A., Ann. Rept. Iowa Geol. Survey, vol. 16, 1906, p. 482.

in nodules that the solution of the limy content of the strata leaves them highly permeable and serviceable as water beds.

On account of their purity the limestones of the Burlington are highly soluble. Sink holes along the outcrops indicate where the run-off flows rapidly down to subterranean channels excavated by solution along bedding planes and joints.

Above the Burlington limestone the Osage group includes cherty coarse-grained limestone and limy shales (Keokuk limestone), which at their outcrop abound in geodes—hollow shells of chalcedony or of lime carbonate lined with crystals of quartz or calcite. The presence of this formation is in some places indicated to the driller by chips of milky chalcedony and pieces of broken crystals of clear quartz brought up in the slush bucket in some abundance. For convenience the lower part of the Warsaw limestone is included in the Osage group of this report.

"ST. LOUIS LIMESTONE."

The "St. Louis limestone," the uppermost division of the Mississippian as here differentiated, forms an important part of the country rock over Keokuk, Washington, Henry, and Lee counties, over minor areas in adjacent counties, and over Story, Webster, and Humboldt counties. Its lowest division consists of shale and shaly limestones, which properly belong to the Warsaw limestone, but which for convenience are included in the "St. Louis." A median division consists of gray sandstones, shales, and brecciated limestones, the sandstones predominating. The upper division is made up largely of heavily bedded impure magnesian limestones with some marls. These different subdivisions are distinguished in the shallower wells of the region of outcrop, but have not been traced to any distance from their outcrop by means of the deeper wells.

THICKNESS OF OSAGE GROUP AND "ST. LOUIS LIMESTONE."

The geologic sections (Pls. V–XVIII) show that the combined thickness of the Osage group and the "St. Louis limestone" as differentiated in this report varies within wide limits. The upper surface of the Mississippian is everywhere a surface of erosion, not only along its outcrops, but also where it is parted by a strong unconformity from the overlying Pennsylvanian, and for this reason inequalities of hundreds of feet are not unexpected. The change of the Kinderhook from shale to limestone in passing north and northwest from its outcrops in southern Iowa increases the thickness of the Mississippian above the shales, but here the upper limestones of the Kinderhook can seldom be discriminated from those of higher terranes. Along the eastern part of the belt of outcrop the terrane is naturally thin because of the absence of the superior members.

The thickness of the Mississippian above the Kinderhook amounts to about 300 feet in the southeastern part of the State (Pl. XIV) where it passes beneath the Pennsylvanian rocks, measuring 270 feet at Pella, 300 feet at Newton, 306 feet at Sigourney, and 320 feet at Dayton. Farther west it apparently thickens, and at Centerville (Pl. XVI) it measures a little more than 500 feet. A like thickening is observed in central and north-central Iowa. At Ames a thickness of 445 feet is assigned to the Osage and the "St. Louis," at Boone (Pl. XI) 485 feet, and at Fort Dodge 500 feet, although at each of these places the base of the Osage is by no means certain. In northwestern Iowa the Mississippian maintains a thickness of more than 200 feet at Cherokee. In southwestern Iowa (Pl. XVIII) it is given 355 feet at Bedford and 280 feet at Glenwood. At Lincoln, Nebr., it seems to have nearly or quite disappeared.

PENNSYLVANIAN SERIES.

SUBDIVISIONS.

Rocks belonging to the Pennsylvanian series (or "Coal Measures") lie at the surface or immediately beneath the drift in most of southern Iowa and immediately beneath the Cretaceous rocks in western Iowa. (See fig. 6, p. 898.) The series is divided into two groups, the Missouri and the Des Moines. The Missouri group ("Upper Coal Measures") occupies the southwestern part of the State and consists of shales and limestones. The Des Moines group ("Lower Coal Measures") outcrops to the east of the Missouri group, and is composed predominantly of shales, with some sandstones and a few beds of limestone. Drill cores and natural sections show in each group a rapid vertical lithologic alternation, and not infrequently the slush bucket brings up from the cutting of the churn drill samples of thin alternating layers of several different kinds of rock. Field exposures show rapid horizontal changes in the strata. Thick lenses of sandstone, for example, thin out in a few miles and are replaced by argillaceous beds.

DES MOINES GROUP.

The Des Moines group occupies a belt 50 to 80 miles in width, extending from the southern part of Humboldt and Wright counties southeastward to the eastern half of the Missouri State line. An outlier of about 80 square miles overlies the Devonian along Mississippi River in the southern part of Muscatine and Scott counties.

At the base of the Des Moines is a sandstone which though not everywhere present deserves special mention. In the deep wells of eastern Iowa as far west as Des Moines this sandstone is absent from the deeper wells; in southwestern Iowa it occurs in all wells which reach its horizon. At Atlantic it is 50 feet thick, the uppermost half being a gray sandstone of finest grain, succeeded by 5 feet of sandy limestone, 6 feet of brown sandstone, and 15 feet of gray sandstone. At Glenwood gray sandstone of imperfectly rounded grains 107 feet thick, including 25 feet of chert and shale, lies immediately upon the cherts of the Mississippian. At Bedford the sandstone attains 160 feet in thickness. (See Pl. XVIII, p. 898.)

The Des Moines group in southeastern Iowa consists at the base of shales with some sandstones and singularly persistent thin limestone beds rarely exceeding 1 or 2 feet in thickness. These beds are overlain by a series of persistent limestones with shales and coal seams. At the top is the conglomerate to which Bain applied the name Chariton. On the whole, the well sections of the Des Moines show a large predominance of shales, for the most part gray or blue in color, though heavy beds of dark drab and blackish shales are not uncommon, and red shales occur in many places. In composition they range from pure clay shales to limy, or sandy, or carbonaceous shales, and these may shade off horizontally into limestones, sandstone, or coal.

MISSOURI GROUP.

The upper group of the Pennsylvanian, known as the Missouri, occupies the southwest corner of Iowa, extending from the middle of the southern boundary to the middle of the western, but the hypothenuse of the triangle thus formed is overlain in the north-central part by a very broken and irregular extension of the Cretaceous. The sediments are chiefly calcareous shales interbedded with heavy and persistent beds of limestone. The latter are remarkably evenly bedded and extend over wide areas. Individual beds of limestone are much thicker than those of the Des Moines group, in places reaching a thickness of 50 feet or more. About 11 divisions of the Missouri group have been plausibly discriminated by students in the field, but as no attempt has been made to identify them in the deep-well records they need no detailed mention.

PERMIAN (?) SERIES.

The strata tentatively referred to the Permian occupy so small an area that their effect upon the distribution and quality of underground waters is insignificant. The gypsum deposits in the vicinity of Fort Dodge and the associated red sandstones and shales which have been tentatively referred to the Permian on lithologic and stratigraphic grounds are unfossiliferous. They lie unconformably upon strata of the Des Moines group or, where these have been removed by erosion, upon the "St. Louis limestone." An erosion interval of considerable length thus separates the period of their deposition from the Des Moines epoch.

CRETACEOUS SYSTEM.

DAKOTA SANDSTONE AND COLORADO GROUP.

The latest terranes of the country rock of Iowa belong to the Upper Cretaceous. They cover the northwestern part of the State and extend a ragged and broken arm southward almost to the Missouri line in Page County. Over much of the area they occur in more or less isolated patches whose borders can seldom be determined on account of the heavy cover of drift and the infrequent outcrops. On the geologic map of the State the Cretaceous is indicated as a continuous formation over the area embraced by its scattered outcrops.

The Cretaceous rocks of western Iowa belong to the Dakota sandstone and the Colorado group. They overlie the Paleozoic formations with pronounced unconformity. The Dakota is a coarse-grained, ferruginous sandstone, very poorly cemented and locally interbedded with seams of clay. In places it includes beds of very fine incoherent sand. It is of the same age as the great aquifer of the South Dakota artesian slope, but being separated from that area by outcrops of the Sioux quartzite it does not show the high artesian pressure which characterizes the formation in the South Dakota field.

Overlying the Dakota sandstone occur shales and calcareous beds of the Colorado group. Drillers in western Iowa should take special pains to discriminate these from the pebbly clays of the drifts.

TERTIARY SYSTEM.

In a few localities patches of gravel and sand discovered beneath the drift have been tentatively referred to the Tertiary system.

In Tertiary and other preglacial periods the long disintegration and decay of the country rock produced a deep mantle of residual material, which was not wholly swept away by the invasions of the Pleistocene ice sheets. Over the driftless area residual clays remain continuous and heavy. Elsewhere they have been largely removed by glacial erosion and are now found in thin and scattered patches occupying depressions in the rock surface underneath the drift. Formed of the insoluble constituents of the country rock, they spread over the limestone and shale areas of the State as stiff, plastic, and impervious clays colored deep red or brown by iron oxides. Where cherts are present in the parent rock their insoluble fragments may form a large part of the deposit.

Decay and disintegration, no doubt in large part preglacial, have affected the country rock in another way which directly concerns the distribution of ground water. Sandstones have been broken down into beds of incoherent sand by the removal of their cements, and heavily bedded limestones have disintegrated into a surface zone of thin spalls by the detachment and fracture of their constituent laminæ. Thus has been opened up beneath impervious residual clays and till sheets a zone of ready passage for ground water.

QUATERNARY SYSTEM.

PLEISTOCENE SERIES.

The Pleistocene series in Iowa comprises the deposits of five distinct glacial stages and of four interglacial stages. The deposits of the glacial invasions consist of stony clays—the ground moraines of ancient ice sheets—together with beds of sand and gravel sorted and laid by the waters of the melting ice. The stratified and unstratified deposits together constitute the drift. The deposits of the interglacial epochs include old soils, marsh, and forest beds, and sands and gravels laid by the rivers of the time. (See Pl. III, in pocket.)

NEBRASKAN DRIFT.

The oldest and lowest glacial deposit is that of the Nebraskan or sub-Aftonian stage. It embraces both sands and gravels laid down on rock by streams deploying in front of the advancing glacial ice, and also a ground moraine of blackish till bearing a large number of greenstone pebbles.

AFTONIAN GRAVEL.

The Aftonian interglacial epoch derives its name from Afton Junction, Union County, Iowa, where heavy deposits of sands and gravels were found lying between the Nebraskan drift and that of the succeeding glacial stage—the Kansan. These type deposits were at first supposed to have been laid down by floods of the melting ice of the Nebraskan glaciers, but the recent discovery at a number of localities in western Iowa of Aftonian gravel carrying a rich mammalian fauna proves that they were laid down during an interglacial time whose climate was far from boreal.[1]

On the uplands these gravels are generally thin and in places are entirely wanting; in the lowlands they form extensive beds, in many places filling the preglacial valleys to depths of 50 to 60 feet. To the same stage belong old soils and forest beds developed on the Nebraskan drift sheet. In the southwestern part of the State these layers bear decaying organic matter known by drillers as "sea mud," "stinking clay," and "black muck," which not infrequently renders the waters of deep-bored wells obnoxious.

KANSAN DRIFT.

The deposits of the second ice invasion consist largely of a clayey till, dense, tough, and difficult to excavate, charged with many small pebbles and sparse bowlders. Little stratified material is intermingled or associated with the Kansan drift. The till is blue drab in

[1] Calvin, Samuel, Bull. Geol. Soc. America, vol. 20, 1909, pp. 341-356.

color where unweathered, but so great is its antiquity that it is reddened by oxidation to a considerable depth. The Kansan drift was spread over all the State outside of the driftless area, and to it belongs the larger part of the stony clays pierced by the drill in any county.

DEPOSITS OF THE YARMOUTH STAGE.

In eastern Iowa, where the Illinoian drift sheet overlaps the Kansan, there are found old soils and weathered surfaces belonging to the interglacial stage called the Yarmouth, from the village of that name in Des Moines County. The gravel, that is widely spread over the Kansan drift in Buchanan and other counties of northeastern Iowa overrun by the Iowan ice and hence termed the Buchanan gravel, was probably laid down in Yarmouth time. Two phases are discriminated by the Iowa State Survey—an upland phase, heavily rusted and decayed, and a valley phase of sands and gravels more quartzose in character.

ILLINOIAN DRIFT.

Within the narrow belt of its occurrence along Mississippi River in southeastern Iowa the Illinoian drift consists mainly of a clayey till differing from the Kansan till in the larger proportion of dolomite pebbles which it carries, in a slightly less compact structure, and in a weathered zone of lesser depth. The upper surface of the drift sheet underneath its cover of loess is marked by a leached gray soil and vegetal deposits of the Sangamon interglacial stage.

IOWAN DRIFT.

The Iowan drift, as discriminated by Calvin, is recognized most readily by the characteristic topography already described (pp. 51–52). It is exceptionally thin. It consists of a light-yellow clayey till and numerous large superficial bowlders, generally of granite.

WISCONSIN DRIFT.

The latest ice invasion of the State laid down a ground moraine of clayey till containing a notably large proportion of limestone pebbles. The slight extent to which it has been oxidized and leached of lime marks its recency. The drainage of Wisconsin time was exceptionally vigorous. Gravel hills called kames mark the places where glacial streams reached the margin of the ice and threw down their loads. Outwash sands and gravels cover whole townships in continuous sheets, and deep gravel deposits were laid down by swollen rivers along all waterways leading outward from the area of this drift.

LOESS.

Loess is a gritless loam intermediate in size of particles between sand and clay. Because of its loose texture it is highly permeable. Much of the surface yellow loess is underlain by a blue-gray loess supposed by some to be of greater age. In other places it may graduate into a reddish loam intermediate in texture and color between loess and the red residual clays or the red weathered clays of the drift on which it rests.[1]

About the Iowan border and also over wide areas of the Illinoian drift the loess passes downward into sand by interbedded alternate layers of the two deposits. Such deposits are sometimes referred to as subloessial sands. Loess is widely distributed in Iowa, covering practically all the State except the areas of the Iowan and the Wisconsin drift sheets, and being found even upon these in some small patches.

ALLUVIUM.

Alluvial deposits consisting of many feet of sand and gravel alternating with clay and covered with silt and loam fill the valleys of most of the larger streams to a considerable depth. Much of this material belongs to deposits already described, but is indistinguishable from the more recent beds.

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[1] Norton, W. H., Geology of Scott County: Iowa Geol. Survey, vol. 9, 1899, pp. 486–487.

CHAPTER III.

GEOLOGIC OCCURRENCE OF UNDERGROUND WATER.

By W. H. Norton, Howard E. Simpson, and W. S. Hendrixson.

CLASSIFICATION OF UNDERGROUND WATERS.

In a prairie region of uniform and abundant rainfall, such as prevails throughout Iowa, the permanent ground-water level may be found at no considerable distance below the surface, and water suitable both in quality and quantity for domestic, farm, and village supplies may generally be obtained from shallow wells. Many such shallow waters are too meager or too liable to pollution to meet the needs of industrial plants and of towns and cities. Where large supplies of the purest ground water are needed it has been necessary to resort to artesian waters of the deeper zones of flow reached by wells hundreds and in some places thousands of feet in depth.

The underground waters of Iowa fall, therefore, into two groups. The first group, comprising those available for home, farm, or village supply, commonly lie less than 100 feet and rarely more than 500 feet below the surface, and are usually obtained from bored, driven, or drilled wells, or in a few districts where the valleys are cut beneath the ground-water table, directly from springs. These waters are frequently termed shallow or local waters, as they are fed directly by local rainfall absorbed through the soils above. Wells drawing their supply from these sources penetrate only the drift or superficial deposits and the country rock—the rock terrane outcropping in the area or immediately underlying the superficial deposits.

The second group of waters, those belonging to rock strata buried below the country rock and circulating through the more permeable layers under greater or less pressure, are termed artesian waters, and wells deriving their supply from such waters are termed artesian wells whether they flow at the surface or not. Many cities and industrial plants resort to these waters, whereas others utilize groups of shallow wells in alluvial deposits or the surface waters of streams.

The line of separation between the country-rock waters and the artesian waters can not be sharply drawn. In the driftless area in northeastern Iowa the deep artesian rock systems rise and become country rock, and practically all the common wells are of the artesian class, though few exceed 500 feet in depth. Artesian wells are also found in both the drift and the country rock immediately under the drift, many of them at depths much less than 500 feet. And again in some portions of the State ordinary wells pass through the shallow drift and country rock into formations not exposed near the surface.

WATERS OF THE ROCK FORMATIONS.

ARTESIAN FIELD.

OCCURRENCE OF WATER.

The artesian field of Iowa is but a part of an extensive area of the upper Mississippi Valley where artesian conditions prevail—an area embracing southern Wisconsin and Minnesota, northern Missouri, and a large part of Illinois. The chief water beds, or aquifers, of the artesian system of this large area outcrop in southern Wisconsin and Minnesota, so that these States include the gathering ground from which the artesian waters are collected. On account of the very gentle inclination of the strata and the thickness of the chief aquifers, the collecting area is exceptionally large, and this, together with the abundant rainfall of the region, insures the artesian field as a whole against exhaustion.

From the intake area, or area of outcrop, the strata of the artesian system have a general southward inclination. They do not, however, show a uniform artesian "slope" but lie in the form of a shallow trough open to the southwest. The axis of the trough enters the State from the north about midway between the eastern and western borders and leaves it at the southwest corner. In southeastern Iowa the lower beds of the Paleozoic rise in a dome now covered and concealed by later Paleozoic formations. It is possible also that in southern Iowa begins the upward rise of the lower Paleozoic strata disclosed in deep wells in north central Missouri. As the strata of southeastern Nebraska dip also toward the axis of the trough, the Iowa field is somewhat spatulate, and needs only to be closed by a rise of strata to the southwest in order to form an artesian basin.

So gentle is the inclination of the strata that the Cambrian and Ordovician water beds remain within reach of the drill and may be profitably exploited over all except the southwestern part of the State, where the dip of the trough carries them so deep that so far no well has reached them. Here, however, higher water horizons of the same system are able in part to take their place.

The map (Pl. I, in pocket) showing the distribution of artesian wells in Iowa roughly indicates the nearness of the chief aquifers to the surface. Thus, in eastern and northern Iowa, where wells are numerous, the depth to the aquifers is slight, and toward the southwest, where they are fewer, the distance to the water beds is steadily increasing.

The Cambrian and Ordovician systems contain a number of thick water-bearing sandstones which supply the deep wells in the northeastern part of the State. These are, in downward succession, the St. Peter, New Richmond, Jordan, Dresbach, and the older Cambrian sandstones. The Paleozoic formations above the St. Peter also contain water-bearing members, chiefly limestones and sandstones, but these can scarcely be compared with the sandstones already mentioned for the quality and quantity of their water.

The Cretaceous system contains considerable water in the Dakota sandstone, which is its basal formation and supplies many wells in the western part of the State.

The Pleistocene deposits, especially the beds of sand and gravel, yield supplies to innumerable shallow wells in nearly all sections and are the most important source of water in the State.

QUALITY OF WATER AS RELATED TO GEOLOGIC SOURCE.

To determine with accuracy the quality of water supplied by the different geologic formations seems well-nigh impossible from the data at hand. This is due to several facts:

In very few, if any, deep wells are the waters known to be derived from a single stratum. Many wells from 1,000 to 2,000 feet deep are cased only to rock. Some are cased for a few hundred feet; few are cased more than 1,000 feet; scarcely a single very deep well is cased to the lowest water-bearing formation. It is evident that the output of most of the deep wells, therefore, represents a mixture of all flows below the casing. This is true, for example, of the wells at Cedar Rapids, cased to 85 feet; of the well at Hampton, cased to 200 feet; of the well of the Murray Iron Works at Burlington, whose water, according to the owner, represents all flows; and the same may be said of many others.

Casings in many Iowa deep wells are short-lived. The casings of well No. 1 at Grinnell, of No. 2 at Centerville, and of the wells at Cedar Rapids (pp. 447–449) illustrate the destructive action of the upper waters on iron tubing. It seems probable that the life of such casing when exposed to the action of the heavily mineralized waters of the Carboniferous may be only 5 to 10 years, and therefore waters shut out when the well is drilled may later enter the well.

Casings are often faultily put down and do not shut out the waters they were intended to exclude. Though the wells at Grinnell have been cased with as much care as others, they are good illustrations of faulty casing. In well No. 1 there was known to be a break in the casing at about 400 feet, and the well always yielded water containing about 2,000 parts per million of solids. The water had the characteristics of the water from several shallower wells in the neighborhood, which are known to derive their waters from the drift just above solid rock and from the Carboniferous. Well No. 2 was provided with a continuous casing for about 840 feet, and while the casing remained in good condition its water contained less than half as much mineral matter as well No. 1, the best analysis showing 881 parts total solids, though even then a small flow of very hard water surely entered at about 1,530 feet. Several years after this well was drilled it was found that the shale had caved, filling the well to 1,700 feet, or just above the St. Peter sandstone, and an analysis at the time, mainly of the flow at 1,530 feet, showed about 5,000 parts of solids. Though several analyses have been made of water from well No. 3, which was drilled and cased to the same depth as well No. 2, none of them have been as low in solids as the 860 parts found in No. 2, the lowest for No. 3 being 1,147 parts. It is probable that the casing of this well is not perfect as far as it goes, and it is certain that none of these wells have yielded water from only the St. Peter and the New Richmond sandstones.

The water in one stratum may find access to another through fissures or more slowly by seepage. The similarity of the waters from the sandstone strata of the Cambrian and the Ordovician gives some support to this view.

Though the stratum supplying the greater part of the water can be determined in many wells, the entrance of a small amount of water from another stratum may render such information valueless in a region like Iowa, where many waters are so highly mineralized. For instance, 90 per cent of a well's yield might come from a formation supplying excellent water, but the other 10 per cent, coming from a formation furnishing salt water, might render the supply nonpotable.

Though the characteristics of the waters from the several aquifers can not be made out with scientific accuracy in all parts of the State, much may be learned of these waters from the data at hand, and there is little doubt as to their quality in general.

WATER IN PRE-CAMBRIAN ROCKS.

SIOUX QUARTZITE.

The close joints which appear in the Sioux quartzite at its outcrops and some little-indurated sandy layers which it includes permit it to contain a considerable quantity of ground water. These joints, however, may be expected to decrease rapidly with increase in depth. It should be clearly understood, then, that the drilling of deep wells below the summit of the pre-Cambrian of Iowa is not only difficult and costly, but also futile. In no place within the limits of the State can it be encouraged. When the drill reaches these crystalline rocks the work should cease. But the question whether the pre-Cambrian rocks have really been reached can not be left to either the workman or to the citizen untrained in the determination of rocks. It must be decided by an experienced geologist.

The Sioux quartzite is known to yield small quantities of water,[1] and at Sioux City about 3 gallons a minute is reported to be obtained from schist at a depth of 1,480 feet, but it is needless to say that such small supplies do not repay deep drilling through hard rocks.

WATER IN CAMBRIAN AND ORDOVICIAN ROCKS.

CAMBRIAN SYSTEM.

DRESBACH SANDSTONE AND UNDERLYING CAMBRIAN SANDSTONES.

Wells.—The porous saccharoidal Dresbach and underlying Cambrian sandstones yield freely an excellent water in northeastern and eastern Iowa. It is these sandstones which supply the many flowing wells of the valley of upper Iowa River and furnish a large part of the flows of the deeper wells of the immediate valley of the Mississippi as far south as Davenport. West of the Mississippi it has seldom been necessary to drill to these horizons. No water was reported in these sandstones at Cedar Rapids and Anamosa, although this fact does not make it certain that none was found. At Boone these sandstones supply the major portion of the flow. With increasing depth to the west and southwest they become less and less pervious as their pore spaces are increasingly filled with cements, and the water which they contain becomes more and more highly mineralized.

Springs.—These sandstones outcrop so slightly as to produce few springs. The high artesian pressure, however, supplies water for a goodly number which flow from joints in the overlying St. Lawrence formation.

ST. LAWRENCE FORMATION.

The shales and, as a rule, the calcareous beds of the St. Lawrence formation are dry. At Waterloo, however, the latter are said to yield water. In general, the impermeable beds of this terrane serve to separate the water of the Dresbach and underlying sandstones from that of the Jordan sandstone, allowing each to maintain its indivdual characteristics.

As already stated, many springs originating in the Dresbach and underlying sandstones find exit through the shales of the St. Lawrence formation.

[1] Hall, C. W., and others, Geology and water resources of southern Minnesota: Water-Supply Paper U. S. Geol. Survey No. 256, 1911, p. 49.

JORDAN SANDSTONE.

Wells.—The Jordan sandstone is one of the chief, if not the chief, of the aquifers of the Iowa artesian system. It is reported as a water bed at Dubuque, Clinton, Davenport, Waverly, Waterloo, Vinton, West Liberty, Ames, and Ottumwa. It no doubt furnishes large yields in many other wells whose water horizons are not recorded. The rather coarse, smooth, well-rounded uncemented grains of quartz afford large pore spaces which permit the ready percolation of artesian water, and the absence of soluble constituents leaves the water with comparatively low mineral content. At few places have any accurate tests been made of the capacity of the Jordan as compared with that of other water beds. At Ames the ability of the Jordan to contribute to the general supply was found to be nearly four times that of the New Richmond and 15 times that of the St. Peter.[1]

In the valleys of the main rivers and their tributaries where the Jordan outcrops it supplies many ordinary wells, some of which give constant flows, but the head is not strong because of the leakage through the many outcrops along the valley walls. The formation is tapped by many upland wells in the northern and eastern portion of Allamakee County, but the head is so low that the wells are commonly continued down into the Dresbach or underlying sandstones, where no better water is found but where a stronger head is obtained, owing to the presence of the overlying shaly limestones of the St. Lawrence formation, which prevent the upward dispersal of its artesian waters, and the very small area of outcrop from which leakage in the form of springs may occur. Farther from the numerous outcrops the head of the Jordan rises, and many wells in the northeastern portions of Winneshiek and Clayton counties pass through the Oneota limestone to procure the excellent water of the Jordan.

Springs.—Springs are very numerous in the Jordan sandstone owing to the large pore space between its grains and the lack of interstitial filling. Many flow freely from the rock where it overlies the limestone of the St. Lawrence formation and from above the scattered shaly or limy bands.

Wherever the Jordan outcrops on the valley walls its waters drain away freely in seeps and springs, and wherever its contact with the underlying shaly limestones of the St. Lawrence is exposed the water collected over this impervious floor flows out, frequently in powerful streams.

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[1] Beyer, S. W., Iowa Agricultural College water supply, 1897, p. 11.

ORDOVICIAN SYSTEM.

PRAIRIE DU CHIEN GROUP.

Wells.—The Prairie du Chien group is one of the most important of the aquifers of Iowa. Underground waters have no doubt opened passages along joint and bedding planes through their solvent action on the limestone. The sandy intercalated layers, although neither thick nor persistent, offer easy paths for ground water and, communicating as they must with the channels of solution, form water beds which the drill seldom fails to tap. The New Richmond sandstone especially is a water carrier and adds materially to the supply at Dubuque, Waterloo, Vinton, Grinnell, West Liberty, Ames, and Des Moines. A still larger number of wells find water in the lower limestone, the Oneota dolomite, these being so far as reported, the deep wells at Waterloo, Clinton, Sumner, Anamosa, Cedar Rapids, Homestead, West Liberty, Ottumwa, Des Moines, and Centerville. A few wells, such as those at Waverly, Waterloo, and Grinnell, are reported to obtain water from the Shakopee dolomite, and as this formation has many sandy layers the number of wells which receive accessions to their supply from this source is probably larger than the records show.

The Prairie du Chien in many places seems to offer no impervious floor to the St. Peter, and there appears no reason why the waters of the two should not in general freely mingle; some wells, however, have found shaly beds which lie between the two terranes and locally keep their waters separate.

Springs.—Owing to its many open joints and bedding planes and even large solution caverns, the Oneota produces many large springs. The strongest of these are near the base, where its openings permit the escape of artesian water from the Jordan sandstone. From this horizon flow many of the powerful springs of the Mississippi and Oneota valleys in Allamakee County.

The New Richmond sandstone gives rise to many small flows and much seepage along its contact with the underlying Oneota.

ST. PETER SANDSTONE.

Wells.—The St. Peter is easily distinguished by drillers and is perhaps the best known of Iowa's geologic formations. It never fails to yield some water and in many places yields abundantly. The head of the water differs from that in overlying terranes, so that the inflow of water into the tube at this horizon is readily marked, whereas lower flows, with about the same head as that of the St. Peter, may either escape the observation of the driller or be thought not worthy of record. The list of wells which are reported as drawing water from the St. Peter is too long for mention, including as it does a large number of the deep wells of the State.

The pore spaces of the St. Peter are large, owing to its "millet-seed" structure, and the moderately large, well-rounded grains, fairly uniform in size, do not pack so closely as do sandstone grains more diverse in size and in shape. The pore spaces are unfilled. No clay was laid down along with the quartz grains on the ancient sea floor. Since the uplift of the formation ground water has seeped freely through it, and, if interstitial deposits were ever made by mechanical or chemical processes, they have long been dissolved and washed away. The smoothness of the grains brings the friction of water in transmission to a minimum. For all these reasons the capacity of the St. Peter for storage and transmission of water must equal that of a bed of ordinary incoherent sand.

On account of the well-nigh complete absence of soluble materials in both the constituent grains and the interstitial cements of the St. Peter, the water seeping through it has little opportunity to take minerals into solution, and it therefore remains of exceptional purity for long distances from its sources.

The St. Peter is within reach of farm wells in all of Clayton County, the southern and western portions of Allamakee County, the northern and eastern portions of Winneshiek County, and the eastern portion of Dubuque County. (See Pl. I, in pocket.) Throughout this area one of its striking characteristics is its low head in comparison with overlying terranes, especially near the areas of outcrop. Wells sunk through overlying strata with a high head of little water immediately lose 100 or 200 feet of this head on penetrating the St. Peter but find at the same time an abundance of water. The reason may be found in the freedom with which water flows through this very permeable rock both to outcrop and to well holes giving a constant supply but little pressure; whereas in the overlying rocks with small storage and transmission capacity the pressure is relieved and the water is drawn away immediately on pumping.

Springs.—The massiveness and the lack of stratification planes and crevices are not favorable to the gathering of the abundant water of the St. Peter into definite channels and its discharge in copious springs. Nevertheless small springs from it are common and seepage universal, and it is an important contributor to the flow of all streams over its area of outcrop.

PLATTEVILLE LIMESTONE AND DECORAH SHALE.

The shale of the Platteville limestone and the Decorah shale yield no water and in many borings must be cased to prevent caving. They serve an important office in maintaining the head of the waters of the St. Peter sandstone, whose upward leakage they prevent, and also in separating them from the waters of the Galena dolomite.

GALENA DOLOMITE.

Wells.—Sealed between two shales, either the Decorah shale or the shales of the Platteville limestone below and the Maquoketa shale above, the Galena forms a water bed of no little value. Where dolomitized and nonargillaceous, it is porous, not indeed sufficiently to permit free percolation, but enough to give rise to incipient waterways along joints, bedding planes, and specially porous layers, and these have developed by solution into definite channels capable of a large yield to wells. Though no assurance can be given that the drill will strike one of these channels, it has done so in a good many of the Iowa wells, as at Clinton, Davenport, Fort Madison, Sumner, Osage, Mason City, Hampton, Webster City, Holstein, Grinnell, and Pella. At Davenport the Galena water is so nearly identical with that of the St. Peter in quality and head that a rise of the latter through the crevices of the Galena is strongly suggested. The yield from the Galena and Platteville is in some places abundant, amounting in some of the wells in Davenport and Rock Island to 300 or 400 gallons a minute. At Mason City the entire city supply is drawn from these formations.

In shallow wells the Galena affords excellent water throughout its area of outcrop. Its base at least is saturated, and southward and westward, where it dips under the Maquoketa shale, it continues waterlogged. Thus it remains the chief source of farm wells in large areas of Winneshiek, Clayton, and Dubuque counties, where wells penetrate the Maquoketa shale and are drilled to depths of 300 to 400 feet to reach it. The waters are hard, from limestone dissolved in passage, and may be in places contaminated by surface drainage, through the numerous sink holes opening into fissures which everywhere traverse the rock. The freedom of circulation and the potency of the Galena waters to carry materials in solution for long distances is shown in the deposits of lead and zinc ores which are found in abundance in the old crevices, fissures, and caverns of the Galena about Dubuque. In West Dubuque there is an area so cut up by labyrinthine passages underground and so full of water that it is known as the McPoland Pond. On one occasion a small skiff was taken down a shaft and used in exploring this ground.

Springs.—The springs issuing from the Galena dolomite are among the most copious in the State. This is a direct result of the many channels, some cavernous in size, that have been opened by solution along bedding planes and intersecting joints. The chief horizon is that at the base of the formation, immediately above the impervious Decorah shale. Over the wide areas where the Galena is the country rock, large numbers of sink holes pit the surface and lead the storm waters directly into the fissures and thus furnish a ready supply of water. In some places storm waters are led so directly to a near-by valley that they form a large part of the supply of some spring, which readily responds to every rainfall by showing a proportional increase in volume and turbidity. Such springs, however, should be avoided, as they are very liable to pollution by organic impurities washed into the sink holes with the water.

MAQUOKETA SHALE.

Wells.—The thick impervious clay shale known as the Maquoketa shalé not only prevents the rise of Cambrian and Ordovician artesian waters into higher terranes but also forms an impermeable floor for the Niagara waters above it. In this respect it is of especial value over the large area of the Niagara outcrop in eastern Iowa, where, by preventing the downward leakage, it causes the water of the Niagara to accumulate sufficiently for the supply of small towns and villages. The dolomites of the middle Maquoketa, which occur in a few counties of northeastern Iowa, are water bearing, as was found in the deep wells at Sumner and Green Island.

Springs.—Although springs from the contact of the Maquoketa and the overlying Niagara derive their water from the latter, their value inures almost entirely to the Maquoketa areas. They are of greatest importance in Clayton, Dubuque, and Jackson counties, where they supply many perennial streams with water, such, for instance, as Little Maquoketa River, which never ceases to bear its contribution to the Mississippi just north of Dubuque, whereas its neighbor, Catfish Creek, which parallels it immediately to the south but is not spring fed, responds to every drought. Two miles north of Strawberry Point a mill is operated by a turbine wheel run by a strong stream piped from a spring of this horizon to the wheel pit.

SPRINGS FROM CAMBRIAN AND ORDOVICIAN ROCKS.

The area over which Cambrian and Ordovician strata form the country rock is especially noted for its springs. No other part of Iowa is so well supplied, and perhaps in all the other provinces of the State taken together there will not be found so large a number of strong streams of pure water flowing from the bedrock as are found here. The conditions which are so favorable to spring formation in this area are these: (1) Several heavy, porous beds of sandstone and creviced limestone with large capacity for both storage and transmission of water; (2) beds of impervious clay and shale which check the downward movement of the ground water, causing it to collect in large quantities; (3) many deeply carved valleys and innumerable ravines, the bottoms of which are well below ground-water level; (4) a slight dip, which facilitates the movement of the water along the surface of the impervious layers to the outcrops on the sides of the valleys; since this dip is to the southwest, springs are commonly found on the north and east sides of the valleys; (5) an ample rainfall (over 30 inches annually); and (6) the exposure of the porous beds over a relatively flat surface unsealed by drift, thus permitting them to absorb the rainfall.

The chief spring horizons in the Cambrian and Ordovician, named from oldest to youngest, are the contacts of the Dresbach and St. Lawrence, the St. Lawrence and Jordan, the Jordan and Oneota, the Oneota and New Richmond, the Shakopee and St. Peter, the Decorah and Galena, and the Niagara and Maquoketa. All except the first and third are contacts between heavy porous sands or creviced limestone and underlying impervious shales. The two exceptions, the Dresbach-St. Lawrence and the Jordan-Oneota contacts, occur at the base of heavy limestones that overlie sandstone aquifers, the waters of which are under artesian pressure, the lower beds not outcropping. The open joints of the limestone connect with the porous sandstone over large areas and admit the waters from below, and they flow out through crevices in copious and at times even powerful streams. Owing to the fact that many of the springs emerge through talus and washed soil at the foot of the bluffs and on the valley sides, it may be impossible to determine the formation from which they come. Again, many springs, some very strong, come from local beds lying above shaly layers in the heavy aquifers. Many are, however, readily identified.

The economic value of these springs to the residents of the fertile valleys of northeastern Iowa can hardly be estimated. The water power of the many small springs which in many places issue a hundred feet above the base of the bluffs and fall in cascades has been but slightly utilized. Here and there, however, a mill is operated, and at some of the many farmhouses whose location has been determined by the presence of a spring the stream is so piped as to generate power for separating the cream, churning the butter, and driving small labor-saving machinery about the farm. In a few places, too, a portion of the power of the flowing water is utilized in a ram to drive another portion into a system of waterworks for home and farm. The possibilities in these lines have as yet been but slightly developed, but even in its simplest use, where the pure, clear, cold stream flows through the tanks of the spring house, giving the most wholesome kind of water for home use, passes through the simple refrigerator, cooling the milk and preserving the butter, and then flows through the barnyards and pasture, supplying the stock with water that is cool in summer and warm in winter, its value in health and comfort is difficult to estimate in dollars and cents.

Because of the large number and the great size of the springs of the area of outcrop of the Cambrian and Ordovician rocks in the northeastern counties of the State, the streams of this area are exceptional in the constancy of their flow and the purity of their waters.

QUALITY OF THE CAMBRIAN AND ORDOVICIAN WATERS.

The four great sandstone layers of the Cambrian and Ordovician may be discussed together, since there is generally no essential difference in the quality of their waters. These layers are the water bearers for all the deeper wells in the northeastern part of the State within the area of good water, so often mentioned, extending south and west to about the line of the Mississippian. With the exception of the very deep park well at McGregor, all deep-well waters within this area have low solids, rarely exceeding 500 parts and averaging about 400 parts per million. In this part of the State there are no formations later than the Devonian, and in a considerable portion of it rocks of the Cambrian and the Ordovician underlie the drift. Except perhaps in the drift there are no objectionable waters to be cased out or to contaminate the waters in the sandstones below.

Some examples may be given to illustrate the fact that the waters are about the same whether from the St. Peter or from lower strata. On page 142 are given analyses of seven deep waters in Allamakee County, six of which are supposed to be derived from the Dresbach or underlying Cambrian sandstones, and one at Postville from the St. Peter. The six have about the same total solids and their average solids are about the same as those of the water from the Postville well. In Clayton County the 1,006-foot well at McGregor is exceptionally deep and reaches salt water. A much shallower well at the same place also shows the influence of the salt. Six other wells in Clayton County (p. 143) show about the same amount of solids, though their depths are greatly different, and their footings are believed to range from the Dresbach or the underlying Cambrian sandstones to the Galena. In Cerro Gordo County six analyses of well waters show about the same total solids, though two of the wells are supposed to draw from the St. Peter, three from the Platteville, and one from the Devonian (p. 146). The wells are cased only to rock. No inference can safely be drawn from the analyses of water from the 1,473-foot well as to the character of the water below the St. Peter at this point, as it is doubtful whether the sample of water was collected while the well was in active use. The analysis of water from the well at Hampton shows that the softness of the waters from the lower sandstones is preserved as far south and west as Franklin County. This well is cased only 200 feet, foots in the Jordan, and may draw water from all strata from the Jordan to the Mississippian.

The water of the St. Peter is soft as far west as Emmetsburg, for the well at that place owned by the Chicago, Milwaukee & St. Paul Railway foots in the St. Peter and gives excellent water. In the same county two shallower wells in the Dakota sandstone give hard water. The low solids in the well at Emmetsburg may be ascribed to the successful casing out of a strong flow of hard water from the Dakota sandstone which probably finds access to the deep well at Mallard, also footing in the St. Peter. Successful casing to preserve from contamination the waters of the St. Peter or lower strata has not been accomplished so far as known in wells located where the surface rock is later than the Mississippian. Owing to the similarity of the waters of the lower sandstones one might be inclined to infer that the waters of these strata mingle, and this may be true. Numerous wells, however, reaching higher levels show, as at Grinnell and Emmetsburg, that strata not far removed from one another in geologic succession may contain very different waters.

WATER IN SILURIAN ROCKS.

NIAGARA DOLOMITE.

Wells.—The Niagara dolomite, like the Galena dolomite, is traversed by irregular channels of solution through which water flows with considerable freedom, and includes porous beds through which it seeps with some difficulty. The ground water which the formation receives over its outcrop area is held within it by the impervious Maquoketa shale beneath and passing down the dip acquires artesian pressure and feeds wells as far distant as Burlington, Keokuk, Centerville, and Des Moines.

The Silurian sandstones in southeastern Iowa largely increase its water resources, and these are drawn upon freely at Washington, at Centerville, and probably at Ottumwa.

Throughout its area the Niagara is the almost exclusive source of supply for shallow rock wells, as it ranges from 200 to 400 feet in thickness and overlies the Maquoketa, a bed of impervious shale whose thickness is more than 100 feet. To the south and west, where the Devonian is the country rock, the Niagara is the source of many wells, for the overlying Devonian limestones feather out eastward.

The Niagara transmits water very freely, not only through many small cavities, but especially through a large number of joints, cracks, bedding planes, and open crevices formed by solution in the soluble rock, through which an active circulation obtains. In number and size, however, the open cavities are small compared with those of the Galena.

The water absorbed over the large intake area of this formation is held by the impervious shale beneath from passing downward, so that at least the base of the limestone is waterlogged and the contact with the shale forms a strong well and spring horizon.

The margin along the bold eastern escarpment is so well drained that in many places it is difficult to secure good wells. Farther back the ground-water level rises until along the margin of the overlying Devonian the formation is almost entirely saturated and wells obtain an abundance of water soon after penetrating it. Though rarely dry at the base, it is subject to the disadvantage common to other limestones—the possibility that the drill may go a long distance, even through the formation to the shale, without striking one of the crevices or water passages. Perhaps the most constant water-bearing bed of the formation is an especially porous, granular stratum lying some distance above the base.

The Niagara is commonly saturated immediately below the drift and it is from this part of the formation that many of the large farm-stock wells of its country-rock area draw their supply. The upper portion of the rock is very generally broken and shattered by the glacial ice and the fragments are mingled with the old residual soil and with gravels deposited by waters flowing out in front of the advancing ice. The whole makes a good waterway and a remarkably strong source for wells. The water is perhaps more truly that of the drift than that of the rock, but all drilled wells which draw from it should have casings driven into the rock and should draw from the many crevices therein.

The water from the Niagara is usually copious enough for the public supply of towns of 1,000 or 2,000 population or for minor industrial purposes, though in some places it may be unsatisfactory as a boiler water on account of its hardness. Unless it is desired to seek the deep artesian supplies it is not advisable to attempt to drill below the base of the Niagara, as the Maquoketa shale is dry. If the shale is reached without the drill's having found a water crevice and it is decided not to penetrate the artesian aquifers an attempt may be made to open the drill hole to a water-bearing crevice by torpedoing the well with nitroglycerin. This, however, should be done only after it is fully decided to abandon the hole if water is not found in this way, as drilling can not be resumed after the shooting. The drill hole should be filled up to the base of the Niagara and the shot fired on the top of this filling. If this course fails it will be necessary to try a new hole.

Springs.—Springs are very numerous along the base of the Niagara escarpment and in the heads of the narrow ravines which deeply notch it all the way from the headwaters of Turkey River in Winneshiek County along the bluffs overlooking Volga and Mississippi rivers as far south as Clinton. Owing to the numerous thin shaly layers interbedded with the limestone, springs are abundant well up within the formation. Many are found in Delaware County along Maquoketa River and all its tributaries, which have cut their channels well into the limestone. Among the most notable are the group about the "Backbone," in Richland Township, and the many that supply Spring Creek, in Delaware and Milo townships. The purity and abundance of the waters poured into Spring Creek are attested by the location here of a large Government fish hatchery controlled by the United States Bureau of Fisheries.

SALINA (?) FORMATION.

The Silurian beds which are tentatively regarded as representing the Salina formation are, wherever found, distinctly deleterious to underground waters owing to their content of lime-sulphate minerals. The presence of sulphate in the form of anhydrite indicates that it has been hermetically sealed from all underground waters since its deposition and can increase their mineralization only when new channels are opened by the drill. But the high content of lime sulphate in deep-well waters when these strata are penetrated indicates that much of the gypsum lies in the path of artesian waters. The analyses of the water of the deep city well at Pella show that it contains 4,678 parts per million of SO_4 and 444 parts per million of calcium and is entirely unfitted for municipal supply. At Nevada the very heavily sulphated water suggests that the Silurian here, as at Marshalltown, 28 miles east, is gypsiferous, although this can not be proved as no samples were preserved. At Mount Pleasant any seleniferous waters from the well-marked gypsum beds were successfully cased out from the later wells drilled at the State hospital for the insane. At Grinnell the first well drilled for the city showed an abnormally high lime-sulphate content, but with better casing the quality of the waters of the later wells was very much improved. At Glenwood the water veins occur above the gypseous beds, which are apparently dry, as the water contains little calcium sulphate. At Bedford the waters from the supposed Salina horizon showed an enormous increase in lime sulphate and were pronounced unfit for city supply. The presence of these strata in southern Iowa constitutes a distinct discouragement to artesian drilling in that part of the State, though otherwise the Silurian might prove valuable, for it is much more accessible than the Cambrian and Ordovician beds.

QUALITY OF SILURIAN WATERS.

A number of wells of very moderate depth foot in the Silurian where it is overlain only by the drift or by the Devonian and the drift. Examples are wells at Covington, Mount Vernon, and Lisbon, in Linn County; Morley and Onslow, in Jones County; and Grand Mound, in Clinton County. All except the Covington well have lightly mineralized waters, and that well contains only about 700 parts per million. All other wells footing in the Silurian are deep, such as Mrs. Huber's at Tama and the city wells at Farmington, Centerville, and Bedford. They penetrate water-bearing strata above the Silurian, which are probably not cased out, and their waters can give little indication as to the real character of the Silurian water at those places.

WATER IN DEVONIAN ROCKS.

ARTESIAN CONDITIONS.

Wells.—The Devonian rocks can not be classed among the important water beds of Iowa, although they contribute somewhat to the general deep-well supply in several places, as at Vinton, Cedar Rapids, Davenport, Webster City, and Ottumwa. In many places they yield sufficient water for hotel and small factory wells, but they can not be relied on to furnish public supplies. In deep wells the Devonian waters should be cased out because their head is lower than that of the Cambrian and Ordovician artesian waters, which will otherwise leak out through the channels opened by solution in the Devonian limestones.

In the southern portion of the Devonian area large fissures and crevices exist in many of the heavier layers. Though the limestone itself is compact and impervious, the drill usually reaches some one at least of the many openings which bring the well into communication with the entire system of circulation and supply it with fresh water at a rapid rate not affected by any drought.

Throughout the larger northern portion of the Devonian area the overlying drift is generally thin, and very many of the best wells end in the lime rock. Plenty of water of the best quality may be obtained by going a short distance into the rock for it, and a driller should not stop before limestone is reached unless the supply coming from the drift is satisfactory in every respect. The rock water of the whole area is under some degree of artesian pressure and rises within easy pumping distance. The expense of pumping and maintenance is slight, so that it is more and more resorted to for a pure and permanent supply.

Springs.—The Devonian area is so heavily mantled with drift that springs from the country rock are of little importance. They are not uncommon in the rock-cut valleys in the limestone, but are rarely utilized except for watering stock in the pastures that occupy most of the valley land. For such purposes some of them have been walled and piped out to a tank, but even this care is seldom exercised. Probably the strongest springs of this region are found in Howard and Winneshiek counties, where, owing to the absence of the Niagara, the Devonian limestones overlap on the Maquoketa shale, giving vent to many good streams that feed the headwaters of Oneota and Turkey rivers.

A spring from the Devonian worthy of special mention is that from which the public supply of Cedar Falls was until recently derived. It is located just south of the city in the valley of Dry Run, a small intermittent tributary of Cedar River. It flows perennially from one of the open channels in the rock common to the Devonian in this region, and was sufficient to meet all the demands of the city, with a waste of many times the amount used. Marion is another city similarly supplied by a spring from the Devonian. Water from springs from the Devonian is sold to customers in Cedar Rapids.

QUALITY OF DEVONIAN WATERS.

Perhaps the best evidence of the good quality of the Devonian water is the fact that many wells located where the Devonian immediately underlies the drift and deriving their main supplies from lower strata do not require casings to shut out the hard water of the Devonian. In fact, the Devonian water, as separately known, differs little from the waters of the deep-lying sandstones (pp. 102–103). Several wells footing in the Devonian, as at Jesup, Lake Mills, and Hanlanton, supply water of good quality. They are, however, shallow and probably reach only short distances into the Devonian and may derive their waters largely from the drift. Farther south wells in the Devonian yield hard waters, as at Gowrie, Grundy Center, and Burlington. At all these places the Devonian is deeply overlain by later formations, which may supply the major portion of the hard waters. This source is directly indicated for the city well at Gowrie by the fact that it supplies essentially the same quality of water as the well at Dayton, which is located only a few miles south and foots in the Mississippian. It is not certain that the well at Grundy Center reaches below the Mississippian. Regarding the water from the Devonian, therefore, it may be said, as of the water from the Silurian, that there is little or no evidence to show that it is essentially more heavily mineralized than that of the great sandstone layers of the Cambrian and the Ordovician.

WATER IN CARBONIFEROUS ROCKS.

MISSISSIPPIAN SERIES.

GENERAL CONDITIONS.

The limestones of the different formations of the Mississippian series no doubt absorb large quantities of ground water along their wide belts of outcrop and carry these beneath the cover of the coal measures as they sink toward the west. Thus, confined between thick beds of shale, the water is under artesian pressure that is sufficient in places to bring it to the surface. The flow, however, is meager, and, as with all limestones, is not reliable. The drill may strike or may fail to strike the water channels. The white limestones of the Burlington, the lower formation of the Osage group, seem to yield the greatest quantity of water. The only deep wells which report definite water beds in the Mississippian are at Cherokee, Ottumwa, Mount Pleasant, Mitchellville, Des Moines, Bedford, Council Bluffs, and Logan. The two cities last named are situated in an area where the Mississippian yields an exceptionally abundant supply.

KINDERHOOK GROUP.

Over the entire north end of the area in which the Mississippian series forms the country rock the Kinderhook is a fine-grained, heavy-bedded limestone, an excellent water carrier in which all rock wells end and in which they rarely, if ever, fail to secure a large quantity of excellent hard water under sufficient artesian pressure to place it within easy pumping distance of the surface. In some counties, as Kossuth, Humboldt, and Wright, the artesian head in the Kinderhook is so well developed beneath the impervious clay of the drift that many wells flow (pp. 650, 654, 665). The shale beds of the Kinderhook, so unpromising for wells along their outcrop, are of distinct advantage as they sink below the surface and form part of an artesian system. They prevent the upward escape of waters from the underlying strata and conduct down their dip the waters of the limestones of the Mississippian along their impermeable floor.

OSAGE GROUP.

Wells.—The drill on penetrating the Osage group (Keokuk and Burlington limestones) rarely fails to find water in some crevice, especially near the base, before reaching the dry shales of the Kinderhook. Should the driller reach the latter he has the alternative already presented in the discussion of the Niagara-Maquoketa contact (p. 104). He may continue to drill in search of the deep artesian supplies, though this is impracticable for the ordinary farm or village well, or he may make another boring some distance away in the hope of better success in striking some crevice in the limestone. Before beginning a new boring it is advisable to fill the hole to the base of the limestone and shoot the well with nitroglycerin in an attempt to so shatter the rock that connection may be made with water-bearing crevices and to enlarge the area of intake. By such means excellent wells have been secured from holes practically dry in the Osage.

Springs.—Springs are not uncommon throughout the Mississippian area where the valleys have been cut into the country rock. They are commonly small and are unimportant except for watering stock in the valley pastures. The most important in southeastern Iowa come from the base of the Burlington limestone, of the Osage group, where the impervious shales of the underlying Kinderhook check the downward movement of the circulating water and cause it to collect in large quantities in the open spaces in the limestone, whence it flows through some passage to an outcrop. Such springs are common along the base of the Mississippi bluffs in Des Moines and Lee counties and on the lower course of Skunk River, and are of still greater importance farther south in the vicinity of Louisiana, Mo. These springs are frequently used for household and stock purposes.

"ST. LOUIS LIMESTONE."

The median bed of the "St. Louis limestone" is an important water carrier in Keokuk, Washington, Henry, and Lee counties, where it forms the country rock, and in Monroe, Mahaska, Wapello, Jefferson, and Van Buren counties, where it is reached by the drill after passing through Pennsylvanian rocks at depths ranging from 200 to 500 feet. It is penetrated in many places in the Pennsylvanian areas on account of the dryness of the coal measures or the mineralized condition of their waters. It is in this area that it is known as the "white-water sand rock" and is sought for by all drillers of deep farm wells when a satisfactory sandstone water is not found above. Farther north it is drawn on by a few wells in Hamilton, Webster, and Story counties. Locally it produces flowing wells. The upper and lower portions of the "St. Louis" are, on the whole, very indifferent water carriers.

PENNSYLVANIAN SERIES.

DES MOINES GROUP.

Wells.—Owing to the presence of impermeable shales the Pennsylvanian is almost dry. Water is commonly found in the seams of coal but, owing to the abundance of iron and sulphur compounds it carries in solution, is never potable. In fact, it is characteristic of the waters of this division that they are strongly impregnated with mineral matter and in most places are unfit for use.

The chief water bed of the Des Moines group is the basal sandstone, which has its greatest development in southwestern Iowa. At Council Bluffs it is apparently this terrane which supplies the deep wells of the city, but the yield of these wells is by no means large compared with that of wells tapping Cambrian and Ordovician water-bearing beds in eastern Iowa. At Glenwood water from this sandstone rises to a height of 1,006 feet above sea level and overflows at the surface in the lowest parts of the town, but the yield is not large. At Bedford the water from the same terrane rises to 1,008 feet above sea level. On the whole, it can not be recommended that deep wells be sunk to this sandstone with the expectation of obtaining any considerable amount of water, such as would be required by even a small town.

Small amounts of water may also be found in the sandstone lenses of the Des Moines and Missouri groups, but as these lenses are not continuous over any considerable area, and as their vertical position can not be predicted, no local forecasts can be based on them. They give rise to numerous small flowing wells. One of the best known lenses of this type is the Red Rock sandstone, which outcrops at the village of Red Rock, in Marion County, in a brilliant red cliff 100 feet in height overlooking Des Moines River. This sandstone occupies less than 30 square miles, but within this area it lies near the surface and furnishes an abundance of good water to all wells penetrating it. It is, however, missed in many wells where it might be reasonably expected, owing to the effects of erosion, which is in part at least contemporaneous.

The rapid alternation of impervious shales and porous sandstones underlying heavy drift clays produces conditions favorable to the formation of small artesian basins which frequently give rise to flowing wells. Especially in the larger and deeper valleys like those of the Des Moines and its major tributaries where the "bottoms" are depressed well below the upland surface, flowing wells with a head of but a few feet above the surface and a delivery of but a few gallons a minute are not uncommon. Stronger flows may be had from the "St. Louis" and the Kinderhook. The most notable wells of this type are the Colfax Mineral Springs of Jasper County. These are supplied by a "St. Louis" aquifer.

Springs.—Throughout the area where the Pennsylvanian forms the country rock springs are of little importance. Seeps from shales are common but are small and highly mineralized. A few crevices in outcrops of sandstone lenses produce small springs of excellent water for domestic purposes, but these are rarely strong.

MISSOURI GROUP.

Wells.—In some places in the area where the Missouri group forms the country rock a scant supply of hard water is found in the limestone below 100 to 300 feet of drift. The risk of a dry hole is probably greater than in any other area, since below the Missouri group lies the very uncertain Des Moines group, and rock wells in this area are therefore comparatively few. There are some excellent exceptions to these general conditions, but the wells of the region are chiefly in overlying drift. The beds of shale are invariably dry. The heavy limestones carry a scant supply of water between the shale beds and this is always hard. The overlying drift is very deep over much of the area, especially on the great Mississippi-Missouri divide, and comparatively few wells reach bedrock.

Cities and towns in the western portion of the province are largely located in the broad river valleys, where an abundance of water may be found at slight depths in the gravel. In the eastern part the interglacial gravels furnish water most copiously. There is little need to resort to the deeply buried rock save on the great divide itself, where in many places any ground water is hard to obtain.

Springs.—Small springs are common along the deeper valleys at the contact of limestone and shale, but the only rock horizons of importance noted in the Missouri group area lie along the ragged eastern edge, where the limestone rises almost in an escarpment and is thickly overlain with drift. Here in eastern Madison and Clarke counties good stock springs are numerous.

QUALITY OF CARBONIFEROUS WATERS.

No general statement can be made as to the quality of the waters from the Carboniferous or any of its divisions, save that the quality seems to vary greatly from one locality to another. In a general way it may be stated that the waters of this system are usually more highly mineralized than those of lower ones, and that the mineral matter is greatest in the upper beds of the Carboniferous. A reason for the want of uniformity may possibly be found in the fact that no extensive sand layers or other strata with high power of transmission of water are found in the Carboniferous. It follows that the waters of this system are more local in origin; they are not transmitted from far-away sand plains, as in the lower sandstones, but are derived from the Iowa rainfall, perhaps from the immediate vicinity, and must pass through the drift, in some localities through hundreds of feet of it. There is thus every opportunity for the water to take up any soluble matter that may exist in the drift or immediately under it. (See Pl. IV, p. 178.)

In the area where the Mississippian is the surface rock all wells footing in this series supply soft to only moderately hard water, as far south as Hardin County. Even those in Hamilton County, to the west of Hardin, give lightly mineralized waters, though in Hamilton County the Mississippian is overlain by the Pennsylvanian. Farther south, however, well waters from the Carboniferous are hard to very hard. Several good examples are found in Tama County. Their waters are not very different from those of the flowing drift wells of the Belle Plaine district, but the hardness of their waters can not be credited to the drift, as the mineral content seems to increase with the depth. Near Grinnell, in Poweshiek County, all the wells in the Carboniferous which have been investigated supply hard water containing about 2,100 parts per million of total solids. There are other centers of hard water from this system in Jasper and Polk counties. Wells footing in the Carboniferous in other parts of the State apparently always yield hard waters. It is apparent that wells footing in or passing through the Pennsylvanian yield more highly mineralized water than most those that are in the Mississippian only (in areas where the Pennsylvanian is absent), though the wells of Tama County, a Mississippian area, yield very hard water. It seems fair to conclude that the waters of the upper Carboniferous are, on the whole, harder than those of the lower Carboniferous.

WATER IN CRETACEOUS ROCKS.

DAKOTA SANDSTONE.

Wells.—The Dakota is everywhere a good water carrier, yielding copious and permanent supplies, but the water is commonly mineralized—as a rule highly mineralized. In the northwestern portion of the province the overlying drift is very deep and the sandstone water head, though under slight artesian pressure, is so far below the surface as to make pumping difficult. General difficulty throughout the northern end of the Dakota area is found in the very fine incoherent sand which enters the well, cements itself in the screens, and wears out the pumps. In the central and southern portions, however, no such difficulties have been reported, and on the whole the Cretaceous sandstone may be regarded as the best shallow-rock water carrier in the western part of the State.

Slight artesian pressure is common throughout the Cretaceous area and in the deeper valleys weak flowing wells are not uncommon.

Springs.—Sand-rock water strata like the Dakota are prolific sources of seeps and springs wherever outcrops are found, but as there are few outcrops in the Cretaceous area, because of the deep drift, springs are correspondingly scarce. The most important spring horizon is at the base of the sandstone formation where it overlies the shales of the Missouri group. The contact is exposed in places in the deep valleys which trench the area in the southwest. It gives rise to strong springs in the vicinity of Lewis, in Cass County, and of Red Oak, in Montgomery County.

QUALITY OF CRETACEOUS WATERS.

Of the Cretaceous little need be said. Apparently all wells penetrating it deeply yield hard waters. A few wells in the northwestern part of the State which penetrate the Cretaceous for a few feet yield fairly good water, but this water is probably from the drift. As a matter of fact, it has been stated and reiterated by those who have been over the ground that experience does not encourage drilling deeply into the rock in the northwestern part of the State.

WATERS OF UNCONSOLIDATED DEPOSITS.

QUATERNARY DEPOSITS.

The water-bearing beds in the Quaternary are numerous and their positions are extremely variable. Yet many localities have what the drillers recognize as "first water bed," "second water bed," and in some places even "third water bed," above the country rock. These water beds may in some places be identified by certain well-known sand or gravel beds in the drift, but they vary greatly with locality and in many places are either dry or wanting.

The Quaternary water carriers most frequently recognized and reported are as follows, in order of age from the top downward: Alluvium, Wisconsin drift, loess (including subloessial sands), Iowan drift, Illinoian drift, Buchanan gravel, Kansan drift, Aftonian gravel, Nebraskan or sub-Aftonian drift, and preglacial residual soil.

PRE-KANSAN DEPOSITS.

RESIDUAL SOIL.

The residual soil, which occurs in the driftless area and which immediately overlies bedrock in the drift area, is not a good water bearer, but is drawn on in some places on the broad, flat uplands as a source of shallow wells. The supply of water is scant and uncertain and is probably derived in part from the sandy base of the overlying loess.

NEBRASKAN DRIFT.

The Nebraskan or sub-Aftonian till is of no particular value as a water bed and the old soil and forest beds that accompany it render the waters offensive in some places. The sand and gravel layers, however, buried many feet beneath the surface of the ground, form very valuable aquifers, the water being under artesian pressure beneath the relatively impervious till.

AFTONIAN GRAVEL.

The water of the Aftonian gravel is generally pure, wholesome, and abundant. In some local areas the presence of decaying organic matter in the old soil and peat beds associated with the gravel imparts a disagreeable odor and taste to the water; in other areas, as in the Belle Plaine artesian basin, the water carries sulphates and other salts in solution in such quantities as to be unsuitable for either boiler or domestic use. Such occurrences, however, are exceptional. Wherever the gravel outcrops in the valleys, as in the vicinity of Afton, it gives rise to springs of no mean proportions. On the whole the Aftonian gravel is probably the strongest Pleistocene water bearer in the State.

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KANSAN DRIFT.

The great thickness of the Kansan drift over large areas necessitates its use for domestic and farm wells and it probably supplies more wells than any other water bed in the State, whether of the drift or of the country rock. The supply of many of the shallower wells comes from the sands at the base of the overlying loess and from the gravelly phase in the upper portion of the Kansan, but this supply is extremely uncertain in quantity and generally fails in dry weather. The deeper wells are supplied by the many small sandy lenses and layers and the "veins" in small, more or less open tubular channels scattered through the heavy till. The deep-well water is of good quality, provided care is taken to prevent surface contamination, but it is variable in quantity. Though deep wells in the Kansan are not likely to be affected by drought, neighboring wells may differ very greatly in yield. On the flat divides of the Kansan, where ground water stands high, dug wells are not uncommon, and these are constructed of so large a diameter that a large surface for seepage and an ample reservoir for storage are secured.

Over the much more extensive area of the dissected Kansan dug wells have been superseded by drilled or bored wells, the greater depth more than compensating for the smaller diameter. The windmill or the gasoline engine forms part of the necessary equipment of every farm.

ILLINOIAN DRIFT.

The Illinoian drift is penetrated by many wells but is not clearly distinguished from the Kansan, which it resembles in its water-bearing qualities.

BUCHANAN GRAVEL.

Within the area of the Iowan drift the Buchanan gravel lies between the Iowan and Kansan drift sheets and forms a most valuable water carrier, supplying innumerable shallow wells and giving rise to numerous springs wherever it outcrops. Its greatest importance, however, is in the lowlands and in the old filled valleys. On the uplands it is thin and scattered.

The Buchanan gravel has been of great importance in the development of manufacturing in the northeast quarter of the State. Owing, however, to its slight depth and its open texture its waters are easily polluted by organic matter from the surface. They frequently have a slight taste and leave a brown stain due to compounds of iron in solution.

IOWAN DRIFT.

Water occurs in the Iowan drift in small sandy layers and lenses and in the small "veins" of the till. From these it seeps into the wells slowly but constantly, supplying them with a moderate amount of hard water, which will be pure provided care is exercised to prevent the entrance of surface water and its accompanying contamination. Owing to the thinness of the drift and the strength and purity of the country-rock aquifers below, rock wells are very commonly replacing wells to the Iowan drift.

LOESS.

The loess was formerly an important source of supply for farm wells throughout the State, but drainage and cultivation have so lowered the ground-water level as to greatly lessen its importance. The subloessial sands lying beneath the loess and over the till near the Iowan margin yield a somewhat more plentiful but very uncertain supply. Many shallow wells dug in sloughs and other moist places still utilize this source for stock water. Both the loess and the subloessial sands are extremely liable to contamination from surface waters, cesspools, etc., and should be avoided for domestic purposes, especially in towns or villages and in the neighborhood of barnyards on the farms.

WISCONSIN DRIFT.

In the Wisconsin drift shallow wells are general, the supply being obtained, as in the other drifts, from sandy layers and "veins" in the till, but they are especially liable to pollution owing to the prevalence of surface waters. The better drift wells go below the base of the Wisconsin and draw their supply from underlying beds of the loess or lower horizons.

ALLUVIUM.

The sands and gravels of the alluvium yield an inexhaustible supply of good water at depths ranging from 15 to 100 feet. They may be reached throughout the "first bottoms" and in places on the "second bottoms" of the larger rivers and tributaries. Water is generally obtained at slight cost by means of open or driven wells and in larger quantities for city supplies through infiltration beds and collecting galleries. These deposits furnish the chief underground water supply for several large cities within the State.

In towns and cities these alluvial waters are generally contaminated from the surface or through cesspools. The public supply should always be taken at some point above the city and private wells should be closed. All such supplies, when used for drinking or domestic purposes, should be carefully tested and guarded.

UNDERGROUND-WATER PROVINCES OF THE QUATERNARY.

The regional differences between the waters of the different drifts are not so characteristic as to form well-defined provinces. The limits of the several water-bearing strata are, however, determined by the limits of drift sheets to which they belong or are related as interbedded deposits. These limits do not coincide with those of the districts into which the State has been divided and for specific consideration of drift waters it seems advisable to redivide it on the basis of drift sheets coextensive with the topographic areas already described (pp. 46–53), and known as the Wisconsin, Iowan, Illinoian, and Kansan drift provinces and as the driftless province.

In the driftless province water is obtained from the alluvium, the loess, and the residual soil. The loess and the residual soil supply shallow wells on the broad, flat uplands, but the yield of both is so scanty that most good wells are sunk to one of the numerous and excellent country rock horizons, which may there be reached at comparatively little expense. On the flat valley floors shallow wells draw an abundance of good water from the gravel and sands underlying the alluvium. Springs from the outcropping rocks of the valley sides are so numerous as to greatly decrease the number of wells necessary.

In the Kansan drift province water may be obtained from the alluvium, the loess, the Kansan drift, the Aftonian gravel, and the Nebraskan drift. The great thickness of the Kansan drift and the presence of Pennsylvanian rocks immediately underneath a large part of this area causes the Kansan drift to be one of the most fully utilized waterbeds of the State, even though its yield is scanty. Owing to the depth of the drift and the scanty yield, deep-bored wells are now becoming common, especially in the vicinity of the Mississippi-Missouri divide. Many wells in the southeastern district penetrate the Aftonian gravel and are abundantly supplied. The base of the drift, where this is sufficiently shallow to be reached by ordinary farm wells, is a favorite source of supply; it probably includes the Nebraskan as well as the Aftonian horizon.

Under the broad floors of the valleys the flow is ample for the cities of several thousand people located thereon. The waters are obtained by wells fitted with drive points and Cook strainers. On the broader uplands many of the shallowest wells draw a small supply from the sandy layer in the base of the loess immediately overlying the impervious till.

In the Illinoian drift province water is obtainable from the loess, the Illinoian drift, the Kansan drift, and the Aftonian gravel. The Illinoian and Kansan drifts are not clearly differentiated in the wells; both are used indifferently by wells, and even the loess affords a meager supply for many wells. The better drift wells draw from basal gravels, probably those of Aftonian age.

In the Iowan drift province water is obtained from the Iowan drift, the Buchanan gravel, the Kansan drift, and the Aftonian gravel.

The Iowan and Kansan drifts are both generally used, but the strongest wells draw from the Buchanan or Aftonian gravels. Such wells are generally best developed on lowlands and in old stream channels. The loess supplies some shallow wells on the margin of the area where it overlies the edge of the Iowan drift.

In the Wisconsin drift province water is obtainable from the Wisconsin drift, the loess, the Buchanan gravel, the Kansan drift, and the Aftonian gravel. The porous loess is very generally recognized where present and is the best shallow-well aquifer in the area. Owing to the immaturity of the topography the ground-water level is high, wells are generally shallow, and all not well guarded are liable to surface pollution.

CHAPTER IV.

ARTESIAN PHENOMENA.

By W. H. Norton.

DEFINITION OF ARTESIAN WATER.

The term "artesian" has been used with several meanings, but, in accordance with the usage now prevailing, artesian waters include not only the water of flowing wells but also well waters that rise to a considerable height within the tube under hydrostatic or artesian pressure. Thus, in the deeper river valleys of Iowa, the head of the water from the Paleozoic aquifers is higher than the valley floors, and the water overflows in natural fountains, many of which are of considerable height. On the uplands, however, water from the same water beds, rising through the same strata, under the same driving force, and with the same head, fails to reach the surface of the ground. The important and definite fact is that under hydrostatic pressure the water rises to or nearly to the surface. In classifying ground waters it is comparatively unimportant whether the surface of the ground at any given point is slightly above or below the level to which the water from the deep source rises.

HEAD OF ARTESIAN WATERS.

DEFINITION.

The water beds of the Iowa artesian slope dip southward from their outcrop on the high lands of the States adjacent on the north. The water confined within these beds is therefore under hydrostatic pressure, much as is the water in a city's mains from the weight of the column of water in the standpipe. Under this artesian pressure it rises in deep wells far above the level of the water bed. It may fall short of reaching the surface of the ground, or it may overflow and in an open tube connected with the well may even rise and maintain itself at a considerable height above the well mouth. The height at which artesian water stands under hydrostatic pressure is called its static level or head. It may be expressed in its relation to sea level, to the level of the water bed, or to the level of the well mouth. As artesian wells may head either above or below the well mouth, they are divided into two classes, flowing and nonflowing.

MEASUREMENT.

The head of flowing artesian wells may be measured in two ways. The pressure may be measured at the well mouth, in pounds per square inch, by means of a gage, and the head may then be computed in feet. As a column of water 1 inch square and 2.3 feet in height weighs 1 pound, the number of pounds pressure at the well multiplied by 2.3 equals the head in feet. Somewhat less conveniently the head of flowing wells may be measured by tubing coupled water tight and carried up until the water stands at the top but does not overflow. The size of the tube is immaterial. The test is most easily made with a hose of any convenient diameter, carried up a ladder or trestle, since, owing to its flexibility, it may be lifted or lowered until the exact head is obtained and the cuttings and coupling needed with metal pipe are obviated.

To obtain the true hydrostatic balance a day or even several days may be necessary, and for this as well as for other reasons the test is most conveniently made with the pressure gage.

FACTORS AFFECTING HEAD.

ELEVATION OF AREA OF SUPPLY.

The head or static level depends on several conditions, chief among them being the elevation of the intake area, or area of supply, where the water bed or beds outcrop and gather their water from the rainfall. The area of supply of the principal water beds of the Iowa artesian system—the Cambrian and Ordovician sandstones—lies for the most part in southern Minnesota and Wisconsin, where it comprises about 14,500 square miles. The area presents a considerable diversity in elevation but in few places is more than 1,200 feet above sea level. With a gathering ground whose altitude is relatively so low, the water beds of Iowa furnish only a moderate pressure to their artesian waters. The enormous pressure of the South Dakota artesian wells, for example, due to the high gathering ground on the flanks of the Black Hills—pressures which equal heads of 400 feet in places and which can be utilized for power in manufacturing plants or to supply fire protection for a city—are not to be expected in Iowa.

ELEVATION OF SURFACE AT THE WELL.

The highest heads, relative to the top of the well, are found where the elevation of the ground surface above sea level is least. From Des Moines River eastward the artesian wells situated in the deeper valleys are flowing wells, and the wells of the deepest valley, that of the Mississippi, register the greatest pressure. The following table exhibits the maximum initial head reported from the wells in the Mississippi Valley in Iowa from north to south:

Maximum initial head of wells in the Mississippi Valley in Iowa from north to south.

Town.	Head above low water in river.	Head above sea level.
	Feet.	*Feet.*
Lansing	88	690
McGregor	87	694
Dubuque	153	740
Sabula	70	656
Green Island	84	665
Clinton	66	632
Davenport	103	643
Fort Madison	136	638
Burlington (on bluffs)	136	647
Keokuk	190	667

On the other hand, on the uplands of the State the water generally fails to rise to the top of the wells, although it generally rises higher (above sea level) than it does in the valleys.

AGE OF WELL.

Owing to various causes, some remediable and some irremediable, the artesian head in any given well commonly decreases with lapse of time. Any plans to utilize the pressure for fire protection, as at Sabula, or for running dynamos for city lighting, as at Keokuk, should take account of this fact.

After the first wells are drilled in any locality, it is often difficult to determine the true head. Leaks are liable to develop by which more or less of the water escapes laterally from the drill hole, and the head of the water is correspondingly reduced. As other wells are drilled from time to time and are left to discharge freely, the head is further lowered and it is difficult to determine the pressure in any given well, unless all the other wells can be closed for the occasion. In many places the flow of a new well on lower ground has drawn down the head of other wells in the neighborhood.

HYDRAULIC GRADIENT.

Most water-bearing formations are cut at greater or less distances from their outcrops by river valleys, into which more or less of their water escapes. Such leakage necessarily reduces the pressure, or head, of the water, the effect increasing as the point of escape is neared. It has been found that, owing to this and to certain other factors (such as the friction of the rock particles through which the water percolates), the height to which artesian water will rise above sea level declines more or less uniformly from the intake area to the point of escape. This decline is known as the hydraulic gradient.

GROUND-WATER LEVEL.

Under certain conditions the height of the ground-water level of the area and the head of minor and higher artesian aquifers tapped by the drill may affect the head of a well.[1] The effect of these agencies is illustrated in the map (Pl. I, in pocket). In Iowa the hydraulic gradient declines from Boone eastward to Clinton on Mississippi River, 310 feet in 190 miles, the surface of the ground falling 550 feet in the same distance. (See Pl. XI, p. 382.)

RELATIVE HEADS OF IOWA AQUIFERS.

When a deep well is being sunk, the question is often asked whether water under greater pressure, giving a higher head, will be found at greater depths or whether the deeper water will be under less pressure, causing the well perhaps to lose its flow. It is greatly to be regretted that the data at hand so seldom permit a conclusive answer to this question. When a deep well penetrates several different water beds, the head of each bed should be tested as the drilling is in progress, but as this testing of flowing wells involves considerable trouble and some expense it is seldom if ever done. In nonflowing artesian wells the fluctuation of water in the drill hole due to the different heads of different aquifers can be readily observed, but in few wells have such observations been made and placed on record. When the head of a well is given, it is seldom known by what particular water vein the pressure is determined or to what extend the head has been lowered by the discharge of other wells.

The chief aquifers of the Iowa water system, the St. Peter sandstone, Prairie du Chien group, Jordan sandstone, and Dresbach sandstone and underlying Cambrian formations, afford considerable evidence that the lowest water beds give the highest head. Thus at Dubuque the original heads of the wells ending above the Dresbach sandstone seem to have been from 700 to 740 feet above sea level, whereas the head of wells which tapped the Dresbach or underlying Cambrian sandstone reached perhaps 753 feet. At Waterloo the head of the water from the St. Peter is given at 865 feet above sea level, and that from the water beds between the St. Peter and the Dresbach at 867 feet, but at Davenport the beds below the St. Peter seem to have a somewhat greater head. In the deep wells at Holstein the waters from the higher formations, including the St. Peter and probably

[1] Chamberlin, T. C., Requisite and qualifying conditions of artesian wells: Fifth Ann. Rept. U. S. Geol. Survey, 1885, pp. 125-173.

the Jordan, stood 325 feet below the curb; when the Dresbach was struck, the water rose to 270 feet below the curb. On the other hand, in some nonflowing artesian wells, as at Pella, Centerville, Burlington, and Anamosa, the water seems to have maintained about the same level while the drill was passing through the various Cambrian and Ordovician water beds. At Ottumwa the aquifers of the flowing wells seem to have a common head at about 700 feet above sea level. At Boone, on the other hand, the head of the water of the St. Peter is 1,080 feet above sea level, but that of the main vein in the deeper sandstone is 940 feet above sea level, 140 feet lower.

The head of the water beds above the St. Peter may be either higher or lower than that of the Cambrian and Ordovician beds. In upland wells of northeastern Iowa the head of the water from the Niagara, the middle part of the Maquoketa, the Galena, and the Platteville is higher than that of the water from lower aquifers. Thus at Sumner the waters from the middle Maquoketa and the Galena stood 18 feet below the curb, and those from the Cambrian and Ordovician beds 144 feet below. This difference is especially marked in the extreme northeastern counties, where the main river valleys dissect the St. Peter and even the Jordan and permit water to escape. Thus at Calmar the water from the Galena and Maquoketa rises 76 feet higher and at Postville 170 feet higher than the water from the St. Peter. In wells outside of this area and in valley wells within it the water from the Cambrian and Ordovician aquifers usually rises higher than that from superior terranes. Thus at Vinton the water from the St. Peter rises 38 feet higher than that from the Devonian, and at Davenport it rises 10 feet higher than that from the Galena. At Holstein the water from the St. Peter rose 40 feet and at Osage about 10 feet above that from higher water beds.

The head of the Dakota sandstone in northwest Iowa seems to be higher than that of lower water beds, exceeding that of the St. Peter at Cherokee by 120 feet. In fact, the reported high head of many deep wells in this part of the State may be largely due to the Dakota waters.

The map showing artesian head (Pl. I, in pocket) presents the scanty data at hand, but forecasts must not be based on it with undue assurance. The head of any well depends on a number of factors and is perhaps the least predictable matter connected with the subject. In a number of the wells the head probably depends on that of waters of drift or country rock. The map presents, however, the salient facts of the decreasing head with increasing distance from the area of supply and the heightening influence of the ground waters of the uplands in central and northwestern Iowa.

YIELD OF ARTESIAN WELLS.

MEASUREMENT.

No deep-well data are more unreliable than those relating to yield. The reported discharge of flowing wells is seldom more than a loose estimate and often, no doubt, a gross exaggeration. For pumped artesian wells, the amount delivered by the pump can and should be calculated with considerable accuracy and may be assumed to be the capacity of the well when the latter does not exceed the capacity of the pumps. The yield of flowing wells may be estimated by the flow over a weir, by a current meter set in the pipes or by the time necessary to fill a receptacle of known capacity. If the yield is moderate, measures as small as hogsheads may be used for this purpose. Slichter [1] describes a very simple method of determining the yield of a flowing well devised by J. E. Todd. Pumping tests should last at least 24 hours and should be conducted with pumps of adequate capacity.

PERMANENCE OF YIELD.

FACTORS AFFECTING PERMANENCE.

The length of time which an artesian well may reasonably be expected to remain in service, the causes which impair or ruin it, and their remedies are questions of vital importance on which some light should be shed by the collated history of the hundreds of deep wells of the Iowa field, some of which have been in operation for a quarter of a century.

It may naturally be expected that, like any other mechanism, this apparatus for bringing water from its subterranean sources to the surface is liable to deteriorate with age, to need from time to time repairs of various kinds, and, indeed, to break down from one cause or another and to become altogether useless. To know the points of weakness in this mechanism, which is not quite so simple as it at first view may seem, and to know the dangers which threaten it is absolutely necessary if the well is to be so constructed and so cared for as to insure its permanence.

A deep well drilled in Iowa for a quarter or half a mile, straight toward the center of the earth, passes through rocks of various kinds. Some are strong and unyielding; and some are mobile or plastic, creeping under the enormous weight of overlying rocks they carry and thus constricting or closing the drill hole. Some are brittle and fragile, and from such rocks movements of water in the well dislodge fragments which, on falling, leave cavities along the bore hole and, accumulating at the bottom, choke the discharge of the water beds

[1] Slichter, C. S., The motions of underground waters: Water-Supply Paper U. S. Geol. Survey No. 67, 1902, pp. 90-93.

situated there. Some are close textured; some are spongy and porous; and some are creviced. Some are dry, and some are water logged, and of the latter class some contain good water and some water so highly mineralized as to be unpotable or injurious to the health. Of the good waters, some may be under so little pressure that another flow under higher pressure will drive them back and escape through their channels if left free to do so.

The main water bed may consist of loose and crumbling sandstone, which with time breaks down and forms a chamber, roofed, perhaps, with shale, which, when left unsupported, caves in and closes the waterway.

For some distance from the surface the well commonly penetrates incoherent material incapable of standing in a solid wall. A casing is therefore inserted and bedded in solid rock. But unless the juncture of casing and rock is water tight, the ascending water of a flowing well will in time find a way through it out of the drill hole.

Finally, even if the well is perfectly constructed and the supply in the water bed is large, the yield may be diminished through overdraft by other wells put down in the vicinity.

Permanence of an artesian yield, therefore, depends (1) on the construction and care of the well itself; (2) on the character of the water bed from which it draws; and (3) on the combined draft on the water bed by all the wells in the vicinity.

FACTORS RELATING TO THE WELL.

CASING AND PACKING.

Heavy iron casing is inserted where the well passes through weak rocks liable to cave or creep and where it passes through aquifers containing salt or bitter water or good water under so low head as to permit lateral escape of the main flow. The upper casing is carefully packed at the base to prevent any escape of water. Where the water bed is of weak rock it is protected with strong casing perforated to admit the entrance of water.

All these precautions are taken if the job is thoroughly done. But as casing is costly, as the nature of the rocks to be penetrated is in many places not well known, as the heads of the various water veins are not tested—for all these and for less excusable reasons it is not seldom that some of these points of danger are left unguarded. The upper casing is left unpacked but is simply grounded on bedrock, which in Iowa is usually limestone. This soluble rock gradually decays about the base of the casing, a thin thread of water escapes into the surrounding overlying sands or shattered rock, and the opening is enlarged by solution until the leakage is sufficient to stop the flow of the well.

Uncased shales, although to all appearances at first sufficiently firm, may yield to the action of the water passing over their exposed surface and cave within a few years after the completion of the well. Limestones, although strong enough to stand indefinitely, may contain crevices, openings, and porous beds of which the driller is entirely unaware. Water from other pervious beds under heavy pressure is driven into these passages until most of it escapes through these leaks and the well ceases to flow.

The main water bed may be a loose-grained sandstone, which, if not cased, gradually breaks down and tends to fill the well with its detritus. It may be a fine-grained as well as a loose-grained sandstone, and even when the well is cased the grains may be fine enough to pass through the perforations of the casing and the strainers, likewise causing the drill hole to fill. Where casing is sunk to prevent leakage the pressure under which it is driven down may split or break it at the joints, and through these breaks the water may escape.

DIAMETER OF DRILL HOLE.

Very obvious causes of difference in the yield of artesian wells are differences in the capacity of the drill hole or its casing. The cross section of a tube varies as the square of the diameter; thus, disregarding other factors, an 8-inch pipe would carry 16 times as much water as a 2-inch pipe. But the larger the diameter the less the frictional resistance; hence the difference in favor of the larger pipe is still greater. Taking into account both cross section and frictional resistance, the discharge of pipes varies as the 2.5 power of the diameter.[1]

The yield of a deep well is controlled, not by the maximum diameter of the bore hole—that at the well mouth—but by the diameter of the hole at the water-bearing stratum. In sinking deep wells it is necessary from time to time to reduce the diameter of the drill hole. The first deep well at Boone, for example, which began with a diameter of 8 inches, was reduced four times, and reached the bottom at 3,010 feet with a diameter of 3 inches. The Greenwood Park well at Des Moines, 3,000 feet deep, beginning with 10 inches, reached the bottom with 3 inches. For this reason and because of the rapid increase in the cost of drilling with increase of depth, it may be concluded that the limit of profitable drilling lies under rather than over 3,000 feet. The cost of tapping a water bed at this distance from the surface with a drill hole large enough to carry its waters is so great that the outlay is seldom warranted.

Large holes also have an advantage in that they offer a larger surface of transmission within the water rock, and thus give a more

[1] Slichter, C. S., op. cit., p. 84.

generous yield, but this increase is comparatively slight. Thus, of two wells, each sunk 100 feet in water beds presenting similar conditions of pore space, pressure, etc., a 6-inch well yielded 36 cubic feet a minute and a 12-inch well only 41 cubic feet a minute, although its carrying capacity is four times as large.[1] Several small wells will secure a larger inflow than one large well. Furthermore, to secure the maximum efficiency of a number of wells, they should be spaced as widely as practicable so as to interfere as little as possible with one another.

FACTORS RELATING TO THE WATER BEDS.

PRESSURE.

The yield of flowing wells from beds of equal porosity varies with the pressure of the water at the point of discharge, or with the difference between the surface level at the point of discharge and the level to which the water will rise by artesian pressure. The relatively large yield of the deep wells of the valley towns of Iowa compared with that of upland wells is explained by their greater head, and the assumption made by some persons that natural cracks and fissures of great extent coincide with river valleys is quite gratuitous. The law is well illustrated in a test made of a flowing well at Hitchcock, Tex., whose water rose about 30 feet above the curb, the point of discharge being taken at different heights and therefore at different distances below the static level. When the point of discharge was 25.35 feet above the curb the well yielded in a given period 8,022 gallons, and when it was 0.76 foot above the curb it yielded in the same period 95,000 gallons. This change, which was equivalent to increasing the head from 4.65 feet to 29.24 feet, increased the flow of the well nearly twelvefold. In the location of wells this law of pressure variations should be considered. Other things being equal, the lowest ground available should be chosen as the site of the well, for here the head and discharge will be the greatest.

To the same law is due the greatly increased flow when pumps or air lifts are used. Thus, at Charles City, the yield of the city well, whose estimated natural flow was 200 gallons a minute, was increased by a vacuum of 7 pounds to 900 gallons per minute. At Mason City, Waterloo, and Dubuque greatly increased flows are obtained by means of air lifts. Advantage is taken of the same principle when the pumping cylinder is set low in nonflowing wells. At Ames a test made with the cylinder set 270 feet below the ground gave a maximum discharge of 7,400 gallons an hour; at 149 feet below the surface it gave 5,000 gallons an hour; and 105 feet below the surface it gave only 3,525 gallons an hour.

[1] King, F. H., Principles and conditions of the movements of ground water: Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1899, p. 285.

Pressure is a controlling factor in the transmission of water through porous rocks. Experiments have shown that the yield of porous sandstones varies with the pressure, but doubling the pressure usually more than doubles the amount of water transmitted. The moderate pressures of the Iowa artesian basin suffice to overcome the frictional resistance and to drive the water on its way but are not sufficient to force such immense yields as are reported from wells of the Dakotas. The moderate pressure may also result in a comparatively rapid lowering of the head in any local area, for the slower the transmission the more rapidly will the area be depleted under a given draft.

THICKNESS.

Few if any wells yield as much water as would be indicated by the theoretic capacity of their pipes and the velocities due to their pressures. This is because the water is delivered to the pipe through porous rock through which water seeps from distant sources under great frictional resistance. The yield depends, therefore, on a number of conditions relating to the rock constituting the water beds. It depends on the amount of surface exposed in the drill hole within the water bed. When the bottom of the hole barely touches the water bed, or an unperforated casing extends to the bottom of the well, this surface is at a minimum and gives a minimum yield, for it is then merely the area of the circle whose diameter is the diameter of the bore. When the entire water bed is penetrated and the hole is uncased, the surface of transmission is at a maximum and gives a maximum yield, for it is then the surface of a cylinder whose height is the thickness of the water bed. Thus a thick water bed will not only hold and carry more water than a thin one, but may also deliver more water to a well. Several water beds will yield more than a single water bed of less than their combined thickness. The thickness and the number of the Iowa aquifers therefore constitute one cause of the large flow of the wells. It follows that a deep well should be sunk completely through any given water bed, and that the more water beds it traverses the larger will be its yield, provided of course that certain beds do not drain away the waters of others because of differences in head. Several Iowa wells that have stopped in the St. Peter sandstone would have obtained a much more copious yield if they had been carried through the Prairie du Chien and the Jordan.

On the other hand, there are places where the lower waters should be left undisturbed even though the yield would be increased by drilling to them. At Cedar Rapids and at McGregor the first wells drilled encountered salty and corrosive waters in the Cambrian sandstones, and wells drilled later in these towns were, therefore, stopped before they reached the horizons at which the deleterious waters were obtained. In northeastern Iowa, along the Mississippi Valley, the lowest of the aquifers, the Dresbach and underlying Cambrian sandstones, is drawn upon freely; but outside of this area the expense of reaching it, and the probability of finding its waters highly mineralized, are so great that it is generally advisable to stop the drill at the base of the Jordan sandstone.

In loose, friable sandstone it may be necessary to case through the water bed. In such wells the casing should be perforated through the entire thickness of the water bed.

TEXTURE AND POROSITY.

Yield depends very largely on the texture and porosity of the water rock. Gravel yields its store of water more freely than coarse sand, and coarse sand than fine sand. Doubling the effective size of grain quadruples the yield. Stratified rocks transmit water most readily parallel to their bedding planes, and this fact gives an additional reason for the large yield of wells which penetrate water beds deeply and are fed from the sides by horizontal currents, as compared with the yield of wells which touch only the upper surface of the water bed and are fed from the bottom by currents rising transverse to the bedding planes.

The main sandstone aquifers of the Iowa artesian system include many highly porous beds through which water seeps freely into wells. Their grains are moderately large, are exceptionally smooth and well rounded, and are fairly uniform in size, thus increasing the pore space, as few minute grains are packed in the interstices of the larger grains. Cements filling the pore spaces to a greater or less extent are practically absent in many of these water-bearing beds. In consequence of these conditions, the sandstone aquifers of Iowa yield exceptionally abundant supplies.

With increasing distance from outcrop and with increasing depth and slackening of the ground-water circulation clogging and filling of pore spaces may be expected in any water-bearing terrane accompanied by restriction of the water channels to special horizons kept open after the remainder of the rock of the terrane has become impervious by cementation. The yield of aquifers, such as the St. Peter and the Jordan, can not be expected to be as great where they reach great depths in central Iowa as it is in northeastern Iowa, where they lie much higher and their circulation is far more active.[1]

CREVICES.

The yield of the artesian wells of Iowa is increased by the fact that the waters flow not only through the pore spaces of sandstones and loose-textured limestones but through the fissure cracks and crevices

[1] The St. Peter struck at Nebraska City, Nebr., at a depth of 2,783 feet, although 64 feet thick, was found dry.

that are common in limestones and occur even in many sandstones. The existence of these passages might be inferred from general considerations and from experience elsewhere, but in the Iowa field it has frequently been proved by the sudden drop of the drill, by the deflection of the drill, and by the underground disappearance of drillings. Many of these passages through limestone are in connection with the sandstone aquifers.

Between the St. Peter and the Jordan sandstones lies a heavy body of creviced limestone, more or less arenaceous and in places interleaved with layers of porous sandstone, and below the Jordan sandstone lie the limestones of the St. Lawrence formation. Throughout this entire body of rock, from the base of the Platteville to the summit of the impervious beds of the St. Lawrence, artesian waters may participate in a common movement. Water sinks or rises from sandstone to limestone, and vice versa. Where its course lies in the solution passages in limestone its velocity is greatly increased, and where the drill penetrates such crevices the flow is proportionately abundant. Even the delivery of the sandstone is no doubt increased by communication with the more open ways of the limestones.

CLOGGING.

The yield of some wells diminishes because the water bed becomes clogged. Fine material in the rock is carried little by little toward the well and accumulates immediately about the drill hole in the interstices between the larger grains, thus lessening the porosity and the transmission capacity of the aquifer and lessening correspondingly the yield of the well. The danger is believed to obtain especially with incoherent sandstones which have large diversity in size of grain and contain material of siltlike fineness, either interleaved or disseminated through it. In the main water beds of Iowa—the Cambrian and Ordovician sandstones—clogging to any noticeable extent from this cause should be rare. In the artesian wells at Savannah, Ga., an effectual remedy for clogging was found in forcing a strong flow down the well by means of fire engines.

Clogging may be the result of the growth of microscopic plant life and gelatinous deposits of iron, as in the Linwood Park deep well at Dubuque, where the obstruction was a fibrous growth, probably of Crenothrix, and where churning an iron rod in the well doubled the diminished flow.

OVERDRAFT.

Artesian wells may fail because of overdraft. In many large towns and cities the fact that a copious supply of water, whose purity is above suspicion, can be obtained at moderate cost, leads to the multiplication of wells beyond the local transmission capacity of the aquifers. The head of old wells gradually diminishes and that of the new wells drilled from time to time fails to reach the initial head of the wells first drilled. The opening of a well of unusually large yield, resulting from its exceptionally large diameter or from its location on low ground, may cause a sudden fall of pressure in all the wells of the locality.

Finally, the artesian head in a locality may be so reduced that all the wells cease to flow and all require pumping. The cause of this lowering of artesian head is simply that more water is being drawn from the water beds at this place than can flow in. The storage capacity of the artesian basin is not overdrawn, nor is there a deficiency in the rainfall and absorption over the area of supply of the artesian system. The limiting factor is the transmission capacity of the water-bearing strata at that locality. For such a condition there is obviously no remedy. The most that can be done is to guard against any waste of the water, either above ground or by leakage below the surface. The real overdraft may be due not to necessary consumption but to leakage from a number of wells.

In the towns and cities of Iowa where many wells have been drilled loss of pressure has been noted too generally to be accounted for by deterioration of individual wells. Such a loss, for instance, has occurred at Dubuque, Clinton, Davenport, Burlington, Keokuk, and elsewhere (pp. 132–133). In none of these places has the decrease been sufficient wholly to prevent artesian flow, though in several pumps are used to increase the yield.

REMEDIES FOR DECREASED YIELD.

The first step in remedying decreased yield is to discover whether the error is not in the well itself. Even when properly constructed the mechanism of a deep well can not be expected to last indefinitely. Packing may deteriorate with age and leaks develop about the lower end of the uppermost casing. Casings in time rust out, and under the chemical action of certain waters this deterioration may be rapid. The casing may be attacked at the joints, the screw threads becoming so rusted that when the casing is drawn to recase the well each joint has to be lifted separately; or the water may corrode the sides of the casing, perforating it with holes as large, sometimes, as a 5-cent piece, thus causing leakage. The remedy here is to recase the well.

In a number of Iowa wells where this has been done the initial yield has been restored. Thus the Atlee well, at Fort Madison, used for a public fountain in the street and for a private fountain on the grounds of the owner, which lost its head of 55 pounds, is said to have had this entirely restored by recasing. Unfortunately a well may be drilled a little out of vertical and the insertion of a casing is impossible when a need of repairs arises. An example is afforded by the deep well at Monticello, one of the oldest artesian wells of the State, which furnished excellent water but had to be abandoned because the crooked bore hole prevented the essential repairs.

In wells ending in sand the screen at the foot may become incrusted and the flow of the water stopped. The remedies for this are discussed on pages 192–195.

In many oil wells an increase in yield has been obtained by torpedoing with nitroglycerin. This method has not been attempted with the Iowa artesian wells, nor, indeed, can it be recommended except as a last resort where drill holes would otherwise be failures. In close-textured limestones the shattering of the rock under the torpedo may not extend to any passageways. It must be remembered that an artesian well is expected to be far more permanent than an oil well. Torpedoing a well usually not only makes it impossible to sink it deeper but also to repair it at any time.

Still less excusable is the use of nitroglycerin in repairing drill holes. At Vinton in 1910 two adjacent deep wells needed repairs of the same nature and extent. In attempting to pull a corroded casing in the north well several shots of high explosives were fired and the drill hole was so damaged that the total cost of the repairs exceeded $7,400, whereas the repairs on the south well made by an experienced company cost but $1,600.

STATISTICS OF DECREASED YIELD.

The following tables present all the information which has been gathered concerning the deep wells of Iowa which have been abandoned or whose yield has decreased:

Artesian wells whose yield has diminished.

Location.	Depth.	Date of completion.	Date when diminution first noticed.	Head above or below curb. Original.	Head above or below curb. Present (1908).	Yield. Original.	Yield. Present (1908).	Remarks.
Cedar Rapids:								
City well—	*Feet.*	*Year.*	*Year.*	*Feet.*	*Feet.*	*Gallons per min.*	*Gallons per min.*	
No. 1	2,225	1883	1901	28	2	250	150	Well plugged at 1,450 feet; loss gradual; casings rusted; no repairs.
No. 2	1,450	1883	1901	28	2	250	150	Loss gradual; casings rusted; no repairs.
No. 3	1,450	1883	1901	28		250		Casings rusted; no repairs; not in use.
Young Men's Christian Association well.	1,450	1894						Casings rusted; no repairs.
Clinton:								
Clinton Paper Co.	1,065	1883	1895	42	$\frac{1}{12}$			Loss gradual; casing rusted; recased to depth of 160 feet in 1896, but no improvement noted.
Chicago & North Western Ry.; near station.	1,159	1896	1905	12	±12		500	Loss gradual; leaked about old packing; yield increased by recasing and repacking in 1905.
Chicago & North Western Ry.; South Clinton.			1908		−20			Loss sudden on completion of well of Sugar Refining Co.; flows as usual when the well of sugar company is closed; no repairs.
Amana:								
Woolen mill	1,640	1883	1893	30	20	200	+50	Loss gradual; repacked in 1889.
Burlington:								
Murray Iron Works	831	1903		92 69	46			Yield decreased from time to time as other wells were drilled; no repairs.
Iowa Soap Co	509	1904	1905	33	4			Loss sudden when Clinton Copeland well was sunk; no repairs.
Sanitary Milk Co.	487	1905	1905					Head decreased 46 feet when Clinton Copeland well was sunk; no repairs.
Smith and Palton	460	1905	1905	30		40		Loss sudden, presumably owing to drilling of other wells; no repairs.
Council Bluffs:								
Chicago, Milwaukee & St. Paul Ry.	750						+ 3½	Loss gradual and continuous; cause unknown. No repairs.
School for the Deaf—								
Well No. 1	1,090	1886		50	10	59	+ 3 15	Loss gradual; increased flow temporarily by deepening, cleaning, and recasing in 1893.
Well No. 2	1,100						+ 6 30	Loss gradual; no repairs.
Geisse Brewery	1,114						(*b*)	Casing rusted.
Davenport:								
Woolen mills	1,053	1890		87	1			Flow temporarily increased by recasing in 1895 and in 1901.
Davenport Packing & Provision Co.	1,100	1893		46	7			
Gas works	1,200	1891		52	4			Loss gradual
Glucose factory	2,101			81	24			
Do	2,105	1889		81				
Do	2,107	1892		81	24			
Do	1,500	1876			24			

Independent Malting Co.—								
Well No. 1	1,285	1896			9		400	Loss sudden, due to pumping of other wells.
Well No. 2	1,285	1904			9		400	Do.
Kimball House	1,100			58				Flow ceases when wells of glucose factory are used; cleaned out and reamed.
Dubuque:								
City well, Eagle Point—								
South well	1,308			23	10			Under air lift said now to yield 435,000 gallons per day.
North well	1,306			23	10			Under air lift said now to yield 1,208,000 gallons per day.
Schmidt Brewery	886	1891						Decrease caused by interference; flow ceased in 1908.
Linwood Cemetery—								
No. 1	1,954	1891	1900	36				Pump installed in 1905, when water stood 45 feet below curb.
No. 2	1,765			−23				Water level lowered by unknown amount.
Butchers' Association	1,000			133	±20			
Chicago, Milwaukee & St. Paul Ry. round house.	1,262			76	29			
Julien House	1,660			109	70			Original depth, 896 feet; deepened to 1,660 feet in 1898.
Dubuque Packing Co	955			55	34			Loss gradual.
Dubuque Brewing & Malting Co	1,165				½			Loss gradual; original depth, 999 feet; repacked, recased, and drilled to present depth; results beneficial.
E. Hemmi	973	1895.			− 5			Stopped flowing in 1902, with use of air lifts on Brewing & Malting Co.'s well.
Key City Gas Co	1,310			48				Interference of other wells noted.
Dubuque city well—								
Eighth Avenue	1,310	1888			10			Slightly decreased by use of air lift in Eagle Point wells.
Sixth Avenue	1,908	1900		22	11			Decreased to one-third normal yield by use of air lift in the Eagle Point wells.
Fort Madison:								
Atchison, Topeka & Santa Fe Ry., hospital.	764	1892	1902	20	(*a*)			Loss sudden; yield slightly improved by deepening and recasing in 1903.
Keokuk:								
Hubinger wells	2,000		1904–1906					Loss gradual.
Do	2,230							Ceased to flow in 1908.
Ottumwa:								
Iron works	1,150	1888		50				Loss gradual; defective packing.
John Morrell & Co. well—								
No. 1	1,110	1888	1892	36		800	207	Loss gradual; well filled with sediment; flow increased by reaming in 1892.
No. 2	1,554	1892	1901				214	Well filling with sediment.
No. 3	1,702	1898	1901	50		1,500	244	Do.
No. 4	2,205	1905	1907			1,450	1,500	Do.
Sabula city well	973	1895	1903	74	64	720	550	Loss gradual.
West Liberty city well:								
No. 1	1,768	1888		9		120		Gradual loss; in 1900 water stood 12 feet below curb and pumping capacity was 75 gallons.
No. 2	1,594	1900	1902			225		Loss gradual; still flows.
Wilton city well	1,360	1891	1898	1½	−20	300	120	Loss gradual; partly reamed in 1900, without effect.

a Few inches. *b* Small.

Abandoned artesian wells.

Location.	Depth.	Year completed.	Year abandoned.	Yield. Original.	Yield. Present.	Remarks.
	Feet.			*Gallons per minute.*	*Gallons per minute.*	
Ackley:						
City well	2,030	*a* 1893	*a* 1908	(*b*)	....	
Boone:						
City well—						
No. 1	3,010	1890	1906	70	....	Abandoned for cheaper supply from shallower wells.
No. 2	2,914	1897	1906	70–80	70–80	
Centerville:						
City well No. 1 in public square	2,495	....	....	200	200?	Drilled before waterworks were installed in 1895; never pumped; abandoned in favor of new well at a more convenient location.
Des Moines:						
Greenwood Park well	3,000	1896	1902	....	....	Water mains extended into park; no deterioration of yield or head.
Dubuque:						
City well on Eighth Street	1,310	1888	....	2,500?	100	Original head, 46 feet; head in 1908, 3 feet; loss noted years ago; no repairs ever made.
Fort Madison:						
Brown Paper Co	689	1888	1902	600	....	Casing gave way in 1898 and well filled with sand; inside casing was inserted and well was used a few years, when it again caved and was abandoned.
Glenwood:						
Asylum for Feeble-minded	1,910	1897	....	70	60	Abandoned because of scanty supply and infection with typhoid germs.
Monticello:						
City well	1,198	1875	1900	200	....	Abandoned because of decreased yield; crooked hole made recasing impossible.
Newton:						
City well—						
No. 1	1,400	1890	....	....	....	
No. 2	705	....	....	....	....	
Sigourney	1,888	1882	....	....	....	Poor water; never used.
Clinton:						
Dewitt Park	1,675	1890	....	625	....	Original head, 44 feet; flow ceased; disconnected from waterworks.

a Before. *b* Ample.

CHAPTER V.

CHEMICAL COMPOSITION OF UNDERGROUND WATERS.

By W. S. Hendrixson.

INTRODUCTION.

NATURE OF ANALYSES.

The analytical work of this investigation has been confined to determination of those mineral or inorganic constituents that are commonly found in nearly all ground waters and that have an important bearing on the suitability of the waters for municipal and industrial uses. The following are the substances determined:

Silica (SiO_2).
Iron (Fe).
Aluminum (Al).
Calcium (Ca).
Magnesium (Mg).
Sodium (Na).
Potassium (K).
Carbonate radicle (CO_3).
Bicarbonate radicle (HCO_3).
Sulphate radicle (SO_4).
Nitrate radicle (NO_3).
Chlorine (Cl).

In calculating the averages of the analyses potassium has been included with sodium, as potassium was separately determined in only a few of the waters. In most of the analyses not made by the writer iron and aluminum were determined together as oxides. In a few analyses silica was included with those oxides. It is, therefore, impossible to find true averages of iron and aluminum, and these are omitted from the tables. The proportion of the analyses giving silica separately is large enough to justify including its average in the table, though the average can not be rigidly construed. Where considerable quantities of nitrate were indicated the nitrate radicle (NO_3) was determined.

Many deep-well waters contain amounts of ammonia that would be sufficient to cause suspicion of pollution if they were found in waters from shallow wells. The presence of ammonia in water from deep wells is probably due to the reduction of nitrates by pyrite or other reducing substances. Whatever the cause, both the ammonia and the nitrate are to be regarded as due to fermentation long since completed and therefore as without significance from the sanitarian's point of view.

Eleven waters are included for which only total solids were obtainable from the analyses. These are waters analyzed only with a view to their use in boilers, and only the total solids, incrusting matter, and chemicals necessary for softening them are given; they are included in the general tables because there are few available analyses of waters in the regions in which they occur.

The 400 analyses that are tabulated represent waters from all but two of the 99 counties in the State. The majority are analyses of waters from wells of the northeastern part, or deep-well district, of the State. Some counties have no wells of considerable depth which enter sources of water of more than local character. In some this may be due to the absence of easily available sources of large water supplies, as is apparently true in some parts of southern Iowa. In others the existing deep-water resources have not been developed; for example, six counties—Worth, Howard, Chickasaw, Butler, Grundy, and Buchanan—all favorably located in the artesian district, have, so far as known, no wells penetrating the lower sandstones. Five others—Mitchell, Floyd, Franklin, Black Hawk, and Delaware—have only one such well each. In these counties there are few large towns, and most of the small towns having water systems procure supplies to meet present needs from shallow wells or from streams. As they grow and their demands increase a large development of the deep-water resources may be expected.

STATEMENT OF ANALYTICAL RESULTS.

FORM OF ANALYSES.

In the statements of results of analyses by other chemists the mineral constituents are frequently expressed in the form of salts and oxides. As the oxides of aluminum and iron are commonly weighed together, it is impossible to separate the iron and aluminum in the recalculated analyses and their combined oxides are therefore given in this report unchanged. The same applies to silica when it was weighed with the oxides of aluminum and iron.

Until recently it was customary to represent the results of analyses of water in terms of hypothetical compounds as they were supposed to exist in solution. Many have been the discussions, not to say controversies, as to whether, for example, calcium would combine with the sulphate radicle rather than with chlorine, according to inherent selective affinity. All such discussions have been rendered irrelevant by general acceptance of the ionic theory, for it is now well known that the mineral matter in such dilute solutions as the average well water exists almost entirely as free radicles, with the exception of silica, which is given as SiO_2. There is no longer any scientific reason why the results should be represented as compounds, and there is very little in the way of practical convenience to justify such practice. It is true that if any given water be evaporated to dryness the contained substances separate out as compounds according to the law of least solubility, and in a definite order according to the relative amounts of the substances present, but the order would scarcely be the same for any two waters. The only logical procedure is, therefore, to give the constituents as radicles, though it may be a little confusing to those who are unaccustomed to this mode of expressing results.

In the enumeration of radicles that were determined, two forms of combined carbonic acid have been given. As a matter of fact, Iowa deep-well waters are almost without exception acid to phenolphthalein and contain free carbon dioxide. The carbonate radicle is regarded, therefore, as HCO_3 and is so given in the tabulated results of analyses. It has been thought better in summing up the radicles determined to give the total solid matter as it would be weighed on evaporation to dryness; that is, with the carbonates as normal salts. The change on evaporation is represented by the decomposition of acidic calcium carbonate, $Ca(HCO_3)_2 = CaCO_3 + CO_2 + H_2O$. The ratio of $2HCO_3$ to CO_3 is 2.03 to 1, or, with sufficient accuracy, 2 to 1. Therefore, one-half the weight of the bicarbonate radicle, HCO_3, is subtracted from the sum of the radicles as they are in solution to obtain a figure representing the probable amount of solids left by evaporation to dryness and heating to 180° C., according to common practice.

The amount of mineral matter in solution is given in parts per million instead of in grains per gallon. To avoid any confusion at this point the following considerations may be presented with certain simple rules derived from them for changing data in one system into their equivalents in another:

1. One liter of water weighs 1,000,000 milligrams, and it follows that 1 milligram or 0.001 gram of solids per liter of water is equivalent to one part per million.

2. One grain per United States gallon is equivalent to 17.118 parts per million, or 0.017118 gram per liter.

To change from one system to another, therefore, the appropriate rule may be selected from the following and applied to the data at hand.

To get grains per United States gallon from parts per million, divide by 17.1; or from grams per liter, divide by 0.0171.

To get parts per million from grains per United States gallon, multiply by 17.1; or to get grams per liter from grains per United States gallon, multiply by 0.0171.

RECOMPUTATION OF FORMER ANALYSES.

Though there is at the present time very little scientific justification for representing the mineral matter dissolved in water in terms of compounds, it has been the almost universal custom till very recently. From such theoretical combinations the temporary and permanent hardness of waters have been determined, their power to form boiler scale has been calculated, and the nature and amounts of the agents necessary to soften them have been decided. It is not necessary for any of these purposes to assume the existence of compounds in waters. (See pp. 136–137.) Many persons, however, prefer to have an analysis of water stated in terms of compounds, and it certainly is necessary in the comparison of the qualities of two waters to have the analyses expressed in the same terms. For these reasons it seems desirable to make certain statements regarding the relations of the two methods of stating results and to give a logarithmic table to facilitate the conversion of the data of one system into those of the other.

In the calculation of the results of analysis to compounds the practice is by no means uniform. Perhaps the most common method is as follows: Granting that the water contains the usual kinds of mineral matter and is acid to phenolphthalein, the bicarbonate radicle is calculated to calcium and magnesium in order till it is exhausted. The remaining calcium and magnesium, or very probably magnesium only, is calculated to sulphate. Any remaining sulphate radicle and also the chlorine are calculated to sodium compounds, and to potassium if that element is separately determined. Silicon, iron, and aluminum are commonly reported as the oxides. The calculation must be varied, of course, in accordance with the water in hand. This statement applies to a typical Iowa water of moderate mineralization.

In order to facilitate recomputation of analyses of that nature, a table of logarithmic factors is given. It contains all the compounds that have been found in converting the data of old analyses for use in this report. Column A contains the logarithms of the chemical factors necessary to find the radicles on the left from their compounds on the right. For example, the factor for computing the amount of calcium in calcium carbonate is $40.1 \div 100.1$, and its logarithm is 0.6027. In column B are the logarithms of the chemical factors plus the logarithm of the factor necessary to convert grains per United States gallon into parts per million. According to a recent determination of the Bureau of Standards, this factor is 17.117967, or, with sufficient accuracy, 17.118, and its logarithm is 0.23345. The logarithm for computing parts per million of calcium from grains per gallon of calcium carbonate is, therefore, 0.8361.

As is usual in such logarithmic tables, the characteristics are omitted. It is hardly necessary to state that one may obtain logarithms of compounds corresponding to radicles by subtracting the appropriate logarithmic factor from the logarithms of the weights of the radicles.

Logarithmic factors necessary for recomputing analyses.

Amount of—	In—	Logarithmic factors.		Amount of—	In—	Logarithmic factors.	
		A.	B.			A.	B.
Ca	$CaCO_3$	0.6027	0.8361	Cl	$CaCl_2$	0.8053	0.0388
Ca	$CaSO_4$	.4691	.7025	Cl	$MgCl_2$	.8717	.1052
Ca	$Ca(HCO_3)_2$	.3934	.6268	Cl	NaCl	.7825	.0159
Ca	$CaCl_2$	.5577	.7912	Cl	KCl	.6769	.9103
Ca	CaO	.8542	.0876	SO_4	$CaSO_4$	.8485	.0819
Mg	$MgCO_3$	.4605	.6940	SO_4	$MgSO_4$	.9018	.1353
Mg	$MgSO_4$	.3060	.5394	SO_4	Na_2SO_4	.8298	.0632
Mg	$MgCl_2$	.4077	.6411	SO_4	K_2SO_4	.7411	.9745
Mg	$Mg(HCO_3)_2$	.2213	.4547	SO_4	$BaSO_4$	.6143	.8478
Mg	MgO	.7807	.0142	SO_4	SO_3	.0791	.3126
Mg	$Mg_2P_2O_7$	.3399	.5734	CO_3	$CaCO_3$	.7777	.0112
Na	Na_2CO_3	.6380	.8714	CO_3	$MgCO_3$	.8520	.0855
Na	$NaHCO_3$	.4381	.6716	CO_3	Na_2CO_3	.7524	.9859
Na	Na_2SO_4	.5109	.7444	CO_3	K_2CO_3	.6373	.8708
Na	NaCl	.5955	.8290	CO_3	$FeCO_3$	.7141	.9475
Na	Na_2O	.8706	.1041	CO_3	CO_2	.1347	.3681
K	K_2CO_3	.7529	.9864	NH_4	NH_3	.0248	.2583
K	K_2SO_4	.6523	.8858	NH_4	N	.1091	.3426
K	KCl	.7200	.9534	HCO_3	Na_2CO_3	.9393	.1727
K	K_2O	.9193	.1528	HCO_3	K_2CO_3	.0545	.2879
K	$KHCO_3$	.5921	.8255	HCO_3	$CaCO_3$	.9140	.1474
K	K_2PtCl_6	.2073	.4407	HCO_3	$MgCO_3$	.8397	.0731
Fe	Fe_2O_3	.8449	.0783	HCO_3	$FeCO_3$	.9777	.2111
Fe	$FeCO_3$	.6833	.9168	HCO_3	CO_3	.6918	.9251
Al	Al_2O_3	.7245	.9580				

CHEMICAL COMPOSITION OF WATER BY DISTRICTS.

To facilitate the study of well waters in relation to geographic distribution, the State has been subdivided into eight arbitrary districts (see fig. 2), known as the northeast, north-central, northwest, east-central, central, southeast, south-central, and southwest districts. The composition of the waters will be discussed according to these districts, the analyses within each being arranged alphabetically by counties. The tables contain both analyses of well waters made originally for this report and those received from other sources.

NORTHEAST AND NORTH-CENTRAL DISTRICTS.

The northeast and north-central districts contain most of the slightly mineralized water of the State. The quality of the waters in the two districts is so nearly the same that both may as well be considered together.

With two exceptions—those of the deep wells at Bancroft and McGregor—the solids of the deep-well waters do not reach 1,000 parts per million, and in only three waters do they much exceed 500. The McGregor well is unnecessarily deep, for there are several others at the same place and at North McGregor which have only about

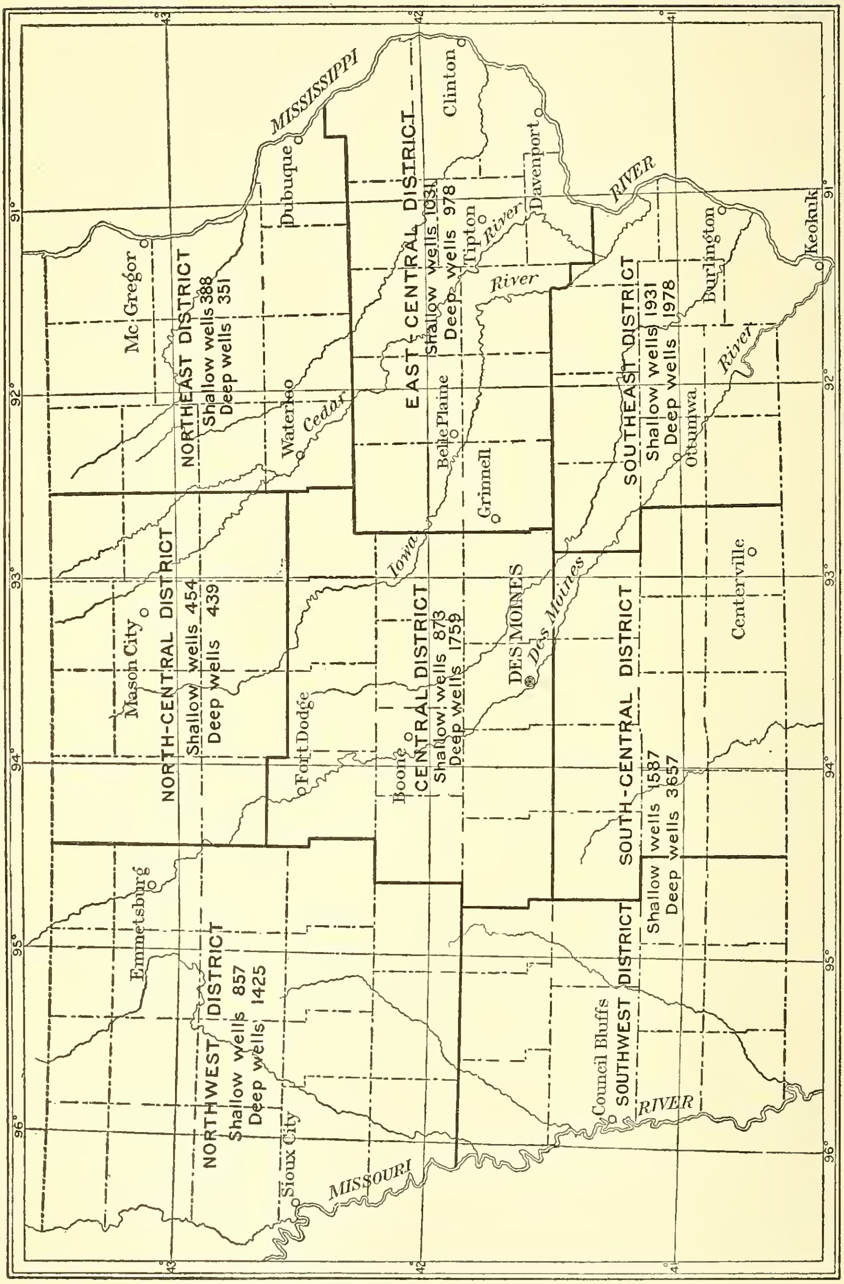

FIGURE 2.—Map showing division of State into districts, and the average mineral content of waters of deep and shallow wells in each district.

half its depth and yet yield an abundance of excellent water. Its excess of solids is due to salt, and it is the only well in these two districts that shows this substance in considerable amount.

The following table shows the average amounts of certain constituents carried by the deep and the shallow wells in these two sections:

Average mineral content of waters in northeast and north-central districts of Iowa.

[Parts per million.]

Source.	Silica (SiO_2).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.[a]
NORTHEAST DISTRICT.								
30 deep wells	10	63	31	28	321	38	24	351
20 shallow wells	15	89	32	16	347	83	12	388
NORTH-CENTRAL DISTRICT.								
7 deep wells	11	87	33	20	328	92	14	439
37 shallow wells	18	99	32	253	418	68	8.8	454

[a] The sum of the constituents minus one-half the bicarbonate radicle.

The average solids for the deep wells and for the shallow wells of the districts are nearly the same. The best wells of each sort contain about 270 parts per million of mineral matter. The shallow-well waters are as uniformly good as the waters of the deep wells, the only two shallow wells approaching or reaching 1,000 parts of solids being those at Bancroft and at New Hampton. The waters of a few of the best wells of both classes contain about the same amounts of solids as the waters of Des Moines, Iowa, and Cedar rivers, which rise in these districts. The shallower wells, unlike many in the southern and southwestern parts of the State, are not commonly located in the flood plains of rivers. In fact flood plains are less common in this part of the State, the rivers more often flowing between bluffs of considerable height.

With the exception noted at McGregor the waters of the districts are entirely normal—that is, they contain for the most part magnesium, calcium, and bicarbonates, and the harder ones contain notable amounts of sulphates. They are the best boiler waters of the State, as well as the best for general municipal and industrial purposes.

Analyses of water in the northeast district of Iowa.

[Parts per million.]

Locality.	Owner.	Depth of well.	Lowest geologic division.	Silica (SiO_2).	Oxides of iron and aluminum. ($Fe_2O_3+Al_2O_3$).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.[a]	Name of chemist.
HOWARD COUNTY.		*Feet.*															
Cresco	City	400	Galena	20	......	......	2	115	36	26		315	66	71	46	540	W. S. Hendrixson.
Do	do	200	Devonian (?)	26	......	......	3	116	29	32		306	80	68	58	565	Do.
Lime Springs	J. W. Davis	166	Devonian limestone.	20	......	......	1	121	49	10		446	10	......	28	462	Do.
WINNESHIEK COUNTY.																	
Calmar	Chicago, Milwaukee & St. Paul Ry. Co.	1,223	St. Lawrence	......	2	......	......	90	24		1	302	36	......	2	306	H. E. Smith.
Decorah	Union Springs	......	......	13	......	......	.5	78	27	4	1	330	18	......	4.3	311	W. S. Hendrixson.
Ossian	T. V. Gilbert	730	New Richmond	18	......	......	1	124	36	20		392	73	......	50	518	Do.
Do	Chicago, Milwaukee & St. Paul Ry. Co.	155	......	......	3	......	......	89	46	2		478	21	......	2	402	Geo. N. Prentiss.
ALLAMAKEE COUNTY.																	
New Albin	Hotel	500	Cambrian sandstone underlying the Dresbach.	7	......	......	1.3	49	56	6	2.5	390	18	......	8	343	W. S. Hendrixson.
Do	Creamery	470	do	9	......	......	.5	48	53	14	2	378	19	......	6.5	341	Do.
Lansing	City	668	do	9	......	......	......	42	17	99	5	284	63	......	73	450	Do.
Do	A. C. Doehler	640	do	12	......	0.3	......	44	16	95	9	274	59	......	64	436	Do.
Postville	Chicago, Milwaukee & St. Paul Ry. Co.	80	......	......	......	......	1	99	32	7		402	33	......	4	377	Geo. N. Prentiss.
Do	City	515	St. Peter	8	......	......	1	77	41	11	4	402	35	......	4	382	W. S. Hendrixson.
Village Creek	A. C. Doehler	750	Cambrian sandstone underlying the Dresbach.	9	......	.2	......	57	23	50	8	274	46	......	42	372	Do.
Waukon	City	600	do	10	......	......	2	88	24	5	2	324	30	......	7	330	Do.
CHICKASAW COUNTY.																	
New Hampton	City	235	Devonian & Maquoketa.	8	......	1	.1	64	27	18	3	289	35	......	5	306	W. S. Hendrixson.

Do	Chicago, Milwaukee & St. Paul Ry. Co.	188	Devonian	......	3	......	......	219	50	24			456	366	......	33	923	Geo. N. Prentiss.
Ionia	....do	148		......	7	......	......	78	26	25			389	28	......	1	364	Do.
Do	....do	155		......	3	......	......	81	27	24			393	37	......	1	370	Do.
BREMER COUNTY.																		
Fairbank	H. Leistikow	113	Drift	8	......	2	.3	70	28	25			406	1	......	2	339	W. S. Hendrixson.
Sumner	City	1,720	St. Lawrence	8	......	1	1	43	20		63	9	353	8	......	4	334	Do.
Waverly	....do	1,740	....do	6	......	......	2	66	30		32	9	341	56	......	7	379	Do.
FAYETTE COUNTY.																		
Fayette	......	......	......	......	......	......	2	66	20		4	2	238	22	......	5	240	W. S. Hendrixson.
West Union	City	70		......	3	......	......	75	24	11			348	9	......	10	306	Geo. N. Prentiss.
CLAYTON COUNTY.																		
Elkader	City	186	St. Peter	8	......	.3	.2	68	28	12			288	57	......	.5	318	H. S. Spaulding.
McGregor	....do	520	Cambrian sandstone underlying the Dresbach.	7	2	......	......	58	29	47			510	54	......	36	488	J. B. Weems.
Do	City (No. 2)	1,006	....do	6	6	......	......	160	20	706			509	465	......	968	2,585	Do.
Do	City (No. 3)	520	....do	9	......	.4	2	89	36	179			345	133	......	246	867	W. S. Hendrixson.
North McGregor	City	430	....do	10	......	......	3	68	28		51	4	301	54	......	61	429	Do.
Do	Chicago, Milwaukee & St. Paul Ry. Co.	480	....do	......	......	......	......	67	28	45			309	44	......	59	397	Geo. N. Prentiss.
Monona	Wellman	420	Galena	......	2	......	......	101	44	16			371	133	......	19	500	Do.
Do	City	450	....do	14	......	.5	.6	86	42	16			335	86	......	10	423	W. S. Hendrixson.
BLACKHAWK COUNTY.																		
Hudson	City	158		9	......	.1	1	100	27		11	4	206	186	......	3	444	W. S. Hendrixson.
Waterloo	Water Co	1,373	St. Lawrence	7	......	......	1	78	38		41	5	368	106	......	8	468	Do.
BUCHANAN COUNTY.																		
Jesup	City	312	Devonian	14	......	......	3	83	30	9			283	48	......	7	335	W. S. Hendrixson.
DELAWARE COUNTY.																		
Manchester	U. S. Fish Hatchery (spring).	......	......	10	......	......	1	50	20		5	1	207	11	......	4	206	W. S. Hendrixson.
Do	City	1,870	Cambrian sandstone underlying the Dresbach.	33	......	......	2	60	17	6			96	134	......	9	309	Do.

a Sum of constituents minus one-half of bicarbonate radicle.

Analyses of water in the northeast district of Iowa—Continued.

Locality.	Owner.	Depth of well.	Lowest geologic division.	Silica (SiO_2).	Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.	Name of chemist.
DUBUQUE COUNTY.		*Feet.*															
Dubuque	Steam Heat Co.	802	Cambrian sandstone underlying the Dresbach.	......	......	......	......	56	36	2		342	15	......	2	282	
Do	Butchers Association.	936	.....do	......	2	......	......	54	31	2		294	17	......	1	254	C. F. Chandler.
Do	Malting Co.	900	.....do	......	......	......	......	76	22	14		256	26	......	21	287	Geo. N. Prentiss.
Do	Brewing & Malt Co	1,165	.....do	8	......	0	1	58	37	7	3	310	20	......	8	297	W. S. Hendrixson.
Do	Eighth Street well, City.	1,200	.....do	12	......	0	.5	54	32	4	3	284	16	......	5	268	Do.
Do	J. Cushing's foundry.	965	.....do	......	......	......	......	52	32	8		310	15	......	4	266	Wahl & Henius.
Do	Brewing & Malt Co	999	.....do	......	......	......	......	71	21	11		302	15	......	18	287	Do.
Do	City Gas Co.	1,310	.....do	5	......	1	1	56	33	4	3	310	12	......	10	280	W. S. Hendrixson.
Do	Chicago, Milwaukee & St. Paul Ry. Co.	937	.....do	......	1.5	......	......	57	35	5		332	15	......	2	281	Geo. N. Prentiss.
Do	.....do	1,262	.....do	......	......	......	......	56	33	9		322	18	......	7	284	Do.
Do	Bank & Insurance Building.	973	.....do	5	11	......	......	51	25	21		300	21	......	0	284	J. B. Weems.
Do	City, Eagle Point.	1,327	.....do	5	......	......	1	55	33	2	4	316	13	......	5	276	W. S. Hendrixson.
Do	Linwood cemetery	1,954	Sandstone	14	......	2	3	64	32	3		326	34	......	9	324	Do.
Farley	Chicago, Milwaukee & St. Paul Ry. Co.	100	Niagara (?)	......	1.2	......	......	85	28	17		260	128	......	10	399	Geo. N. Prentiss.
Worthington	.....do	95		......	a109	......	......	49	41	9		172	151	......	5	450	F. O. Bunnell.

a Probably this is mostly suspended clay.

Analyses of water in the north-central district of Iowa.

[Parts per million.]

Locality.	Owner.	Depth of well.	Lowest geologic division.	Silica (SiO_2).	Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.[a]	Name of chemist.
KOSSUTH COUNTY.		*Feet.*															
Algona	City	1,050	Oneota	10	......	1	1.5	104	54	41	11	420	205	......	10	647	W. S. Hendrixson.
Do	W. Lacey	227	Cretaceous	14	......	1.6	.6	101	32	44		464	84	......	4	549	H. S. Spaulding.
Bancroft	Chicago & North Western Ry. Co.	438	......	3	2	......	......	180	65	93		436	518	......	11	1,090	Geo. M. Davidson.
Burt	do	600	......	9	3	......	......	136	32	38		494	129	......	6	600	Do.
Germania	Chicago, Rock Island & Pacific Ry. Co.	235	......	......	5	......	......	105	42	50		454	151	......	6	586	F. O. Bunnell.
Irvington	Chicago & North Western Ry. Co.	178	......	26	......	......	......	96	37	7		632	65	......	10	557	Geo. M. Davidson.
Luverne	City	35	Drift	......	14	......	......	112	41	......	......	366	140	28	......	518	F. O. Bunnell.
WINNEBAGO COUNTY.																	
Forest City	City	300	200 ft. in rock	15	......	......	.2	102	34	19	3	460	40	......	4	447	W. S. Hendrixson.
Lake Mills	Minneapolis & St. Louis R. R. Co.	240	Mississippian	22	......	......	......	88	27	15		398	22	......	6	379	Geo. M. Davidson.
Do	Chicago & North Western Ry. Co.	334	Devonian limestone.	17	......	......	2.2	87	28	5		406	8	......	1.5	352	Do.
Woden	S. Stenerson	116	......	19	......	3	2	67	24	54		442	31	......	1	422	H. S. Spaulding.
WORTH COUNTY.																	
Hanlonton	Chicago & North Western Ry. Co.	260	Devonian limestone.	22	3	......	......	73	16	24		277	40	......	23	340	Geo. M. Davidson.
Maney	Chicago, Rock Island & Pacific Ry. Co.	320	Devonian	......	3	......	......	71	21	2		246	48	......	15	283	F. O. Bunnell.
Northwood	City	87	Devonian limestone.	18	......	.3	.5	74	24	8		318	1.5	......	8	293	W. S. Hendrixson.

[a] Sum of constituents minus one-half of the bicarbonate radicle.

Analyses of water in the north-central district of Iowa—Continued.

Locality.	Owner.	Depth of well.	Lowest geologic division.	Silica (SiO_2).	Oxides of iron and aluminum (Fe_2O_3+Al_2O_3).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.	Name of chemist.
MITCHELL COUNTY.		*Feet.*															
Carpenter	Chicago, Milwaukee & St. Paul Ry. Co.	113			1.5			72	26		6	304	35		7	299	Geo. N. Prentiss.
Osage	City	780	St. Peter	17			5	116	25	34	3	314	61		42	460	W. S. Hendrixson.
Do	do	280	Maquoketa					150			21	357	111		8	468	Do.
Riceville	McGue (spring)			24		1	2	84	14		24	142	94	30	31	375	Do.
HANCOCK COUNTY.																	
Britt	Chicago, Milwaukee & St. Paul Ry. Co.	533			2.6			106	41		2	456	51		2.3	433	H. E. Smith.
Do	do	640			4			109	40		19	512	47		1.6	477	Do.
Corwith	City	118	Mississippian	21		1	4	92	35		101	448	188		.5	671	W. S. Hendrixson.
Garner	Chicago, Milwaukee & St. Paul Ry. Co.	80			10			92	32		15	396	45		15	307	Geo. N. Prentiss.
Goodell	C. Wesenburg	65	Drift	23		2.5	3	82	35		18	469	16		.2	414	H. S. Spaulding.
CERRO GORDO COUNTY.																	
Dougherty	Chicago & North Western Ry. Co.		Devonian	11	1.5			62	26		2	240	70		3.3	296	Geo. M. Davidson.
Mason City	do	862	St. Peter	14	2			60	20		18	240	57		8	299	Do.
Do	do		do	15	4			59	20		18	242	58		7	302	Do.
Do	City (No. 2)	651	Platteville	9		.6	1	79	35	12	6	424	9		6	370	W. S. Hendrixson.
Do	City (No. 3)	651	do	9		5	1.3	81	34	14	5	423	11		5	377	Do.
Do	City (No. 4)	651	do	8			1	83	34	13	6	402	11		6	363	Do.
Do	Chicago, Milwaukee & St. Paul Ry. Co.	1,473	Dresbach					123	59		32	446	211		23	671	Geo. N. Prentiss.
FLOYD COUNTY.																	
Charles City	City	1,588	St. Lawrence	9			1	68	23		16	270	40		3	295	W. S. Hendrixson.
Marble Rock	do	154	Devonian limestone.	13			1	81	18		15	268	35		4	301	Do.

Nora Springs	Chicago, Milwaukee & St. Paul Ry. Co.	100	......	......	......	......	......	72	28		12		384	0	......	3	307	Geo. N. Prentiss.
HUMBOLDT COUNTY.																		
Livermore	City	135	Drift	28	......	.5	1	110	34	40		6	444	97	......	4	542	W. S. Hendrixson.
Renwick	Chicago, & North Western Ry. Co.	81	....do	......	12	......	......	108	41		48		523	96	......	5	571	Geo. M. Davidson.
WRIGHT COUNTY.																		
Belmond	F. Luick	55	Drift	19	......	3	1	89	28		20		456	......	......	1.6	390	W. S. Hendrixson.
Clarion	J. Wilson	273	Mississippian	19	......	2	2	104	31		13		468	17	......	13	435	H. S. Spaulding.
Eagle Grove	Chicago & North Western Ry. Co.	72	Drift	......	6	......	......	114	46		37		568	70	......	7	564	Geo. M. Davidson.
Do	....do	59	....do	......	28	......	......	97	39		18		486	34	......	3	462	Do.
Do	Dr. McGrath	115	Mississippian	18	......	1	1	99	31		11		466	20	......	6.5	420	W. S. Hendrixson.
Clarion	City	283	....do	18	......	.4	2.4	96	26		15		440	23	......	6	407	Do.
FRANKLIN COUNTY.																		
Hampton	City	1,708	Jordan	13	......	1.4	2	81	33	21		8	364	59	......	5	405	W. S. Hendrixson.
Latimer	....do	150	Mississippian	20	......	2	3	90	25		21		442	24	......	6	412	Do.
BUTLER COUNTY.																		
Dumont	Chicago & North Western Ry. Co.	14	Alluvium (?)	19	2	......	......	152	43		55		548	100	......	85	730	Geo. M. Davidson.

NORTHWEST DISTRICT.

Hard waters abound in Kossuth and Humboldt counties in the western part of the north-central district of the State, and in Emmet, Palo Alto, Pocahontas, and Calhoun counties in the eastern part of the northwest district. Hard waters are, in fact, the rule throughout the northwest district, the average in total solids for all deep wells within the district being 1,425 parts, and for shallow wells 857 parts per million, as indicated in the following table:

Average mineral content of waters in the northwest district of Iowa.

[Parts per million.]

Source.	Silica (SiO_2).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.[a]
9 deep wells	16	210	67	181	373	719	10	1,425
60 shallow wells	24	160	48	60	420	321	62	857

[a] Sum of the constituents minus one-half the bicarbonate radicle.

The deep wells, unlike those of the northeast and north-central districts, contain hard waters as the rule and soft waters as the rare exception. The only deep waters containing less than 1,000 parts per million of solids are those at Emmetsburg, in Palo Alto County, and at Manson, in Calhoun County. The former belongs to the class of those considered in the northeast and north-central districts, for it contains only 410 parts of solids. The well is in a location where the Cretaceous forms the surface rock. The shallow wells in the county yield hard water, and the Emmetsburg well is probably one in which the casing was very successfully done, the upper hard waters having been effectively excluded. The well at Manson is the only deep well in the State whose water was found to contain normal carbonates; the magnesium and calcium in it are very low, the solids being mostly alkaline chlorides and sulphates. It may be questioned whether its comparatively soft water and its alkalinity may not be due to contamination by surface water owing to faulty casing.

There are few deep wells in the northwest district. Out of the 19 counties only 8 have deep wells. It is, of course, possible that future borings may develop the fact that good deep well water may be obtained in this section.

The waters from shallow wells show a very great variation in quality, ranging from those comparable with the best well waters of the northeast district to those containing more than 2,000 parts of solids per million, as in O'Brien County. The wells in the river bottoms, such as those at Sioux City, supply waters almost uniformly good, but the deeper drift wells usually contain hard water. Of the wells which do not enter rock and which supply soft water a large proportion are known to derive their water from river alluvium. All but two of the remaining wells of this class are located near rivers and may get their water in part or wholly from the same source. It may, therefore, fairly be questioned whether any considerable number of wells of this district supply slightly mineralized waters wholly from the drift. Aside from the two deep wells already discussed the well of Henry Steinecke, of Aurelia, which is supposed to enter the Dakota sandstone, is the only one in the district so far as investigated that enters rock and supplies comparatively soft water.

Detailed analyses follow.

Analyses of water in the northwest district of Iowa.

[Parts per million.]

Locality.	Owner.	Depth of well.	Lowest geologic division.	Silica (SiO_2).	Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.[a]	Name of chemist.
LYON COUNTY.		*Feet.*															
Rock Rapids	City	25	Alluvium	25		1	1	133	41	20		380	186		16	613	W. S. Hendrixson.
Doon	do	30	do	28	5			126	38	9		306	208		13	580	Geo. M. Davidson.
OSCEOLA COUNTY.																	
Sibley	Chicago, Rock Island & Pacific Ry. Co.	408						288	62	(b)		460	569			1,752	F. O. Bunnell.
DICKINSON COUNTY.																	
Lake Park	City	98	Drift	32		7	5	316	105	32		513	833		4	1,590	H. S. Spaulding.
Montgomery	G. R. Badgerow (spring).			26		2	2	84	26	6		386	7		3	349	W. S. Hendrixson.
Spirit Lake	City	100	Drift	27		2	1	213	52	52		463	433		20	1,031	Do.
EMMET COUNTY.																	
Gridley	Chicago & North Western Ry. Co.	430		26	1			151	52	32		382	317		6	776	Geo. M. Davidson.
Halfa	Farm well	149		28	2			117	37	18		534	35		2	506	Do.
Maple Hill	do	455		18	3			186	56	65		390	491		2	1,016	Do.
SIOUX COUNTY.																	
Hull	City	1,256	Algonkian	18		6	5	322	124	192	23	384	1,380		33	2,295	W. S. Hendrixson.
Orange City	do	24	Drift	17			.5	122	66	22		373	78	64	61	617	Do.
O'BRIEN COUNTY.																	
Hartley	do	205	do		30			335	149	304		506	1,522		33	2,626	F. O. Bunnell.
Primghar	J. J. Shonts	372	do	29		11	7	375	156	51		570	1,199		7	2,120	W. S. Hendrixson.
Sanborn	City	40	do		3			72	21	17		47	245		6	387	Geo. N. Prentiss.
Do	Chicago, Milwaukee & St. Paul Ry. Co.	1,250	Cambrian					353	114	182		458	1,282		26	2,186	H .E. Smith

Sheldon	do	300	Drift		22			238	38	126	567	530		7	1,244	Geo. N. Prentiss.
CLAY COUNTY.																
Bridgewater	Mill	250	do		5			154	46	134	440	461		12	1,032	Do.
Peterson	Chicago & North Western Ry. Co.	26	do	35	3			181	63	28	542	247		43	871	Geo. M. Davidson.
Spencer	City	16	Alluvium	25			3	105	22	19	242	161		11	467	W. S. Hendrixson.
PALO ALTO COUNTY.																
Ayrshire	do	385	Dakota	24		2.4	2.6	264	83	114	414	852		5	1,554	Do.
Emmetsburg	Chicago, Milwaukee & St. Paul Ry. Co.	874	St. Peter		9			96	32	17	444	29		5	410	H. E. Smith.
Mallard	City	1,100	do	13		10	8	171	55	69	582	386		10	1,013	W. S. Hendrixson.
West Bend	do	381	Mississippian	6				174	40	69	672	171		6	802	J. B. Weems.
PLYMOUTH COUNTY.																
Le Mars	Chicago & North Western Ry. Co.	70	Drift	21	8			123	39	18	404	127		28	566	Geo. M. Davidson.
Ellendale		202			23			112	38	48	472	43		74	574	F. O. Bunnell.
CHEROKEE COUNTY.																
Aurelia	H. Steinecke	300	Dakota	34		.3	.8	82	24	18	330	56		1	381	W. S. Hendrixson.
Cherokee	State Hospital	1,126	St. Peter	13		8	1	220	53	258	306	651		20	1,378	Do.
Do	do	242	Dakota	24		2	1	161	45	68	368	398		4	887	H. S. Spaulding.
Marcus	Larson Bros.	400	do	45		1	1	303	73	221	368	1,163		12	2,003	W. S. Hendrixson.
Do	G. Arnold	400	do	16		5	.5	287	77	187	383	1,080		17	1,861	Do.
BUENA VISTA COUNTY.																
Alta	City			28		.3	.2	314	97	77	320	693	40	134	1,546	Do.
Albert City	Chicago, Milwaukee & St. Paul Ry. Co.	373						204	76	(c)	472	409			1,302	Geo. N. Prentiss.
Marathon	Hawks	83	Drift					250	105	11	820	203		128	1,107	Do.
POCAHONTAS COUNTY.																
Fonda	City	331	Dakota	33		6	4	171	92	65	518	475		6	1,111	W. S. Hendrixson.
Laurens	Chicago, Rock Island & Pacific Ry. Co.	570			9			206	57	102	464	509		15	1,130	F. O. Bunnell.
Rolfe	City	108	"St. Louis"	28		2	2	176	10	34	522	145		7	665	W. S. Hendrixson.

[a] Sum of the constituents minus one-half the bicarbonate radicle.

[b] Alkali chlorides and sulphates, 603 parts.

[c] Alkali, sulphates, and chlorides, 377 parts.

Analyses of water in the northwest district of Iowa—Continued.

Locality.	Owner.	Depth of well.	Lowest geologic division.	Silica (SiO_2).	Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.	Name of chemist.
WOODBURY COUNTY.		*Feet.*															
Luton	Chicago, Milwaukee & St. Paul Ry. Co.	85	......	......	13	......	......	92	33	13		434	24	......	1	393	Geo. N. Prentiss.
Sioux City	Starch works	298	Cretaceous	......	4	......	......	124	35	32		374	200	......	3	585	Do.
Do	Cudahy Packing Works.	355	.....do	17	'4	......	......	312	30	12		471	93	......	10	713	Geo. M. Davidson.
Do	Water Co	2,011	Algonkian	16	......	......	6	226	73	222		406	859	......	84	1,689	J. B. Weems.
Do	(*a*)	50–80	Alluvium	28	2	......	......	91	30	14		416	30	......	6	409	Geo. M. Davidson.
Do	City	104	.....do	......	3	......	......	88	22	16		279	101	......	3	372	Geo. N. Prentiss.
IDA COUNTY.																	
Battle Creek	A. Harper	217	Sand	22	......	0.4	1.2	84	21	18		368	41	......	5	376	W. S. Hendrixson
Galva	Chicago & North Western Ry. Co.	60	.....do	27	......	......	6	161	32	23		392	232	......	12	689	Geo. M. Davidson.
Holstein	City	2,004	Dresbach	28	......	4	2	243	66	115	10	348	782	......	12	1,436	W. S. Hendrixson.
SAC COUNTY.																	
Nemaha	Creamery	400	Drift	14	......	8	1	88	35	171		391	419	......	14	946	Do.
Sac City	City	40	.....do	19	......	......	......	98	43	29		508	40	......	16	499	Geo. M. Davidson.
Do	Canning works	378	.....do	14	2	......	......	192	60	257		434	874	......	7	1,623	Do.
Schaller	C. O. Porter	432	.....do	18	......	2	5	272	88	182		386	975	45	13	1,793	W. S. Hendrixson.
Wall Lake	City	25	.....do	20	......	......	1	90	28	7		308	78	......	4	382	Do.
CALHOUN COUNTY.																	
Lake City	Chicago & North Western Ry. Co.	210	.....do	18	1	......	......	164	33	86		476	320	......	6	866	Geo. M. Davidson.
Do	.....do	69	.....do	......	5	......	......	106	42	25		535	47	......	3	495	Do.
Lohrville	City	180	Sand	19	......	2.5	.5	214	72	264		544	493	......	18	1,355	W. S. Hendrixson.
Manson	.....do	1,260	Galena (?)	10	......	.2	.8	16	1	221		*b* 4	162	......	206	651	Do.
Pomeroy	.....do	149	Sand	39	......	1.3	3	168	61	138	4	524	522	......	7	1,205	H. S. Spaulding.
Rockwell City	.....do	967	......	18	......	2.5	2.4	118	53	45		440	215	......	7	680	W. S. Hendrixson.

MONONA COUNTY.																	
Mapleton	Chicago, Milwaukee & St. Paul Ry. Co.	59	Alluvium	......	28	......	......	91	34	8		366	61	......	11	416	Geo. N. Prentiss.
Onawa	City	863		10	......	1	1.5	244	81	184	33	207	943	......	166	1,767	W. S. Hendrixson.
Do	Chicago & North Western Ry. Co.	78	Drift	25	2	......	......	141	47	17		494	144	......	24	647	Geo. M. Davidson.
Soldier	....do	30		18	5	......	......	60	19	3		268	9	......	2	250	Do.
CRAWFORD COUNTY.																	
Denison	City	25	Alluvium	31	......	.5	2	91	24	12		270	72	......	18	385	W. S. Hendrixson.
Charter Oak	....do *c*	26	....do	......	6	......	......	85	24	16		400	7	......	5	343	Geo. N. Prentiss.
Manilla	....do	68	Drift	25	......	2.5	2	90	23	15	1	361	20	......	5	364	W. S. Hendrixson.
Ricketts	Chicago & North Western Ry. Co.	34	Alluvium	22	1	......	......	94	29	13		302	119	......	5	434	Geo. M. Davidson.
CARROLL COUNTY.																	
Carroll	City	120	Drift	21	1	......	......	95	29	16		374	61	......	9	419	W. S. Hendrixson.
Do	Chicago & North Western Ry. Co.	153	....do	27	2	......	......	99	29	20		410	62	......	4	448	Geo. M. Davidson.
Glidden	City	122	....do	21	......	.5	3	123	36	28		337	70	......	4	454	W. S. Hendrixson.
Lanesboro	Lane	128		......	......	......	......	88	28	28		442	19	......	......	384	W. H. Chadbourn.
Manning	Chicago & North Western Ry. Co.	20		18	1	......	......	101	31	17		318	110	......	26	463	Geo. M. Davidson.

a 123 drive wells.

b Carbonate radicle (CO_3), 38 parts.

c 11 city wells.

EAST-CENTRAL DISTRICT.

The following table of averages is made from analyses showing great diversity in the quality of the waters, in both the deep and the shallow wells, of the east-central district:

Average mineral content of the waters of the east-central district of Iowa.

[Parts per million.]

Source.	Silica (SiO_2).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.[a]
35 deep wells	10	103	47	182	326	425	83	978
45 shallow wells	14	177	58	90	364	495	25	1,031

[a] Sum of the constituents minus one-half the bicarbonate radicle.

On the Mississippi at Clinton are many deep wells whose waters are among the best, having only 100 parts of solids more than the well waters at Dubuque. The Clinton waters are really not harder than those at Dubuque, as hardness is ordinarily understood and determined by the soap test—that is, their calcium and magnesium are no more abundant and their excess of solids is made up of alkalies, chlorides, and sulphates. The same is practically true of the wells at Davenport, where the waters carry more than 1,000 parts per million of solids, but the calcium and magnesium are actually smaller in amount, the excess over Dubuque being due to the alkalies. The tendency is for the amounts of sodium and potassium in well waters to increase down the Mississippi until at Keokuk these radicles amount to about 900 parts. The deep wells at Tipton, in Cedar County, at Vinton, in Benton County, and at Cedar Rapids, Monticello, and Green Island all yield good water. Vinton may be regarded as about the western limit of the area of good water, since the well at that place yields only lightly mineralized water, whereas those farther south at West Liberty and Wilton contain more than 1,000 parts of solids. The line from Vinton through Iowa City to Davenport forms the southwestern boundary of the district of good deep-well water in the district. This line coincides in a general way with the median line of the strip of Devonian rocks trending northwest and southeast. (See Pl. I, in pocket; Pl. IV, p. 178.) Southwest of this line all deep-well waters are comparatively highly mineralized, as shown by the analyses from Amana, Homestead, Wilton, West Liberty, and Grinnell. The average solids in deep-well water at Grinnell since the first well was drilled 15 years ago have been about 1,200 parts per million, but well No. 2 at its best contained only 881 parts. It is probably true generally that wells penetrating thick layers of Carboniferous and Devonian formations, as at Grinnell, take from them more or less of their waters, owing to imperfect casings, and the waters yielded by such wells rarely or never show the quality of the water of the deeper sandstone formations which they penetrate.

The waters of the shallow wells of the east-central district show great variation. Generally speaking, those in the eastern and especially the northeastern portion have low total solids and are to be rated with those of the wells of the northeast district in regard to quality; probably they draw their water from drift having the same origin and the same general character. On the other hand, wells in the western part of the district have, as a rule, hard waters. A well-marked area of hard waters from wells in the drift and upper strata may be considered to center not far from Tama, in Tama County. All waters in Tama County, so far as investigated, are hard with the exception of that from the very shallow city well at Tama, which probably derives its water from the underflow of Iowa River. The area includes numerous wells, many of them flowing, in the noted Belle Plaine neighborhood. As far south and east as Marengo flowing wells deliver very hard water. It is possible that the same area may extend as far as Amana and Homestead and may account for the hardness of the waters in the deep wells at those places. Farther south, at Williamsburg, the drift wells yield waters that are comparatively little mineralized. All wells investigated in Poweshiek County, save that at Brooklyn, yield hard waters. It is probably true that the Brooklyn well is not exclusively a drift well but obtains its water in part from river alluvium.

Analyses of water in the east-central district of Iowa.

[Parts per million.]

Locality.	Owner.	Depth of well.	Lowest geologic division.	Silica (SiO_2).	Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.[a]	Name of chemist.
TAMA COUNTY.		*Feet.*															
Buckingham	Chicago & North Western Ry. Co.	318		33	1			215	61	118		336	704		3	1,318	Geo. M. Davidson.
Chelsea	City	100	Drift	15		5	2	489	204	38		240	1,923		7	2,803	H. S. Spaulding.
Clutier	F. Kiezeks	210	Mississippian	14		1.5	3	97	47	164		160	636		9	1,051	Do.
Do	Chicago & North Western Ry. Co.	225	do	11	2			215	92	157		344	917		7	1,573	Geo. M. Davidson.
Gladbrook	A. Angel	310	do	15		3	4.4	138	57	61		320	481		6	925	E. B. Benger.
Tama	Mrs. C. A. Huber	861	Silurian	11		3	1	471	200	1,016		260	3,572		128	5,532	Do.
Toledo	County Home	545	Devonian	11		3	2	275	144	64		251	1,119		7	1,750	W. S. Hendrixson.
Traer	City	249	Mississippian	12		2	0	132	51	101		252	362		7	793	E. B. Benger.
Vining	do	235	do		3			348	135	46		263	1,244		7	1,914	Geo. N. Prentiss.
Tama	do	23		19	2			82	19	12		296	32		18	332	Geo. M. Davidson.
BENTON COUNTY.																	
Belle Plaine	City	1,520	Prairie du Chien	22		1	3	346	135	72	11	268	1,247		9	1,980	W. S. Hendrixson.
Do	(b)	193	Drift	2		6	0	504	201	38		334	1,814		6	2,738	L. W. Andrews.
Keystone	City	130						106	40			524				408	Geo. N. Prentiss.
Vinton	W. H. Whipple	2,000	Dresbach (?)	10		3	2	79	44	82		312	248		1	625	W. S. Hendrixson
Do	City	1,402	Jordan	7			1	72	38	66	12	353	179		10	561	Do.
Van Horne	Van Dusen's Spring.							58	18	2		240	21		3	222	Geo. N. Prentiss.
Do	Creamery	365						140	59	172		481	542		4	1,157	Do.
Do	City	198		1				570	77	173		1,836	580		3	2,322	Do.
Do	John Hollar	795	Maquoketa	2.2	2.6			168	107	216		385	945		11	1,669	Fidelity and Casualty Co.
LINN COUNTY.																	
Cedar Rapids	Young Men's Christian Association.	1,450	Jordan	3			0	70	31	91		340	207		.4	572	J. B. Weems.
Do	East City	1,450	do	8			1	73	36	83		312	315		14	586	W. S. Hendrixson.
Do	West City	1,450	do	9	.3		.2	75	39	85	11	318	219		14	611	Do.

Covington	A. Laing	241	Silurian	......	1.4	......	......	155	56	18		452	264	......	2	722	Geo. N. Prentiss.
Lisbon	Chicago & North Western Ry.Co.	260	Niagara	22	2.5	......	......	73	40	6		332	74	......	9	392	Geo. M. Davidson.
Do	Chicago & North Western Ry.Co. at station.	26	......	7	2	......	......	157	68	11		334	379	......	17	808	Do.
Marion	Chicago, Milwaukee & St. Paul Ry. Co.	100	......	......	......	......	......	71	21	4		330	3	......	1	265	Geo. N. Prentiss.
Mount Vernon	City	330	Niagara	21	3	......	......	53	30	9		298	7	......	14	286	Nicholas Knight.
JONES COUNTY.																	
Anamosa	State Penitentiary.	2,200	Cambrian sandstones underlying Dresbach.	10	......	......	1	92	36	11	3	362	68	......	15	417	W. S. Hendrixson.
Monticello	City	1,198	Jordan	23	25	......	......	98	5	39		392	17	......	6	409	J. B. Weems.
Do	do	319	Maquoketa	13	......	.5	1	82	29	9		360	22	......	8	344	W. S. Hendrixson.
Morley	Chicago & North Western Ry. Co.	214	Niagara	......	4	......	......	72	25	6		346	10	......	2	292	Geo. M. Davidson.
Onslow	do	214	do	15	14	......	......	91	33	7		412	27	......	6	399	Do.
JACKSON COUNTY.																	
Green Island	Chicago, Milwaukee & St. Paul Ry. Co.	923	St. Peter	......	......	......	......	52	36	2		320	17	......	1	268	Geo. N. Prentiss.
Maquoketa	Chicago & North Western Ry.Co.	185	......	18	1	......	......	100	46	96		510	33	......	134	683	Geo. M. Davidson.
Preston	City	108	......	......	.7	......	......	70	12	38		338	27	......	1	318	Geo. N. Prentiss.
Sabula	do	973	Oneota	3	6	......	......	54	32	14		337	21	......	0	298	J. B. Weems.
POWESHIEK COUNTY.																	
Brooklyn	City	180	......	13	......	.6	.5	47	18	120	4	432	87	......	3	509	W. S. Hendrixson.
Grinnell	do.(1)	2,002	New Richmond [c]	16	......	2	4	260	117	192	9	336	1,274	......	20	2,062	Do.
Do	do.(2)	2,002	do	11	......	.4	1	103	41	142	15	358	368	......	21	881	Do.
Do	do.(3)	2,020	do	13	......	2	.3	131	48	183		324	574	......	34	1,147	Do.
Do	John Goodfellow [d]	268	Carboniferous	11	......	......	2	250	93	263		116	1,342	......	10	2,029	Do.
Do	Creamery	400	Mississippian	21	......	3	2	216	142	145		368	1,429	......	13	2,155	Do.
Do	H. M. Bray	635	Devonian (?)	11	......	3	5	337	134	1,483		330	3,424	......	470	6,032	Do.
Montezuma	City	180	......	14	......	2	1	360	168	97	13	328	1,462	......	6	2,287	Do.
Do	Farwell estate	2,800(?)	......	13	......	3	2	175	92	279	9	341	1,052	......	40	1,835	Do.
Deep River	Chicago & North Western Ry. Co.	40	......	20	1	......	......	120	40	41		406	193	......	12	630	Geo. M. Davidson.

[a] Sum of the constituents minus one-half of the bicarbonate radicle. [b] Jumbo. [c] Water probably from Carboniferous. [d] 3 miles northeast of town.

Analyses of water in the east-central district of Iowa—Continued.

Locality.	Owner.	Depth of well.	Lowest geologic division.	Silica (SiO_2).	Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.	Name of chemist.
IOWA COUNTY.																	
Amana	Amana Society	*Feet.* 1,640	Prairie du Chien	5	6.4	......	......	104	42	181		320	517	......	18	1,033	J. B. Weems.
South Amana	do	......	......	9	......	......	2	354	148	133	15	258	1,510	......	14	2,314	W. S. Hendrixson.
Homestead	do	2,224	Dresbach	17	10	......	......	101	33	186		249	512	......	33	1,016	J. B. Weems.
Marengo	A. M. Henderson	......	......	8	......	3	3	407	170	125		257	1,668	......	13	2,525	W. S. Hendrixson.
Do	City	......	......	......	14	......	......	75	18	......	......	224	75	......	......	322	F. O. Bunnell.
Williamsburg	Hughes well	195	......	......	10	......	......	47	15	*a* 97		473	0	......	2	407	Geo. N. Prentiss.
Do	City	95	......	......	1	......	......	57	19	106		536	2	......	6	459	Do.
JOHNSON COUNTY.																	
Solon	Chicago, Rock Island & Pacific R. R. Co.	80	......	......	61	......	......	119	12	45		214	223	......	24	591	F. O. Bunnell.
CEDAR COUNTY.																	
Lowden	Chicago & North Western Ry. Co.	75	......	15	1	......	......	70	21	3		308	6	......	4	274	Geo. M. Davidson.
Stanwood	do	116	......	8	2	......	......	71	26	11		368	3	......	0	305	Do.
Tipton	City	2,696	Cambrian or Algonkian.	15	......	......	1	82	26	12	1	378	4	......	2	332	W. S. Hendrixson.
CLINTON COUNTY.																	
Brown	Chicago, Milwaukee & St. Paul Ry. Co.	103	......	......	......	......	......	65	34	1		364	0	......	2	284	Geo. N. Prentiss.
Clinton	Chicago & North Western Ry. Co.	1,125	Jordan	8	2	......	......	54	23	123		292	110	......	96	562	Geo. M. Davidson.
Do	Clinton Brewing Co.	1,620	Cambrian sandstones underlying Dresbach.	16	......	......	2	70	26	39		312	41	......	25	375	W. S. Hendrixson.
Do	National Papier Mâché Co.	1,065	Oneota	9	......	2	1	60	21	90		306	63	......	54	451	Do.
Do	Chicago & North Western Ry. Co. (old roundhouse).	1,159	Jordan	9	6	......	......	56	20	62		272	69	......	42	400	Geo. M. Davidson.
Do	Clinton Gas Co	1,085	Oneota	11	......	......	2	50	22	85	9	318	54	......	44	436	W. S. Hendrixson.

Do.	4 city wells	1,075–1,763	Jordan to Dresbach.	8	......	0	1	66	26	46	10	308	47	......	37	395	Do.
Clinton	Clinton Sugar Refining Co.	1,226	Jordan	8	1	......	......	62	25	56		288	69	......	55	420	A. P. Bryant.
Do.	Iten & Sons	1,180	....do	2	1	......	......	44	41	24		246	73	......	32	340	Do.
De Witt	Chicago & North Western Ry. Co.	267	......	8	1	......	......	90	43	15		372	90	......	20	453	Geo. M. Davidson.
Do.	....do	163	......	11	2	......	......	85	39	30		412	65	......	23	462	Do.
Grand Mound	City	100	Silurian	12	......	1	1	60	31	5		305	1	......	1	364	W. S. Hendrixson.
Do.	Geo. Jordan	144	....do	17	......	1	3	64	23	6		317	1	......	2	275	Do.
Lyons	Chicago, Milwaukee & St. Paul Ry. Co.	......	......	......	......	......	......	64	26	74		282	74	......	85	464	Wahl & Henins.
SCOTT COUNTY.																	
Davenport	Davenport Malting Co.	1,076	St. Peter	......	......	......	......	17	23	374		166	239	......	396	1,132	Geo. N. Prentiss.
Do.	People's Gas Co.	1,200	Prairie du Chien	9	......	4	2	46	18	340		288	249	......	320	1,132	W. S. Hendrixson.
Do.	Wilts Bottling Works.	780	Galena and Platteville.	7	......	4	......	14	8	429		410	271	......	272	1,210	E. T. Burghausen.
Do.	Crystal Ice Co.	1,067	St. Peter	9	......	2	......	20	5	407		286	275	......	273	1,134	J. B. Weems.
Do.	Independent Baking Co.	900	......	8	2	......	......	17	8	452		430	340	......	244	1,286	E. G. Smith.
Do.	Bettendorf Metal Wheel Co.	1,650	......	11	2	......	......	60	36	356		462	200	......	337	1,233	Do.
Eldridge	Chicago, Milwaukee & St. Paul Ry. Co.	180	......	......	8	......	......	105	41	16		270	193	......	31	529	Geo. N. Prentiss.
Walcott	City	143	Drift	18	......	4	3	82	27	10		400	5	......	2	351	W. S. Hendrixson.
MUSCATINE COUNTY.																	
West Liberty	City	1,768	......	8	......	......	2	82	33	225	15	280	457	......	102	1,064	W. S. Hendrixson.
Wilton	....do	1,360	......	8	......	......	2	72	34	274	13	292	397	......	200	1,146	Do.

a Alkali, sulphates, and chlorides, 28 parts.

CENTRAL DISTRICT.

The central district of Iowa contains few deep wells, but they are fairly well distributed. The northeastern part falls within the territory of good deep wells. It is an interesting fact that in Hamilton, Hardin, Grundy, and Marshall, the four counties nearest the northeast corner of the district, in all of which the artesian possibilities are probably best, there is only one deep well. There is also a deep gas boring at Webster City, but this probably receives water from all horizons and therefore can not be used for purposes of prognostication.

The one deep well in the northeast part of the district is at Ackley, in Hardin County. Its water contains 605 parts of solids per million and is the best deep-well water in the district, if judged by total solids alone. Fort Dodge has the next best deep well in the order of solids, but not in the order of softness of water. Though the wells at Ames, in Story County, and at Jefferson, in Greene County, supply waters containing more than 1,100 parts of solids, these waters are as low in calcium and magnesium as the waters from the deep wells at Davenport, and, as at Davenport, by far the larger portion of their solids consists of sodium chloride and sulphates. The waters of all other deep wells of the district contain large amounts of solids and are also very hard, as rated by their content of calcium and magnesium.

The average mineral matter in the waters of the shallow wells of the central district is about half that in the deep-well waters, the ratio being 873 to 1,759. The waters of the shallow wells are not excessively hard save in Marshall and Polk counties and in the region immediately surrounding Colfax in Jasper County. There is a rather close analogy between the mineral matter of the Colfax waters and that of the waters of shallow wells at Des Moines, and the wells at both places apparently draw their waters from the same source, the upper Carboniferous or Pennsylvanian. The shallow-well waters of Webster and Hamilton counties are moderately hard. All other counties of the district show shallow-well waters which could, at no great disadvantage, be compared with the waters of shallow wells in the eastern part of the State.

Average mineral content of waters of the central district of Iowa.

[Parts per million.]

Source.	Silica (SiO_2).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.[a]
10 deep wells	14	174	62	286	262	947	19	1,759
69 shallow wells	23	124	44	125	446	344	88	873

[a] Sum of the constituents minus one-half the bicarbonate radicle.

The average total solids for the deep wells of the district is 1,759; they vary all the way from the 605 parts of solids at Ackley to the 4,369 parts in the deep well at Newton, which is now abandoned. Newton now draws its water supply from driven wells in the valley of South Skunk River.

It is very probable that the four northeastern counties of the district should be included with those of the northeast district. They have no deep wells but from their location should have good deep artesian possibilities, though, of course, as they lie farther to the south and west, they can not be expected to possess water of the same degree of freedom from mineral matter.

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Analyses of water in the central district of Iowa.

[Parts per million.]

Locality.	Owner.	Depth of well.	Lowest geologic division.	Silica (SiO_2).	Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.[a]	Name of chemist.
WEBSTER COUNTY.		*Feet.*															
Dayton	City	65–95	Drift	15	1			69	46	65		268	255		7	592	Geo. M. Davidson.
Do	....do	688	Kinderhook	27		2	0.6	85	41	70		366	205		10	624	W. S. Hendrixson.
Do	Chicago & North Western Ry. Co.	92	Drift		9			137	51	94		662	193		3	818	Geo. M. Davidson.
Do	....do	91	....do	21	3			91	31	111		442	142		5	625	Do.
Fort Dodge	City (new well)	1,827	Jordan	12		1	1	114	40	145		410	205		144	867	W. S. Hendrixson.
Do	County farm	366	Mississippian	9			1	287	77	97		432	797		24	1,508	Do.
Do	City	129	Rock	13		.3	1	117	42	33		454	137		4	574	Do.
Gowrie	....do	620	Devonian	9			1.3	103	46	66		421	206		10	652	Geo. M. Davidson.
Do	Chicago & North Western Ry. Co.	400	Carboniferous		14			190	69	117		919	234		10	1,093	Do.
Harcourt	....do	63	Drift	26	2			132	45	32		478	134		33	643	Do.
HAMILTON COUNTY.																	
Duncombe	John Mahoney	177	Drift	25		12		128	44	78		630	128		2	732	W. S. Hendrixson.
Ellsworth	W. H. Brinton	91	....do	14		5	1	59	28	46	4	440	0		.4	377	H. S. Spaulding.
Jewell	City	160	Des Moines	30		8	5	93	30	33		512	1		20	476	W. S. Hendrixson.
Stanhope	Ole Satre	328	Carboniferous	21		3	.2	106	39	99		473	54		4	563	E. B. Benger.
Rowland	W. E. Waugh	108	Drift	16			1	60	26	22		352	0		.5	301	H. S. Spaulding.
Stratford	Chicago & North Western Ry. Co.	440	Carboniferous	7			1	125	57	89		329	433		16	892	Geo. M. Davidson.
Do	Creamery	520	....do. (?)	7			1	123	63	138		606	332		10	977	Do.
Webster City	Gas company	1,250	Galena	33				176	27	112		297	515		10	1,021.5	J. B. Weems.
Do	City (several wells)	90–100	Drift	17			3	103	52	32		467	137		11	588	W. S. Hendrixson.
HARDIN COUNTY.																	
Ackley	Mrs. John Carroll		Mississippian	24		3	1	72	25	19		402	0		1	346	H. S. Spaulding.
Do	City	2,032	Jordan	7		0	2.5	84	33	75	20	372	183		15	605	W. S. Hendrixson.
Eldora	....do	200	Des Moines	10		1	.2	55	24	14	3	300	0		2	259	Do.
Do	Boys' Home	250	....do	14			2	61	25	16		330	1		3	287	Do.
Hubbard	City	325	....do	128		4	14	47	20	21		297	1		3	386	Do.
Do	Chicago & North Western Ry. Co.	84	Drift	28	2			90	31	16		428	33			414	Geo. M. Davidson.

Iowa Falls	City	240	Kinderhook	13		.6	1.4	77	29	9	2	383	2		5	329	W. S. Hendrixson.
GRUNDY COUNTY.																	
Dike	Chicago & North Western Ry. Co.	358	Mississippian	18	5			67	25	20		322	40		3	339	Geo. M. Davidson.
Grundy Center	City	469	Devonian	9		.4	1	155	71	21		283	447		4	850	W. S. Hendrixson.
Holland	L. Beenken	344	Mississippian (?)	15		.4	2	56	33	97		457	26		2	460	Do.
Reinbeck	City	339	do	40		1	1	109	41	24		288	270		5	635	Do.
GREENE COUNTY.																	
Cooper	Chicago, Milwaukee & St. Paul Ry. Co.	190			6			127	39	31		466	130		13	579	Geo. N. Prentiss.
Grand Junction	Chicago & North Western Ry. Co.	300	Des Moines	9	1			70	26	67		502	0		6	430	Geo. M. Davidson.
Do	Chicago & North Western Ry. Co.	70	Drift	17				113	38	28		470	93		7	531	Do.
Jefferson	City	2,000	Below St. Peter	13		5		39	16	331		198	536		114	1,153	A. A. Bennett.
Do	Chicago & North Western Ry. Co.	100	Drift	15				160	45	17		620	94		7	648	Geo. M. Davidson.
Scranton	City	200	do	14		1		80	29	23	4	406	33		1	388	H. S. Spaulding.
Do	Chicago & North Western Ry. Co.	151	do	14	2			95	33	11		438	25		4	403	Geo. M. Davidson.
BOONE COUNTY.																	
Boone	City	3,010	Dresbach or underlying Cambrian sandstones.	10			4	152	64	310	22	300	871		128	1,711	W. S. Hendrixson.
Do	do	50	Sand	27		1	1	101	34	12	3	450	1		4	409	Do.
Do	Chicago & North Western Ry. Co.	104	do	31				92	35	5		462			1	395	Geo. M. Davidson.
Madrid	City	100	do	22		1	1	103	30	43		496	38		6	492	Geo. N. Prentiss.
Do	J. Barclay	104	Drift	34		6	6	94	28	32		514	0		2	459	W. S. Hendrixson.
Ogden	City	2,800	Below St. Peter	10		7	4	139	60	231		270	736		59	1,381	Do.
STORY COUNTY.																	
Ames	City	97		28	3			78	32	10		392	16		3	366	Geo. M. Davidson.
Do	Iowa State College	2,215	Jordan	3			4	35	15	391		204	516		204	1,270	J. B. Weems.
Colo	Chicago & North Western Ry. Co.	374		11	1			83	33	91		400	188		9	616	Geo. M. Davidson.
Maxwell	City	100		1.3	5			87	24	17		432	0			350	Geo. N. Prentiss.
Nevada	do	980	Maquoketa	9		5	2.5	426	84	141	19	315	1,390		42	2,276	W. S. Hendrixson.
Zearing	H. C. Wickham	300		27				99	31	18		496	13		.2	436	Do.

a Sum of constituents minus one-half the bicarbonate radicle.

Analyses of water in the central district of Iowa—Continued.

Locality.	Owner.	Depth of well.	Lowest geologic division.	Silica (SiO_2).	Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.	Name of chemist.
MARSHALL COUNTY.		*Feet.*															
Marshalltown	Artificial Ice Co	257		20		0.2	2	197	71	25	2	359	354	46	68	964	W. S. Hendrixson.
Do	City	30	Sand	19	5			65	20	13		268	46		5	307	Geo. M. Davidson.
Rhodes	T. W. Dickey	174		12		5	1	116	48	93	8	368	381		3	851	Geo. N. Prentiss.
State Center	City	161	Drift	22	14			363	136	341		1,062	1,254		7	2,668	Geo. M. Davidson.
Do	Farm well	170		22		5	7	136	42	118		548	286		9	887	Do.
GUTHRIE COUNTY.																	
Bagley	Chicago, Milwaukee & St. Paul Ry. Co.	120	Cretaceous		2			91	33	11		422	29		2	379	Geo. N. Prentiss.
Guthrie Center	City (7 wells)	42	Drift	21				66	18	15		214	49		14	290	W. S. Hendrixson.
Herndon	H. Miller	110	Cretaceous					87	24	22		416	9		13	354	Geo. N. Prentiss.
Do		534						73	37	212		313	368		108	954	Do.
Stuart	City	90						90	27	32	2	408	18		2	390	W. S. Hendrixson.
DALLAS COUNTY.																	
Perry	City (2 wells)	115	Sand		6			43	23	67		415			3	349	Geo. N. Prentiss.
Do	do	117	do		2			51	27	55		420			5	350	Do.
POLK COUNTY.																	
Des Moines	City Library	375	Des Moines	14		1	3	237	53	559	7	312	1,569		107	2,706	W. S. Hendrixson.
Do	West Side School	286	do	7			2	21	9	509	5	582	530		85	1,459	
Do	Courthouse	380	do	148			4	339	96	508		200	1,916		107	3,218	Floyd Davis.
Do	Greenwood Park	3,000	Dresbach or underlying Cambrian sandstones.	4.5		10	4	212	190	541	13	124	1,780		124	2,941	W. S. Hendrixson.
Mitchellville	Industrial School	452	Mississippian	13		2	1	99	45	529	7	384	1,144		58	2,090	Do.
Do	do	563	do	19		4	2	97	35	450		360	895		61	1,743	Do.
Runnells	Robert Blee	228	Des Moines	12		.5	1	108	39	715		414	1,520		43	2,645	Do.
Sheldahl	Chicago & North Western Ry. Co.	303		7	6			129	56	112		336	421		48	947	Geo. M. Davidson.

JASPER COUNTY.																	
Colfax	Sanitarium	371	Mississippian	10	.....	.2	1.5	211	99	420		260	1,505	.....	29	2,406	H. S. Spaulding.
Do	News Station	.....	do	9	.....	.....	1	104	52	580		324	1,338	.....	37	2,283	W. S. Hendrixson.
Do	Mills Hotel	350	do	11	.....	.7	1	235	97	463		260	1,495	.....	27	2,460	H. S. Spaulding.
Lynnville	City	255	.....	11	.....	.....	.....	83	30	32		274	161	.....	6	460	Iowa Central Ry. Co.
Monroe	Chicago, Rock Island & Pacific Ry. Co.	287	.....	.....	8	.....	.....	124	45	83		426	301	.....	5	779	F. O. Bunnell.
Newton	City (drive)	50	River bottom	16	.....	.....	1.5	54	19	9		222	25	.....	5	240	H. S. Spaulding.
Prairie City	Chicago, Rock Island & Pacific Ry. Co.	360	Carboniferous	.....	36	.....	.....	331	126	41		662	1,110	.....	5	1,980	F. O. Bunnell.
Newton *a*	City	1,400	Maquoketa	37	16	.....	.....	360	88	893		106	2,739	.....	183	4,369	
Colfax	Grand Hotel	.....	Mississippian	127	.....	5	.....	706	77	405	3	1,722	1,435	.....	32	2,651	Louis G. Michael.
Newton	Memphis & St. Louis Ry. Co.	450	do	9	.....	.....	.....	110	55	41		592	79	.....	13	603	W. D. Wheeler.

a Free CO_2=7,856 (?).

SOUTHEAST DISTRICT.

Both the Mississippian and the Pennsylvanian series, which lie nearest the surface in the southeast district, as a rule contain highly mineralized waters. The waters of the St. Peter and the deeper aquifers are much better but are nevertheless more highly mineralized than the waters of the same aquifers farther to the north and east. In a number of deep wells the higher mineralization of the water may be ascribed to defective casing which allows the sulphated waters of the country rock to enter. When deep wells are being drilled the waters of each aquifer should be analyzed and all deleterious waters should be thoroughly cased out. Such precautions and the use of inner tubes leading directly to the lower aquifers will probably greatly lessen the danger of failure. The least promising part of the area is in Keokuk and Mahaska counties. In quantity, the artesian supply of the southeast district is unexcelled within the State.

Average mineral content of the waters of the southeast district of Iowa.

[Parts per million.]

Source.	Silica (SiO_2).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.[a]
16 deep wells	15	143	56	463	285	998	256	1,978
29 shallow wells	27	165	82	188	367	1,040	69	1,931

[a] Sum of the constituents minus one-half the bicarbonate radicle.

All deep wells of the southeast district yield hard, heavily mineralized waters. The best are the wells at Ottumwa and the very deep well in Crapo Park, Burlington. All other well waters at Burlington so far as analyzed are very hard. The great amount of solids of the wells reaching only into the Devonian may come largely from the Carboniferous, at any rate in the Clinton-Copeland Co.'s well, for this is cased only to a depth of 70 feet. It is evident that this water does not sensibly enter into the Crapo Park well, a fact which is difficult to understand, as the well is cased to 18 feet only. This water is very high in incrusting solids and also contains large amounts of sodium and potassium. Water of about the same amount of total solids but lower in calcium and magnesium and higher in alkalies and chlorides is found in the deep wells at Keokuk. This water as it occurs at either place can hardly be called suitable for any purposes save for extinguishing fires and sprinkling streets. The waters at Ottumwa, Washington, and even at Mount Pleasant, may be used if no better can be obtained and if a great deal of mineral matter is overlooked for the sake of probable organic purity.

The wells at Keokuk end in the Silurian and those whose waters have been analyzed have about the same depths, 700 to 769 feet. The three deepest ones have about the same amounts of solids. The Young Men's Christian Association well is cased only to a depth of 56 feet, which is probably to rock, and hence this well, and probably the two deeper ones, receive water from all penetrated strata that are water-bearing, as the quality of their waters is the same. It seems probable also that at both Burlington and Keokuk no serious attempt was made to case out upper waters in the wells whose analyses are here given, though it ought to be easily practicable in wells of such depths.

Shallow wells from 100 to 300 feet deep seem to be rare in this section, for few could be found. Apparently, with the exceptions noted, the people are dependent on river water in the larger towns and on very shallow wells in the small towns and rural districts. The number of shallow wells investigated is too small to permit very definite generalizations to be made. With one or two exceptions all drift wells of the shallow sort supply soft water, whereas all wells which penetrate rock supply hard, usually very hard water.

Analyses of water in the southeast district of Iowa.

[Parts per million.]

Locality.	Owner.	Depth of well.	Lowest geologic division.	Silica (SiO_2).	Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.a	Name of chemist.
MAHASKA COUNTY.		*Feet.*															
New Sharon	Allen Bros	227		14		3	3	124	71	409		522	1,026		58	1,969	E. B. Benger.
Do	City	155		17			1	83	24	15	1	396	2		5	346	W. S. Hendrixson.
Stark	Chicago & North Western Ry.	40	Drift	14			2	374	139	75		410	1,262		6	2,277	Geo. M. Davidson.
Do	Farm well, 0.5 mile north of station.	25		34			2	77	36	12		278	42		62	404	Do.
Southern Iowa Junction.	Farm well, 1¼ miles southwest.	185		20			1	93	27	17		428	18		3	393	Do.
Do	Well near station	200		7			33	58	33	49		418	27		4	420	Do.
Do	Farm well, 1.5 miles northeast.	286		21			1	98	31	40		504	33		3	479	Do.
KEOKUK COUNTY.																	
Ollie	P. Hollingsworth	250		17		2	2.5	99	26	22		497	23		5	445	H. S. Spaulding.
Richland	P. Vastine	75		20		1	1	82	24	21		407	8		7	367	E. B. Benger.
Sigourney	City	24					3	40	10	53		268	19		8	267	Geo. N. Prentiss.
What Cheer	Thompson & Walker.	90	Sandstone	24	11			269	102	138		474	841		85	1,707	Geo. M. Davidson.
Keota	City	150		7	2			142	37	14		538	110		1	582	Roland Neal.
WASHINGTON COUNTY.																	
Washington	City	232						33	13	194		558	54		25	598	W. S. Hendrixson.
Do	City No. 1	1,617	St. Lawrence	14			1	109	47	218	19	280	590		71	1,209	Do.
Do	City No. 2	1,217	St. Peter	10			3	113	45	367	19	288	810		123	1,634	Do.
Wellman	Chicago, Rock Island & Pacific Ry. Co.	129			4			97	41	37		214	196		81	563	F. O. Bunnell.
LOUISA COUNTY.																	
Wapello	Chicago, Rock Island & Pacific Ry. Co.	60			14			62	10	22		200	51		18	277	F. O. Bunnell.

WAPELLO COUNTY.																	
Ottumwa	Young Men's Christian Association.			13			1	96	31	368	20	298	688		141	1,507	W. S. Hendrixson.
Do	John Morrell (2)	1,554	New Richmond	12			1	95	41	298	18	305	587		140	1,344	Do.
Do	J. Morrell, No. 4	2,200	Oneota	11			1	96	35	247	16	308	500		119	1,179	Do.
Do	Artesian Well Co.	2,047	do					90	37	265		356	474		119	1,163	L. W. Andrews.
Do	Mineral Springs Sanitarium Co.	314	Mississippian	125		24		345	152	1,464		1,297	2,807		533	6,098	D. D. Carter.
Do	do	85		25				54	26	167		472	152		28	688	W. S. Hendrixson.
South Ottumwa		50		20		1	2	96	23	11		230	126		20	414	Do.
Farson	G. Thompson	100					9	97	32	43		544	11		7	471	Geo. N. Prentiss.
Rutledge	Phillips Fuel Co.	42						89	24	18		420	6		3	350	Do.
Eddyville	Spring			96		880	1,288	464	984	80			15,112	(b)	8	18,912	T. E. Pope.
HENRY COUNTY.																	
Mount Pleasant	Hospital for Insane	1,230	St. Peter	14		3	1	102	37	326	12	262	669		151	1,446	W. S. Hendrixson.
Do	do	1,267	do	10		8	1	198	71	400	14	280	1,214		157	2,313	Do.
Winfield	Chicago, Burlington & Quincy R. R. Co.	70														370	M. H. Wickhorst.
DES MOINES COUNTY.																	
Burlington	Murray Iron Works	1,000	St. Peter	11		1	1	342	115	514	11	232	1,860		235	3,206	W. S. Hendrixson.
Do	Sanitary Milk Co.	484	Silurian	13		5	1	389	131	707	19	268	2,414		276	4,089	Do.
Do	Crapo Park	2,430	Dresbach or underlying Cambrian sandstones.	13			1	79	25	253	11	274	386		161	1,066	Do.
Do	Clinton-Copeland Co.	500	Silurian	13			2	398	140	783	21	260	2,338		276	4,101	Do.
Northfield		300			8			93	33	2		398	28		9	372	F. O. Bunnell.
DAVIS COUNTY.																	
Bloomfield	City	1,817		74	5			237	71	303		192	1,203		86	2,080	Dearborn Drug & Chemical Works.
VAN BUREN COUNTY.																	
Cantril	Sam Teter	230		25		6	9	340	92	279		147	1,635		15	2,474	W. S. Hendrixson.
Do	C. J. Manning	900	Maquoketa	16		3	1	270	89	299		228	1,306		19	2,117	Do.
Farmington	City	800	Silurian (?)	13			2	340	112	442	15	248	1,658		230	2,936	Do.
Milton	Chicago, Burlington & Quincy R. R. Co.	135														725	M. H. Wickhorst.
Stockport	do	40														310	Do.

a Sum of the constituents minus one-half the bicarbonate radicle.

b Very strongly acid.

Analyses of water in the southeast district of Iowa—Continued.

Locality.	Owner.	Depth of well.	Lowest geologic division.	Silica (SiO_2).	Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.[a]	Name of chemist.
LEE COUNTY.		*Feet.*															
Fort Madison........	S. Atlee...........	110	....	12	......	......	1	90	37	428	15	272	505	......	428	1,652	W. S. Hendrixson.
Do..............	Columbia Paper Co	689	Galena............	7	14	......	......	150	22	501		514	587	......	429	1,967	Do.
Keokuk..............	Young Men's Christian Association.	769	Silurian (?).......	12	......	......	1	198	81	894	15	292	1,610	......	632	3,589	Do.
Do..............	Keokuk Pickle Co.	769	.....do............	7	......	......	8	172	87	837		121	1,546	......	633	3,350	J. B. Weems.
Do..............	Keokuk Poultry Co.	700	.....do............	6	......	......	1	206	35	1,044		311	1,589	......	674	3,710	Do.

SOUTH-CENTRAL AND SOUTHWEST DISTRICTS.

There are few deep wells in the southwest and south-central districts, and the waters of these are without exception hard. Some of them are too heavily mineralized to be used for any purpose. Three wells in Marion County all contain more than 8,000 parts of solids. As shown by the well of Thomas Craig, near Knoxville, which is only 346 feet deep, the hard water probably comes from the upper rock strata, though it may come from the lower beds also. This conclusion is reached by comparing the water of this well with the waters from the deep wells at Pella and at Flagler. The similarity of the solids in quality and in quantity indicates that the waters have a common origin. The character of the water at Pella has been used, perhaps justly, to discourage deep drilling in that part of the State. It should be said, however, that this water probably comes from strata lying very little, if any, deeper than those in the Craig well, and not from the St. Peter, in which the well is supposed to have its footing. If this is true, it is not impossible that the hard water could be shut out and a reasonably good supply obtained by using deep casings, carefully put in, in borings of equal or greater depth in this vicinity. The St. Peter alone did not seem to yield enough water in the Pella well, and the casing was raised so as to admit the harder water.

The best deep wells in the southwest and south-central districts are at Council Bluffs and at Dunlap, both near Missouri River. Though all are about equally high in mineral content, the wells at Council Bluffs have the advantage of containing only small amounts of calcium and magnesium, and on that account they may be rated as soft waters.

Two deep wells at Glenwood, about 2,000 feet deep, yield highly mineralized waters but have long been in use, one to supply the city and the other the institution for the feeble minded. The latter well is supposed not to go below the Silurian and its water is better than that of the city well, which probably enters the Maquoketa, in containing less calcium and magnesium. This well has now been abandoned on account of contamination and insufficiency of water, and a new supply for the institution has been obtained from shallow wells in the alluvium near Missouri River. This water from one of the test wells contained 460 parts per million of solids.

The latest deep well to be drilled in this part of the State is at Bedford, in Taylor County, and reaches a depth of 2,000 feet. An analysis of water encountered at 1,300 feet showed 4,827 parts per million of solids, mostly salt, chlorine being 2,545 parts. Another vein of very different water was struck at about 2,000 feet. An analysis of water at this depth showed about half as much salt, though the total solids reached 5,373 parts per million. The lower water contains large amounts of calcium, magnesium, and sulphate radicle, and the water last analyzed was a mixture in about equal volumes of the flows from the two sources.

From the data now at hand the outlook for good deep-well water in the southwest and south-central districts is not encouraging. The Bedford well reaches only into the Silurian at 2,000 feet, and its bottom is probably several hundred feet above the great sandstone formations, which are doubtfully productive of good water in quantity in that locality. Their depth is certainly at about the limit of practicable drilling, not to mention the great difficulties of putting down casings to sufficient depths to shut out the undesirable waters that have been encountered at every point where deep wells have been drilled.

Not only are the deep-well waters in this section highly mineralized, but the same is true of every water analyzed from a well which is known to enter rock. The Carboniferous and the Cretaceous cover the entire region and seemingly supply hard water. On the other hand, no other region of the State is so well supplied with small rivers having broad valleys that contain water-bearing sand layers. At least a dozen of these rivers or large branches of rivers flow through the south-central and southwest districts, generally in a southwesterly direction and enter into the Missouri. Many towns get their water supplies from the sands in the flood plains or valleys of these rivers. Notable examples are Red Oak, Elliott, Griswold, and Atlantic, on the Nishnabotna, and Clarinda, Villisca, and Corning, on the Nodaway. Where obtainable, driven or dug wells in river valleys in this part of the State are the best sources of water. Many districts away from rivers, in Mahaska, Marion, and Monroe counties, find the water problem a serious one. In some localities gravel and sand layers in the drift supply abundant water to driven or bored wells, and this is true over large portions of Mills, Page, Appanoose, and probably Union counties. Union County seems to be particularly well supplied with water; at least four branches of Platte and Grand rivers flow across it, and C. A. White, of Talmadge, writes that it contains very many unfailing springs, that there are large areas of sand and gravel which supply abundant water, and that there is probably not a farm in the county that can not easily have a constant supply of good water.

Average mineral content of waters in the south-central and southwest districts of Iowa.

[Parts per million.]

Source.	Silica (SiO_2).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.[a]
13 deep wells	32	157	66	618	346	1,484	556	3,657
37 shallow wells	26	167	43	374	363	745	62	1,587

[a] Sum of the constituents minus one-half the bicarbonate radicle.

Analyses of water in the south-central district of Iowa.

[Parts per million.]

Locality.	Owner.	Depth of well.	Lowest geologic division.	Silica (SiO_2).	Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.[a]	Name of chemist.
ADAIR COUNTY.		*Feet.*															
Fontanelle	J. H. Hubert	269	Cretaceous	20	......	3	1	231	69	412		264	1,322	......	84	2,274	W. S. Hendrixson.
Orient	Chicago, Burlington & Quincy R. R. Co.	34	......	......	......	......	......	......	......	......		......	......	......	......	236	M. H. Wickhorst.
MADISON COUNTY.																	
Winterset	Chicago, Rock Island & Pacific Ry. Co.	38 x 16	......	......	6	......	......	101	34	10		298	126	......	24	450	F. O. Bunnell.
WARREN COUNTY.																	
Carlisle	P. Shoemaker	220	Des Moines	168	......	2	11	26	10	816		636	1,104	......	128	2,583	W. S. Hendrixson.
MARION COUNTY.																	
Columbia	F. Carruthers	150	"St. Louis"	15	......	5	2	490	72	772		276	2,754	8	27	4,283	W. S. Hendrixson.
Flagler	S. C. Johnson	752	Kinderhook	22	......	.4	3	486	167	2,236		306	4,839	......	925	8,831	Do.
Knoxville	Hospital for Inebriates.	326	Des Moines	10	......	.4	3	303	52	436		262	1,600	......	18	2,553	Do.
Do	T. Craig	346	....do	36	......	3	1	207	114	2,589		330	4,728	......	980	8,823	Do.
Do	P. M. Stentz	142	Sandstone	28	......	......	5	80	19	14		256	38	......	10	323	Do.
Pella	City	1,803	St. Peter	10	......	4	3	488	148	2,107		280	4,678	......	775	8,353	Do.
Pleasantville	J. Worthington	180	Des Moines (?)	10	......	1	1	321	95	886		330	2,515	......	128	4,122	Do.
UNION COUNTY.																	
Talmadge	Mormon Spring	......	......	31	......	1	1	142	21	17		374	47	......	6	453	W. S. Hendrixson.
Lorimer	Private well	450	......	......	......	......	......	369	154	(b)		304	1,243	......	(b)	3,360	W. H. Chadbourn.
Shannon	Chicago Great Western Ry. Co.	38	......	......	......	......	......	18	15	161		388	154	......	9	551	Do.
Kent	Chicago, Burlington & Quincy R. R. Co.	161	......	......	......	......	......	......	......	......		......	......	......	......	951	M. H. Wickhorst.

[a] Sum of constituents minus one-half the bicarbonate radicle.

[b] "Other alkalies," 1,442 parts.

Analyses of water in the south-central district of Iowa—Continued.

Locality.	Owner.	Depth of well.	Lowest geologic division.	Silica (SiO_2).	Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.	Name of chemist.
LUCAS COUNTY.		*Feet.*															
Woodburn	Mrs. J. R. Rhodes.	270	Drift	13	......	3	2	157	46	577		261	1,405	......	17	2,350	H. S. Spaulding.
MONROE COUNTY.																	
No. 10 Junction	Chicago & North Western Ry. Co.	1,345	Silurian	12	......	......	......	278	59	602		580	1,496	......	142	2,879	Geo. M. Davidson.
RINGGOLD COUNTY.																	
Diagonal	Chicago Great Western Ry. Co.	36	......	......	......	......	......	65	20	(a)		284	10	......	(a)	335	W. H. Chadbourn.
Kellerton	Robt. Hall	375	Des Moines	55	......	5	9	249	87	521		439	1,477	......	46	2,673	H. S. Spaulding.
Do	L. Myers	400	......	11	......	2	4	85	53	793		397	1,417	......	244	2,830	Do.
DECATUR COUNTY.																	
Leon	Wm. Haslitt	803	Des Moines	b 53	......	8	2	95	36	735		376	1,489	......	90	2,696	W. S. Hendrixson.
WAYNE COUNTY.																	
Sewal	Chicago, Milwaukee & St. Paul Ry. Co.	80	......	......	8	......	......	151	51	41		526	206	......	15	735	Geo. N. Prentiss.
Cambria	Chicago, Burlington & Quincy R. R. Co.	16	......	......	......	......	......	......	......	......	......	......	......	......	......	400	M. H. Wickhorst.
APPANOOSE COUNTY.																	
Centerville	City (No. 2)	1,540	Silurian	10	3	......	......	263	90	755		90	1,961	......	339	3,465	J. E. Siebel.
Do	City (No. 3)	2,054	New Richmond	35	......	3	1	191	66	555		274	1,229	......	328	2,545	W. S. Hendrixson.
Moulton	Electric Light Co.	400	Des Moines	7	......	2	1	350	77	373	8	170	1,764	......	20	2,687	Do.

a "Other alkalies," 98 parts.

b Including clay.

Analyses of water in the southwest district of Iowa.

[Parts per million.]

Locality.	Owner.	Depth of well.	Lowest geologic division.	Silica (SiO_2).	Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.[a]	Name of chemist.
HARRISON COUNTY.		*Feet.*															
Dunlap	City	1,535	St. Peter	8	.....	0	0	176	72	146	27	272	776	.....	33	1,374	W. S. Hendrixson.
Do	Chicago & North Western Ry. Co.	60	.....	25	3	.....	.....	138	45		30	384	234	.....	21	688	Geo. M. Davidson.
Logan	City	821	.....	10	.....	.3	2	35	15		461	411	728	.....	121	1,578	E. B. Benger.
Missouri Valley	Chicago & North Western Ry. Co. (shops).	90	.....	22	3	.....	.....	112	41		14	482	62	.....	14	509	Geo. M. Davidson.
Do	Farm well	328	.....	34	12	.....	.....	90	52		45	524	68	.....	21	584	Do.
Mondamin	Chicago & North Western Ry. Co.	90	.....	26	3	.....	.....	160	55		35	724	90	.....	4	735	Do.
SHELBY COUNTY.																	
Harlan	City	30–40	.....	18	2	.....	.....	80	31		12	344	37	.....	18	370	Geo. M. Davidson.
AUDUBON COUNTY.																	
Audubon	City	35	.....	27	.....	1	3	205	48		36	250	364	25	82	916	W. S. Hendrixson.
POTTAWATTAMIE COUNTY.																	
Council Bluffs	Woodward Candy Co.	830	Basal Mississippian (?).	.....	.....	.....	.....	28	22		414	288	666	.....	89	1,363	W. H. Chadbourn.
Do	School for Deaf	1,091	Silurian (?)	9	.....	.....	2	40	9	416	4	312	649	.....	78	1,363	Floyd Davis.
Do	C. Hafer	138	.....	31	.....	.6	2.4	104	23		24	442	29	.....	6	441	H. S. Spaulding.
Do	do	100	.....	26	.....	.....	2	109	25		20	430	34	.....	5	436	Do.
Honey Creek	Chicago & North Western Ry. Co.	118	.....	22	.....	.....	1	126	41		162	348	403	.....	87	1,016	Geo. M. Davidson.
McClelland	Chicago Great Western Ry. Co.	225	.....	.....	.....	.....	.....	87	29		28	438	30	.....	.....	393	Do.
Minden	City	50	.....	.....	.....	.....	.....	105	34		31	410	60	.....	47	482	W. H. Chadbourn.
Neola	Chicago, Milwaukee & St. Paul Ry. Co.	100	.....	.....	.....	.....	.....	70	23		14	354	2	.....	.....	286	Geo. N. Prentiss.

[a] Some of the constituents minus one-half the bicarbonate radicle.

Analyses of water in the southwest district of Iowa—Continued.

Locality.	Owner.	Depth of well.	Lowest geologic division.	Silica (SiO_2).	Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.	Name of chemist.
CASS COUNTY.		*Feet.*															
Anita	City	207	Sandstone	28	......	0.1	2	304	84	125		392	970	......	12	1,721	W. S. Hendrixson.
Atlantic	do. *a*	40–60	Alluvium, river bottom.	......	5	......	......	75	20	7		274	40	......	10	294	F. O. Bunnell.
Griswold	W. H. Spencer	100	Drift	20	......	3	.5	48	13	8	2	230	6	......	1.1	217	H. S. Spaulding.
MILLS COUNTY.																	
Glenwood	Institute for Feeble-minded.	1,910	Silurian	131	16	......	......	37	14	647		486	754	......	185	2,027	W. S. Hendrixson.
Do	Institute for Feeble-minded (test well).	....	Missouri bottom	12	......	......	2	97	41	27		504	25	......	4	460	Do.
Do	City	2,000	Maquoketa	22	9	......	......	75	26	790		518	886	......	282	2,349	Do.
Hastings	Chicago, Burlington & Quincy Ry. Co.	41	....	......	......	......	......	......	......	......	......	......	......	......	......	416	M. H. Wickhorst.
MONTGOMERY COUNTY.																	
Red Oak	City	38	River bed	10	......	......	3	43	9	14		226	37	......	5	234	W. S. Hendrixson.
Villisca	City (No. 1)	....	Alluvium, river bottom.	*b*404	......	2	......	36	13	5		150	18	......	4	557	Do.
Do	City (No. 2)	....	do	28	......	2	2	50	15	20		152	31	......	43	270	Do.
ADAMS COUNTY.																	
Corning	City	....	do	18	......	7	5	92	21	27		262	100	......	31	432	W. S. Hendrixson.
FREMONT COUNTY.																	
Hamburg	Chicago, Burlington & Quincy Ry. Co.	75	....	......	......	......	......	......	......	......	......	......	......	......	......	530	M. H. Wickhorst.
McPaul	do	40	....	......	......	......	......	......	......	......	......	......	......	......	......	500	Do.

PAGE COUNTY.																
Clarinda	Chicago, Burlington & Quincy Ry. Co.	56													900	M. H. Wickhorst.
Do	do	60													270	Do.
Shenandoah	do	62													718	Do.
TAYLOR COUNTY.																
Bedford	Water Co. (1)	1,300		10			2	77	34	1,768	312	235		2,545	4,827	W. S. Hendrixson.
Do	Water Co. (2)	2,002	Silurian	18		1	1	486	116	1,161	300	1,920		1,420	5,273	Do.

a City water from many drive wells.

b Including clay; excluded from averages.

SUMMARY.

WATERS OF THE DEEP WELLS.

QUALITY.

In this paper all wells that penetrate at least the St. Peter sandstone and all other wells more than 700 feet deep are considered to be deep wells.

The average mineral content of the deep wells in the various districts is summarized in the following table:

Average mineral content of waters from deep wells in Iowa.

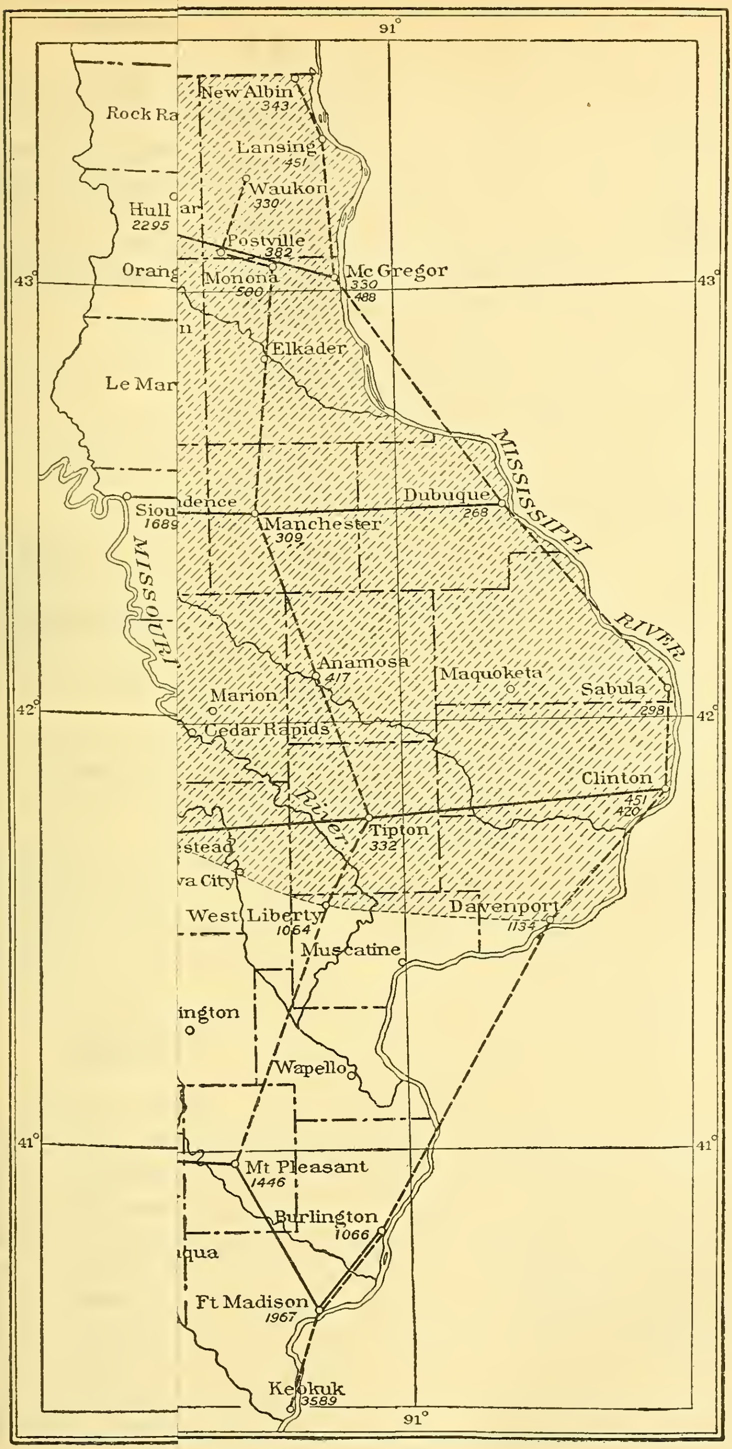
[Parts per million.]

District.	Number of analyses averaged.	Silica (SiO_2).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.[a]
Northeast	30	10	63	31	28	321	38	24	351
North-central	7	11	87	33	20	328	92	14	439
Northwest	9	16	210	67	181	373	719	10	1,425
East-central	35	10	103	47	182	326	425	83	978
Central	10	14	174	62	286	262	947	19	1,759
Southeast	16	15	143	56	463	285	998	256	1,978
South-central and southwest	13	32	157	66	618	346	1,484	556	3,657

[a] Sum of the constituents minus one-half the bicarbonate radicle.

The deep-well waters of the northeast, north-central, and east-central districts are decidedly lower in the amount of mineral matter they contain than the waters of the other districts, and it may be inferred that increase of mineral content progresses from the northeast to the southwest corner of the State.

The change in mineral content is, however, abrupt and not progressive. (See Pl. IV.) This can be strikingly illustrated by tabulating the total solids of the deep waters along north-south and east-west lines across the State. In the first tabulation figures for waters along east-west lines are given with the locations and depths of the wells, the sharp transition in amount of dissolved mineral matter on each line being indicated by heavy rules. Column A represents the waters of wells beginning at McGregor, Clayton County, and going west to Missouri River along a line passing through the second tier of counties from the north. Column B contains wells for the most part in the fourth tier of counties from the north, along a line beginning at Dubuque and ending at Sioux City. Column C includes wells mostly in the sixth tier of counties beginning at Clinton and ending at Logan in Harrison County. The figure for Grinnell represents the best deep water found there, that of city well No. 4; the water from most of the Grinnell wells contains about 1,200


91°
Rock Ra
New Albin
343
Lansing
451
Waukon
330
Hull
2295
Postville
382
Orang
Monona
500
Mc Gregor
330
488
43°
Elkader
Le Mar
MISSISSIPPI
RIVER
Dubuque
268
Siou
1689
Manchester
309
MISSOURI
Anamosa
417
Maquoketa
Sabula
298
Marion
Cedar Rapids
42°
Clinton
451
420
Tipton
332
West Liberty
1064
Davenport
1134
Muscatine
ington
Wapello
41°
Mt Pleasant
1446
Burlington
1066
Ft Madison
1967
Keokuk
3589

APHY.

ion.

MAP SHOWING MINERAL CHARACTER OF UNDERGROUND WATER WITH REFERENCE TO GEOGRAPHY.

Shading indicates area of lightly mineralized water; figures indicate amount of total solids in parts per million.

parts of solids per million, a great change having taken place since the first well was put down in 1894, doubtless owing to the imperfect casing of Carboniferous and Silurian waters. Column D represents wells in the eighth and ninth (the two southernmost) tiers of counties. Fewer wells have been drilled in this part of the State than elsewhere, but these are sufficient to show that all the present wells along the southern line yield waters of high mineral content.

Change in total solids in well waters along east-west lines.

A.

Location of well.	Depth.	Total solids.
	Feet.	*Parts per million.*
McGregor	520	488
Calmar	1,223	306
Charles City	1,588	295
Mason City [a]	651	370
Algona	1,050	647
Emmetsburg	874	410
Sanborn	1,250	2,186
Hull	1,256	2,295

B.

Location of well.	Depth.	Total solids.
	Feet.	*Parts per million.*
Dubuque [b]	1,200	268
Manchester	1,870	309
Waterloo	1,373	468
Fort Dodge	1,827	867
Manson	1,954	651
Holstein	2,004	1,436
Sioux City	2,011	1,689

C.

Location of well.	Depth.	Total solids.
	Feet.	*Parts per million.*
Clinton	1,065	451
Tipton	2,696	332
Homestead	2,224	1,016
Amana	1,640	1,033
Grinnell City well No. 2	2,002	881
Des Moines [c]	3,000	2,941
Dunlap	1,535	1,374
Logan	821	1,578

D.

Location of well.	Depth.	Total solids.
	Feet.	*Parts per million.*
Burlington [d]	2,430	1,066
Mount Pleasant [e]	1,230	1,446
Fort Madison	689	1,967
Ottumwa [f]	2,200	1,179
Centerville	2,054	2,545
Leon	803	2,696
Bedford	2,002	5,273
Glenwood [g]	2,000	2,349

[a] City well No. 2.
[b] City 8-inch well.
[c] Greenwood Park well.
[d] Crapo Park well.
[e] Well at State Hospital.
[f] Well of J. Morrell Co.
[g] City well.

The same sharp change in the mineral content of the deep waters may be observed along north-south lines. Wells yielding soft water occur farther south the nearer they are to Mississippi River—that is, such wells occur near the river as far south as the parallel of Des Moines—but on the meridian of Des Moines only wells near the northern border of Iowa supply soft water. West of this meridian only two or three deep wells have slightly mineralized water. The relations of the north and south lines are shown in Plate IV. Column A in the next table contains the total solids and depths of deep wells on or near Mississippi River, beginning at New Albin and ending at Keokuk. Column B shows the mineral content of wells near, but not on, Mississippi River, beginning at Waukon in Allamakee County and ending at Mount Pleasant in Henry County. Column C gives the amount of mineral matter in wells beginning at Osage on the north and extending south in a line approximately parallel to the eastern border of the State and ending at Centerville. Column D leaves much to be desired. The well at Tama is only 861 feet deep and probably foots in the Silurian, for its mineral content is higher than would be expected in the lower sandstones. The region along Iowa River in Tama, Benton, and Iowa counties is one having waters high in mineral content in the drift and probably for some distance in the strata underlying the drift, as the shallow wells penetrating these strata show. It may be that the wells of this region are contaminated by the heavily mineralized waters from beds far above the strata in which the wells foot. The well at Montezuma, depth reported 2,800 feet, had long been unused at the time the sample was taken, but the sample was taken only after the well had been pumped an hour or more. The lowest geologic formation this well penetrates is unknown. Owing to uncertainties regarding the Montezuma well the one at Pella was also included in the series. Column E begins with the well at Emmetsburg and ends with that at Centerville. In general the wells are near Des Moines River. High mineral content is found a little farther north on this line than on the next preceding line to the east. The line connecting the wells north of Boone marks about the western limit of lightly mineralized waters in deep wells, and with the exception of the well at Emmetsburg these wells contain considerably more mineral matter than the wells in the same latitude in the next line east beginning at Osage.

Change in total solids in well waters along north-south lines.

A.			B.			C.		
Location.	Depth.	Total solids.	Location.	Depth.	Total solids.	Location.	Depth.	Total solids.
	Feet.	*Parts per mil.*		*Feet.*	*Parts per mil.*		*Feet.*	*Parts per mil.*
New Albin	500	343	Waukon	600	330	Osage	780	460
Lansing	668	451	Postville City	515	382	Charles City	1,588	295
Village Creek	750	372	Monona	420	500	Waverly	1,740	379
McGregor	520	488	Manchester	1,870	309	Waterloo	1,373	468
Dubuque [a]	1,200	268	Anamosa	2,200	417	Vinton	1,402	561
Sabula	973	298	Tipton	2,696	332	Belle Plaine	1,520	1,980
Clinton [b]	1,226	420	West Liberty	1,768	1,064	Homestead	2,224	1,016
Davenport [c]	1,067	1,134	Mount Pleasant	1,230	1,446	Ottumwa	2,200	1,179
Burlington [d]	2,430	1,066				Centerville	2,054	1,228
Fort Madison	689	1,967						
Keokuk [e]	769	3,589						

[a] City 8-inch well.
[b] Sugar Refining Co.
[c] Davenport Ice Co.
[d] Crapo Park.
[e] Young Men's Christian Association.

Change in total solids in well waters along north-south lines—Continued.

D.			E.		
Location.	Depth.	Total solids.	Location.	Depth.	Total solids.
	Feet.	*Parts per mil.*		*Feet.*	*Parts per mil.*
Mason City	862	299	Emmetsburg	874	410
Hampton	1,708	405	Algona	1,050	647
Ackley	2,032	605	Fort Dodge	1,827	867
Tama	861	5,532	Dayton	688	624
Grinnell	2,020	900	Boone	3,010	1,711
Montezuma	(?) 2,800	1,835	Ames	2,215	1,270
Pella	1,803	8,353	Des Moines	3,000	2,941
Ottumwa	2,200	1,179	Flagler	752	8,831
			Centerville	2,054	[a] 1,228

[a] The water of this well was analyzed five times at intervals of about a year. The total solids were 1,228 in the first analysis and 2,545 in the fourth.

DISTRIBUTION OF HARD AND SOFT WATERS.

The preceding tables show that the change from lightly mineralized to very hard waters from north to south and from east to west is not gradual, as might be expected, but is sudden, waters containing almost as small amounts of mineral matter as any in the State giving place to waters containing two or three times as much. The dividing line between these two regions of high and low mineralized waters is approximately shown on Plate IV. It starts at Davenport, on Mississippi River, and runs west to Grinnell, then swings in a wide arc northward through Ames, Manson, and Emmetsburg. This location, however, should not be too strictly interpreted. Some wells supplying hard water are north of this line, particularly at Tama and at Belle Plaine. Good waters are usually found northeast of the line if the wells have been properly cased and are kept in good condition. Reference to the geologic map of Iowa (Pl. I, pocket) and to the account of geologic formations (pp. 60–90) brings out the relations between the quality of the deep waters and the character of the rocks from which they come and makes it clear why the difference in mineral content occurs. The part of the State northeast of the dividing line (Pl. IV) includes the region where the older sandstones and limestones lie immediately under the surface covering of drift. It also includes considerable areas of the Carboniferous, whose formations yield hard waters in many places. The formations of this system northeast of the line are, however, the older ones, whose waters are less objectionable than those of the later deposits, and they lie so near the surface that their waters can be cased out, thus permitting the entrance of only the good waters from the older rocks underneath. If the area were restricted so as to exclude the Carboniferous entirely—that is, if the line between the Devonian and the Carboniferous were taken as the southwestern boundary—then practically no deep wells yielding hard waters would be included. With few exceptions the total solids in wells northeast of such line are less than 500 parts per million, and in most of these are less than 400 parts. A few notable exceptions occur, as at Davenport and Amana and at McGregor, where the 1,000-foot well going into the basal sandstone yields water containing considerable salt, whereas wells about 500 feet deep at the same place yield excellent water. The chief difficulty with the Davenport water is salt, but the amount is small. Both Davenport and Amana are apparently on the border of the Devonian and very near the Carboniferous.

With the present material used in casings and the methods employed in finishing wells, experience shows that outside of the northeastern area mentioned above it is very difficult, perhaps wholly impracticable, to procure from the deep-lying sandstones or any other deep-lying stratum water comparable in quality with that yielded by most of the deep wells in the northeastern part of the State. The strata bearing the very hard waters lie too deep to permit the successful and permanent casing out of these waters, and in the southwestern part of the State the lower sandstones seem to lie too deep to make it practicable to reach them with the drill. This practical difficulty of casing out the upper bad waters apparently explains why some wells within the Carboniferous area yield good water while others yield bad water. Future improvements in methods of protecting deep wells against the influx of undesirable waters from strata that may be penetrated may result in extension of the area of wells yielding water of low mineral content.

The waters of deep wells outside the district of good waters are not necessarily so highly mineralized as to be unfit for use, though several of them belong to this class. The majority belong to that class of waters which may be used for municipal supplies if none more satisfactory is available. Only about 28 cities and towns have wells more than 750 feet deep. Some places have two or more wells, making the total number of deep wells in the district of poor water about 40. For the most part these wells are located in the southeast and in the northwest districts of the State. The south-central portion of the State has very few deep wells. In the three southern tiers of counties west of Ottumwa and extending to the counties bordering on Missouri River 17 counties contain only three deep wells—those at Knoxville, Centerville, and Bedford. A study of the records of the 40 wells shows that only two, at Rockwell City and Manson, both just outside of the area of good well water already defined, contain less than 1,000 parts of solids per million. The average of the total solids for the wells in the 28 towns, taking only one typical well in places where there are two or more, is 2,434 parts per million. From all the facts it seems probable that the southwestern part of the State will have to depend mainly on water supplies from shallow wells in drift and in river alluvium or on treated water from the rivers themselves.

WATERS OF THE SHALLOW WELLS.

The term "shallow wells" is used in this paper to describe wells penetrating only the drift and others that do not penetrate any of the great water-bearing sandstones. Definite statements like those used for deep wells can not be made regarding the relations between the geographic location and the mineral content of shallow wells. The averages by districts of the analyses of water from shallow wells in Iowa are repeated here for comparison. (See fig. 2, p. 140.)

Average mineral content of the waters from shallow wells in Iowa.

[Parts per million.]

District.	Number of analyses averaged.	Silica (SiO_2).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.
Northeast	20	15	89	32	16	347	83	12	388
North-central	37	18	99	32	253	418	68	8.8	454
Northwest	60	24	160	48	60	420	321	62	857
East-central	45	14	177	58	90	360	495	25	1,031
Central	69	23	124	44	125	446	344	88	873
Southeast	29	27	165	82	188	367	1,040	69	1,931
South-central and southwest	37	26	167	43	374	363	745	62	1,587

The amounts of mineral matter in the waters of the shallow wells in general parallel those of the waters of the deep wells in the same localities, but the relation is only general and marked exceptions are frequent. Shallow wells derive their waters more from the country immediately surrounding them, and the character of their waters, therefore, depends more largely on local conditions. Some drift wells only a few miles apart show very different amounts of mineral matter. In certain areas the drift waters are notably hard; in others they are soft. Many wells, especially in the southern part of the State, derive their waters from the sands of river flood plains. Their waters are usually soft, as a rule containing very little more mineral matter than the waters of the rivers themselves.

CHAPTER VI.

MUNICIPAL, DOMESTIC, AND INDUSTRIAL WATER SUPPLIES.

By W. S. Hendrixson.

SOURCES OF SUPPLY.

Iowa has few rivers capable of supplying sufficient water throughout the year to cities of considerable size. According to the best opinion of the present time there are few rivers and lakes in any part of the country that are capable of supplying water suitable for drinking without filtration. The time has probably passed when the water from any river within the State or from any bordering river may be used with safety without treatment.

The Iowa lakes are few, small, and shallow, and consist chiefly of one group near the northern border of the State well to the west, in Dickinson, Emmet, Clay, and Palo Alto counties. No large towns are near them, and with one or two exceptions the smaller towns of that vicinity draw their water from other sources.

But although Iowa has few rivers or lakes affording potable water through a considerable portion of the year, the conditions are unusually favorable for the storage of ground water and its easy utilization. Most of the features that tend to decrease the amount of surface water are features that tend to produce a large supply of ground water; the level surface that gives the rivers slow currents and wide bottoms and flood plains and the deep drift that affords storage combine to make the run-off small and the absorption of water by the soil large.

If the shallow wells only a few feet deep, which foot below the water line during most of the year and derive their water from seepage are left out of account, there are three main sources of ground water in Iowa—the drift, the alluvial sands and gravels in the river valleys, and the sandstone and limestone formations.

Nearly the whole State is covered by deep drift, containing extensive sand and gravel beds, usually near or just above the stratified rock. The beds afford storage for large quantities of water, which in most localities is easily reached by the bored well or drive point. In many regions these layers seem to be in the form of basins or troughs and in such localities many wells flow.

As a rule the small rivers of Iowa meander with low velocity through wide valleys instead of cutting the deep channels common in more rugged country. In such valleys shallow, bored, or driven wells obtain water from the drift layers of sand which may dip toward the river or from the so-called underflow of the river alluvium. Commonly the waters of wells in the river alluvium are softer than drift water, the mineral content in some wells being nearly as low as in the water from the rivers on whose banks the wells are located. Water supplies from this source are numerous, especially in the southwestern part of the State, where there are many such small rivers and streams and where water from other sources is not so abundant or easily reached. Good wells supplying water from this source have been driven or dug to depths of 30 to 60 feet at Red Oak, Griswold, Elliott, and Atlantic, all on Nishnabotna River. The average mineral content of their water is usually less than that of the drift wells and does not greatly exceed that of the average river water in that section of the State.

The lower sandstones furnish an abundant supply of fair to good water to most of the deep wells of Iowa. A few deep wells in the southern and southwestern parts of the State do not reach these sandstones, which in the regions named lie at depths so great that it is hardly practicable to reach them with the drill or to case out the hard waters of the strata above them.

Leaving out of account water supplies for fire protection only, 324 towns [1] have waterworks of the more highly developed sort with standpipes, reservoirs, street mains, and fire taps. (See Pl. I, in pocket.) Many towns of fewer than 200 inhabitants are thus supplied with waterworks, and the fact indicates much for the prosperity and progressiveness of the people. Of the 324 towns, only six draw their water supplies from lakes or artificial ponds, chiefly the latter. Twenty-four towns get their water from rivers and 294 from wells. The urban population supplied from lakes and ponds was 21,000; from rivers, 341,700; and from wells, 534,500.

From these figures it appears that about 60 per cent of the population of towns having water supplies use well water. It should be remembered, moreover, that the people of the towns without public water supplies and nearly the whole of the rural population use well water. The total population in 1900 was 2,231,853, of which about 84 per cent used well water and about 16 per cent water from other sources. The population in 1910 was 2,224,771, but it is

[1] Based on figures of the Underwriters' handbook of Iowa, in which are given all towns, with their population and brief descriptions of their means of fire protection.

not probable that the percentage using well water has markedly changed.

The requirements for ground water are likely to increase more rapidly than the population. Many of the 324 towns in Iowa having water systems of some sort are villages of 150 to 300 inhabitants, and many towns of 500 to 2,000 inhabitants now without waterworks will be obliged to provide them in the near future. It is certain that many towns will outgrow their water systems and must find means of enlargement. In fact, many municipalities have been obliged to put down more wells, and more often to change from shallow wells having a local supply of water from the drift to deep wells having their source of supply in the deep-lying sandstone strata.

Artesian wells in Iowa, excluding flowing wells in drift and country rock, now exceed 250, and the amount of capital invested in them probably reaches well up to $750,000. Artesian wells in Iowa are used for municipal supply, for State institutions, for hotels, hospitals, and office buildings, for baths and swimming pools, for railway locomotive and shop supply, for stock farms, and for a wide variety of industries, such as packing houses, gas plants, glucose factories, breweries and bottling works, lumber, woolen, paper, and powder mills, soap factories, condensed-milk factories, creameries and dairies, ice plants, and iron works. In one place they have furnished power for a city electric plant.

It is interesting to note the development in stock wells on Iowa farms. The primitive stock well, dug only a few feet deep in a swale and fitted with a hand pump, has always been inadequate and has failed utterly in times of drought. The live-stock interests have developed so rapidly that the need of perennial supplies of plenty of good water has been keenly felt, and as a result many farms have been provided with wells 100 to 500 feet deep, and some with wells 1,000 feet deep or more. In such wells pumps operated by windmills or gasoline engines are used instead of hand pumps. In the last few years the farming population has greatly increased in wealth, the values of farm lands have doubled and even trebled, and the advantages of a never-failing supply of good water for stock and for domestic use are being more and more appreciated. These facts make it probable that the deep farm well will soon become the general source of water supply of the rural population in those parts of the State where satisfactory deep water-bearing formations exist.

Underground water is thus the chief source of water supply in Iowa for all purposes; and it does not seem probable that it will ever assume less importance relatively than it now holds. On the contrary, there are reasons why its importance should increase. With the growth of the population it seems likely that river water will become even more unsatisfactory in quality for municipal supplies, though it is possible that improved methods of filtration for smaller cities and towns may to some extent remove the difficulty due to pollution.

ADEQUACY OF SUPPLY.

The storage capacity of the aquifers which supply the Iowa deep wells is conditioned by their thickness, extent, and porosity. Their supply of water depends on the area of their outcrop—the area from which their waters are gathered—and on the rainfall in this area. Without going into any elaborate calculations it may be said that all conditions necessary for an abundant and continual yield are so fully met that the storage capacity of the Iowa water beds over any large area is far in excess of any possible draft upon them. Locally they may be overdrawn, but for the artesian field of Iowa as a whole there need not be the slightest apprehension of any diminution of supply. The maximum yield of wells is not limited by the present rainfall on the collecting area, by the absorption over the area, nor by the storage capacity of the basin, but by the conductivity of the rocks.

The yield of the Iowa deep wells is comparable with that of the deep wells of Minnesota, Wisconsin, and Illinois, which draw water from the same formations. It seems at least equal to the yield of the wells of the artesian basin of New Jersey, where as light or lighter pressures prevail. It is considerably less than the yield of wells in the artesian basin of the Dakotas, chiefly because of the lower pressure in the Iowa field, which in turn is due to the more gentle dip of the Iowa aquifers—to the lower relative height of the area of supply.

SELECTION OF SOURCE OF SUPPLY.

Emphasis must be laid on the fact that the writers of this report offer no specific advice as to municipal or other water supplies. They hold no brief for artesian wells against other sources of supply, such as shallow wells or river waters filtered by any effective method. No city supply should be chosen until all possible supplies have been carefully investigated. Some towns of the State have rested content with a scanty supply of impure water, where pure artesian water could be cheaply obtained in large quantities; others have sunk expensive artesian wells where a far larger and more permanent supply of good water could have been more cheaply obtained and maintained from shallow wells, for example, in drift gravels of adjacent river valleys. But in the selection of a supply the sinking of a deep well will usually be considered, and any information as to the probable depth, quality, and quantity of artesian waters will be of value whatever source of supply is chosen.

WELL DRILLING.

DEEP WELLS.

No new methods in drilling deep wells in Iowa have been introduced since the publication of W. H. Norton's report on the artesian wells of the State in 1897.[1] The following description, summarized from that report, is therefore equally applicable at the present time:

To drill an even and straight tube a quarter or a half a mile in depth requires experience and a high degree of mechanical skill. Deep-well drilling has become a special trade. Only one deep well in the State has been put down by amateur labor, and this proved a costly experiment whose repetition is not recommended. Most of the wells in Iowa have been drilled by firms whose territory is much wider than the limits of the State, and the methods and the machinery which they use in Iowa present nothing novel. In all drilling so far the drill has been the ordinary plunge or churn drill, essentially the same in action as that employed in sinking common drilled wells. The diamond drill has been used only in search for coal and building stone.

The rig differs slightly from that used in the oil fields of Pennsylvania and Ohio, and so fully described by Carll[2] and by Newell.[3]

The derrick tower is commonly about 18 feet square at the base and 60 feet high. An adjoining shed contains the forge at which the tools are dressed and an engine of 15 or 20 horsepower by which the drill is operated and the tools raised and lowered in the well. The drill consists of a steel chisel-shaped bit, screwed to an iron auger stem, to the upper end of which is fastened the "slips" or "jars." These consist of two slotted iron links joined together by a crosshead and crotch slot permitting a vertical play or slip, one upon the other, of about 13 inches, in about the same manner as the play of two links of a chain. The bit, the auger stem, and the lower member of the jars, thus fastened together, fall with each downward stroke about 20 inches and deliver a cutting and crushing blow of about 3,500 foot-pounds upon the rock. On the upward stroke the weight of the rig above the union of the two members of the jars delivers an upward blow whose purpose is to jar loose the drill beneath. No sinker bar is used above the jars. In some Iowa wells the string of drilling tools just mentioned has been swung from a rope, but in most wells rods of wood have been used, each about 33 feet long, with iron couplings. The string of rods and drill is attached by a swivel and heavy iron chain to the end of the walking beam, which plays up and down above the mouth of the tube. This chain is wrapped several times about the end of the beam and is let out little by little as the drill cuts deeper and deeper into the rock. The temper screw used for this purpose in the oil regions is not generally employed.

Month after month the same tedious routine continues. Night and day a driller sits at the bench over the boring. As the rods rise and fall with the monotonous motion of the walking beam, he slowly twists them round and round so that the drill may strike every portion of the bottom in its rotation and drill the hole round and true. So simple is this, apparently, that a boy could do it. But the experienced driller feels every stroke of the drill and movement of the jars, and interprets each vibration passing upward from a thousand feet below. A tyro in his place would churn the water without striking bottom and never know it. When no accidents delay, the drill cuts its way downward with surprising rapidity, making sometimes 60 or 70 feet a day. Every few feet the bore becomes clogged with the chips from the

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[1] Norton, W. H., Artesian wells of Iowa: Iowa Geol. Survey, vol. 6, 1897, pp. 115–428. See also Bowman, Isaiah, Well-drilling methods: Water-Supply Paper U. S. Geol. Survey No. 257, 1911.

[2] Carll, J. F., Geology of the oil regions: Second Geol. Survey Pennsylvania, Rept. III, 1880, pp. 284–330.

[3] Newell, F. H., Drilling and care of oil wells: Ohio Geol. Survey, vol. 6, 1888, pp. 476–497.

drill. The whole string is then hoisted and the hole cleaned out with the sand pump—a bucket with a suction valve at the bottom—and the drill is again lowered. This interruption takes less time than one would suppose. In hoisting the string the foreman sits with his left hand on the hoist lever and his right on the brake. The scaffold man stands on a platform in the tower about the length of a rod above the bench. The third man of the shift stands at the bench, catch wrench in hand. The string is rapidly hoisted by the engine; as soon as the upper end of the second rod from the top appears above the bench the brake is applied to the hoist, the string stops, the second rod is grasped by the wrench under the collar of the upper end. With the weight of the string thus resting on the wrench and bench, the scaffold man and the man at the bench together uncouple the upper rod from its connections above and below and set it at one side. The swivel whirls down and is coupled to the second rod, the hoist lever is pulled, the string rises, the third rod is caught fast, the second uncoupled, and so the work goes on. To hoist 1,600 feet of rods and tools needs only 20 minutes, and less time is taken in lowering them again.

Scarcely a well is drilled without more or less time being lost by accidents. Fragments of rocks become detached from the side of the shaft, fall, and wedge in with the string, preventing the slips from doing their work in jarring loose the drill. As soon as the drill stops, the sediment, with which the water is thick, settles about it, fastening it so securely that it can not be dislodged without special instruments. Fishing for drills and other lost tools may be the longest and most costly part of drilling a deep well.

Occasionally the drill strikes a slanting crevice and slips to one side. If this difficulty is not met at once the boring is deflected from vertical and the drill soon becomes fast. Some crevices can be filled, but most of them must be passed by a special tool or by casing.

In no well has it been found practicable to drill a deep boring of the same diameter throughout. Through the incoherent deposits of the Pleistocene the bore is relatively large—possible 10 or 12 inches in diameter—and casing of this size is driven firmly into the underlying rock to shut off all surface and drift waters. In a few wells Pleistocene gravel, mingled with drillings from lower horizons, has indicated that this work was not effectively done. Changing the drill to one of smaller diameter, the driller proceeds with the work until rock so incoherent or fissile is reached that it caves into the boring. The only remedy is to case this portion of the shaft. The method of inserting the casing is described by Mr. Seth Dean [1] in his description of the Glenwood well, as follows:

"On the lower end of the pipe a cast-steel shoe with a cutting edge was fitted, the outside diameter of the shoe being a little larger than the coupling bands that connected the joints of the pipe, so as to give clearance room. Fitted in this way it was possible to drive a line of pipe through most of the strata after they had first been pierced by the drill, the shoe cutting out a portion of the rock somewhat in the manner that a carpenter enlarges a hole in a piece of wood with a gouge. When the harder beds of limestone were struck, the pipe was raised a few feet with jacks and the hole enlarged by what is known as an expansion reamer, a tool so constructed as to pass down inside the casing and open when it meets with the resistance afforded by the rock bed under the pipe. When the friction of the mass of earth and shale against the sides of the pipe became so great that it could not be driven farther without danger of crushing or collapsing, it was bedded firmly in some stratum of rock and a pipe of smaller size was inserted inside this and driven in the same way. The rate of progress made in driving pipe was, of course, dependent on the nature of the material being worked. Sometimes in soft shales the weight of the pipes alone was euough to sink it, and at other times 6 hours' driving would not settle it more than 3 or 4 inches."

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[1] Proc. Iowa Civ. Eng. and Survey Soc., 1895, p. 36.

FINISHING WELLS IN SAND.

By O. E. Meinzer.

INCRUSTATION OF SCREENS.

Throughout northwestern Iowa and adjacent portions of Minnesota and South Dakota the majority of drilled wells end in sand belonging either to the glacial drift or to the Cretaceous system. The successful finishing of these wells is perhaps the most important problem in connection with water supplies in this area. Most of them are 2 inches in diameter, and the well casing is made to serve also as the pump pipe. The sand rises with the water so persistently that it is found necessary to put a screen or strainer at the bottom of the casing to shut out the sand while admitting the water. Various types of screens are in use, but the common type for wells of small diameter consists of a perforated iron pipe surrounded by a brass gauze of fine mesh, the whole inclosed in a perforated jacket to protect the gauze. The screen is small enough to be let down inside the casing.

Wells finished in this manner prove satisfactory for a time, but in the course of a few years the yield diminishes and eventually almost no water can be obtained. When the screens are removed, they are found to be effectually sealed by a coating of silt, etc., firmly cemented into a hard, impervious mass. The cost of a screen is not great, and the substitution of a new one for the old every few years would not be a serious matter were it not that the removal of the old screen is attended by great difficulties. In many instances the coating of cemented silt becomes so thick that the screen can not be withdrawn on the inside, and it is then necessary to pull up the entire casing in order to remove it. The labor and difficulty involved in this process is considered by many drillers to be equivalent to that of sinking a new well. Moreover, the rusted casing is liable to break, or the hole may cave, and the well is then usually lost.

The clogging of the screen has been found to be so great a nuisance that in many localities nearly all drilled wells have been abandoned, and shallow sources again used. Especially has this been done in the recent years of abundant rainfall following a series of dry years in which many of the drilled wells were sunk. The aggregate cost of the wells which have thus been abandoned in this region amounts to hundreds of thousands of dollars; furthermore, the return to shallow wells is not a solution of the problem. Recognizing the magnitude of the difficulty, the writer has investigated the entire matter, with a view to finding a practical remedy.

In order to ascertain the composition of the incrustant and the chemical changes involved in the incrusting process, a typical 2-inch well was selected, from which a screen of the ordinary construction, coated with the usual hard, dirty-gray substance had recently been removed. Both the water from this well and the incrusting material were analyzed. The data are presented below.

The well was owned by George Clynick, and was located in the SW. ¼ sec. 33, T. 104 N., R. 29 W., in Martin County, Minn. It was drilled in 1899 to a depth of 70 feet, with a diameter of 2 inches. It yielded "all that the windmill could pump." Its head was 13 feet below the surface. The material penetrated in drilling was (1) blue clay; (2) bluish-white sand, at first very fine, but changing into coarse grit, in which the well ends. The well was finished with an iron casing, ending with a screen of perforated galvanized iron pipe surrounded by a brass gauze, the whole being surrounded by a perforated brass sheath. The screen is 3 feet long and about 1 inch in diameter, and the length of time required for it to become effectually clogged was reported to be about 5 years.

Analysis of water of Clynick well, Martin County, Minn.

[Analyst: H. A. Whittaker, chemist, Minnesota State Board of Health, July 25, 1907.]

	Parts per million.
Silica (SiO_2)	24
Iron (Fe)	2.6
Calcium (Ca)	140
Magnesium (Mg)	54
Sodium and potassium (Na+K)	22
Carbonate radicle (CO_3)	0.0
Bicarbonate radicle (HCO_3)	259
Sulphate radicle (SO_4)	389
Chlorine (Cl)	4
Nitrate radicle (NO_3)	1.5
Free ammonia	2.0
Free carbonic acid (CO_2)	54
Total solids	772

Analysis of the material which incrusted the screen.

[Analyst: R. B. Dole, United States Geological Survey, Sept. 26, 1907.]

Clay, sand, silica, etc	56.0
Oxides of iron and aluminum	2.8
Calcium	13.0
Magnesium	1.3
Sodium and potassium	.7
Carbonate radicle	20.6
Sulphate radicle	.4
Chlorine	.1
Phosphate radicle	.0
Organic and volatile matter	5.3
	100.2

To this analysis the following note was added:

Of the 56 per cent comprising the silica and insoluble silicates, only 31 per cent is volatilized by hydrofluoric acid, showing that there is probably considerable clay present. Indeed, clay, sand, and carbonates of calcium and magnesium comprise 90 per cent of the deposit. The probable presence of sand particles is indicated by the fact that the substance was gritty when first pulverized, and required two days' grinding to reduce it to a powder fine enough for analysis.

The principal cementing substance is probably calcium carbonate precipitated from the water. The sand, silt, and clay are packed about the screen by the inflow of the water, and the interstices are then filled with calcium carbonate and other materials. Thus, the whole becomes a nearly impervious sheath which shuts out the water.

Whenever, in any well, the pump is operated, the weight of the water column is decreased by the removal of water, and it is this diminution in pressure that causes a new supply of water to flow through the screen into the well. The reduction of the pressure may allow a portion of the carbon dioxide to pass out of solution, disturbing the equilibrium between the free carbon dioxide and the bicarbonate radicle and effecting partial decomposition of the latter substance. As a result of this reaction, calcium carbonate is probably precipitated and is incorporated in the incrusting material. Only minute quantities of calcium carbonate need be deposited in order to effect the sealing of the screen in the course of several years. Possibly precipitated iron also adds to the cementing material. Electrolysis may occur between the brass and the iron portions of the screen, but the fact that some screens made entirely of brass have become incrusted as readily as the ordinary brass and iron ones seems to make this explanation inadequate. If the diagnosis given is correct, the process does not depend chiefly on the nature of the screen, but on changes which unavoidably accompany the withdrawal of water from the well, and hence the remedy must be sought along mechanical rather than chemical lines.

REMEDIES FOR INCRUSTATION.

A study of the mechanical aspects of the problem makes it possible to put forth some suggestions which, if followed, should prove of value by diminishing the annoyance and expense connected with wells finished in sand.

LARGE DIAMETERS.

Two-inch wells should not be drilled in regions where the screens become incrusted. For farm purposes wells from 4 to 6 inches in diameter can generally be finished successfully with open ends, whereas it is invariably necessary to put screens into those only 2 inches in diameter. The explanation is simple. With a given rate of pumping, the upward velocity of the water in a well varies inversely as the square of the diameter, and the capacity of a current to lift solid particles varies as the sixth power of the velocity. Consequently, sand that will cause no trouble in a large well will persistently rise in a small one if it is not screened. Practically, the effect is probably even greater than the ratio indicates, because in the wells of large diameter the inflow and upward velocity are nearly constant as long as the rate of pumping is kept constant, whereas in a well of small diameter the casing usually serves also as the pump pipe, and hence the upward current is not uniform, being zero during the downward stroke and varying from zero to a maximum and back to zero during the upward stroke. In general, it will be found more satisfactory and ultimately more economical to drill wells at least 4 inches in diameter than to put down the small 2-inch tubulars.

It is important, however, to understand that the finishing of sand wells with open ends should be attempted only where the rate of pumping is to be slow—for example, in farm wells where windmills are used. As a rule, wells furnishing water for public supplies and others pumped by steam or gasoline engines should be provided with screens. A number of sand wells used for public supplies in this region were finished without screens, and nearly all of these have given trouble. The sand rises with the water, cutting out the pump valves, clogging the mains, and filling the wells to such an extent that the supply is greatly diminished or the wells are totally ruined.

Drilled sand wells of large diameter invariably require screens if the rate of pumping is to be rapid, and some require them even though the rate of pumping is slow. Wherever there is danger that the sand will rise, it is the part of discretion to put in a screen. It should be remembered, however, that a 5-inch well with a screen is much better than a 2-inch well similarly finished. In the latter the screen must of necessity fit snugly into the casing, and when it becomes incrusted it may be impossible to pull it up, thus causing much trouble and frequently making it necessary to pull the entire casing. In a 5-inch well, on the other hand, a screen can be used so small that there will be no difficulty in removing it. Experience shows that it is poor economy to drill 2-inch wells.

ENDING IN A COARSE LAYER.

The glacial deposits, in which many of the wells under consideration end, are irregular and may alternate rapidly from fine sand to coarse gravel. It is a matter of great importance to finish a well where the material is coarsest. Drillers understand the significance of this but are not always successful in practice. As a rule the coarsest part of a sand and gravel bed is at the bottom, but this is not invariably so.

DRIVING TO THE PROPER DEPTH.

Commonly a thin layer of "hardpan" lies at the contact between a bed of clay and a deposit of water-bearing sand and gravel. Frequently there is difficulty in driving the casing through the "hardpan," and hence it is often allowed to stop above this hard layer or to fit only loosely into it. If a screen is inserted, it is somewhat smaller than the casing and may sometimes be projected through the hole in the "hardpan" and into the water-bearing sand. This is a careless method of finishing a well. The clay is liable to be washed down and to come in contact with the screen, thus greatly hastening the clogging process; or if the well has an open end the caving of the clay may obstruct the entrance. Not infrequently wells are ruined by neglect of the driller in this respect. Whether they are to be finished with or without a screen, it is important to have the casing driven completely through the cap of "hardpan" and down into the coarsest part of the sand or gravel.

DEVELOPMENT OF GRAVEL SCREENS.

Glacial deposits and to some extent also Cretaceous strata are poorly sorted, fine sand and coarser grit being more or less mixed together. When a well is to be finished in one of these deposits it should be pumped for a protracted period in such a manner as to remove the fine silt and leave a natural screen of coarser material. This frequently makes it possible to finish the well without a screen where otherwise one would have been required, but it should be done even where a screen is to be inserted. Proper treatment in this respect requires patience and skill but it undoubtedly results in superior wells.

The process of developing a natural screen is sometimes supplemented by introducing into the well a quantity of gravel or crushed tile of proper coarseness. This method has proved successful with drillers who are willing to devote sufficient time and effort to it, and often makes it possible to finish a well without putting in an ordinary screen.

INDEPENDENT PUMPS.

As has already been explained, in 2-inch wells the casing usually serves also as the pump pipe, a device that produces more or less unsatisfactory results. The water must enter as rapidly as it is drawn up by the pump. This gives an intermittent and irregular current into the well and increases greatly the danger of drawing up sand. Even where a screen is used, this arrangement is liable to force fine silt through the meshes or to break holes in the screen, and the great reduction of pressure in the well on the up stroke probably increases the precipitation of calcium carbonate. When the yield is small or when the inflow of the water is obstructed by the incrusting of the screen, pumping becomes difficult and the wear and tear become great. An independent pump hung in a well of adequate diameter involves some additional cost but is much more satisfactory.

FREQUENT RENEWAL OF SCREENS.

Much of the difficulty with the screens could be avoided if they were renewed more frequently. A screen which is left in the well until it has become so completely sealed that its removal is absolutely necessary is not only practically useless for a long time before its removal but is also liable to be so thickly coated that it can not easily be withdrawn.

SUMMARY.

Only wells of large diameter (4 inches or more) should be drilled. Care should be taken to drive the casing through the cap of "hardpan" and through any beds of quicksand which may exist to the coarsest portion of the deposit. The fine sand should then be removed by protracted pumping and a natural screen of coarser sand or gravel developed. Gravel of the proper coarseness may also be introduced into the well to be added to the natural strainer. If the water is to be drawn at a slow rate and an independent pump is used, it is generally not necessary to put on a metal screen. If, however, the water will not become clear and the sand persists in rising, a screen should be inserted and tightly attached to the bottom of the casing. It should be considerably smaller than the latter so that it can be easily removed when it has become incrusted. As soon as the yield of the well shows distinct signs of reduction, the screen should be drawn up and cleaned or else replaced by a new one.

MUNICIPAL AND DOMESTIC WATER SUPPLIES.

POLLUTION

SOURCES.

From the sanitarian's point of view waters from wells tapping the deep-lying sandstones or the deep sand layers of the drift may be considered above suspicion if the wells are protected from the access of surface water from their immediate vicinity. The diseases ordinarily communicated by water are bacterial in origin—that is, the immediate causes are microscopic single-cell plants, called bacteria, which come from previous cases of typhoid fever or other diseases and find their way into river or well water through sewage or surface water. According to present standards of sanitation it may be definitely stated that the waters of rivers flowing through moderately well inhabited regions and having the usual number of towns and villages along their courses are unsuitable for drinking or general domestic use without being purified. The experience of a number of Iowa towns, such as Waterloo (p. 259) proves that typhoid bacilli in river water may pass the guard of filtration plants and cause serious epidemics unless the process of filtration is constantly maintained at its highest efficiency. That springs rising from creviced and cavernous bedrock which receives the drainage from adjacent cities may be polluted has been recently shown at Cedar Falls (p. 259). Even the purest artesian waters from wells thousands of feet deep are liable to become contaminated by shallow ground waters if such are allowed to enter through corroded casings. Epidemics of typhoid fever at Clinton, in the shops of the Chicago & North Western Railway, and at Glenwood, in the Asylum for Feeble-minded Children, were caused by leakage from adjacent privies and drains into deep artesian wells.

TOWN WELLS.

Shallow dug wells, walled as they generally are by brick or tile, that permit the inflow of water from top to bottom, are usually unsafe in a town or even in the country unless they are well protected from contamination by kitchen or household waste, privies, drainage from stable yards, and all similar sources of pollution. Though the water of any one such well may be used for a long time without serious results, it is nevertheless a constant menace to life and health. Infectious material is likely to enter it at any time that it may be brought into the neighborhood. In towns the danger attending the use of well water is undoubtedly in direct proportion to the prevalence of privy vaults, cesspools, badly drained streets, and decaying garbage. All persons are not equally susceptible to disease, and it is not to be taken for granted that because a family or a certain number of persons have long used the water without ill effects others may do so with impunity.

Some wells given in this report as the sources of municipal supplies belong to the class of shallow wells just described. They are dug and walled wells or driven wells in river bottoms or in superficial sand layers. Nothing protects them from the surface water in their immediate vicinity. The surrounding land should be as scrupulously protected from human habitation, factories, and other sources of contamination as the collecting ground of lakes and artificial reservoirs whose waters are used for municipal supplies. The underflow where the wells are located should be toward the town, not from it toward the wells. If the town is on a river, the wells should be above and not below the town. There should be no higher inhabited land in their immediate vicinity. In the course of this investigation evidence has not been wanting that such simple and reasonable provisions as above suggested have not received attention in some towns that derive their water from wells of this character.

The sanitary character of well water is improved in proportion to the exclusion of surface water from the immediate vicinity, because water coming through earth or sand for considerable distances is freed from organic matter and bacteria by fermentation and filtration. Herein is the advantage that the deep well has over the shallow one. Deep wells derive their waters in most places from the deeper sand layers, sand rock, and other porous filtering material. The water they supply fell upon areas at considerable distances and reached the wells through long stretches of natural filter. For example, most of the water in the deep-lying sandstones in Iowa fell in Wisconsin and Minnesota and reaches the consumer only after passing through many and in some places hundreds of miles of sandstone filter. Whatever organic matter and living organisms the water originally took up at the surface where it fell have long since been destroyed and removed.

Fortunately, most wells which supply Iowa cities are of this character and derive their water from far-removed collecting grounds. They are generally driven wells, or bored or drilled and cased. In such wells water can enter only at considerable depths, in the shallower ones only near the bottom; and even if the water fell near the well it could enter only after filtration through many feet of earth. It must be said, however, that some town wells are bored and walled with sewer or fired tile placed loosely one upon another, and in such cases water may enter at any point, dependent only on the weather and the height of the water table.

The experience of sanitarians is in harmony with these considerations. The number of bacteria in well water decreases as surface drainage is cut off. The pathogenic species are absent from the water of properly constructed deep wells, and in some very deep wells bacteria are totally absent. If a town or a home draws its water supply from a deep cased well in thorough repair, having its footing in some large source of water, it is probable that the water as it comes from the well is free from contamination, and its wholesomeness as it reaches the consumer depends only on the character of the reservoirs and the conducting system. It is, of course, absolutely necessary that all storage tanks should be protected from dust, animals, and any other sort of accidental or intentional contamination; that all underground conducting pipes should be of nonporous material; and that all joints should be water-tight.

FARM WELLS.

By O. E. Meinzer.

The most common type of well in the western part of the State is the shallow bored well. It is made with a machine called a "well auger," is generally between 1½ and 3 feet in diameter, and is cased with wood or some other material that will admit water freely from all levels. In this way a great surface admitting water to the well is made to compensate for the low pressure of the water and the poor conductivity of the water-bearing material. Since the water comes from so near the surface it can easily become polluted, and care should be taken to have everything which might produce contamination removed from the vicinity of the well and from the ground that drains toward it. Unfortunately such precautions are not usually taken. Though some householders are to be commended for carefully protecting their wells, the majority are guilty of inexcusable negligence and many seem to utterly disregard the sanitary aspects of their water supply.

The well is generally located on low ground and frequently in a favorable position to receive the drainage from the barnyard and outhouses. This is because the farmer wants his house and barns on high ground and yet as near the well as possible. On many farms, too, it is located in the barnyard and is surrounded by manure. The upper part of the casing in many wells is decayed and the ground where the well is situated is on a level with the rest of the barnyard, so that seepage from the yard inevitably enters the well. Many farmers cover their wells in the autumn with manure to prevent the pumps from freezing, and this is not always removed in the spring. Thus some of the matter leached from the manure by the rains is washed into the wells. Some wells, also, are situated on ground so low that they are flooded in heavy rains.

In a few wells clay or concrete tiles are employed for casing, but more commonly boards are used. The wood is most subject to decay near the surface where it is alternately wet and dry; farther down in the well, where it is more constantly submerged and thus protected from the atmosphere, it decays less rapidly. Consequently the wooden casing in many wells is partly removed near the top, giving excellent opportunity for surface wash and also for small animals to enter. Drillers and borers whose business it is to clean out these wells declare that it is common to find decaying mice, rats, rabbits, and other small animals in wells which are at the time being used for domestic purposes, and that many families are using water which contains so much putrid matter that it is nauseating to one who has not become accustomed to it. These conditions are due largely to carelessness and could easily be prevented by the application of ordinary good judgment and by a regard for ordinary cleanliness.

MINERAL CONTENT.

RIVER AND WELL WATERS.

Compared with waters of the Northern and Eastern States, all Iowa waters are highly mineralized, or, as it is commonly expressed, they are hard waters. The State is deeply covered by drift and soil, composed mostly of finely divided material which is highly calcareous and contains considerable amounts of calcium sulphate and other more soluble compounds. The rainfall comes into intimate contact with this material, and that which becomes ground water, from which wells are supplied, must pass for long distances through it, giving the water great opportunity to take up mineral matter. The amount of run-off from igneous rock surfaces is practically nothing in this State and that from bare rock surfaces of any sort is insignificant. Only very small superficial sand areas in the State take up the rainfall and transmit it as soft water to wells or to rivers. The deep rich soil also contributes indirectly to the mineralization of water. Nearly the whole area is covered with vegetation of some sort and the soil contains large amounts of decaying vegetable matter. An unusual amount of carbon dioxide is thus supplied to the water at the surface, which enables it to dissolve large amouuts of calcium and magnesium carbonates.

The waters of both rivers and wells are considerably more highly mineralized than those of the Eastern States, and three of the largest Iowa rivers contain very much larger amounts of mineral matter in solution than the average of the rivers of the whole continent. The average total solids of Des Moines, Cedar, and Iowa rivers, as determined by analyses by the United States Geological Survey [1] extending from September, 1906, to September, 1907, is 262 parts per million, whereas the average of the river waters of the continent is stated to be 150 parts per million.[2] The average mineral content of these three rivers and that of the best wells of moderate depth in the regions where the rivers take their rise are remarkably alike in both the amount and the character of their total solids. The same general agreement is found between the mineral matter of the rivers and that of the best deep wells. For purposes of comparison, there are given below the analyses of the 3 rivers already named, the average analyses of 12 of the best wells of moderate depth, for the most part in the northern and eastern portions of the State, and the analysis of a representative of the best deep wells, that of the Eighth Street city well at Dubuque, which has a depth of 1,200 feet and foots in the sandstones underlying the St. Lawrence formation.

Comparison of analyses of well and river water in Iowa.

[Parts per million.]

	Three rivers.	Twelve wells.	Deep well.		Three rivers.	Twelve wells.	Deep well.
SiO_2	18	13	12	Na	14	9.7	7.0
Fe	.20	.25	.00	HCO_3	212	273	284
Al		1.0	.5	SO_4	46	26	16
Ca	52	62	54	Cl	4	5	5
Mg	18	25	32	Total solids	262	279	268

[1] Dole, R. B., The quality of surface waters in the United States: Water-Supply Paper U. S. Geol. Survey No. 236, 1909, pp. 116–119.

[2] Chamberlin, T. C., and Salisbury, R. D., Geology, 2d ed., vol. 1, 1905, p. 108.

The total solids for the rivers include only the dissolved mineral matter. If the suspended matter is added, the total matter carried by the river waters is 553 parts per million.

The averages of the analyses of river waters represent samples taken as follows: Cedar River at Cedar Rapids, dissolved solids 228; Iowa River at Iowa City, dissolved solids 247; and Des Moines River at Keosauqua, dissolved solids 312. The dissolved solids of the three rivers are not very different in amount and closely agree in their composition, which is similar to that of the solids of the best well waters. The three rivers show considerably smaller amounts of dissolved mineral matter than the water of Missouri River on the west, as might be expected, for the Missouri derives a large portion of its water from the northwest and to a large extent from the so-called alkali regions. The Missouri shows at Florence, Nebr., 454 parts of total solids.[1] On the other hand, the solids of the three Iowa rivers are greater than those of the upper Mississippi, which comes largely from Minnesota and Wisconsin, where much of the collecting ground is covered with sand and sandstone. The Mississippi near Moline, Ill., shows 179 parts of dissolved solids.[2]

The general impression that river waters are soft and well waters are hard is in a general way true. However, no sharp line of demarcation can be drawn, at any rate in northeastern Iowa. The very best well waters from both shallow and deep wells in the northeastern part of the State, which is the main collecting ground for the river waters, show about the same mineralization as the river waters. These wells are, however, comparatively few, most wells in this same region showing solids ranging from 300 to 500 parts per million.

EFFECT OF MINERALIZED WATERS ON HEALTH.

Though the water of a considerable number of Iowa wells contains as low as 280 parts per million of mineral matter, and most of those in the northeastern part of the State contain less than 500 parts, the great majority of well waters in the whole State contain 400 to 2,000 parts of solids. Several contain 2,000 to 5,000 parts and a few 5,000 to 9,500 parts. It is a matter of especial interest that several towns have for a number of years used as city supplies waters containing 2,000 parts per million of solids. Though waters containing as much mineral matter as 2,000 parts per million are clearly unsuitable for many purposes in the untreated condition, such as for boilers and for laundry purposes, so far as is known no serious effects on the health of the people can be traced to the use of such waters. At present there seem to be no generally recognized standards by which to judge

[1] Water-Supply Paper U. S. Geol. Survey No. 236, 1909, p. 78.
[2] Water-Supply Paper U. S. Geol. Survey No. 239, 1910, p. 81.

of the fitness of hard waters for drinking. The only limit in the use of hard water in Iowa is the unpalatableness caused by the presence of considerable amounts of chlorides and sulphates. It is a curious fact that although people as a rule will not tolerate a distinct taste in a water supply for ordinary daily use, at watering places they will readily drink large quantities of similar water containing even more of the constituents which at home they consider distinctly objectionable.

Apparently waters containing more than 2,000 parts of mineral matter are unpalatable, and this amount may be taken as the maximum allowable in a water supply for city use and particularly for drinking. So far as general observation and the testimony of physicians are concerned, this limit seems practical and safe, though it can not be confidently asserted that the use of such water for a few generations might not be attended with injurious results.

Standards of other regions, particularly of those where the surface rock is granite or sandstone, can not be applied in judging Iowa waters. The Iowa standard must depend on what sort of water can actually be secured and on experience in the use of the waters of the State. Of course, the standard for a boiler water or one for any other industrial purpose must be different from that of a water for a town supply. The latter must be obtained in large quantity, must serve for a multitude of domestic and industrial purposes, and must have a high degree of organic purity, if it is not to be filtered. Much mineral matter may be tolerated for the sake of bacteriologic purity. Therefore, a city in Iowa with a water supply which is organically pure and which contains less than 400 parts per million of solids is very fortunate. An organically pure water containing less than 600 parts may be considered good, one with less than 1,000 parts fair, one with less than 1,500 parts tolerable, and one with 2,000 parts usable if no better can be obtained. Above 2,000 parts the water may be considered unpalatable, and that of private shallow wells would be preferable. Of course, these statements apply to the average hard water, in which the excessive solids are composed largely of calcium, magnesium, sodium, and sulphates.

EFFECT OF MINERALIZED WATERS ON WELL CASINGS.

CORROSION.

Many waters act vigorously on iron in the cold, and many well casings in Iowa have been rusted through in a few years. At Cedar Rapids a wrought-iron casing was corroded to a perforated shell in about five years. At Grinnell the water of well No. 1, containing 2,000 parts per million of mineral matter, rusted through the casing in about eight years. In many other wells the waters have become progressively and notably more highly mineralized, and though this may be due to other causes, the chief cause is most probably the perforation of the casings and the access of the upper hard waters that the casings were designed to shut out. Deep well No. 2 at Centerville, for instance, was drilled to a depth of 2,054 feet in 1904. The following are the results of four analyses in terms of total solids, at intervals of about a year:

Total solids in water in well No. 2, Centerville, Iowa.

	Parts per million.
September 18, 1905	1,228
September 8, 1906	1,637
November 26, 1907	1,930
September 9, 1908	2,594

The rusting out of casings must be regarded as one of the most serious difficulties in maintaining a supply of artesian water, and how to prevent it or retard it so as to lengthen the life of wells is a problem which merits the most earnest consideration. After a casing has become weakened by corrosion and has become packed in the boring by sediment derived from the walls or deposited from the water, it is very difficult or impossible to withdraw it so as to replace it by a new tube. The only remedy in such instances is to put a smaller tube within the old one, thus reducing the effective diameter of the well.

SOFT-STEEL VS. WROUGHT-IRON TUBING.

At the present time soft-steel tubing, on account of its cheapness, has for most purposes replaced wrought-iron tubing. It is not easy to get wrought-iron tubing without a special order, and this has led to the casing of many wells with steel. Experience seems to show that this is a mistake. Wrought iron withstands the corrosive action of water much better than soft steel and it should always be preferred to steel for well casings.

Cast-iron tubing may yet be proved practical for casings. It has far greater resisting power against the corrosive action of water than steel or wrought iron, and it is considered the only suitable material for water mains and for sewer pipe inside of buildings.

In this connection the casing of well No. 4 at Grinnell is of peculiar interest. Several flows of highly mineralized waters are encountered above the New Richmond and St. Peter sandstones, which furnish the main supply. After experiencing a good deal of difficulty due to the corrosion of casings and the caving of shale below the casings of the older wells, the city authorities determined to case the new well with cast-iron tubing to the depth of 1,700 feet, or to a point just above the St. Peter sandstone. Owing to difficulties connected with reaming out the well the casing was finally put down only to 1,461 feet. It consists of 6-inch heavy cast-iron tubing, the sections of which are closely joined together with wrought-iron couplings. No difficulty was experienced in lowering the casing. The well was completed in January, 1910, and has been in use since that date. So far as known to the writer there is no other cast-iron casing in the State and none of greater length than 200 or 300 feet in neighboring States. The experiment at Grinnell seems to demonstrate the practicability of lowering cast-iron casings of lengths as great as are likely to be desired.

As this enterprise has proved successful, it is likely to influence greatly the casing of wells in the future, and the cast-iron casing should be instrumental in prolonging the life of artesian wells in localities where upper waters cause rapid deteriorations of ordinary casings. It is possible that it may extend the area of successful artesian wells in this State.

CAUSES OF CORROSION.

The cause of the corrosion of iron has in recent years been the subject of much research and not a little controversy. The work and discussion have centered around the question whether water and oxygen alone are able to produce corrosion, or whether carbonic acid or some other acid is necessary. No fewer than eight research papers have appeared on this subject in the last four years. Of these, one by Walker and others [1] and one by Tilden [2] sum up the results of the whole investigation and give all needed references.

PURE WATER.

It appears beyond a doubt from the work of Walker and his associates that pure water alone is able to dissolve iron in very small amounts. This is shown by direct experimental evidence, and it is fully in accord with the present ionic theory of the solution of metals. Water is to an exceedingly small degree an electrolytically dissociated substance, its ions being $\overset{+}{H}$ and $\overset{-}{OH}$. Iron, like other metals, has its own particular tendency to go into solution in the form of ions—that is, its solution pressure, and this pressure is slightly greater than that of hydrogen. Very slowly and to a very limited extent iron goes into solution in pure water as positive ions, $\overset{++}{Fe}$, while hydrogen is forced out of solution, its positive charge going to neutralize the negative charge of the undissolved iron. Walker could easily detect the iron thus dissolved by testing with potassium ferrocyanide or potassium sulphocyanide, after evaporating the solution to small volume.

[1] Walker, W. H., Cederholm, A. M., and Bent, L. N., The corrosion of iron and steel: Jour. Am. Chem. Soc., vol. 29, 1907, p. 1251.

[2] Tilden, W. A., The rusting of iron: Jour. Chem. Soc. Trans., vol. 93, pt. 2, 1908, p. 1356.

Water thus acts much like an acid, but its action is exceedingly slow, and an equilibrium is soon reached when the action ceases unless oxygen is present to oxidize the iron and cause its removal from solution by precipitation. As a matter of fact, carbonic acid is present in most natural waters as free acid, or as the bicarbonate. The free acid is partly dissociated into its ions, $\overset{+}{H}$ and $\overset{-}{HCO_3}$. The number of hydrogen ions that can thus occur in natural waters very greatly exceeds the number due to the dissociation of water itself, and under similar conditions the rate of solution of the iron will be proportional to the number of hydrogen ions. The iron dissolved under these circumstances may be regarded as being present in the water as ferrous bicarbonate, $\overset{++}{Fe}, 2\overset{-}{HCO_3}$. In the presence of oxygen the iron becomes quickly oxidized to the ferric condition, hydrolysis occurs, and the iron is precipitated as a hydrated ferric oxide. If the oxidation takes place as fast as the iron is ionized and at once, the apparent result of the corrosion may be a coating of more or less adherent rust. When hydrolysis occurs hydrogen ions are again released equivalent to the negative ion of the carbonic acid, and thus the same molecule of carbonic acid may cause the corrosion of its equivalent of iron over and over again.

Nearly all Iowa waters contain 5 to 25 parts per million of free carbonic acid and large amounts of bicarbonates, which gradually give off in the cold one-half of their carbonic acid on standing, with the precipitation mainly of normal calcium carbonate. The decomposition is of course greatly accelerated when the water is boiled. The free carbonic acid that may be derived from this source varies in Iowa waters from 100 to 200 parts per million. In view of the above statements it may readily be understood why boilers rust more at some points than at others. At the water level the metal may be acted upon by the carbonic acid in the water and by the dissolved oxygen at the surface of the water. At the intake, where much corrosion occurs, carbonic acid is being rapidly set free from the bicarbonates, and neither it nor the oxygen has yet been expelled from solution by boiling.

ACID WATER.

Hydrogen ions, which may be regarded as the main initial cause of the corrosion of iron in boilers, are not alone due to the slight dissociation of water or to carbonic acid. Salts containing a weakly basic metal or a weakly acid radicle or both undergo to a greater or less extent what is known as hydrolysis; that is, water reacts with the metallic radicle forming an oxide or a hydroxide and hydrogen ions, or, what amounts to the same thing, free acid. Salts of copper aluminum, and iron offer good examples. A solution of copper sulphate is always faintly acid, its hydrolysis taking place thus:

$$\overset{++}{Cu}, \overset{=}{SO_4}+2\overset{-}{HO}, 2\overset{+}{H}=Cu(OH)_2+2\overset{+}{H}, \overset{=}{SO_4}.$$

The hydroxide may be nearly insoluble and the main portion of it may form a precipitate, it may remain in true solution, or it may assume an intermediate state known as the colloid condition. In the cases of iron, copper, and aluminum the last is probably true. However, in any case a small part goes into true solution and is to some extent ionized. The hydroxyl ions thus accumulate and react with the hydrogen ions to form water; or, to take another view, they force back the dissociation of the water, thus bringing the reaction to a state of equilibrium. Some sulphuric acid, however, remains in solution and is highly ionized. Its hydrogen ions escape as neutral hydrogen and, as with carbonic acid, their place is taken by the ions of iron from the boiler or from other iron that may be in contact with the solution. The iron may be oxidized to the ferric condition and precipitated, its place being taken by fresh iron ions.

From recent work it appears that salts of the alkali metals and strong acids which undergo no hydrolysis and can not form hydrogen ions do not greatly influence the corrosion of iron. Heyn and Bauer [1] found that the rusting of iron at room temperature is in general greater in distilled water than in dilute solutions of simple electrolytes. With increasing concentration, however, the rusting increased somewhat and then decreased. In general, salts at their maximum of activity caused more rusting than distilled water, but contrary to popular opinion solutions of potassium, sodium, and calcium chlorides, sodium and potassium sulphates, and sodium bicarbonate showed less activity at their maximum than distilled water. With certain salts corrosion decreased very rapidly with increased concentration and soon ceased altogether. Salts of ammonium and particularly those of phosphoric acid showed high corrosive power, probably owing to their hydrolysis.

The salts just enumerated as having less corrosive action than distilled water include most of the readily soluble salts usually calculated as possibly present in natural waters. From the experiments cited corrosion at ordinary temperature can not apparently be ascribed to them, and this conclusion is in harmony with theory, for they can form no hydrogen ions. It is a common observation, however, that metals in contact with some chemical substances, particularly common salt, corrode more rapidly when exposed to the air. This corrosive action is probably to be ascribed to the fact that

[1] Heyn, E., and Bauer, O., Mitt. K. Prüfungs-Anstalt, Gross-Lichterfelde, vol. 26, 1907, pp. 1–104.

such chemicals are usually hygroscopic, and the corrosion is probably due to the water which the salt takes from the air and holds in contact with the metal.

ALKALINE WATER.

As already intimated hydroxyl radicles counteract or neutralize hydrogen ions and thus inhibit corrosion. Alkaline waters do not corrode iron. Ordinary corrosive waters lose that power when treated with sufficient sodium hydroxide or any other chemical which when highly dissociated gives OH radicles, such as lime or soda ash. The action of the latter is to be ascribed to its hydrolysis, which gives highly dissociated sodium hydoxide:

$$2\overset{+}{Na}, \overset{=}{CO_3} + \overset{+}{H}, \overset{-}{OH} = \overset{+}{Na}, \overset{-}{OH} + \overset{+}{Na}, \overset{-}{HCO_3}.$$

Even sodium bicarbonate is slightly alkaline—that is, it dissociates to a small extent into highly dissociated sodium hydroxide and very slightly dissociated carbonic acid, which can, therefore, give few hydrogen ions in comparison with the sodium hydroxide. Of course, if a water is heated any acid carbonate the water may contain is changed into the normal carbonate, which in turn will dissociate as given in the equation. Moreover, the free carbonic acid set free when the normal carbonate is formed decomposes at the boiling temperature into water and carbon dioxide (which escapes), thus making impossible the formation of hydrogen ions from its own dissociation as would occur in the cold. Therefore it is evident that water containing relatively large amounts of alkali carbonate can not be corrosive.

INDUSTRIAL SUPPLIES.

IMPORTANCE.

Every town large enough to have a water system contains some industry dependent on a suitable supply of water. Steam-power plants are of primary importance, and water that can be used in boilers must be obtained for them. Many towns have steam laundries, artificial-ice plants, tanneries, dye works, starch works, sugar refineries, and many other industries which demand water suitable for their particular needs. These needs can not be discussed in detail. Suffice to say that all desire the clearest and softest water they can get. However, on account of the universal need of boiler water, it seems desirable to devote some space to its consideration.

BOILER WATER.

QUALITIES OF GOOD BOILER WATER.

Water may affect the boiler in which it is used in two chief ways—by the deposition of foreign matter (scale) and by direct corrosion of the metal. A good boiler water is one which will not foam, which will deposit the minimum of scale or sediment and which will not to any considerable degree corrode the metal of the boiler. The characteristics of a good boiler water are too many to mention in detail, but the following are those of most practical importance: (1) It should be normal in the sense that it must contain only the substances ordinarily found in natural water. It should not contain iron salts in excess of a few parts per million and it should contain no free mineral acids. Water from a coal mine or from a shale bed may contain not only iron salts but also free sulphuric acid, due to the oxidation of iron pyrite and other sulphides. The same may be true of water collected from ground near a coal yard or near heaps of ashes and cinder from soft coal. (2) It must contain as small a total amount of mineral matter as is practicable to find in a natural water in the locality, and its incrusting solids should be relatively low. (3) It should contain only small amounts of suspended matter, organic matter, oil, or any other foreign substance of similar nature.

As already stated, the chief difficulty in the use of Iowa waters is their high content of mineral matter, largely of the incrusting sort. On that account they appear at a disadvantage as boiler waters when they are compared with ideal standards. It may be interesting to compare them with what is perhaps the best practical standard, that of the committee on water service of the American Railway Engineering and Maintenance of Way Association.[1] This standard is given in terms of incrusting solids and, stated in round numbers in parts per million, is as follows:

Standard of quality of water.

Less than 90 parts per million	Good.
90 to 200 parts	Fair.
200 to 430 parts	Poor.
430 to 680 parts	Bad.
Over 680 parts	Very bad.

This standard, in view of the actual conditions the country over and the effects of hard water, is to be taken as liberal in its allowance of incrusting solids. It applies to incrusting substances and not necessarily to corrosive ones. Though highly mineralized waters may in general be more corrosive, this action depends not on amount of matter in solution but mainly on its content of hydrogen ions under boiler conditions. Rated by this standard, probably practically none of the Iowa waters can be called good for boilers. A small percentage fall within the class "fair," but most of the best waters, even in the northeastern part of the State, are to be classed as "poor." On the whole the deep well waters and those of most of the rivers and ponds must be regarded as being too hard to give the best boiler service, though many of them give good results when the boilers are properly managed.

[1] Proc. Am. Ry. Eng. and Maintenance of Way Assoc., vol. 5, 1904, p. 595.

BOILER SCALE.

DEPOSITION.

Nearly all Iowa well waters are acid to phenolphthalein—that is, they contain bicarbonates and from 5 to 25 parts per millon of free carbon dioxide. On being exposed to the air, even without being heated, they lose carbon dioxide and precipitate normal calcium carbonate, usually colored by small amounts of iron hydroxide. The precipitation is due to the breaking up of the bicarbonate radicle, $2HCO_3$, into $H_2O+CO_2+CO_3$; the CO_2 being evaporated and the carbonate radicle uniting with calcium to form calcium carbonate ($CaCO_3$), which is precipitated. Magnesium also is precipitated, but as a basic carbonate, which may possibly change to hydroxide in a boiler under high pressure. The magnesium hydroxide found in boilers may originate partly in this way and partly by the direct hydrolysis of its salts at the high temperature of the boiler. The mixture of calcium carbonate and magnesium basic carbonate or hydroxide thus formed, with small amounts of silica, iron, and aluminum hydroxides, settles ordinarily as a powder and does not alone form a hard scale. When, however, it is deposited in company with calcium sulphate, it forms the hardest and most refractory of all boiler scales, apparently uniting into a cement of stonelike texture and properties.

The deposition of calcium sulphate is slightly different. When a water containing the usual radicles is evaporated several compounds may be precipitated. If they were present in amounts proportional to their chemical equivalents the precipitation would occur approximately in the reverse order of their solubilities in hot water. This proportion is practically never realized, however, and, moreover, waters in boilers are rarely allowed to become concentrated enough between blow-outs to precipitate more than one other compound, namely, calcium sulphate.

Calcium sulphate is only slightly soluble in cold water, the amount contained in water at saturation being about 2,000 parts per million. According to the determinations of Tilden and Shenstone, however, water when raised to the temperature attained in a steam boiler run at average pressure can retain only one-tenth of this amount, or about 200 parts of calcium sulphate. It follows that the calcium sulphate in many of the hardest Iowa waters would be precipitated in part if the water were not concentrated at all by evaporation, but only heated to the temperature corresponding to a steam pressure of about 150 pounds. The conditions are even more favorable to precipitation, because the temperature of the film of water in immediate contact with the boiler tubes and plates is probably raised to a temperature considerably higher than that corresponding to the steam pressure.

The deposition of calcium sulphate is more rapid the more the water is concentrated by evaporation.

The calcium sulphate deposits in a more or less crystalline condition and cements together the particles of the other compounds of calcium and magnesium, often forming a scale so hard that it can be removed only with some such instrument as a cold chisel.

When a hard water is used in a boiler, scale usually accumulates rapidly in the manner above indicated, and being a very poor conductor of heat it insulates the boiler metal from the water to be heated, thus greatly decreasing the efficiency of the boiler and increasing the consumption of fuel. The difficulties do not end there. Corrosion usually accompanies the formation of scale, shortening the life of the boiler. There is also a loss of time in cleaning and repairing the boiler. The residual water must be frequently replaced by fresh water, and the accumulated scale must be from time to time mechanically removed, which is a difficult and time-consuming operation and may cause considerable injury to the boiler. Even a loosely adhering scale or sediment in considerable amount is undesirable in a boiler. Not only is there loss of heat effect, but injector tubes become clogged and the sediment is likely to settle in a compact mass while the boiler is out of use. The plates may then be overheated when the fires are again started, and the breaking up of the mass and the sudden contact of hot plates and water may cause serious injury to the boiler or even cause it to explode. Numerous boiler explosions have been traced to this cause.

CHEMICAL COMPOSITION.

The most important scale formers are calcium and magnesium salts, but to these must be added silica and hydroxides of iron and aluminum, which are usually present in water in very much smaller amounts. Suspended matter, for the most part clays, may become entangled in the deposit so as to form a considerable portion of it.

The scale-forming power of a water is not proportional to its total solids, but rather to the sum of certain radicles which on boiling form sparingly soluble or insoluble compounds. It depends, too, on the amounts of other constituents in the water than those commonly called scale formers, and on the conditions, such as temperature and the frequency of blow-outs, under which the boiler is operated.

It is evident that boiler scale can not have a definite chemical composition, even if the same water is used, as its make-up depends on the conditions named. It is hardly necessary to state that the composition of the scales in different waters depends on the relative quantities of the scale-forming constituent in the waters.

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Attempts to combine the sulphate radicle and the small amount of the carbonate radicle, as shown in analyses of scale, with the calcium and the magnesium, disclose a shortage in the acid radicles, showing that the greater part, and sometimes all, of the magnesium must be present in the form of oxide or hydroxide. In some analyses the acid radicles are not even sufficient to combine with the calcium. Iron, aluminum, and silica are present as oxides in small quantities. Doubtless the proportion of magnesium and calcium hydroxides increases with the temperature inside the boiler and it is questionable whether any magnesium carbonate remains stable in a high-pressure boiler.

PHYSICAL PROPERTIES.

Boiler scale may vary as much in its physical properties as in its composition, which depends on the nature of the mineral content of the waters from which scales are formed. The hardest scales are those containing large amounts of calcium sulphate cementing smaller amounts of calcium carbonate and magnesium oxide, and such scales are deposited from waters containing calcium largely in excess of the CO_3 radicle and large amounts of the SO_4 radicle. From such scales there are all grades to the powdery forms which scarcely adhere at all, yield to the touch, and may be washed from the boiler tubes with a hose. Soft scales do not greatly differ from the deposit formed when a scale-softening boiler compound is used. Some waters are said to carry their own boiler compounds, which means that the bicarbonate radicle is equivalent to or in excess of the calcium and magnesium. When they are boiled the carbonate radicle (CO_3) is formed and nearly all the calcium and magnesium are precipitated. In Iowa most of the waters of small mineral content belong to this class, but heavily mineralized waters of the same type are not wanting. The two deep wells at Glenwood contain the bicarbonate radicle far in excess of the calcium and magnesium and their waters form no hard scale.

SCALE-FORMING POWER OF DIFFERENT WATERS.

As a rule chemists and engineers assume as scale forming all calcium and magnesium carbonates and sulphates that can be calculated from the analytical data, together with silica and the oxides of iron and aluminum. Recently Herman Stabler[1] has proposed formulas by the aid of which may be calculated the corrosive action of a water, the amount of scale it is likely to form, and the amounts of chemicals necessary to soften it, without regard to any rigid assumption as to the chemical compounds that may exist in the water. His formula for calculating the amount of scale assumes that under ordinary boiler conditions all suspended and colloidal matter is precipitated;

[1] Engineering News, vol. 60, Oct. 1, 1908, p. 355.

that all iron, aluminum, and magnesium are precipitated as oxides, and all calcium to the full extent of its ability to combine with the carbonate, bicarbonate, and sulphate radicles. Certain reactions are given, not as necessarily showing all that takes place, but as equations which express the known results of changes that occur within the boiler. They are as follows:

$$2Al+3H_2O=Al_2O_3+6H.$$
$$Fe+H_2O=FeO+2H.$$
$$Mg+H_2O=MgO+2H.$$
$$Ca+CO_3=CaCO_3.$$
$$Ca+2HCO_3=CaCO_3+H_2O+CO_2.$$
$$Ca+SO_4=CaSO_4.$$
$$H+HCO_3=H_2O+CO_2.$$
$$2H+CO_3=H_2O+CO_2.$$

The first three reactions are regarded as practically complete. The division of the carbonate and bicarbonate radicles between calcium and hydrogen and the division of the calcium between the carbonate and sulphate radicles are not definitely known, and they probably differ with different conditions of boiler operation. Formulas were constructed for maximum and minimum scale formation, but the differences were so small that they were rejected for one showing the average scale formation, as follows:

$$Sc\ (\text{scale}) = 0.00833Sm\ (\text{suspended matter}) + 0.00833Cm\ (\text{colloidal matter}) + 0.0107Fe + 0.0157Al + 0.0138Mg + 0.0246Ca.$$

The result is in pounds per 1,000 United States gallons of water, when Sm, Cm, Fe, and the other amounts represent parts per million found by analysis. The value 0.00833 is 1 part divided by 120 to convert parts per million to pounds per 1,000 United States gallons. The value 0.0107 for iron represents 1 part of iron calculated to FeO and divided by 120. The value for calcium is the mean of 1 part of calcium calculated to carbonate and 1 part calculated to sulphate, and the mean divided by 120. From this explanation the remaining values will be evident. The amount of calcium introduced into this formula should not be in excess of the calcium equivalent of the carbonate, bicarbonate, and sulphate radicles—that is, Ca should not exceed $0.668CO_3 + 0.328HCO_3 + 0.417SO_4$, because such excess would not be precipitated.

The precipitated matter may be hard scale, wholly or in part, or it may be powdery sludge. The amount of hard scale that may be expected from a water can be calculated by means of the subjoined formula, which assumes that hard scale is composed of silica, calcium sulphate, and magnesium oxide. All the silica and magnesium are precipitated, together with an amount of calcium dependent on the relative abundance of the chloride, sulphate, and alkali metal radicles.

$$Hs\ (\text{hard scale}) = 0.00833SiO_2 + 0.0138\ Mg + (0.016Cl + 0.0118SO_4 - 0.0246Na - 0.0145K).$$

The first two values will be clear from the preceding explanation. The value 0.016 Cl equals the calcium sulphate corresponding to the calcium that might be associated with chlorine; 0.0118 is the calcium sulphate that might be formed from all the SO_4 radicle present. The values 0.0246Na and 0.0145K represent the calcium sulphate corresponding to these two metals. The value for the parenthesis of this formula must not exceed $0.0118SO_4$ or 0.0283Ca in order that deposition of impossible amounts of scale shall not be indicated.

These two formulas permit calculation of the hardness of the scale which a water will form. The coefficient of scale hardness, h, equals Hs divided by Sc.

PREVENTION.

WATER SOFTENING.

The waters of Iowa are undesirably hard for steam boilers and for most industrial purposes. This is especially true of well waters. The condition is a permanent one and the inconvenience of using such waters in the natural state will increase as the industries of the State are developed. It would seem in the natural order of development that the softening of water for industrial purposes should become general, as the apparatus and processes are improved and as the advantages become better understood. Already good beginnings have been made. Several railroads are successfully operating softening plants within the State. Of these the Chicago & North Western Railway has made the widest application of the process, having 22 plants in Iowa with a total capacity of 5,500,000 gallons a day. Several ice, traction, lighting, heating, and manufacturing concerns are operating on a large scale plants in which the principles of water softening are employed in a thoroughgoing way, aiming at the removal of all the scale-forming material possible. The plants operate in the cold and probably give as good results in point of efficiency and economy as are obtainable at the present time.

METHODS OF SOFTENING.

In softening water the main purpose is to remove those substances which form scale—calcium, magnesium, aluminum, iron, silica, the carbonate radicles, and suspended matter. The hydrogen ions are removed when water is softened by the use of alkalies, thus rendering the water practically noncorrosive. These results should be accomplished with the addition of a minimum of foreign substances, which in small quantities should be harmless. The methods may be classified as follows:

Hot softening:
1. (*a*) Heating the water alone, usually in a feed-water heater.
   (*b*) Heating the water and adding chemicals.
2. Heating in the boiler, and using a boiler compound.
3. Heating in a separate plant with chemicals.

Cold softening:
4. Treating in a separate plant with chemicals, usually lime and soda ash.

HOT SOFTENING.

In feed-water heaters.—Purification of water by heating it is usually carried out in a feed-water heater, or preheater, in which the raw water is heated with exhaust steam and is fed to the boiler at about the boiling temperature. The boiling of water containing considerable quantities of calcium, magnesium, and the bicarbonate radicle causes the precipitation of calcium carbonate and basic magnesium carbonate, which continues till either the basic or the acid radicle is exhausted. The hydroxides of iron and aluminum may be precipitated at the same time. The substances in the water may be present in such proportions that the whole of the incrusting solids are removed to the limit of solubility of the carbonates and hydroxides. In the feed-water heater, however, the water is usually not actively boiled, and any one portion of the water remains near the boiling point only a short time before it is run into the boiler. The result is that the precipitation is far from complete. In most waters the content of calcium and magnesium together is more than equivalent to the bicarbonate radicles. In many installations the aim is, therefore, to add the necessary amount of carbonates in the form of soda ash.

Forms of feed-water heaters are many, but they may all be classified under two general heads, as closed heaters and open heaters. Closed heaters are those heaters in which the steam is conducted through tubes placed in the water to be heated and purified or those in which the water passes through pipes surrounded by exhaust steam. Open heaters include those in which the water is sprayed into chambers or run in thin sheets over plates in immediate contact with the steam, and this style has the advantage of immediate contact of steam and water. In every feed-water heater there should be a reservoir at the bottom, undisturbed by strong currents of either water or steam, where the precipitated matter may settle and from which the "sludge" may easily be drawn off. In some forms the hot purified water is carried from the upper part of this reservoir directly into the boiler and in others it is drawn from a compartment separated from the settling chamber by suitable filtering units.

Aside from their merits as economizers of fuel, feed-water heaters have the advantage of permitting the precipitation of the mineral matter where it can easily be removed—that is, before it reaches the boiler. Furthermore, the mineral matter is far less likely to form scale. For the most part it is deposited as a powdery mass which can easily be washed out. In the closed feed-water heater the temperature of the metal does not rise above about 100° C., and in the open heater metallic heating surfaces scarcely come into account.

In boilers.—Competent engineers generally agree that the time to soften a water is before it enters the boiler, where the sludge can be most harmful and where it is the most difficult to remove.

Softening in the boiler is probably to be regarded as a poor makeshift, justifiable only where the accessory softening apparatus can not be provided; nevertheless, the use of boiler compounds seems to be fairly general.

The number of boiler compounds on the market is large. Some, which are intended to precipitate the mineral matter in the boiler, consist of the soluble alkalies; others, intended to prevent the adherence of hard scale, may contain clay, sawdust, graphite, glycerin, and oils of various sorts; others are said to contain acids and acid salts, such as acid sodium sulphate.

If no better scheme than that of using chemicals in the boiler is available, this should at any rate be done with due regard to the requirements of the case in hand. It is obvious that any general commercial boiler compound can only by chance be suitable for any specific water. To get the best results the substance used, in most cases a mixture of the alkalies, should correspond in its composition and in the amount used to the particular requirements of the water to be treated. An accurate mineral analysis of the water should be made, and then a boiler compound should be made for that water. It should be used only in sufficient amount to cause complete precipitation of scale-forming substances. Sodium carbonate will probably serve the purpose best.

Away from the boiler.—There is no great difference between the chemistry of this process and feed-water heating save that the apparatus is a separate one and the water is stored and used as required. It is less economical, since the water is stored and allowed to cool. The precipitation and settling of the sludge are, however, facilitated by heat.

COLD SOFTENING.

Probably the most thoroughgoing and extensive application of the principles of water softening is to be found in the large plants for the softening of hard water at ordinary temperature. Though there are many forms of apparatus for this purpose now in use, their principles of operation are much the same. They are to a large extent automatic. The water to be softened is measured by some sort of automatic device, and the same may be said of the chemicals in solution or suspension. For example, in the apparatus designed by George M. Davidson for the Chicago & North Western Railway Co. the water to be softened is measured in two tilting vessels holding 100 gallons each. These are geared to pumps with cylinders of adjustable capacity which supply the chemicals in known quantities parallel to the volumes of water to be softened. The weight of the water also supplies power for the stirring in the precipitation tank. In other forms power is supplied by means of a water wheel, as in the Kinnicut apparatus. All forms have several separate vessels, including chemical tanks or boxes, a precipitation tank, usually two settling tanks, and a storage tank. To secure compactness some of these are reduced to compartments, as in the Kinnicut apparatus. The capacities of such plants vary with the requirements, some having as small capacity as 200 and others as large as 60,000 gallons per hour.

The softening of water in the cold is accomplished by precipitating the objectionable or scale-forming material in the form of hydroxides and normal and basic carbonates. It is necessary to add hydroxyl radicles to neutralize hydrogen so as to form the hydroxides of iron, aluminum, and magnesium and to convert the bicarbonate radicles and dissolved carbon dioxide into normal carbonate radicles in order to precipitate calcium. If the amount of normal carbonates is not sufficient to precipitate the calcium, then carbonate radicle must be added, usually in the form of soda ash. Sodium hydroxide might be used to supply the hydroxyl radicles, which would introduce comparatively harmless amounts of sodium, but lime is commonly preferred on account of its cheapness. The calcium introduced by the use of lime must in turn be removed as carbonate, for which extra soda ash may be required.

The following equations express at least approximately the reactions involved:

$$\overset{+}{H} + \overset{-}{HO} = H_2O.$$
$$\overset{+++}{Al} + 3\overset{-}{OH} = Al(OH)_3.$$
$$\overset{++}{Fe} + 2\overset{-}{OH} = Fe(OH)_2.$$
$$\overset{++}{Mg} + 2\overset{=}{OH} = Mg(OH)_2.$$
$$H\overset{-}{CO}_3 + \overset{-}{OH} = H_2O + \overset{=}{CO}_3.$$
$$CO_2 + 2\overset{-}{OH} = H_2O + \overset{=}{CO}_3.$$
$$\overset{++}{Ca} + \overset{=}{CO}_3 = CaCO_3.$$

Leaving out of account the small amount of silica, the sulphate radicle is the only substance, of those commonly found in scale, that remains in the water at the end of this process. However, this radicle is now associated for the most part with sodium. Sodium sulphate is very soluble in water and is not likely to cause trouble until it becomes concentrated enough to aid materially in causing the water to foam.

Stabler[1] has given, perhaps in the most scientific and convenient form, formulas for the calculation of the weights of soda ash and of lime which must be added to soften in the cold a water of known mineral content. The first gives the lime required and the second

[1] Water-Supply Paper U. S. Geol. Survey No. 274, 1911, p. 170.

the soda ash which the same water will require, if it requires any, after the lime has been added:

$$\text{Lime required} = 0.00931Fe + 0.0288Al + 0.0213Mg + 0.258H + 0.00246HCO_3 + 0.0118CO_2.$$

$$\text{Soda ash required} = 0.0167Fe + 0.0515Al + 0.0232Ca + 0.0382Mg + 0.462H - 0.0155CO_3 - 0.00763HCO_3.$$

The two equations give, respectively, the amounts of lime 90 per cent pure and of soda ash 95 per cent pure required to precipitate in the cold the scale-forming ingredients and to neutralize the corrosive ingredients. The manner of deducing the coefficients is explained in Mr. Stabler's report. The symbols in the equations represent the amounts in parts per million of the constituents of the water. If the second equation has a negative value or is equal to zero, no soda ash is required.

It will be noted that these formulas take no account of the hypothetical salts that may exist in the water solution, and rightly so, for the present theory is that in such dilute solutions there is almost complete electrolytic dissociation. In practice the formulas may be simplified without leading to large errors and in many waters the errors would not be perceptible. In Iowa waters iron and aluminum rarely exceed 1 or 2 parts per million, the normal carbonate radicle is rarely present, and acid hydrogen is also exceedingly small in amount. In the majority of computations, therefore, only calcium, magnesium, the bicarbonate radicle, and free carbonic acid need be taken into account. It is probable, moreover, that where only 1 to 2 parts per million of iron and aluminum are present they could not be removed even in part by softening, because the amounts of their hydroxides possible would not exceed the solubility limit of those hydroxides.

LIMITS IN REMOVING INCRUSTING MATTER.

It is not possible to remove all of the incrusting matter from water by precipitation, as none of the compounds that are formed are wholly insoluble. If it is assumed that calcium carbonate and the hydroxides of magnesium, iron, and aluminum would be dissolved in the purified water to the same extent as in pure water, there would be about 40 parts per million of the four incrustants remaining in solution. The solubility of aluminum hydroxide is here rated as about the average of the other three compounds. Forty parts per million may be taken as about the limit of efficiency in water softening ideally carried out. In practice there is not always time for thorough mixing, nor for the reactions to complete themselves, nor for thorough settling. It can scarcely be claimed that analyses are perfect and that the chemicals are accurately adjusted to the work to be done. In view of these difficulties it is not surprising to find that in practice the amount of incrusting matter remaining ranges from 50 to 100 parts per million. The average is about 70 parts, an amount of scale-forming material so small as to be regarded as comparatively harmless. In practice the residual incrusting matter seems to be, within wide limits, largely independent of the amount originally present.

COST OF SOFTENING.

So far as relates to the cost of the plants themselves, little information can be given, as they differ widely in form, materials, and capacities. The cost of operating expenses and chemicals ranges from 1 cent to 10 cents per 1,000 gallons. The average is about 3 cents in Iowa plants, so far as information has been obtained. The cost for chemicals is very small for waters in which the calcium and magnesium do not exceed in chemical equivalence the carbonate radicles present, as for these waters only lime is required. Where the contrary is true the carbonates must be supplemented by the addition of the more expensive soda ash. In a general way, however, the cost of chemicals runs parallel to the unsuitableness of the water for boiler use in its natural state.

Considerable information has been collected relating to the profitableness of softening plants, and it is uniformly to the effect that they far more than repay their cost. The Chicago & North Western Railway Co., which has taken up water softening on a more extensive scale than any other institution in the State, reports that the results are very gratifying, the cost being more than repaid by the economy of fuel, the increased life of boilers, the efficiency of the engines while working, and the great decrease in their periods of idleness in the repair shops.

SUMMARY.

The subject of water softening has been treated fully because it is believed that its use should be greatly extended in the State and should become general where water is used in considerable quantities for industrial purposes. It has already been proved practicable and profitable when carried out on a large scale. Great improvements in the process have been made in the last few years, and still further improvement in the way of cheapness and simplicity is likely. It does not seem probable that a people so thoroughly progressive in other respects should be satisfied with what nature gave them in the way of water for industrial purposes, any more than they have been content to depend for their town supplies on private wells or on a public system with polluted water unsuitable for domestic purposes.

Among the cities and towns of Iowa sharp rivalry and keen competition exists in securing industrial establishments which may contribute to their growth and wealth. Water systems have been installed in many towns sooner than they would otherwise have been, in order to obtain suitable protection from fire and more favorable insurance rates, and especially in the larger towns, to benefit the manufacturing interests and to induce other concerns to locate in them. In some towns private companies have been organized to put in supplementary systems of water more suitable than the city water for boiler and other industrial uses. Several years ago public-spirited citizens of Grinnell bought suitably located land, built a dam for an artificial lake, and put in the necessary conducting mains, pumping machinery, and storage, at a cost of about $40,000, to make the water of this lake available for industrial uses.

Any establishment using large volumes of water can well afford to install its own softening plant, and in some places the manufacturing interests may well combine to erect and operate a softening plant to treat for their purposes water drawn from the city system. It undoubtedly could be done for a small fraction of the outlay necessary to put in a whole extra water system, and probably it would secure a far better water.

CORROSION OF BOILERS.

NATURE AND LOCATION.

Corrosion of boilers may be general over considerable surfaces; it may take the form of grooving in the direction in which the iron was rolled or drawn, or it may be localized at certain points producing depressions, known as "pits." Sometimes the pits may be concealed by prominences composed of adherent rust formed at the expense of the iron. Corrosion is likely to take place more rapidly on the bottom plate of the boiler; at the water line, especially if the boiler is used intermittently; around bolt heads and stays; and near the water intake.

CAUSES.

The corrosive action may be assumed to take place at ordinary temperature, and the theory may be applied to the ordinary rusting of iron in the presence of air and natural water. At boiler temperature the corrosive action is in many respects the same, though it may be much accelerated by heat. Some additional phases, however, must be considered, the most important being the apparent direct decomposition of the water by the heated iron, accompanied by its oxidation, and the supposed hydrolysis of magnesium chloride setting free hydrochloric acid. Ost[1] has furnished much information on these two subjects.

In many textbooks and papers dealing with the corrosive action of water it is stated that magnesium chloride undergoes hydrolysis

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[1] Chem. Zeitung, vol. 26, 1902, pp. 819, 845.

when its solution is boiled, setting free hydrochloric acid, and that, therefore, water containing this salt can not be used in boilers. This statement has apparently been copied from Wagner.[1] It is true that when the hexahydrate of magnesium is heated, it undergoes some hydrolysis and forms some hydrochloric acid, but that any such action takes place on heating a dilute solution of magnesium chloride, such as would occur in boilers, seems doubtful. Ost studied the action of salts and especially of magnesium chloride on iron under the ordinary conditions of temperature and pressure in steam boilers. He used boilers of about 2½ liters capacity, made of iron, copper, and copper lined with tin. He first distilled dilute solutions of magnesium chloride to a concentration of 20 per cent, and found the distilled water free from hydrochloric acid, though the copper and the tin vessels were attacked. He then repeated his experiments with a boiler of Krupp-Siemans-Martin steel, at a pressure of 10 atmospheres, corresponding to a temperature of 183° C. After every experiment, no matter whether pure water or salt solutions were used, the surface of the boiler was covered with a dark layer of ferrous oxide. As air was excluded Ost could assign the formation of oxide only to the decomposition of water, which, as special experiments showed, took place to some extent even at 100° C. In a series of experiments magnesium chloride, potassium chloride, sodium sulphate, potassium sulphate, calcium chloride, and magnesium sulphate, in 5 per cent solution, were tried. The solutions produced approximately the same amount of ferrous oxide, but iron went into solution only when magnesium sulphate or magnesium chloride was used. The solution of iron was not proportional to the decomposition of water and the oxidation of the iron. The last was strongest when calcium chloride, potassium chloride, potassium sulphate, and sodium sulphate were used. Magnesium chloride, therefore, can not dissolve iron through hydrochloric acid formed by its hydrolysis. The fact that iron goes into solution when magnesium salts are used is due, according to Ost, to the reactions:

$$MgCl_2 + Fe(OH)_2 \rightleftarrows FeCl_2 + Mg(OH)_2$$
$$MgSO_4 + Fe(OH)_2 \rightleftarrows FeSO_4 + Mg(OH)_2$$

These reactions are reversible and with equivalents present should run preponderatingly from right to left. The reversal is due to the mass of magnesium salts.

From these experiments it seems evident that magnesium chloride has not the high corrosive action on boilers usually ascribed to it. It is not to be classed with salts of copper, iron, and aluminum, which undergo hydrolysis even at ordinary temperature. The facts seem to be that neither the salts of magnesium, nor those of calcium,

[1] Dingler's Polytech. Jour., vol. 218, 1875, p. 70.

potassium, or sodium, when the negative radicle is that of a strong acid, have essentially more corrosive action on iron than water itself at the same temperature with air excluded.

Ost found that under a pressure of 10 atmospheres a magnesium salt loses its power to carry iron into solution when one-fourth of its equivalent of calcium carbonate is present. The explanation is that the magnesium salt and the calcium carbonate react, forming magnesium basic carbonate and hydroxide, which serve to drive the reaction from right to left. In this and in other ways calcium carbonate may check corrosion. It is not entirely insoluble in water, and the dissolved portion may be assumed to be dissociated. It may react with any strong acid present, forming carbonic acid which will be decomposed and thrown out of the chemical system at higher temperatures, thus,

$$\overset{++}{Ca}, \overline{\overline{CO_3}}+2\overset{+}{H}, \overline{\overline{SO_4}}=\overset{++}{Ca}, \overline{\overline{SO_4}}+H_2O+CO_2$$

INTERPRETATION OF ANALYSES WITH REFERENCE TO CORROSION.

In the corrosion of iron the metal takes the place of some other positive radicle, as for example, hydrogen which may escape, or copper which may be precipitated. There seems little doubt that in practice the hydrogen radicle is almost the only agent of corrosion. As already indicated, ionic hydrogen may be present in the cold water, and its amount may be increased by increased hydrolysis of copper, iron, and aluminum at high temperatures. Though we are hardly justified in adding magnesium, it may, as Ost has indicated, aid in the solution of iron already oxidized.

Certain substances, on the other hand, restrain or prevent corrosion; that is, they tend to neutralize the hydrogen radicles. The soluble carbonates have been mentioned. The water is corrosive or noncorrosive according to the preponderance of the corrosive agents or of the restrainers. It is very desirable to know from the analysis of a water whether it is likely to be corrosive or not, but it is evident from contemplation of the large number of substances that ordinary water may contain that the problem is somewhat complex. Stabler[1] has proposed a formula by which it may be inferred whether a water is likely to be corrosive or not. C, the coefficient of corrosion, is computed thus:

$$C=1.008\ (rH+rAl+rFe+rMg-rCO_3-rHCO_3).$$

Here r is the reacting weight of the respective radicles with which it is associated and the reciprocal of the equivalents of those radicles; H, Al, Fe, etc., are the weights of these substances in parts per

[1] Water-Supply Paper U. S. Geol. Survey No. 274, 1911, p. 175.

million as found by analysis. If r is multiplied by the weight in milligrams of the element and the product multiplied by 1.008, the result will be the weight of acid hydrogen chemically equivalent to the radicle. Supplying the value of r and multiplying through by 1.008, we have the equation:

$$C = H + 0.1116Al + 0.036Fe + 0.0828Mg - 0.0336CO_3 - 0.165HCO_3.$$

That is, the weight of ionic hydrogen that may appear on heating the water is equal to the weight of hydrogen radicle found by analysis (the acidity expressed in terms of hydrogen), plus the hydrogen equivalents of iron, aluminum, and magnesium, minus the hydrogen equivalents of the carbonate and bicarbonate radicles. In interpreting the value of C due regard must be paid to the fact that calcium carbonate may be precipitated on boiling, since this carries out of the system the carbonate radicle with which hydrogen may unite to form water and carbonic acid. Granting that all possible calcium carbonate will be precipitated, and that the neutralizing action of this solid is nothing, the effect of the carbonate radicle to counteract corrosion will be reduced by $1.008 rCa$, or 0.0503Ca. With this latter value in view, three cases may be distinguished:

1. If C is positive, corrosion will certainly occur.
2. If C + 0.0503Ca is negative, no corrosion due to mineral matter will occur.
3. If C is negative and C + 0.0503Ca positive, corrosion may or may not occur.

As the coefficient of corrosion is equivalent to the concentration of the hydrogen ions, corrosion is in general proportional to the positive value that can be assigned to C. There is reason to believe, however, that corrosion is facilitated by certain other conditions. The reason that pure zinc will not readily dissolve in pure acid seems to be that its surface quickly becomes covered with a film of hydrogen which prevents further action. If, however, the zinc is placed in contact with some metal of lower solution pressure, such as lead or copper, or with some indifferent but conducting substance such as graphite, an electric battery or couple is formed. The hydrogen then appears on the second metal or on the graphite, and the action of the acid on the zinc is greatly accelerated. This principle has wide application in accounting for the corrosion of iron. Rust once formed on a boiler plate or tube acts toward the uncorroded iron in the same way as the copper toward the zinc in the instance just described—that is, the mass of rust becomes the cathode plate and the iron the anode of an electric couple, and the rusting of the iron is greatly increased. Once the action is started it is likely to continue and spread at that place, producing a nodule of rust under which is a pit in the metal. A familiar illustration may be given. Every one has observed that a polished tool such as a knife blade, a saw, or a chisel may long remain bright and free from rust, but that once it has been attacked by rust, the action will continue in spite of all ordinary attempts to prevent it. The same electric action may take place around the bolt heads when the bolts and the plates are not made of the same quality of iron. Even the same piece of iron may not be homogeneous in its composition, and therefore, one part may be anode and a neighboring one may be cathode. It is probable that the grooving of iron by rusting may be accounted for in this way.

CHAPTER VII.

MINERAL WATERS.

By W. S. Hendrixson.

DEFINITION.

All natural waters, whether from streams, lakes, or wells, are mineral in the sense that they contain in greater or smaller amounts certain chemical substances occurring on or near the surface of the earth. Popularly, however, the term "mineral waters" is used to designate waters that contain unusual substances in solution or common substances in unusual amounts. The term is often applied to waters containing some constituent observable directly by the senses, such as sufficient iron to stain rocks near springs or enough hydrogen sulphide to be detectable by the odor. Many waters contain enough of certain radicles, such as chloride or sulphate, to possess a decided taste, and these are classed as "mineral waters." Analyses of many commercial mineral waters show that they contain no appreciable amounts of substances not ordinarily found in most natural waters, or that they contain traces of substances not usually sought for in the analysis of water, but in amounts too small to have any medicinal value. The character of commercial mineral waters is well shown by the analyses of 53 of the most prominent of such waters made by the Department of Agriculture.[1]

MEDICINAL VALUE.

Probably the best drinking water for most persons is organically pure water containing in small amounts only the usual inorganic constituents found in nearly all natural waters, for to such water the human system is apparently best adjusted. The amounts of such matter may apparently be greatly varied without causing any observable bad effects. No very definite evidence that waters containing as much as 1,000 parts per million of the common ingredients are temporarily or permanently injurious is obtainable. When the solids are much greater than this amount, the waters are objectionable to many persons because of their taste, and they may prove laxative, at least till persons become accustomed to

[1] Haywood, J. K., Mineral waters of the United States: Bull. No. 91, Bur. Chemistry, U. S. Dept. Agr., 1905.

them. This is, of course, more likely to occur if the sulphates are large in amount.

The medicinal effect of mineral waters is open to investigation and discussion, for no comprehensive and scientific investigation on this subject, dealing with large numbers of patients and a variety of well-characterized waters, has been carried out. It does not inspire confidence in the healing powers of mineral waters to find that the same water is recommended to cure a great variety of unrelated diseases, that very different waters are advertised to cure the same disease, and that, perhaps, the majority of "mineral waters" do not differ materially in their mineral content from widely distributed normal waters that are used by thousands of persons without a thought of their possessing any special medicinal value. It is by no means conclusive evidence of the therapeutic value of mineral waters that many persons who visit mineral-spring resorts and sanitariums are benefited. The very fact that persons suffering from a large variety of diseases are helped by one and the same water would seem to indicate that the mineral content of the water has little to do with it. Persons who visit such institutions are subjected to conditions different from those surrounding their own homes; they are temporarily relieved from burdensome cares and are more or less firmly convinced that they will be benefited or cured; they take normal exercise, stay out of doors, and drink plenty of water, thus cleansing their stomachs and regulating their body functions. Such conditions are powerful factors in curing disease.

Medicinal value may, however, be ascribed to mineral waters of certain kinds. Considerable amounts of lithium may assist in eliminating uric acid and calculi, and the iron of the water may possibly prevent undue loss of organic iron in anemia. Alkaline waters may correct too great acidity in the digestive tract, and magnesium or sodium sulphates may prevent constipation.

EXTENT OF MINERALIZATION.

The main purpose of this study has been to determine the suitability of Iowa waters for industrial and not for physiologic purposes, and no attempt has been made to determine lithium and some other substances occurring rarely and in very small amounts. Doubtless lithium occurs in quantities detectable by the spectroscope in some Iowa waters, but probably not in sufficient amounts to make the waters physiologically beneficial to those using them. Iowa waters, like commercial mineral waters, should be judged by their content of the substances occurring in measurable amount in them. If they are rated in this way, there appears no evident reason why many Iowa waters should not be considered equal to well-known mineral waters. Many waters on sale are so highly mineralized that they are not suitable for general industrial or domestic use, and their characteristics are not unlike many in Iowa that well drillers avoid and case out. To make this fact plain, comparisons of some well-known commercial mineral waters with typical Iowa waters are made. Few well waters in Iowa are so lightly mineralized as those given in the following table:

Comparison of light mineral waters with two Iowa waters and with Lake Michigan water.

[Parts per million.]

Locality and name of water.	Silica (SiO_2).	Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$).	Iron (Fe).	Aluminum (Al).	Calcium (Ca)	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Lithium (Li).	Total.[a]	Analyst.
Manchester, Iowa: Spring, United States fish hatchery.	10	....	0	1	50	20	5	1	207	11	4	....	309	W. S. Hendrixson.
Atlantic, Iowa: City well	22	....	1.4	2.6	43	13	10		144	30	10	....	276	Do.
Lake Michigan	5	....	...	0.2	32	11	3		144	7	2	....	204	Geo. M. Davidson.
Amelia Courthouse, Va.: Otterburn Lithia	43	1.5	...	....	20	6.7	7.8	1.9	112	2.8	4.6	0.03	[b]201	(f).
Danville, Va.: Sublett Lithia	31	1.0	...	....	37	12	15	2.6	166	5.9	10	T.	[c]288	(f).
Fulton, N. Y.: Great Bear	9.7	.3	...	....	31	10	10	1.7	118	8.8	22	T.	[d]300	(f).
Crumpler, N. C.: Thompson's Bromine	63	1.0	...	....	7	2.2	22	2.7	81	6.1	4.0	T.	[e]193	(f).

[a] Sum of constituents without subtracting one-half the bicarbonate radicle.
[b] Nitrite radicle (NO_2), .003 part per million; ammonium radicle (NH_4), .069 part.
[c] Nitrate radicle (NO_3), 7.08 parts; ammonium radicle (NH_4), .005 part.
[d] Nitrate radicle (NO_3), 88.6 parts; ammonium radicle (NH_4), .01 part.
[e] Nitrate radicle (NO_3), 3.54 parts; ammonium radicle (NH_4), .04 part.
[f] Haywood, J. K., op. cit., pp. 42, 51, 61, 73.

The well water from Atlantic, Iowa, is chosen on account of its small content of mineral matter for a well water. That from Manchester, Iowa, may be considered typical of the best waters of the large springs in Iowa. The Lake Michigan water is included because the analysis represents the average quality of water drawn from widely different sources and because it is not considered an exceptional water possessing special medicinal properties.

The next table compares three mineral waters of rather low tota solids with one of the best deep-well waters of Iowa. This water represents in a general way the well waters of the northeastern part of the State, which are excellent drinking waters and which, according to the analyses, are as good as the mineral waters. In the one of these waters containing a weighable amount of lithium the amount is so small that one would have to drink about 75 gallons of the water to obtain a normal medicinal dose of lithium.

Comparison of certain mineral waters with a well water at Dubuque, Iowa.

[Parts per million.]

Locality and name of water.	Analyst.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Lithium (Li).	Total.[a]
Dubuque, Iowa:													
City Gas Co.'s well	W. S. Hendrixson.	5	1	1	56	33	4	3	310	12	10	.....	435
Staunton, Va.:													
Golindo Lithia	(b)	12	.3		74	29	4.7	3.4	333	33	3.4	0.1	c496
Pleasant Valley, Va.:													
Osceola	(b)	20	.14		53	29	7.0	2.0	315	1.6	3.4	N.	d435
Harrisburg, Pa.:													
Massenetta	(b)	12	.3		63	28	3.9	3.1	342	2.8	1.8	T.	e459

a Sum of the constituents without subtracting one-half the bicarbonate radicle.
b Haywood, J. K., op. cit., pp. 53, 52, 34.
c Nitrate radicle (NO_3), 3.5 parts per million.
d Nitrate radicle (NO_3), 4.0 parts; ammonium radicle (NH_4), .04 part.
e Nitrate radicle (NO_3), 2.2 parts; ammonium radicle (NH_4), .185 part.

In the third table four mineral waters are compared with the objectionable well water from Farmington, Iowa. All five are typical hard waters of the calcium sulphate type, a type which should be rejected as a source of municipal supply. A similar parallelism might be drawn between other commercial waters and other more strongly mineralized Iowa waters, but from this table it may be inferred that Iowa is well supplied with mineral waters, according to popular acceptance of that term. The northeastern part of the State has an abundance of organically pure and lightly mineralized water which might legitimately be sold as high-grade table waters.

Comparison of heavily mineralized commercial waters with the city well water, Farmington, Iowa.

[Parts per million.]

Locality and name of water.	Analyst.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Lithium (Li).	Total.[a]
Farmington, Iowa:													
Deep well	W. S. Hendrixson.	13	....	2	340	112	442	15	248	1,658	230	.....	3,060
Geneva, N. Y.:													
Geneva Lithia	(b)	14	0.7	...	522	116	131	4.0	245	1,520	204	0.1	c2,757
Elkwood, Va.:													
Berry Hill	(b)	28	1.5	...	525	59	164	3.4	151	1,686	26	T.	d2,644
Bedford, Pa.:													
Bedford	(b)	37	2.1	...	570	139	13	4.9	192	1,728	10	T.	e2,696
Tate Springs, Tenn.:													
Tate Epsom	(b)	22	2.9	...	475	121	25	8.2	260	1,460	9.2	.1	f2,383

a Sum of the constituents without subtracting one-half the bicarbonate radicle.
b Haywood, J. K., op. cit., pp. 41, 59, 36, 37.
c Nitrate radicle (NO_3) 0.44 part per million; ammonium radicle (NH_4) 0.016 part.
d Nitrite radicle (NO_2) 0.009 part; ammonium radicle (NH_4) 0.53 part.
e Nitrate radicle (NO_3) 0.21 part; ammonium radicle (NH_4) 0.015 part.
f Nitrate radicle (NO_3) 0.21 part; ammonium radicle (NH_4) 0.01 part.

A few Iowa waters are advertised as having curative properties. The most noted is that from wells about 300 feet in depth in and near Colfax. In the lower parts of the city they are flowing wells and all yield the same quality of water. Several hotels and sanitariums owe their popularity in no small measure to the reputation of the Colfax water, which is sold in large quantities. Essentially the same quality of water is found in several wells in the same county and in other parts of the State. Those in Jasper and Polk counties probably draw their water from the same source, the Carboniferous, and probably from the Pennsylvanian or the underlying "St. Louis limestone" (Mississippian). At the beginning and at the end of the following table are analyses of two representative Colfax waters and between them are analyses of several waters from the same locality and from other parts of Iowa. All are highly mineralized but contain only moderate amounts of calcium in comparison with the large amounts of sodium and sulphates.

Comparison of water from Colfax, Iowa, with other hard Iowa waters.

[Parts per million.]

Locality and owner.	Depth of well in feet.	Lowest geologic division.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.[a]	Analyst.
Colfax: Sanitarium....	371	Carboniferous	10	0.2	1.5	211	99	420		260	1,505	29	2,406	H. S. Spaulding.
Des Moines: City Library well.	375	Pennsylvanian.	14	1	3	237	53	559	7	312	1,569	107	2,706	W. S. Hendrixson.
Runnells: Robert Blee...	228	Des Moines...	12	0.5	1	108	39	715		414	1,520	43	2,645	Do.
Mount Pleasant Hospital for Insane.	1,267	St. Peter.....	10	8	1	198	71	400	14	280	1,214	157	2,213	Do.
Fontanelle: J. H. Hulbert.	269	Cretaceous...	20	3	1	231	69	412		264	1,322	84	2,274	Do.
Knoxville: Hospital for inebriates.	326	Pennsylvanian.	10	0.4	3	303	52	436		262	1,600	18	2,553	Do.
Kellerton: Robert Hall...	375	Carboniferous	55	5	9	249	87	521		439	1,477	46	2,673	
Colfax: Mills Hotel....	350	.....do........	11	0.7	1	235	97	463		260	1,495	27	2,460	H. S. Spaulding.

[a] Sum of the constituents minus one-half the bicarbonate radicle.

Water from the well of S. C. Johnston at Flagler is sold in considerable quantities. It is very heavily mineralized, the solids being nearly 9,000 parts per million and very high in calcium, sodium, and sulphates. It differs little from the water of the city well at Pella, which is used only for fire protection and for sprinkling the streets, and both waters are probably derived from the same geologic formation. Thompson Craig's well at Knoxville also yields about the same kind of water. Water is also sold from the Red Mineral Spring at Eddyville. It is recommended as an antiseptic water for both internal and external use. Small samples received at this laboratory seem to justify the statement that it is antiseptic, as they contain considerable amounts of free sulphuric acid, probably due to the oxidation and hydrolysis of ferrous sulphate. The amount of iron in the water is very large. From the character of the water and the description of the spring it may be concluded that the spring consists of a small flow from a layer of disintegrating shale containing iron pyrite. The well of Mrs. Cora A. Huber at Tama supplies a very heavily mineralized water, which is sold. It contains more than 5,500 parts of solids. It is very much the same as the Colfax water, except that the concentration of the constituents is nearly doubled. Water is sold from some other wells and springs in the State, but so far as is known the amounts are comparatively insignificant.

TYPES OF MINERAL WATERS.

SCHEME OF CLASSIFICATION.

The radicles determined in the analytical work of this investigation have already been given (p. 135). It seems desirable to make some general statements concerning the variations in the amounts of these radicles, and to indicate a scheme of classification by which the waters may be arranged in groups so as to bring more clearly before the mind the similarities and differences in their quality.

The ground waters of Iowa can not be separated into distinct classes with the representatives of one class clearly differentiated from those of any other, for they grade into each other by almost insensible differences. Much overlapping of groups occurs in any system of classification, and the relationships of the waters to ideal types can be indicated in only a general way. No attempt is made to classify all the waters of the State, but only to select a few good representatives of each class as illustrations of the method.

For classification the following scheme of J. K. Haywood and R. H. Smith, chemists of the United States Department of Agriculture,[1] is used.

Thermal or non-thermal.	Sodic. Lithic. Potassic. Calcic. Magnesic. Ferruginous. Aluminic.	Carbonated or bicarbonated. Borated. Silicated.	Alkaline.	Arsenic. Bromic. Iodic. Siliceous. Boric. Lithic. Ferruginous, etc.	Nongaseous. Carbon dioxated. Sulphureted. Carbureted. Oxygenated.
		Sulphated. Muriated. Nitrated.	Alkaline-saline.		
		Sulphated. Muriated. Nitrated.	Saline.		
		Sulphated. Muriated.	Acid.		

[1] Haywood, J. K., op. cit., p. 11.

For the classification of Iowa waters, as analyzed, only a few of the classes in this table, which is elaborate enough to include almost any mineral water, are required, but the table is nevertheless given entire for the sake of completeness. In the analyses no attempt was made to determine unusual substances that might occur in small amounts, such as bromine, iodine, arsenic, and the common gases of the air, since these substances in the quantities in which they might occur would have little or no relation to the primary practical objects of this study. It should be stated, however, that free carbon dioxide dissolved in water was determined. It was found present in all but two or three samples, in amounts rarely exceeding 25 parts per million. For this reason all waters with the exceptions noted have been regarded as containing their carbonates in the acid form, or, in other words, as HCO_3. Hydrogen sulphide, H_2S, has often been noted in Iowa well waters, and it has been determined in a few waters. It was rarely apparent when the waters reached the laboratory, and since the small amount that might persist after shipment could give little information as to the amount present in the water as it came from the well, this gas was not determined.

In the following arrangement of examples the classification is governed by the prominence or preponderance of certain radicles. Certain constituents are common to nearly all ground waters within the State. All such natural waters contain some chlorine, some bicarbonates, rarely normal carbonates, and nearly all contain nominal amounts of sulphates. All contain at least a few parts per million of calcium and magnesium. Such constituents are not taken into account in the nomenclature unless they occur in sufficient amounts to give the waters the distinctive characteristics which they might impart. For example, water is not classified as sulphated unless it contains the sulphate radicle in large amount; that is, 250 parts per million or more of SO_4. In the same way a quantity of chlorine less than 100 parts is not regarded as sufficient to justify calling a water "muriated."

SODIC MURIATED ALKALINE-SALINE WATERS.

Waters in which sodium and chlorine predominate and which are alkaline to methyl orange belong to the class of sodic muriated alkaline-saline waters. The other common constituents may be present in small or moderate amounts.

None of the wells in Iowa so far as investigated yields strictly salt water or brine; salt is the largest constituent of the mineral matter in only a few waters. Nevertheless, considerable amounts of chlorine, exceeding 100 parts per million, are of very frequent occurrence in Iowa ground waters. In several wells the chlorine reaches 500 parts or more; in the 1,006-foot well at McGregor and in the deep wells near Knoxville it reaches nearly 1,000 parts, and in the well at Bedford at a depth of 1,300 feet it reached 2,546 parts.

Salt-holding waters are generally distributed throughout the State, but such waters are especially common in certain localities. From the northeastern corner of the State southward along Mississippi River chlorine tends to increase. The deep wells of Allamakee County contain about 70 parts of chlorine. It rises to 246 parts in the 520-foot well at McGregor, in Clayton County, and to 968 parts in the 1,006-foot well at the same place, an amount exceeded only in the well at Bedford and the Craig well at Knoxville. At Dubuque the chlorine is scarcely more than a trace, but at Clinton it rises again to about 50 parts in the deeper wells. It increases southward from Clinton, being about 300 parts at Davenport and Burlington and about 600 parts at Keokuk and Fort Madison. Chlorine is present in amounts ranging from 100 to 2,500 parts in all deep wells tested in the southern part of the State. It reaches nearly 1,000 parts in the wells at Flagler, Pella, and Knoxville (Craig well), all in Marion County, and 2,546 parts at Bedford. The deep wells near Missouri River usually contain notable amounts of chlorine, but the quantities are smaller as a rule than those in the well waters along the eastern border of the State.

The wells in the central part of the State north of Des Moines do not contain excessive amounts of chlorine and rarely more than 100 parts. More than 100 parts are found in the deep wells at Fort Dodge, Boone, Ames, and Des Moines, and all of these penetrate the Jordan or lower formations.

The only essentially salt waters are those of the 1,006-foot well at McGregor and the Bedford well at 1,300 feet.

Analyses of sodic muriated alkaline-saline waters in Iowa.

[Parts per million.]

Locality and owner.	Depth of well in feet.	Lowest geologic division.	Silica (SiO_2).	Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.[a]
McGregor:												
City	1,006	Dresbach or underlying Cambrian sandstones.	6	6	...	160	20	706	509	465	968	2,585
Bedford:												
Water Co	1,300	Dresbach or underlying Cambrian sandstones.	10	....	2	77	34	1,768	312	235	2,545	4,827

[a] Sum of the constituents minus one-half the bicarbonate radicle.

SODIC MURIATED-SULPHATED ALKALINE-SALINE WATERS.

Waters in which sodium, chlorine, and the sulphate radicle predominate are not common in Iowa. As a rule waters that contain much sulphates also contain much calcium and magnesium. Those given in the next table, as will be readily seen, contain little calcium and magnesium and are to be rated as soft waters. The first and second contain bicarbonates in excess of calcium and magnesium and would commonly be said to contain sodium carbonate. Such waters from deep wells are rare in this State.

Analyses of sodic muriated-sulphated alkaline-saline waters in Iowa.

[Parts per million.]

Locality and owner.	Depth of well in feet.	Lowest geologic division.	Silica (SiO_2).	Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.[a]
Glenwood: Institution for Feeble-minded	1,910	Silurian	131	16	....	...	37	14	647	486	754	185	2,027
Logan: City	821	....	10	....	0.3	2	35	15	461	411	728	121	1,578
Ames: State College	2,215	Jordan	3	....	....	4	35	15	391	204	516	204	1,270

[a] Sum of the constituents minus one-half the bicarbonate radicle.

SODIC-CALCIC MURIATED-SULPHATED ALKALINE-SALINE WATERS.

Sodic-calcic muriated-sulphated alkaline-saline waters are much more common than members of either of the preceding classes. This class includes many of the most highly mineralized waters of the State, in which the most abundant constituents are sodium, calcium, chlorine, and the sulphate radicle. None of those enumerated can be regarded as fit for domestic or any other use except street sprinkling and putting out fires. In classification of Iowa waters there is no need of mentioning magnesium, as that radicle bears a regular relation to calcium; the Iowa water usually contains about one-quarter to one-half as much magnesium as calcium, and magnesium never has been found to exceed calcium.

Analyses of sodic-calcic muriated-sulphated alkaline-saline waters in Iowa.

[Parts per million.]

Locality and owner.	Depth of well in feet.	Lowest geologic division.	Silica (SiO_2).	Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.[a]
Bedford:														
Development Co.	2,002	Silurian	18	....	1	1	486	116	1,161		300	1,920	1,420	5,273
Burlington:														
Murray Iron Works	1,000	St. Peter	11	....	1	1	342	115	514	11	232	1,860	235	3,206
Sanitary Milk Co	484	Silurian	13	....	5	1	389	131	707	19	268	2,414	276	4,089
Centerville:														
City, No. 1	1,540	.....do	10	3	....	....	263	90	755		90	1,961	339	3,465
Flagler:														
S. C. Johnson	752	Kinderhook.	22	....	.4	3	486	167	2,236		306	4,839	925	8,831
Keokuk:														
Y. M. C. A.	769	Silurian	12	....	....	1	198	81	894	15	292	1,610	632	3,589
Knoxville:														
T. Craig	346	Des Moines.	36	....	3	1	207	114	2,589		330	4,728	980	8,823
Ottumwa:														
Mineral Spring Co	314	Mississippian	125	....	24	....	345	152	1,464		1,297	2,807	533	6,098
Pella:														
City	1,803	St. Peter	10	....	4	3	488	148	2,107		280	4,678	775	8,353

[a] Sum of the constituents minus one-half the bicarbonate radicle.

SODIC-CALCIC SULPHATED ALKALINE-SALINE WATERS.

The waters classed as sodic-calcic sulphated alkaline-saline are those of the common heavily mineralized type, containing the normal amount of bicarbonates found in nearly all Iowa waters, high percentages of calcium, sodium, and sulphates, and only small amounts of chlorine, usually less than 100 parts per million. Such waters are less objectionable for industrial purposes than plain calcic sulphated waters containing the same amount of total solids. In fact they are equivalent to calcic sulphated waters softened with sodium carbonate to the extent to which sodium replaces calcium. The sodium in them, if low, is comparatively harmless in industrial operations, since it does not consume soap or cause scale; but if the amount of it exceeds 200 parts per million it causes foaming in boilers.

Very many waters of Iowa belong to this class. The following table contains 15 good examples and they could be multiplied almost indefinitely. The more heavily mineralized waters have been selected in order to make the quantity and relative preponderance of the sodium, calcium, and sulphate radicles clear at a glance. Representatives of this class are all the deep wells at Grinnell and the numerous farm wells 250 to 450 feet deep near that city, which apparently get most of their water from the layer of clay and gravel just above the limestone at about 200 feet. Most of the wells in Webster, Tama, Benton, and Polk counties belong to this class.

Analyses of sodic-calcic sulphated alkaline-saline waters in Iowa.

[Parts per million.]

Locality and owner.	Depth of well in feet.	Lowest geologic division.	Silica (SiO_2).	Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.[a]
Amana: Amana Society	1,640	....	5	6.4	....	....	104	42	181		320	517	18	1,033
Cantril: C. J. Manning	900	Maquoketa	16	....	3	1	270	89	299		228	1,306	19	2,117
Cherokee: State hospital	1,126	St. Peter	13	....	8	1	220	53	258		306	651	20	1,387
Colfax: Mills Hotel	350	"St Louis"	11	....	.7	1	235	97	463		260	1,495	27	2,460
Dunlap: City	1,535	St. Peter	8	....	0	0	176	72	146	27	272	776	33	1,374
Grinnell: City (3)	2,020	New Richmond.	13	....	2	.3	131	48	183		324	574	34	1,147
Hartley: City	205	Drift	...	30	....	....	335	149	304		506	1,522	33	2,626
Hull: City	1,256	Algonkian	18	....	6	5	322	124	192	23	384	1,380	33	2,295
Knoxville: Hospital for Inebriates.	326	Des Moines	10	....	0.4	3	303	52	436		262	1,600	18	2,553
Moulton: Electric Light Co	400	.....do	7	....	2	1	350	77	373	8	170	1,764	20	2,687
Ogden: City	2,800	....	10	....	7	4	139	60	231		270	736	59	1,381
Nevada: City	980	Maquoketa	9	....	5	2.5	426	84	141	19	315	1,390	42	2,276
Sanborn: Chicago, Milwaukee & St. Paul Ry.	1,250	Cambrian	....	....	....	....	353	114	182		458	1,282	26	2,186
Sac City: Canning Works	378	....	14	2	....	....	192	60	257		434	874	7	1,623
State Center: City	161	Drift	22	14	....	....	363	136	341		1,062	1,254	7	2,668

[a] Sum of the radicles minus one-half the bicarbonate radicle.

CALCIC SULPHATED ALKALINE-SALINE WATERS.

The waters of this class are not numerous, fewer than 25 having been found during this study; they contain large amounts of calcium and sulphates and less than 100 parts of either sodium or chlorides. With one or two exceptions they come from shallow wells, usually in the drift. They contain in largest proportion the substances that cause hardness, and they are the most difficult and expensive waters to soften. In proportion to their mineral content they produce the largest amount of boiler scale, of the type most difficult to remove. They are, therefore, the least desirable waters for domestic and economic uses in general, considered from the standpoint of their mineral content only.

The following table includes nearly all the very good examples of this class of waters.

Analyses of calcic sulphated alkaline-saline waters in Iowa.

[Parts per million.]

Locality and owner.	Depth of well in feet.	Lowest geologic division.	Silica (SiO_2).	Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.[a]
Belle Plaine: City	193	Drift	2	....	6	0	504	201	38		334	1,814	6	2,738
Belle Plaine: City	1,520	Oneota	22	....	1	3	346	135	72	11	268	1,247	9	1,980
Bancroft: Chicago & North Western Ry.	438	....	3	2	....	....	180	65	93		436	518	11	1,090
Chelsea: City	100	Drift	15	....	5	2	489	204	38		240	1,923	7	2,803
Lake Park: City	98	.....do	32	....	7	5	316	105	32		513	833	4	1,590
New Hampton: Chicago, Milwaukee & St. Paul Ry.	188	Devonian	...	3	....	....	219	50	24		456	366	33	923
Primghar: J. J. Shonts	372	Drift	29	....	11	7	375	156	51		570	1,199	7	2,120
Prairie City: Chicago, Rock Island & Pacific Ry.	360	Carboniferous.	...	36	....	....	331	126	41		662	1,110	5	1,980
Spirit Lake: City	100	Drift	27	....	2	1	213	52	52		463	433	20	1,031
Stark: Chicago & North Western Ry.	40	.....do	14	....	3	2	374	139	75		410	1,262	6	2,277
Toledo: County home	545	Devonian	11	....	3	2	275	144	64		251	1,119	7	1,750
Vining: City	235	Mississippian.	...	3	....	....	348	135	46		263	1,244	7	1,914

[a] Sum of the constituents minus one-half the bicarbonate radicle.

CALCIC CARBONATED ALKALINE WATERS.

Nearly all the best waters of the State belong to the calcic carbonated alkaline class. The amount of bicarbonate does not vary greatly; with a few exceptions, as at Manson, it is not less than 200 parts and in few places does it exceed 450 parts, if some old analyses are discredited, because the chemist apparently has assumed the presence of enough carbonic acid to combine with the bases. In a few waters, as at Davenport, Logan, and Williamsburg, there is not enough calcium and magnesium to combine with the bicarbonates, but in most of the waters that is not the condition. The amount of bicarbonates in waters of this class is about the same as that in more strongly mineralized waters; therefore, the waters high in mineral content may be regarded as waters of this class plus sulphates and more calcium or plus sulphates and chlorine and more calcium, magnesium, and sodium, till the most highly mineralized and most complex waters are formed. Waters of this class are the better the more nearly they approach the ideal type, in which their hardness is almost entirely temporary. They lose their bicarbonates when boiled and to a great extent when exposed to the air. They do not give the hard scale formed by the calcium sulphated waters.

In the examples given total solids seldom exceed 400 parts. Sodium is less than 20 parts. The sulphate and chlorine radicles are low and are practically insignificant. Examples could be greatly multiplied without including waters having more than 50 parts of any one of these three radicles. Waters of this character are most numerous in the northeastern part of the State, to which reference has been made as the region having the best deep-well waters. Such waters are less numerous in other parts of the State, though in some places they are obtained from the sands of the drift and from river bottoms. Though wells supplying such waters may penetrate rock for short distances, it is probable that they derive their waters chiefly from drift gravel and sand just above the rock.

Analyses of calcic carbonated alkaline waters in Iowa.

[Parts per million.]

Locality and owner.	Depth of well, in feet.	Lowest geologic division.	Silica (SiO_2).	Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.[a]
Ackley: Mrs. John Carroll	....	Mississippian	24	....	3	1	72	25	19		402	0	1	346
Boone: City	50	Drift	27	....	1	1	101	34	12	3	450	1	4	409
Dubuque: Chicago, Milwaukee & St. Paul Ry.	1,262	Dresbach or underlying Cambrian sandstone.	...	....	....	....	56	33	9		332	18	7	284
Eldora: City	200	Des Moines	10	....	1	0.2	55	24	14	3	300	0	2	259
Lake Mills: Chicago & North Western Ry.	....	Devonian limestone	17	....	....	2.2	87	28	5		406	8	1.5	352
Manchester: Spring, U. S. Fish Hatchery.	....	....	10	....	....	1	50	20	5	1	207	11	4	206
Mason City: City No. 3	651	Galena and Platteville.	9	....	5	1.3	81	34	14	5	423	11	5	377
Mount Vernon: City	330	Niagara	21	3	....	....	53	30	9		298	7	14	286
Morley: Chicago & North Western Ry.	214	do	...	4	....	....	72	25	6		346	10	2	292
Northwood: City	87	Devonian limestone	18	....	.3	0.5	74	24	8		318	1.5	8	293
Stanwood: Chicago & North Western Ry.	116	....	8	2	....	....	71	26	11		368	3	0	305
Sabula: City	973	Oneoto	3	6	....	....	54	32	14		337	21	0	298
Tipton: City	2,696	Cambrian or Algonkian sandstone.	15	....	....	1	82	26	12	1	378	4	2	332
West Union: City	70	....	...	3	....	....	75	24	11		348	9	10	306

[a] Sum of the constituents minus one-half the bicarbonate radicle.

SODIC-CALCIC CARBONATED ALKALINE WATERS.

The waters of the sodic-calcic carbonated alkaline class are not numerous, and the following table contains nearly all whose analyses have been procured. Those selected have not enough sulphates and chlorine to combine with the sodium and potassium.

Analyses of sodic-calcic carbonated alkaline waters in Iowa.

[Parts per million.]

Locality.	Owner.	Depth of well, in feet.	Lowest geologic division.	Silica (SiO_2).	Iron and aluminum oxides (Fe_2O_3+Al_2O_3).	Iron (Fe).	Aluminum (Al).
Brooklyn	City	180		13		0.6	0.5
Ellsworth	W. H. Brinton	91	Drift	14		5	1
Holland	L. Beenken	344	Mississippian	15		.4	2
Grand Junction	Chicago & North Western Ry. Co.	300	Des Moines	9	1		
Shannon	Chicago Great Western R. R. Co.	38					
Stanhope	Ole Satre	328	Carboniferous	21		3	0.2
Sumner	City	1,740	St. Lawrence formation.	8		1	1
Williamsburg	do	95					1
Do	Hughes' well	195			10		
Washington	City	232					

Locality.	Owner.	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.[a]
Brooklyn	City	47	18	120	4	432	87	3	509
Ellsworth	W. H. Brinton	59	28	46	4	440	0	0.4	377
Holland	L. Beenken	56	33	97		457	26	2	460
Grand Junction	Chicago & North Western Ry. Co.	70	26	67		502	0	6	430
Shannon	Chicago Great Western R. R. Co.	18	15	161		388	154	9	551
Stanhope	Ole Satre	106	39	99		473	54	4	563
Sumner	City	43	20	63	9	353	8	4	333
Williamsburg	do	57	19	106		536	2	6	459
Do	Hughes' well	47	15	97		473	0	2	407
Washington	City	33	13	194		558	54	25	598

[a] Sum of the constituents minus one-half the bicarbonate radicle.

CHAPTER VIII.

NORTHEAST DISTRICT.[1]

INTRODUCTION.

By W. H. Norton.

The northeast district of Iowa comprises the 11 counties of Allamakee, Blackhawk, Bremer, Buchanan, Chickasaw, Clayton, Delaware, Dubuque, Fayette, Howard, and Winneshiek. In no other part of Iowa are geologic structure and artesian conditions better known than here, and in none are artesian forecasts more sure and favorable. In the extreme northeastern part of the district the Jordan, New Richmond, and St. Peter sandstones outcrop at the surface, and the Dresbach sandstone lies near the surface in the deepest valleys. Thus the deepest water-bearing beds come to or near the surface, and nowhere do they lie so deep as to be beyond easy reach of the drill. Artesian wells can be sunk so cheaply that they can be afforded as public supplies by all except the smaller towns and villages. The water supply is abundant and suffices for any but the largest cities, and it ranks in quality among the finest drinking waters of the United States.

The strata incline gently toward the southwest, their maximum descent being at right angles to their strike. Thus from Lansing to Sumner (56 miles) the summit of the Jordan declines 1,018 feet, or 18 feet to the mile. To the west and to the south across the area the decline is less. Thus from McGregor to Charles City (75 miles) the summit of the Jordan falls 833 feet, or 11.1 feet to the mile; from Postville to Charles City (55 miles) the St. Peter falls 532 feet, or 9.1 feet to the mile. (See Pl. V.) Along the southern edge of the area from Dubuque to Waterloo (84 miles) the dip is more gentle, the Jordan falling 5.8 feet per mile and the St. Peter 5.5 feet to the mile. (See Pl. VI, p. 258.) The descent is most abrupt in the eastern part of the area, the Jordan dipping 10.4 feet to the mile from Dubuque to Manchester, and but 2 feet to the mile from Manchester to Waterloo. A similar descent occurs from Sumner to Waverly. Probably both Waterloo and Waverly lie on or near a low upwarp which interrupts in part the normal southwesterly dip. If this is the case, the upwarp either dies

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[1] Counties in each district arranged alphabetically.

out toward the north, as at Charles City the sag of the strata is marked, or its axis is directed to one side of that city. From Charles City to Waverly the Jordan sinks but 45 feet and the St. Peter rises slightly. Though the direction is here parallel with the strike, the slight fall is in contrast with the marked decline of the strata both from Osage to Charles City and from Waverly to Waterloo. (See Pl. VII, p. 272.)

Except in the extreme east and northeast sections, artesian wells should not be carried below the base of the Jordan sandstone. Considerable money has been spent in useless drilling below the Jordan. Thus at Waverly the drill penetrated 480 feet of the dolomites and shales of the St. Lawrence formation and at Sumner 460 feet. At Manchester the well was drilled more than 550 feet below this main water bed and, although the Dresbach was here reached, it was found dry as far as penetrated. The Oelwein city well seems to have been stopped before it reached the Jordan and might advantageously have been drilled deeper.

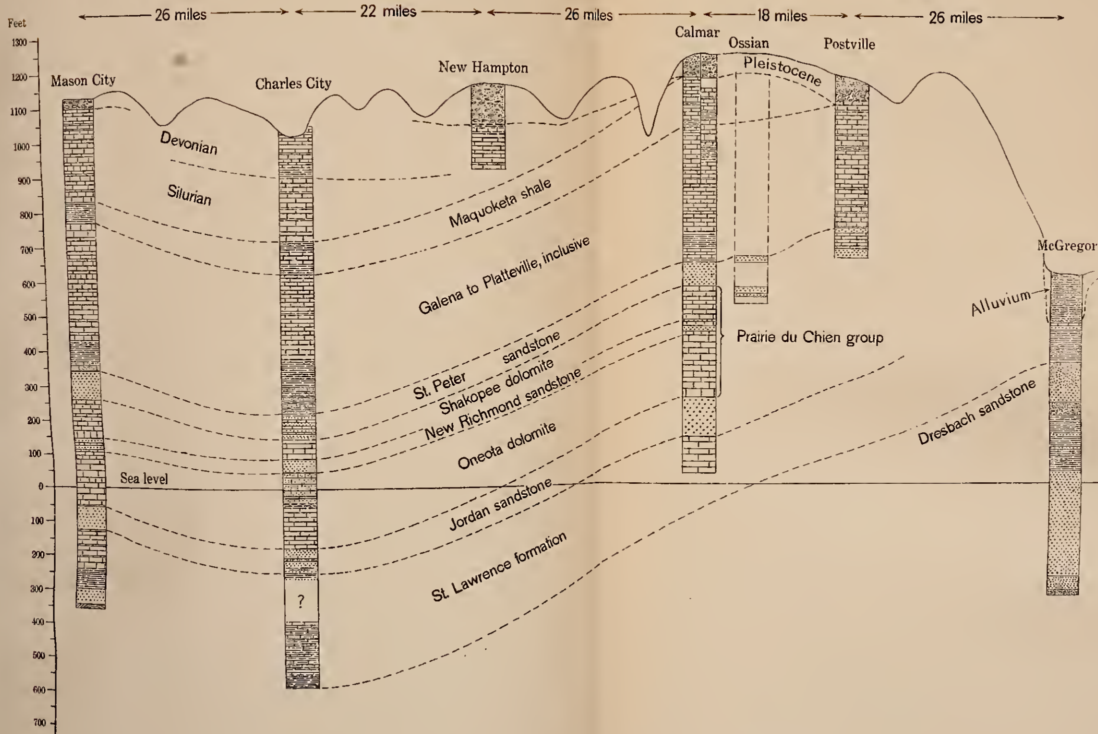
In the valley towns of Allamakee and northern Clayton counties the Dresbach and underlying sandstones are easily accessible and will yield an abundant supply of water. In Dubuque County, along Mississippi River, the Dresbach and underlying sandstones are most valuable water-bearing beds. At Dubuque some of the deepest wells not only tap the Dresbach but, passing through subjacent shaly beds, draw large quantities of water from a still deeper Cambrian sandstone.

On the uplands of the eastern counties the smaller towns and villages may obtain sufficient water from the St. Peter, as in the wells at Postville and Monona. Although the water will stand low in the wells, its supply seems to be fairly ample, notwithstanding its escape where the formation is cut by the valley sides.

Flowing wells may reasonably be expected for considerable distances up the valleys whose floors lie not far above the St. Peter, as those of Turkey and Volga rivers. (See also pp. 244–245.)

The artesian resources are best developed at Mason City, McGregor, and Dubuque. Even in the most favorable artesian sections, however, the ground-water resources are comparatively undeveloped. (See Pl. I, in pocket.) Two counties are without deep wells, and the number of the deeper sort of shallow wells is comparatively small. Development must come as the population and towns of this region grow. The evidence seems to be that for a long time this region will have a practically unlimited source of supply of good water for any probable population. Not the least of its good fortune lies in the fact that all ground waters seem to be about equally good from the point of view of mineral content. The problem of casing is reduced to its simplest terms, for it is only necessary to put down casings to solid rock to and through caving shales. There are no deleterious

Feet
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
100
200
300
400
500
600
700



GEOLOGIC SECTION BETWEEN McGREGOR AND MASON CITY, IOWA
By W. H. Norton

THE NORRIS PETERS CO., WASHINGTON, D. C.

waters to case out, and as the upper waters are comparatively soft the matter of the rusting out of casings is not to be so much feared as it is in other sections of the State.

ALLAMAKEE COUNTY.

By W. H. Norton.

TOPOGRAPHY.

Allamakee, the northeasternmost county of Iowa, lies almost wholly in the driftless area. The region is a deeply and intricately dissected upland, attaining an elevation of 1,300 feet above sea level, and rising about 700 feet above Mississippi River, which forms the eastern boundary of the county. The valleys of the streams are flat floored and wide. The Mississippi flood plain attains a width of 4 miles and embraces a maze of sandy islands and braided bayous. The floor of the valley of the meandering upper Iowa River has a general width of three-quarters of a mile, widening in its lower course to a mile and more. The valley of Yellow River is narrower but conforms to the same general type. The tributary creeks have well-opened mature preglacial valleys, and the courses of even their wet-weather affluents are graded.

The topographic age of the region is best read in the semicircular coves carved by the ancient stream on both sides of the valley of upper Iowa River. These deep amphitheaters are guarded at their entrances by lofty isolated buttes, remnants of the rock spurs cut by the stream as it entrenched its curving course. No such coves and buttes are seen along the bluffs of the Mississippi, though the succession of strata is equally favorable to cliff recession and planation, the vast volume of water of the latter stream in Pleistocene times having cut back any salients of the valley sides and left a wall of rock singularly continuous and even and sweeping in its curves.

The interstream areas consist of parallel east-west ridges or uplands, whose summits, where broadest, are cut by shallow valleys into a gently rolling topography. Their dissected flanks consist of lobate ridges of sinuous crest whose steep sides are gashed by deep ravines.

The summits of the divides rise to a common level. If the valleys could be filled with the material that has been swept away by running water they would constitute a plain whose origin may be ascribed to long subaerial erosion near the level of the sea. An additional proof of the former existence of this ancient peneplain, of which the summits of the divides are the remnants, is found in the valuable limonite and hematite deposits of Iron Hill on the crest of Waukon Ridge, such deposits being not uncommon on peneplains where the rocks have long been wasted by slow decay.

Some evidence of a second and lower erosion plain is seen in the accordant level of the long lateral spurs that separate the valleys of the creeks tributary to upper Iowa River. The crests of these spurs, which are capped by the St. Peter sandstone, fall into a common plane about 1,100 feet above sea level, and thus lie distinctly below the level of the upland. Measured by the distance between the escarpments of the Galena-Platteville limestones of the upland, the width of the valley floor of the upper Iowa, developed 1,100 feet above sea level, was about 10 miles. In age the planation of this valley floor would seem to correspond with that of the similar peneplain of the second generation developed at Dubuque on the weak Maquoketa shale. In each place, however, another explanation may be found in cliff recession under weathering. In Allamakee County the Galena-Platteville escarpment may be supposed to have retreated because of the weak St. Peter sandstone on which it rests and which caps the ridges defining the 1,100-foot level; and in Dubuque County the Niagara escarpment may be held to have receded in a similar manner because of the undermining of the immediately subjacent Maquoketa shale.

GEOLOGY.

The rocks underlying Allamakee County dip slightly toward the southwest. (See Pl. V.) They are also bent in one or more comparatively narrow low northwest-southeast folds. As a result of the southwestward dip the oldest rocks are exposed in the northeastern part of the county along the base of the bluffs bounding the deepest valleys, and the youngest rocks along the crests of the divides in the southwestern parts of the county.

The main valleys have been cut considerably deeper than their present floors and are built up with alluvium, probably Pleistocene in age. Thus the wells at New Albin strike rock only at from 130 to 140 feet from the surface, or more than 100 feet below the present river levels. Moreover, old terraces, remnants of ancient flood plains, standing as high as 60 feet above the rivers, mark the height at which the streams of the region ran when they ceased aggrading their rock-cut valleys and began the task of degradation.

The highest beds of the county (Ordovician) are limestones and shales belonging to the Galena, Decorah, and Platteville formations. The Galena is composed chiefly of limestones which may be dolomitized in whole or part. The combined thickness of the three formations varies within wide limits. On Waterloo Ridge it does not appear to exceed 100 feet; at Postville (Pl. V) it was found to be 364 feet thick in the city well; at Waukon the city deep well found the base of the Platteville 195 feet below the surface.

Beneath the Platteville limestone is the St. Peter sandstone, white and incoherent, or locally stained and hardened by exposure at the surface, its grains uncemented, rounded, and fairly uniform in size in any stratum and locality. Its thickness is reported as about 80 feet. It contains practically no interstitial filling, and water seeps as freely through it as through a bed of incoherent sand.

Underlying the St. Peter sandstone is a thick body of dolomites, known as the Prairie du Chien group, which forms the basal part of the Ordovician. Crowning with white castellated cliffs many a bold bluff along the river courses the Prairie du Chien group forms the most conspicuous terrane within the county. Toward the summit of the group sandy beds, known as the New Richmond sandstone, divide this body of dolomite into an upper formation called the Shakopee dolomite and a lower formation known as the Oneota dolomite. The Shakopee, and to a less extent the Oneota also, includes much silica in sandy layers, desseminated grains, and masses of chert.

Transition beds of limy sandstone and sandy limestone connect the Prairie du Chien with the underlying Jordan sandstone (Cambrian), whose thickness is nearly 150 feet. The Jordan is composed of well-rounded grains of pure quartz sand and in most places is soft and friable. Some layers, however, are well cemented. Where exposed to the weather the Jordan is gray or yellow, although its normal color, as seen in well drillings, is white.

The Jordan sandstone resembles the St. Peter in composition, but because of its greater depth beneath the surface it is less thoroughly drained; because of its greater and more uniform thickness its supply is more abundant.

The Jordan sandstone rests on a formation composed of sandy dolomites, limy sandstones, and sandy and limy shales— the St. Lawrence. These rocks are exposed in the cliffs bordering the Mississippi and its tributaries and are so argillaceous that they are generally dry. They form an impervious floor for the waters of the Jordan, and, where they lie deepest, prevent the rise and escape, under hydrostatic pressure, of the waters of the underlying Dresbach and earlier Cambrian sandstones.

The relations of the St. Lawrence and the underlying Cambrian terranes are not clearly made out from the evidence at hand. In the cliffs at Lansing the St. Lawrence, as described by Calvin,[1] outcrops 96 feet above the level of Mississippi River with a thickness of 44 feet. Beneath it lie gray, yellow, and brown friable sandstones measuring 56 feet, containing greenish layers and near the top argillaceous beds. The underlying strata to the river level, a distance of

[1] Ann. Rept. Iowa Geol. Survey, vol. 4, 1895, pp. 57-59.

40 feet, are concealed from view. The deep well at Lansing continues the section beginning at 640 feet above sea level, 18 feet above mean water level in the river. Unfortunately the tube of drillings which constitutes the only data obtainable gives only the succession and the lithologic characteristics of the beds, and supplies nothing that will serve as a basis of inference as to the thickness of the strata except the relative spaces which the drillings occupy in the tube. Estimating the thickness of the terranes in this way gives the following succession of beds pierced by the drill:

Record of deep well at Lansing.

	Thickness in feet.
Surface clay	37
Shales	70
White sandstone	125
Shales with a thin intercalated bed of sandstone	135
Sandstone resting on hard crystalline rock	381

Near New Albin, which is located about 10 miles north of Lansing, Calvin observed at the base of the bluffs a blue calcareous shale. From the New Albin wells we have a single log uncorroborated by drillings. The well section here begins at 650 feet above sea level, 10 feet above the top of the Lansing boring, and is as follows:

Record of deep well at New Albin.

	Thickness in feet.
Sand and gravel (alluvium of Mississippi)	130
Soapstone	150
Sandstone	190

New Albin and Lansing are nearly aligned with the strike of the strata. At New Albin the base of the Oneota dolomite is placed by Calvin at 320 feet above the tracks of the Chicago, Milwaukee & St. Paul Railway (966 feet above sea level) and at Lansing at 300 feet above the river (918 feet above sea level), giving a southward dip of about 5 feet to the mile. The two sections being correlated, it would seem possible that the shale at the base of the bluffs at New Albin is the same as the first shale in the Lansing well. The first sandstone of the Lansing well is then cut out by the ancient channel of the Mississippi at New Albin, and the first shale (soapstone) of the New Albin log is identical with the second shale at Lansing, with which it also agrees in color and estimated thickness. The base of this shale at New Albin is about 100 feet higher than at Lansing, according to the estimates. The known southward dip of the strata accounts for half of this amount and the remainder is perhaps included in the margin of error in estimates of the thickness of the beds resting on the exceedingly precarious foundations already mentioned.

The thickness of 44 feet assigned by Calvin to the St. Lawrence at Lansing is far less than that of the dolomites and shales intervening between the Jordan sandstone and the first sandstone beneath it, as shown in deep-well sections. Even if all of the 40 feet of concealed strata above the St. Lawrence in the Lansing bluffs belong to that terrane, it still compasses not more than one-third of the thickness common in deep-well sections.

On the whole it seems very possible that the equivalent of the St. Lawrence of the deep-well sections includes at Lansing all the strata between the St. Lawrence of Calvin and the level of the river and also the first shale disclosed in the deep wells. Its total thickness might then reach 230 feet, but this would not be more than that of the formation at Manchester and Anamosa, and but 30 feet more than that given in an imperfect record at Dubuque. The shale at the foot of the bluffs at New Albin would then be assigned to the same terrane.

Under this interpretation of the St. Lawrence the white sandstone first to be found in the Lansing well is the probable equivalent of the Dresbach sandstone of Minnesota, and the underlying shale and sandstone are undifferentiated Cambrian. On the other hand, if Calvin's limitation of the St. Lawrence be correct, the Dresbach outcrops beneath it from Lansing to New Albin.

UNDERGROUND WATER.

SOURCE.

On account of the intimate dissection of the upland, the water-bearing rocks are cut by valleys and ravines and their waters find easy terminal escape. Ground water stands low, wells are deep, and the windmill is a conspicuous feature of the farms.

The Galena dolomite and Platteville limestone have for long ages been subject to the solvent action of ground water. Numerous sink holes pit the surface and lead to well-defined subterranean waterways, which have been opened by solution along joint and bedding planes. Unfortunately, neither the depth nor the position of these watercourses can be predicted. The beds of impervious shale in the Platteville arrest the downward progress of the water, which issues as springs where the valley sides intersect the surface of the shale and which forms the chief supply of wells sunk to it.

Wherever the drill goes deep enough to strike the St. Peter sandstone water is found, except at or near the edges of the bluffs where the formation outcrops. The head of the water is low owing to its easy terminal escape, but the supply is plentiful.

The Prairie du Chien group, with its creviced dolomites and included sandy beds, forms a capacious reservoir for underground water and greatly augments the supply of most wells penetrating it.

The Jordan sandstone contains abundant water, which is prevented from escape by the impervious floor of the St. Lawrence formation.

The Cambrian sandstones underlying the St. Lawrence formation hold vast quantities of ground water. The Dresbach (thus designating the first sandstone of the Lansing well) holds water of the same quality and head as that of the sandstone beneath it, but of less copious flow. The lower sandstone, from which the Dresbach is parted by heavy shales, supplies the New Albin wells.

PROVINCES.

Mississippi Valley.—The Mississippi Valley may be considered a special underground-water province. The unusual width of the flood plain and the materials of which it is composed have already been mentioned. The area is used chiefly for pasture and the few wells needed find water within a score of feet from the surface.

Upper Iowa Valley.—The upper Iowa Valley is a wide and fertile lowland, well watered by springs issuing from the hillsides. Nevertheless, flowing water is obtainable so easily and in such large quantity that within the last decade several artesian wells have been sunk through varying depths of alluvium to the underlying Cambrian sandstones. At New Albin, at the mouth of the valley, the alluvial filling is reported to be 134 feet thick, and 8 miles up the valley it is still 100 feet thick. Wells near the bluffs find rock at less depth. The rock first struck is blue or green, dry, shaly or dolomitic sandstone, ranging in thickness from 110 to 190 feet. Beneath this blue or greenish rock lies what is described as a white "sand rock" in whose more porous layers abundant water is found under strong artesian pressure. The depth to which this sandstone has been penetrated ranges from 30 to nearly 300 feet. The head of water in wells 5 to 10 miles up the valley is about 690 feet above sea level, the water rising about 10 feet above the curb. Still farther up the valley, in Union City Township, the water in a well owned by J. H. Beardmore heads 15 feet above the curb, discharging from a 5¾-inch casing at a rate of 100 gallons per minute. These wells are all cased to solid rock, a distance commonly of more than 100 feet. The abundance of pure water obtained and the saving of labor and cost of pumping make these wells comparatively inexpensive, wells of 300 feet deep having been sunk at a cost, including casing, of $225. A list of these wells is appended.

Flowing wells in the upper Iowa Valley, Allamakee County.

Owner.	Locality.	Depth.	Diameter.	Depth to rock.	Depth to water supply.	Source of supply.	Head above curb.	Remarks.
		Feet.	*Inches.*	*Feet.*	*Feet.*		*Feet.*	
J. H. Beardmore.	......	252	5⅝	......	160	......	15	Cased to 98 feet. Yields 100 gallons per minute.
Otto Bateen......	......	350	4	......	......	......	......	
J. T. Bullman....	......	350	4	......	......	......	......	
J. L. Dirth.......	......	400	4	......	......	......	......	
Thomas Rekurn.	......	480	4	......	......	......	......	
E. J. Sadler......	......	260	4	......	......	......	......	
M. Sadler........	......	250	4	......	......	......	......	
T. 100 N., R. 5 W. (UNION CITY).								
Ed. Bellows......	SE. ¼ sec. 36.	490	......	......	......	......	......	
B. Hartley.......	NE. ¼ sec. 34.	300	4	......	145	Sandstone	8	Curb 20 feet above river. Cased to 112 feet. Yields 20 gallons per minute.
J. Hartley........	Sec. 3	490	4	60	40	...do.......	4	Cased to 80 feet.
James Kibby.....	SW. ¼ sec. 35.	618	......	......	......	......	......	
T. 100 N., R. 4 W. (IOWA).								
Nicholas Colch...	SW. ¼ sec. 28.	524	......	......	......	......	......	
George Meyers...	SW. ¼ sec. 20.	330	......	......	......	......	......	
P. S. Pierce......	SE. ¼ sec. 15.	340	4	80	300	......	22	
J. H. Riser.......	SW. ¼ sec. 11.	550	8	......	......	......	......	
Frank Weymiller	SW. ¼ sec. 10.	450	6	......	......	......	......	
Louis Weymiller.	NW. ¼ sec. 10.	414	4	53	26	Sandstone	9	Curb 23 feet above river. Cased to 20 feet. Yields 15 gallons per minute.

Minor valleys.— The floors of the valleys of Clear, Village, and Paint creeks, and of Yellow River are narrower than the valley floor of the upper Iowa, and the bordering terraces are relatively wider. These high remnants of ancient flood plains are naturally rather dry, as ground water readily escapes along their scarps. The streams are spring fed and permanent, and the springs issuing along the valley sides greatly lessen the need for wells. In Clear Creek and Village Creek valleys artesian wells furnish water for mills. Wells sunk in the wider bottom lands of Yellow River will probably obtain flowing water. From Myron to Ion the stream flows successively over the Platteville limestone, the St. Peter sandstone, and the dolomites and sandstone of the Prairie du Chien group, and wells reaching the Jordan sandstone should yield a generous flow. At present dug and driven shallow wells furnish the chief supply.

Uplands.—On the uplands, as on all maturely dissected areas of high relief, permanent and abundant ground water lies at a considerable depth below the surface. On the high ridge north of upper Iowa

River, back of New Albin, farm wells commonly exceed 300 feet in depth. Below the surface yellow loam (loess) and the underlying reddish residual clays, wells enter a limestone of the Prairie du Chien group, pass thence into a water-bearing sandstone (the Jordan) and traversing a "blue rock shale" (the St. Lawrence) find abundant water in the Dresbach sandstone. As the Jordan outcrops along the river bluffs its waters easily escape and have low head, but the water of the Dresbach is under sufficient head to bring it in some wells within 285 feet of the surface. The following log of a well on this ridge, belonging to Henry Rink (NW. ¼ sec. 26, T. 100 N., R. 5 W.), is probably representative:

Section of Rink well, Allamakee County.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface deposits	40	40
Limestone (Prairie du Chien)	135	175
Sandstone (Jordan)	100	275
Shale, blue (St. Lawrence)	200	475
Sandstone (Dresbach)	35	510

Water is found chiefly in the Dresbach; it commonly stands 225 feet below the surface.

On Waterloo Ridge in the extreme northwestern part of the county accurate surface measurements by Calvin give the following thicknesses to the formations there present:

Thickness of formations on Waterloo Ridge.

	Feet.
Galena dolomite, Decorah shale, and Platteville limestone	100
St. Peter sandstone	80
Prairie du Chien group	250
Jordan sandstone to level of mouth of Bear Creek	100

Water may be found in the Galena dolomite and in the Platteville limestone, especially above the basal shales of the Platteville if the drill strikes a water-bearing crevice, and in the St. Peter and Jordan sandstones.

On Gruber Ridge and May Prairie and on the summits of the lobate ridges whose crests are formed of the St. Peter sandstone, much the same conditions prevail as north of upper Iowa River. Loess and residual clay may reach 40 feet in thickness; the Prairie du Chien group is reported in some wells as 160 feet, and the Jordan sandstone as 100 feet, underlain by "blue rock" (St. Lawrence formation).

On the wide uplands about Waukon and Postville the Galena dolomite and the Platteville limestone yield water to farm wells 75 to 125 feet deep. House wells at Waukon are commonly sunk about 80 feet and end in the Platteville. At Postville some wells obtain water in glacial gravels underlying blue black till at a depth of 85 feet; others obtain water in the Galena dolomite or the Platteville limestone within 150 feet of the surface. For larger supplies than ordinary, and where the drill fails to find a water channel in the limestone, wells on these uplands must go to the St. Peter or, in some localities, to the Jordan. The depth to these sandstones varies with the southward and westward dip of the strata. The St. Peter, for example, outcrops at Radcliffe, 1 mile north of Waukon, at 1,122 feet above sea level; 8 miles south of Waukon it has descended to the valley floor of Yellow River, 872 feet above sea level.

The well, 600 feet deep, of the county farm near Waukon, on high ground, found some water in the Galena dolomite or the Platteville limestone, the water rising to 57 feet below the surface. In the sandstones, which, according to the drillers, were struck at 400 and 500 feet, the water fell, that from the lower sandstone standing 240 feet below the curb.

An exceptionally reliable log of a well northeast of Postville, in the NW. ¼ NW. ¼ sec. 21, T. 96 N., R. 5 W., is no doubt typical of the deeper wells of the southwestern townships. The curb is not far from 1,100 feet above sea level.

Log of well northeast of Postville.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay	24	24
Dolomite (Galena)	50	74
Limestone (Galena)	150	224
Shale (Platteville)	66	290
Sandstone (St. Peter)	31	321

A strong vein of water was found in the St. Peter at 318 feet, but it rose only 8 feet in the well.

SPRINGS.

No area of equal size in the State is so bountifully supplied with springs as is Allamakee County, the principal source being at the contact of the Decorah shale with the overlying Galena limestone. Where the Galena forms the bedrock of the uplands, the ravines on the south side of the ridges are dry only down to where they cut this heavy shale. Here copious springs gush out from the rock and here begin countless rivulets which flow down the hillsides to feed the creeks and rivers. Where the roads follow the ravines farmhouses are commonly located along the Galena-Decorah contact in close proximity to springs, which afford, without cost, pure water for all household uses. Spring houses are built over them for dairy purposes, and the water, flowing in a brook several feet wide through the barnyard, conveniently supplies the needs of the stock. Where the farmhouse is at a lower level than the spring, water can be piped through the house under pressure and used for all domestic purposes, including refrigeration. It may also be sufficient in quantity and head to furnish water power to drive a separator, churn, or other light machinery. Many springs emerge at the base of ledges of Galena that outcrop high up on the sides of narrow and deep ravines. Picturesque as are these cascading springs, they are generally too remote from farmsteads for utilization. The August temperature of several springs from the Galena-Decorah contact ranges from 46° to 47° F.

The Livinggood Spring, the largest in the county, flows from the Galena-Decorah contact near Myron (NW. ¼ SW. ¼ sec. 3, T. 96 N., R. 6 W.), emerging where the floor of the valley of Yellow River crosses the summit of the Decorah shale. On the left bank a group of springs at the base of a semicircular alcove, with vertical walls of rock cut in the side of the bluff, unite to form a swift-running stream a foot deep and a rod wide. Up valley from this spring Yellow River carries but little water except from the run-off at times of rain, since its channel lies above the chief spring horizons. In August, 1906, the water running in the river bed up the valley from the spring was but a very small fraction of the amount contributed by the spring. The summer temperature of the spring at its outflow is about 48° F.

This spring is known in the vicinity as the Rise of Yellow River from the popular belief that up the valley the water of the river sinks from sight and here rises again to the light of day. It is possible that some water of the river may be lost in the opened joints of the limestone over which it flows in its upper course, and any water leaking from the river bed would no doubt form an underflow upon the surface of the next subjacent shale, though not necessarily in a course immediately beneath the river channel or, indeed, beneath the river valley. But the larger part, if not the entire amount of the discharge of the spring, is in all probability drawn from the underground water of the upland to the north, which here finds issue where the main horizon of its seepage is first intersected by the valley of the river.

Springs occur also near the base of the St. Peter sandstone, but these are neither so numerous nor so large as those from the summit of the Decorah shale. The St. Peter lies upon a creviced limestone, through which its waters can seep to lower drainage levels. Moreover, the massiveness of the sandstone, its lack of crevices, and the absence of solution channels in this insoluble rock, make against the concentration of water in definite underground courses issuing in strong springs.

The outcrops of the Prairie du Chien in the northern part of the county are marked by large springs which issue near the plane of contact with the Jordan sandstone, as near Quandahl and Dorchester.

The sandstones underlying the Prairie du Chien supply a large number of powerful springs where they are transected by the valleys. They include along with their permeable water beds other layers intermixed with clay and lime, which are far less porous and which serve to hold ground water upon their surfaces and prevent its leakage either downward under gravity or upward under hydrostatic pressure.

In the valleys of the upper Iowa River and of Mill and Village creeks and in the valleys of their tributaries springs from these sandstones are very numerous. The temperatures measured range from 45° to 49° F., the higher temperatures probably indicating the influence of the summer sun and air on the surface rock waste through which some springs find issue, and on the water of the pool of the spring.

The list of strong springs is too long for publication, but mention may be made of those at the mouth of Paint Creek, at Waukon Junction, which discharge near the level of Mississippi River from the waste-cloaked foot of the bluff on the north side of the valley, along a line of about 100 feet. Typical springs also are the M. Gordon springs, 3 miles southwest of New Albin, in the upper Iowa River valley; the Jacob Knupf spring, in sec. 24, T. 100 N., R. 6 W.; the Dorchester creamery spring, which supplies the creamery and five buildings of the village; the L. C. and C. C. Megordon springs, near Elon; and the Peter Lang spring, on Village Creek, in the NE. ¼ sec. 7, T. 98 N., R. 3 W., which flows a swift stream with a cross section of 2½ square feet.

CITY AND VILLAGE SUPPLIES.

Lansing.—Two 6-inch artesian wells, 675 and 748 feet deep, respectively, were drilled by Swan Bros. in 1877 for the city of Lansing (population, 1,542). The curbs are 640 and 660 feet above sea level. The water originally rose to 690 feet above sea level, and for 20 years and more the pressure continued sufficient to render pumping unnecessary for the delivery of water to the taps. Since 1897 pumps have been installed and a gravity system from a reservoir is used to supply the upper portions of the town. The head has lowered to 35 feet, and the discharge, estimated at first at 700 gallons a minute, has fallen to 300 gallons. The temperature of the water is 50° F. The quality of this water is indicated by the analysis on page 142. The water is distributed under gravity pressure of 95 pounds through 3 miles of mains to 17 hydrants and 150 taps.

The following record of strata in the 748-foot well is based on drillings taken from a tube. As the original record was lost, it was assumed that the length of the tube and the thickness of the respective drillings were proportioned to the depth of the well and the thickness of the beds.

Record of strata in Lansing city well.[a]

	Thickness (estimated).	Depth.
	Feet.	*Feet.*
Clay, yellow; no samples	37	37
Shale, chocolate colored, slightly calcareous; some coarse Pleistocene sand intermixed	35	72
Shale, greenish yellow, calcareous, arenaceous, with minute angular grains of limpid quartz	35	107
Sandstone, white, yellow and buff; grains differing widely in size	125	232
Shale, light purplish and drab; arenaceous	15	247
Sandstone, fine, yellow	5	252
Shale, arenaceous, or sandstone, argillaceous; blue drab, slightly calcareous	70	322
Shale, red, arenaceous, with thin stratum of intercalated drab shale	45	367
Sandstone, light yellow; grains moderately fine, subangular, and rounded	381	748
"Hard crystalline rock." [b]		

[a] See discussion on pp. 242–243. [b] Driller's report.

The Doehler & Schafer well (depth, 630 feet; diameter, 5⅝ inches) heads 35 feet above the curb. The water flows into a mill race, where it joins water from a creek and not only increases the water power but also prevents the water in the race from freezing even in the coldest weather.

The A. C. Doehler well, on Village Creek (depth, 750 feet), was formerly used to furnish power for a woolen mill, but has long flowed into the creek unutilized.

New Albin.—The village of New Albin (population, 588) has no waterworks, but a supply for stores, hotels, and private houses, and fire protection to the business portion of the village is furnished by 8 artesian wells, ranging in depth from 470 to 550 feet. The water is reported to rise 30 feet above the curb, or 682 feet above sea level. These wells end in the undifferentiated Cambrian beneath the Dresbach and draw thence their large supply of excellent water.

The A. F. Kuhn well (depth, 500 feet; diameter, 6 inches) is cased to 130 feet. Its curb is 650 feet above sea level and its head, by pressure, 41 feet above curb. Water is drawn from beds at 315 and 470 feet. It was completed in 1900 by Frank Easton, of New Albin.

Log of Kuhn well, New Albin.

[Supplied by driller.]

	Thickness.	Depth.
	Feet.	*Feet.*
Loose sand and gravel (in ancient channel of Mississippi)	130	130
Soapstone, blue	150	280
Sand rock, blue	190	470

The New Albin Cooperative Creamery Co.'s well (depth, 470 feet; diameter, 4 inches) is cased to 134 feet. Its curb is 350 feet above sea level, and its head, by pressure, is 39 feet above curb. Water from beds at 315 and 470 feet flows about 100 gallons per minute. It was completed in 1905 by Frank Easton at a cost of $300.

The Erikson & Winneka well has a depth of 500 feet and a diameter of 6 inches to 135 feet and thence 4 inches to bottom. Its curb is 650 feet above sea level and its head, by measurement, 29 feet above curb. Its temperature is 51° F. It was completed in 1902 by Frank Easton.

Other wells of approximately the same depth and of essentially the same characteristics have been drilled at New Albin for J. B. Pohlman, H. Martin, F. C. Meyer, Henry Reiser, W. O. Bock, and H. C. Boyer. There are also a number of flowing wells from the same water bed in the upper Iowa Valley west of New Albin. (See pp. 244–245.)

Postville.—The deep well from which the supply of Postville (population, 952) is drawn was drilled by Dickson Bros. in 1895. It is 8¾ inches in diameter and 515 feet deep and ends in the St. Peter sandstone. (See Pl. V.) The elevation of the curb is 1,191 feet above sea level; the water heads 250 feet to 300 feet below the curb. Water was found at a depth of 130 feet and stood at this level till the drill reached a depth of 435 feet, when a second supply was tapped. The pumping capacity is 32 gallons per minute. The temperature of the water is 48° F.

Strata penetrated in drilling this well are shown in the following table:

Record of strata in city well at Postville (Pl. V, p. 258).

	Thickness.	Depth.
Quaternary (72 feet thick; top, 1,191 feet above sea level):	*Feet.*	*Feet.*
Humus	2	2
Loess, yellow	16	18
Loess, ashen	6	24
Clay, yellow, sandy and pebbly, noncalcareous	4	28
Sand, yellow, sharp, and rather coarse	4	32
Clay, dark drab, sandy and pebbly, calcareous	40	72
Ordovician:		
Galena dolomite and Platteville limestone (364½ feet thick; top, 1,119 feet above sea level)—		
Limestone; some buff and magnesian, some lighter colored and of rapid effervescence; cherty	13	85
Shale, green, calcareous, soft	12	97
Limestone, blue, earthy, magnesian; 11 samples	106	203
Shale, soft, gray, calcareous	9	212
Limestone, light yellow and white; hard, by driller's record; earthy to crystalline; nonmagnesian, as judged by rapidity of effervescence	138	350
Limestone as above, but a little softer; 5 samples	35	385
Limestone, greenish gray, argillaceous	10	395
Limestone, light yellow-gray, crystalline to earthy; 4 samples	41½	436½
St. Peter sandstone (78½ feet thick; top, 754½ feet above sea level)—		
Sandstone; usual St. Peter type: grains rounded and smoothed, of limpid quartz, mostly unbroken; with much limestone yellow and gray, rapidly effervescing; in angular sand; no trace of embedded grains in limestone fragments	11½	448
Sandstone as above, but with less limestone	2	450
Limestone, blue-gray, argillaceous, in part macrocrystalline; in flaky chips, largely compacted of comminuted fossils; 2 samples	8	458
Limestone and shale, gray, earthy; in chips	5	463
Limestone, light blue-gray, mottled; in flaky chips, compact, crystalline to earthy	7	470
Limestone, yellow-gray, mottled, macrocrystalline to earthy, fossiliferous; in chips; 4 samples	17	487
Limestone, light gray, compact, fine grained; 4 samples	15	502
Sandstone, calciferous; soluble ingredients form about one-half by weight of drillings; some grains of sand embedded in the minute angular chips of limestone; other fragments show limestone matrix to be large. Limestone, yellow-gray and of rapid effervescence; loose in the drillings, and also embedded are many black opaque grains; ferruginous nodules of calcareous clay; and grainlike nodules of pyrite; 3 samples	13	515

From the starting of the drill, the samples were carefully saved at such short intervals that they afford an exceptional geologic section. If the sandstones at 436½ feet and at 502 feet be set aside, the remaining rocks of the section, in texture and chemical composition, are typically Middle Ordovician limestones and shales (Galena and Platteville). Both of the sandstones just designated are regarded by Calvin as St. Peter, and he has suggested that the 52 feet intervening between them represent an ancient cavern in the St. Peter, now filled with shale and limestone broken down and washed in from the overlying Galena and Platteville.[1]

Water is pumped to an elevated tank and distributed under a gravity pressure of 42 pounds through the mains to 22 hydrants and 150 taps. The consumption is 20,000 gallons daily.

Postville Junction.—The Chicago, Rock Island & Pacific Railway Co. has a track well at Postville Junction the depth which is 361 feet and diameter 8 inches. Its curb is 1,033 feet above sea level. According to the driller's log, the well passes through drift and Galena dolomite, Decorah shale, and Platteville limestone from the surface to 340 feet and the St. Peter sandstone from 340 feet to 361 feet.

Waukon.—Two artesian wells 30 feet apart, drilled by Palmer and Sanbo in 1896 and 1897, supply the city of Waukon (population, 2,025). They are 8½ inches in diameter, and 577 feet deep. The curb is 1,279 feet above sea level, and the water rises to 280 feet below the curb. The depth of the wells indicates that they end in the Jordan sandstone. No diminution in yield has been observed in either well, nor has either been overdrawn by pumping. From the last drilled well alone the pump lifts, if necessary, 3,000 gallons an hour. The average consumption is 21,600 gallons a day, the maximum summer consumption reaching 28,800 gallons. Water is pumped to a standpipe 102 feet high and is delivered under gravity pressure through 6½ miles of mains to 65 fire hydrants and 230 taps.

A well drilled by the Missouri Iron Co. about 3 miles north of Waukon reaches a depth of 396 feet, with a diameter of 10 inches. Water rises to within 137 feet of the surface. The temperature is 52° F. The cost of drilling was $3.50 per foot. Casing extends to 250 feet. The drillers were Walch & Bahr of La Crescent, Minn.

The log of the drillers is as follows:

Driller's log of well of Missouri Iron Co., near Waukon.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay	23	23
Sandstone (St. Peter)	27	50
Limestone (Shakopee)	76	126
Sandstone (New Richmond)	15	141
Limestone (Oneota)	35	176
Gravel (Oneota)	10	186
Limestone (Oneota)	161	347
Sandstone (Jordan)	49	396

[1] Am. Geologist, vol. 17, 1896, pp. 195-203.

Village supplies.—The following table gives data of village supplies in Allamakee County:

Village supplies in Allamakee County.

Village.	Nature of supply.	Depth.	Depth to water bed.	Head below curb.
		Feet.	*Feet.*	*Feet.*
Harpers Ferry	Driven wells and springs, both large and small	45–55	50	40
Dorchester	Springs, open, driven, and drilled wells	12–70		12 to 16
Maud	Drilled wells	50–200		40 to 150
Elon	Cisterns, springs, and wells	100–325	300	285
Church	Cisterns and wells	290–350		

WELL DATA.

The following table gives data of typical wells in Allamakee County:

Typical wells of Allamakee County.

Owner.	Locality.	Depth.	Diameter.	Depth to rock.	Depth to water supply.	Source of supply.	Head below curb.	Remarks (logs given in feet).
		Feet.	*Inches.*	*Feet.*	*Feet.*		*Feet.*	
E. Cooper	6 miles northeast of Lansing.	340		40				Clay, 40; lime rock, 160; sand rock, 100; lime rock, blue, 40.
County Farm	Near Waukon.	600		30	400 500		240	Clay, 30; blue "scale rock," 370; sand rock, yellow, water bearing, 30; blue lime rock, 70; sand rock with water, 100; black clay.
F. M. Ivorson	5½ miles southwest of Dorchester.	30	1¼		15	River sand		River bottom; driven well.
I. M. Ivorson	6 miles southwest of Dorchester.	30	1¼		10	...do...	20	River bottom; driven well.
Erick Gavle	4 miles northeast of Sattre.	90	6	20	60	Rock	30	Valley; about 20 feet above river.
M. O. Nelson	7 miles east of Locust.	407	6	20	390	Sandstone[a]	388	Hill; 400 feet above river.
P. Oleson	6½ miles east of Locust.	250	6	8	35	Limestone	220	Can be pumped dry.
William Nelson	6½ miles southeast of Locust.	245	6	9	40	...do...	210	Hill; 250 feet above river.
Hans Quanrude	6 miles east of Locust.	365	6	10	350	Sandstone.	335	Hill; 375 feet above river
Henry Rink	NW. ¼ sec. 26, T. 100 N., R. 5 W.; on Wheatland Ridge.	510		40			285	Clay, 40; limestone, 135; sandstone, 100; blue shale, 200; sandstone, 35. Another water vein at 260 feet.

[a] Another water bed at 260 feet.

Typical wells of Allamakee County—Continued.

Owner.	Locality.	Depth.	Diameter.	Depth to rock.	Depth to water supply.	Source of supply.	Head below curb.	Remarks (logs given in feet).
		Feet.	*Inches.*	*Feet.*	*Feet.*		*Feet.*	
D. O'Maily	8 miles south of Dorchester.	310		15			160	Clay, 15; limestone, 170; sandstone, 125.
Henry King	6 miles southeast of New Albin.	542		75	530		217	Top of ridge, about 1 mile from edge of bluffs. Clay, etc., 75; limestone, 225; sandstone, 30; blue rock shale, 200; sandstone, water bearing, 12.
M. F. Collins	3½ miles north of Harpers Ferry.	242	6	18			300	Ridge.
Chicago, Milwaukee & St. Paul Ry.	Postville	85				Gravel		Water bed gravel; penetrated blue-black till.
Creamery	Postville	150		65			115	
Dickson Bros	NW. ¼ SW. ¼ sec. 21, T. 96 N., R. 5 W.	244	6¼	40	190 and 242	Platteville and St. Peter.	169	Clay, 40; dolomite, 55; limestone, 120; shale, 28; St. Peter sandstone, 1. Platteville vein, weak. Temperature, 48° F.
John Laud	NE. ¼ SE. ¼ sec. 32, T. 96 N., R. 5 W.	276			260 and 273		244	Clay, 20; shell rock, 10; dolomite, 50; limestone, 150; shale, 45; St. Peter, 1. Chief supply at 273 feet.

BLACKHAWK COUNTY.

By M. F. Arey and W. H. Norton.

TOPOGRAPHY.

Blackhawk County, which lies immediately west of and in the same range with Buchanan County, is crossed diagonally by Cedar River. Its surface is made up chiefly of the valleys of Cedar and Wapsipinicon rivers and their larger tributaries, and the plains of Iowan drift which lie between and on either side of these valleys. Low bluffs rise near the south side of West Fork of Cedar River, and also along the south side of Beaver Creek at a varying distance from the streams; they increase in height eastward and merge into the higher and more precipitous bluffs of the Cedar. At Cedar Falls the bluffs sweep away from the river, leaving a level area on which the older part of the city is built. Below the mouth of Dry Run they gradually recede from the river and lose their height and steepness of slope. Beyond Waterloo they maintain a distinct line between the valley and the drift plain for many miles, though at a considerable distance from the river and with marked diminution in altitude.

Between Cedar Falls and Waterloo the Kansan drift features are manifest in rounded hilltops crowned with loess, though Iowan drift appears in thin veneerings in the immediate neighborhood, and many round granitoid bowlders are seen.

Outside of the region mentioned the Iowan drift plain constitutes the surface of the greater part of the townships of Cedar Falls, Orange, Cedar, and Big Creek, and the whole of Blackhawk, Lincoln, and Eagle. The last three townships are remote from the river, and, except in the narrow, sinuous channels of a few small streams, show scarcely a scar upon their surface.

North and east of the Cedar the valley plain rises very gradually and as a rule imperceptibly to the general level of the drift plain. It is for the most part 3 or 4 miles wide, level, and sandy and was once wood clad, but now much of it has been deforested. Nearly every part of the valley proper has been traversed at some time by the river and many large oxbows are still connected with it at ordinary stages of the water. Narrow, curved bodies of water, locally known as lakes, some of which, as in Cedar Township, are 2 to 3 miles long and are connected more or less completely, plainly indicate former channels. Depressions of every size, but all similar in shape and trend, are remarkably abundant. At the time of freshets the river not only fills the old channels but also occupies much of the intervening valley.

A short distance from the place where the Cedar leaves the county its valley narrows; it is also noticeably constricted at Waterloo. In the northeastern part of the county the entire townships of Union and Washington are in the valleys of the Cedar and its tributaries. The topography of Union Township differs materially from that of any other. The winds seem to have had an unimpeded sweep previous to its settlement and to have gathered the sand into dunes of considerable height and extent. The poplars, bur oak, and other trees and shrubs of similar habitat have taken possession of many of these dunes, and all are now covered with vegetation of some kind.

The drainage of the county is accomplished almost wholly by the Cedar River system, though the Wapsipinicon, with its tributary, Crane Creek, cuts across the northeast corner.

The Cedar is formed by the union of three nearly equal streams—the Cedar from the north and east, the Shell Rock from the northwest, and the West Fork from the west. The Shell Rock and the West Fork, however, unite a mile above their junction with the Cedar. From the latter point, which is within 1½ miles of the north line of the county, the Cedar flows for 4 or 5 miles nearly south, then southeast to Gilbertsville, whence it again goes southward for 4 or 5 miles, finally bending to the southeast and keeping that direction till it leaves the county. Except for short distances below the dam at Cedar Falls and at Waterloo, its bed is in unconsolidated material. Indurated rocks outcrop in but few places along its banks, even the high bluffs in the neighborhood of Cedar Falls and Waterloo being apparently made up wholly of drift material.

From the west the Cedar receives Beaver, Dry Run, Blackhawk, Miller, Big, and Rock creeks; from the east, Elk, Indian, and Spring creeks. It is noteworthy that each of these streams approaches the Cedar at nearly a right angle, in marked contrast with the tributaries of the Wapsipinicon and the Iowa. The basin of the Cedar is therefore proportionately much wider than that of either of the other rivers named. The headwaters of Spring and Elk creeks are within 2 miles of Wapsipinicon River and Crane Creek, respectively; the Blackhawk takes its rise within 5 or 6 miles of the Iowa.

GEOLOGY.

The geologic formations of Blackhawk County are comparatively simple. Heavy deposits of Kansan drift covered by a thin veneer of Iowan drift and in places the intervening Buchanan gravel conceal the hard rocks in the northeastern and southern parts of the county. Rock is exposed mainly along the margins of the valley of the Cedar or outcrops in the banks along the lower courses of its tributaries.

Except in a small area in the southwest corner of the county, where the drift probably rests on rocks belonging to the Kinderhook group (basal Mississippian), and a small area in the eastern part of Fox Township, where it overlies the Wapsipinicon limestone (Middle Devonian), the drift in Blackhawk County is underlain by the Cedar Valley limestone (Middle Devonian). The rock is everywhere limestone, though in places very shaly or earthy. The total thickness of the Cedar Valley limestone in the county is not less than 75 feet. The rock is for the most part thin bedded, soft, and much jointed and serves as a very good water bearer.

UNDERGROUND WATER.

SOURCE AND DISTRIBUTION.

Except at Waterloo and Cedar Falls the water supply of Blackhawk County is obtained from the Buchanan gravel, the Cedar Valley and Wapsipinicon limestones, and the Kansan drift. On the farms pumps are universally operated by windmills. Flowing wells are rare.

In the valley of Wapsipinicon River, which is confined to the eastern half of Lester Township, the northeastern township of the county, the alluvial deposits are everywhere underlain by gravels, which vary somewhat in fineness and in thickness but which almost everywhere afford satisfactory supplies of good water to comparatively shallow wells. The village of Dunkerton, in sections 29 and 32, gets its water supply wholly from driven wells ending in these gravels. Norton reports two flowing wells on the slopes of the river bottom. One, the well on H. Flattendorf's place, flowed up to 1905; the other, on William McGee's place, still flows. The depth of these wells is not known.

On the Iowan drift plain lying between the Wapsipinicon Valley and Cedar River valley in the north tier of townships and in general in all that part of the county east of the Cedar River valley a few wells end in sand or gravel beds or streaks within the Kansan drift, but by far the greater number end a short distance within the underlying Cedar Valley limestone. The wells range in depth from 85 to 300 feet.

A well on Clubine's place, 2½ miles north of Dunkerton, on high ground near the edge of the Wapsipinicon River bottom, is 274 feet deep and ends in sand. In a well in section 21 rock was reached at 140 feet.

Near the Bartlett quarry in East Waterloo Township, on the bluffs just back from the river bottom, where the thickness of the limestone is unusually variable, wells are about 100 feet deep, the depth in rock ranging from 60 to 90 feet. Water is found just below the blue limestone.

On a small creek called Rock Run, 2½ miles east and 1½ miles north of Waterloo, two flowing wells, 109 and 87 feet deep, are reported by Mr. Purington, a pump dealer of Waterloo. Both end in coarse gravel without reaching rock.

In the immediate neighborhood of the flowing wells northeast of Waterloo are several springs. Probably springs and wells have a common source in the Cedar Valley limestone.

In Fox and Spring Creek townships rock outcrops along the slopes of Spring Creek valley up to the prairie level in many places, making it necessary for the farmers to drill all their wells.

On the wide river bottom of the Cedar most of the wells are driven, are about 18 feet deep, and end in the Buchanan gravel. The depth of the wells depends on the surface elevation, the water being found at about the level of the water in the river. Some wells on the river bottom must penetrate the blue limestone before obtaining an adequate supply of water.

At Westfield, in section 22, West Waterloo Township, a 15-inch well gives the following section:

Section of well at Westfield.

	Thickness.	Depth.
	Feet.	*Feet.*
Sand	14	14
Gravel (Buchanan)	½	14½
Clay, light blue	18	32½
Broken rock	7	39½
Limestone, porous (first vein, water not abundant)	9	48½
Limestone, firm (second vein)	30	78½
Limestone (third vein, water abundant)	28½	107

At Washburn, Cedar Township, wells 30 to 35 feet deep obtain a plentiful supply in sand. A mile and a half to the southwest is a well 60 feet deep, 12 feet in rock, and another 60 feet deep near by goes 30 feet into rock. Some wells in this vicinity are 100 feet deep. The water of these deeper wells is reported as disagreeable to the taste.

On Mr. Marble's place, half a mile east of the packing house at Waterloo, the well is 44 feet deep, 30 feet being in a very hard, compact limestone that is unusual in this county. The water rises within 14 feet of the surface.

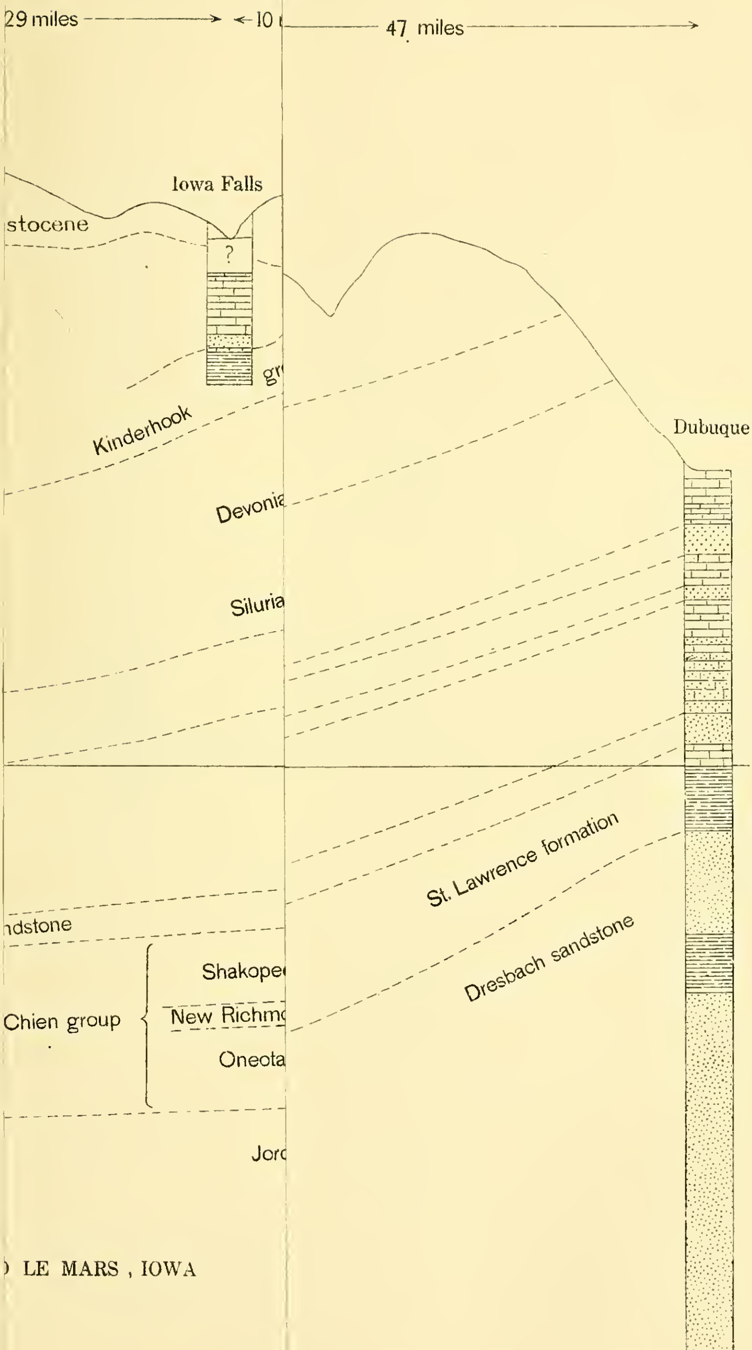
The city well at La Porte obtains its supply from the Buchanan gravel, not entering rock. As La Porte is 812 feet above sea level (Chicago, Rock Island & Pacific Railway track elevation), an artesian well 1,400 or 1,500 feet deep should yield water that will rise 10 to 20 feet above the surface. The Maquoketa shale will be reached at a depth of about 300 feet, the Galena dolomite at 550 feet, the St. Peter sandstone at 930 feet, and the Jordan sandstone at 1,300 feet. Such a well should be sunk to the bottom of the Jordan, which is about 1,450 feet below the surface.

The area southwest of Cedar River is a typical Iowan drift plain, crossed diagonally by the shallow valley of Blackhawk Creek. Limestone outcrops in the immediate neighborhood of Cedar Falls, Waterloo, and La Porte, and in a limestone ridge in sec. 24, Eagle Township. Everywhere else the rock is deeply buried beneath the drift materials.

Wells in this area range in depth from 60 to 250 feet. A few derive their supply from sand or gravel beds within the drift, but most enter the rock from 2 to 12 feet, and exceptionally penetrate rock to a depth of 20 to 60 feet. In the southwest half of this area, making due allowance for differences of surface level, the underlying rock surface is fairly uniform, but in the northeast half it varies much more. Most of the water is reported as good, but one well driller, whose experience is mainly in the southwest half, reports considerable diversity in its quality.

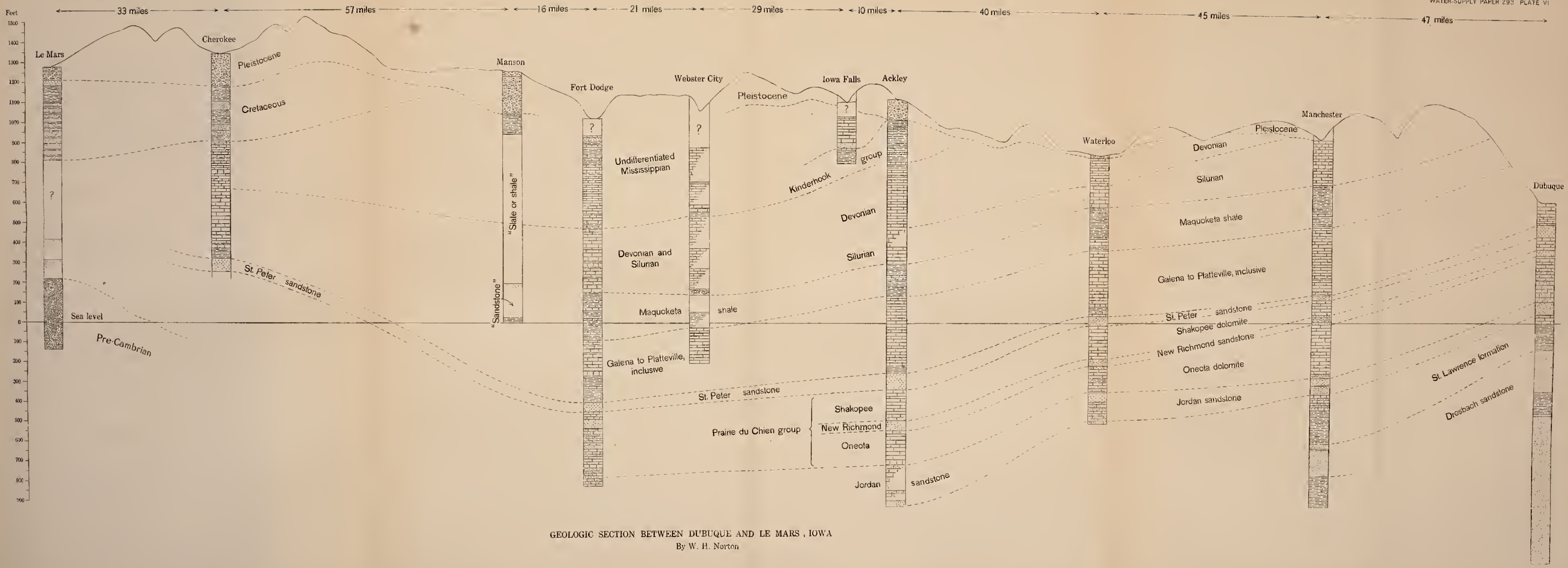
In Waterloo Township, in the W. ½ sec. 22, at the old Hummel place, 60 feet of quicksand was passed through below 100 feet of clay. Water was obtained, but the supply did not prove permanent.

In Orange Township, at the county poor farm (NE. ¼ sec. 3), where the surface elevation is about 100 feet above the river bottom, the well is 175 feet deep, 110 feet being in clay and 65 feet in limestone, where the second vein yields water plentifully. A well near by is 139 feet deep, 100 feet of which is in limestone. One mile west of the poor farm, on N. Miller's place, at about the same surface level, the well is 115 feet deep, 10 feet being in rock. All these wells yield unfailing supplies.



) LE MARS, IOWA

THE NORRIS PETERS CO., WASHINGTON, D. C.



GEOLOGIC SECTION BETWEEN DUBUQUE AND LE MARS, IOWA
By W. H. Norton

THE NORRIS PETERS CO., WASHINGTON, D. C.

CITY AND VILLAGE SUPPLIES.

Cedar Falls.—The water supply of Cedar Falls (population, 5,012) is now taken from wells, but was, until recently, obtained from springs in fissured Cedar Valley limestone in Dry Run, a mile from the post office.

A sudden epidemic of typhoid fever occurred in the city in the fall of 1911, during which more than 100 persons were afflicted and nearly 20 died. It was the opinion of three independent investigators that the city water supply had become infected and was the cause of the epidemic. The limestone from which the water issues is exposed in the beds of Cedar River and of Dry Run and is covered throughout a greater part of the city by a mantle of coarse gravel only 5 to 15 feet thick. Many cesspools and wells enter the limestone and thus afford opportunity for contamination, as the rock is broken and full of crevices and water channels that allow free circulation of water without filtration.

The abandonment of the springs was recommended and a new supply sought.

After careful consideration, an experimental well was sunk at the pumping station, passing through 38 feet of alluvium, sand, and gravel, then through 78 feet of limestone, heavy bedded for the most part, though shaly for the lower 14 feet. At a depth of 116 feet a copious supply of water was encountered, rising within 11 feet of the well mouth. A galvanized iron cylinder was inserted through the alluvial filling well into the rock. Within this cylinder an 8-inch casing was carried to within 14 feet of the bottom of the well, or to the shaly limestone, which is the aquifer. Water was pumped for 24, 36, and 48 hour periods at the rate of 500 and 600 gallons per minute without being lowered except for 4 feet at the starting of the pumps. At the time of high water, when the spring water taken at the station was turbid, the water of the well remained clear. The well water, however, is disinfected by calcium hypochlorite as an additional protection.

As a result of this experiment, two similar wells were sunk, No. 2 at a distance of 20 feet from No. 1, and No. 3 at a distance of 40 feet from No. 2.

The city is installing a pumping engine with a capacity of 2,000,000 gallons daily, against a pressure of 90 pounds per square inch. The wells are so connected with the main suction pipe that one or more can be used at any one time.

Waterloo.—The city of Waterloo (population, 26,693) obtains its supply from deep wells, 1,373, 1,377, and 1,365 feet deep. (See Pls. VI, VII.) Prior to the drilling of these wells the water supply had been drawn from Cedar River and treated by mechanical filtration. In 1903 and 1904 a severe epidemic of typhoid fever was traced to the contamination of the water supply by sewage from a town situated up the valley, filtration having failed to destroy the microorganisms of the disease. The city officials then asked the United States Geological Survey and the Iowa Geological Survey for information as to other possible sources of supply, and W. H. Norton was detailed to make an investigation. In his report[1] a hypothetical geologic section at Waterloo was given, which is reproduced here with a parallel column showing actual depths at which the formations were encountered by the drill.

Hypothetical and actual geologic section at Waterloo.

	Estimated thickness.	Estimated depth of base.	Actual depth of base.
	Feet.	*Feet.*	*Feet.*
Limestone and shales (Devonian)	125	125	158
Limestone (Silurian)	135	260	265
Shale (Maquoketa)	165	425	480
Limestone (Galena and Platteville)	410	835	815
Sandstone (St. Peter) (50 to 100 feet)	80	915	862
Shakopee, New Richmond, and Oneota	400	1,315	1,205
Sandstone (Jordan)	100	1,415	(?) 1,362

The report stated that an experimental well, 1,400 feet deep, would test the capacities of the chief zones of flow, and the city officials were advised to carry the experimental boring as much farther as necessary to test the capacity of the Dresbach and underlying Cambrian sandstones. The head was estimated at between 20 and 30 feet and the discharge from a 6-inch well at between 100 and 300 gallons per minute. The Waterloo Water Co. had such confidence in the artesian resources available that, instead of sinking an experimental well of small diameter, an 8-inch well was put down to a depth of nearly 1,400 feet. As the capacity was found to be 290 gallons under natural flow and 700 gallons under the pump, it was decided to carry the drilling no deeper to explore the Dresbach and underlying sandstones, but to drill at once a second well of about the same dimensions. The two wells together yield under the pump, 1,550 gallons per minute.

Detailed information concerning these wells follows:

Well No. 1 has a depth of 1,373 feet and a diameter of 20 inches at top, 8 inches at bottom; casing, 35 feet of 20 inch, 106 feet of 15 inch, 284 feet of 9 inch, and 122 feet of 7 inch, making a total of 547 feet from the surface. The curb is 847 feet above sea level and the head 20 feet above curb. The well flows 290 gallons per minute; its tested capacity is 700 gallons per minute. The water first overflowed, from a depth of 840 feet, and very slightly increased between this and next strong flow at 1,360 feet. Temperature in August, at well mouth, 56° F. The well was completed in 1905 at a cost of about $6,000 by W. H. Gray & Bro., of Chicago.

[1] Contributions to the hydrology of the eastern United States: Water-Supply Paper U. S. Geol. Survey No. 145, 1905, pp. 148–155.

Record of strata in Waterloo Water Co.'s well No. 1 (Pl. VI, p. 258; Pl. VII, p. 272).

	Thickness.	Depth.
	Feet.	*Feet.*
Quaternary (30 feet thick; top, 847 feet above sea level):		
Surface deposits; no samples	30	30
Devonian (128 feet thick; top, 817 feet above sea level):		
No samples	70	100
Limestone, light brown, hard, very fine grained; rapid effervescence, some chips brecciated, fragments brown, matrix yellow, facies of Wapsipinicon limestone, considerable sand, and yellow limestone from above	5	105
Limestone, blue gray, rough, vesicular, and drab, hard, dense; both of rapid effervescence	7	112
Limestone, buff, porous, mottled; rapid effervescence	14	126
Chert, gray and black, and limestone, yellow; rapid effervescence; some gray sandstone of fine rounded grains at 136 feet; 2 samples	17	143
Limestone, light gray; slow effervescence; soft, with dark flint and sandstone as above; residue of limestone chips, highly argillaceous, with particles of translucent gray flint, rounded grains of fine quartz sand and grains of pyrite; 2 samples	15	158
Silurian (107 feet thick; top, 689 feet above sea level):		
Niagara dolomite—		
Dolomite, blue gray, hard, porous, pure, crystalline; in small chips	12	170
Dolomite, as above, with shale, light blue gray, calcareous	60	176
Dolomite, blue gray, crystalline; some shale and some fragments of mottled sandstone from above	10	186
Dolomite, blue gray	14	200
Dolomite, light blue gray, rough, siliceous, vesicular; with cavities lined or filled with crystalline quartz	5	205
Dolomite, in fine meal; light yellow, almost white, highly argillaceous; residue shows much cryptocrystalline quartz in flakes and some particles of crystalline quartz	5	210
Dolomite, blue gray, rough, crystalline, siliceous, and cherty; 2 samples	20	230
Dolomite, light yellow gray, finely saccharoidal; 2 samples	10	240
Dolomite, gray; in sand	5	245
Dolomite, light yellow gray, argillaceous, and siliceous; minute grains and particles of quartz; 3 samples	20	265
Ordovician:		
Maquoketa shale (215 feet thick; top, 582 feet above sea level)—		
Shale, greenish blue and drab; in concreted masses; calcareous; at 425 traces of buff dolomite; 21 samples	165	430
Dolomite, crystalline, buff and brownish gray; in chips and sand; 3 samples	35	465
Shale, drab, concreted powder, calcareous; 2 samples	15	480
Galena limestone to Platteville limestone (335 feet thick; top, 367 feet above sea level)—		
No samples	15	495
Limestone, light yellow gray; thin flakes, earthy; rapid effervescence	15	510
Limestone, argillaceous, rapid effervescence; in white powder; 6 samples.	95	605
Limestone, soft, buff, and chert, yellow; drillings chiefly chert	11	616
Limestone, light gray; rapid effervescence; argillaceous; 7 samples	149	765
Shale, light green gray, highly calcareous (probably Decorah shale)	20	785
Limestone, soft, brownish and gray	30	815
St. Peter sandstone (47 feet thick; top, 32 feet above sea level)—		
Sandstone; white, rounded grains	47	862
Prairie du Chien group—		
Shakopee dolomite (168 feet thick; top, 15 feet below sea level)—		
No sample	11	873
Dolomite, gray and white, hard, crystalline; in chips; much clear quartz sand, largest grains 0.8 millimeter in diameter	17	890
Dolomite, pink, vesicular; considerable quartz sand in drillings	10	900
Dolomite, gray; with much quartz sand in drillings but no grains found embedded in dolomite	63	963
Dolomite; buff, cherty, almost free from quartz sand	17	980
Dolomite, gray; in chips; sparingly arenaceous	30	1,010
Dolomite, gray; in fine chips with some quartz sand	20	1,030
New Richmond sandstone (30 feet thick; top, 183 feet below sea level)—		
Sandstone, white; well-rounded grains; largest grains 1.5 millimeters in diameter	15	1,045
Dolomite and sandstone, gray; much quartz sand in fine rounded grains	15	1,060
Oneota dolomite (145 feet thick; top, 213 feet below sea level)—		
Dolomite, gray and blue; cherty in places; 4 samples	65	1,125
Marl, in light yellow-gray powder; very large residue of minute particles of quartz	25	1,150
Dolomite, light buff; some white chert	20	1,170
Marl, in finest yellow-gray meal; very large residue of minute particles of chert	15	1,185
Dolomite, yellow gray, highly cherty	20	1,205
Cambrian:		
Jordan sandstone (157 feet thick; top, 358 feet below sea level)—		
Sandstone, yellow gray; grains rounded; largest 0.5 millimeter in diameter; in loose sand and in small chips of buff calciferous sandstone	15	1,220
Sandstone, gray; largest grains about 1.5 millimeters; in loose sand, with some chips of soft, very fine-grained bluish sandstone	15	1,235
Sandstone, gray; clean rolled grains, largest 1 millimeter in diameter	18	1,253

Record of strata in Waterloo Water Co.'s well No. 1 (Pls. VI, VII)—Continued.

	Thickness.	Depth.
Cambrian—Continued.		
Jordan sandstone—Continued.	*Feet.*	*Feet.*
Dolomite, highly arenaceous; in small chips and sand of fine rolled grains.	17	1,270
Dolomite, minutely arenaceous; in fine light yellow-gray powder; large residue of minute quartz particles	10	1,280
Dolomite, yellow-gray, minutely arenaceous; with considerable fine quartz sand in drillings	22	1,302
Dolomite, light gray, crystalline, vesicular, arenaceous; in chips	60	1,362
St. Lawrence formation (11 feet penetrated; top, 515 feet below sea level)—		
Dolomite, yellow gray	11	1,373

The Waterloo Water Co.'s well No. 2 is located about 1,600 feet from well No. 1. It has a depth of 1,377 feet and a diameter of 20 inches to about 201 feet, 10½ inches to 626 feet, and 8¼ inches to bottom; 20-inch casing to 139 feet 4 inches, 16-inch to 201 feet 2 inches, and 9-inch to 626 feet; hemp packing at 198 feet. The curb is about 847 feet above sea level and the head, 4 feet 5 inches below the curb. The tested capacity is 850 gallons per minute; temperature, 54° F. The well was completed in 1907 by W. H. Gray & Bro., of Chicago.

The Waterloo Water Co.'s well No. 3, recently drilled, has a depth of 1,365 feet and a diameter of 20 inches to 200 feet and of 12 inches to bottom; casing 200 feet of 20-inch and 660 feet of 12-inch, casing off the St. Peter. Temperature, 54° F. The well cost $11,000. It was drilled by the Whitney Well Co., of Chicago, in 1911.

BREMER COUNTY.

By W. H. Norton.

TOPOGRAPHY.

Topographically Bremer County is part of the wide Iowan drift plain of northeastern Iowa. Cedar, Wapsipinicon, and Shell Rock rivers cross it in three wide valleys cut 60 to 80 feet below the adjacent prairie levels. The broad alluvial floor of the Cedar is in places 2 and even 3 miles wide and is incised below its ancient gravelly flood plains, but the Wapsipinicon, whose valley is 1½ to 2 miles wide, still flows up to the level of the glacial outwash of its aggraded floor.

About Waverly and near Denver small insular areas of high loess-capped hills of Kansan drift, separated by intricate and deep ravines, overlook the Iowan drift plain.

GEOLOGY.

Nearly the whole of Bremer County is underlain by rocks of the Devonian system. Owing to local deformation the Niagara dolomite (Silurian) comes to the surface in two or three isolated areas. An ancient wide, rock-cut valley, now completely filled with drift, extends from north to south between the valleys of the Wapsipinicon and the Cedar, and in it the drill discovers beneath the drift the blue Maquoketa shale (Ordovician).

UNDERGROUND WATER.

SOURCE.

The ground-water beds of the county consist of alluvial sands and gravels on the flood plains of the rivers, sands at the base of the loess, lenses of sand included within the drift sheets, beds of sand and gravel parting the Iowan and Kansan drift sheets and separating the Kansan from the still earlier Nebraskan drift beneath it, sand resting on bedrock, broken layers of rock immediately underlying the drift, and indeterminate beds within the Devonian limestones.

DISTRIBUTION.

The lateral extent of the beds just named may be briefly stated. Alluvial sands and gravels are restricted to the valley floors of the larger streams. As a rule they furnish plentiful supplies for stock and for house wells, except on well-drained terraces which are remnants of ancient flood plains, now left some distance above the present stream by the downcutting of the channel. The towns of Plainfield and Horton in the valley of Cedar River are thus supplied.

Loess is restricted to an area extending southeast from Waverly to Denver, and in the northwestern part of this area is limited to isolated hills and groups of hills rising from the Iowan drift plain. In the southeastern part of the area it forms a continuous and heavy sheet mantling a deeply eroded upland of Kansan drift. This porous deposit acts as a sponge, absorbing water during rains and discharging it somewhat freely, both by evaporation and downward percolation in dry weather. But the supplies drawn from its basal silts and sands have not as a rule been found to be either permanent or large. Moreover, where the loess is thickest and most extensive it rests directly on clays of Kansan age with no intermediary gravels to furnish a reservoir. Even here, however, seepage wells that furnish sufficient water for house use or for small farms not carrying much stock can be had in favorable situations from the somewhat more porous silts at the base of the loess.

The loess passes downward into a yellow water-bearing sand about the margins of the Iowan drift plain and along the bases of the isolated hills about Waverly, but here there is no great extent of loess to act as an intake area, so that the supply must be small.

The several beds of sand and gravel associated with the drift occur throughout the county and form reliable and much-used water beds.

The Devonian is also nearly as extensive as the county. Where the drift is thick drillers report that in many localities water is found in the shattered surface rock broken in part by preglacial weathering. As the Devonian limestones are easily soluble well-opened waterways have been dissolved out along joints and bedding planes and in places connected with the surface by sink holes. Over a considerable area, where these limestones have been cut away by preglacial river erosion, wells depend entirely on water-bearing beds in the drift.

PROVINCES.

Wapsipinicon Valley.—The valley of Wapsipinicon River from Frederika south to the county line is a plain $1\frac{1}{2}$ to more than 2 miles wide, cut about 60 feet below the level of the adjacent prairie. (See fig. 3.) The ill-drained valley floor descends from the bases of the gentle slopes of the bordering hills by almost imperceptible degrees to the little river. From 10 to 20 feet of alluvial sands cover the surface, beneath which the drill finds, from Tripoli south, a stony clay 50 to 80 feet thick, the deposit of an ancient ice sheet, probably the Kansan. Underlying these impermeable beds lie water-bearing sands and gravels of unknown thickness, laid apparently on the floor of a preglacial or interglacial valley cut either in bedrock or in an older drift. As this water bed rises up the valley with the gradient and also on the valley sides, where no doubt it connects with glacial sands on the adjoining uplands, and as it is covered by heavy clays, the water it contains is under artesian pressure and wherever tapped gives rise to flowing wells. The same conditions obtain in the lower part of the valley of the East Wapsipinicon.

Although farmsteads are few on these valley floors, which, owing to their ill-drained condition, are used chiefly for pasture and grass land, and although the rivers themselves furnish a supply for stock, yet nearly all the farmsteads in the valley and several located some distance up the valley sides have obtained copious flows of palatable and pure artesian water.

The pioneer wells of this field were sunk more than 30 years ago, and the head of a number has diminished. The static level of some wells on the hill slopes has been so drawn down that they have ceased to flow, but the supply is still ample on all the bottom lands. It is usually wisely economized by discharge pipes not more than three-fourths of an inch in diameter. Some wells are plugged during the portion of the day when they are not in use.

The reported head varies considerably. The highest given is that of the J. J. Cook well, in the SE. $\frac{1}{4}$ sec. 1, T. 92 N., R. 12 W., in which the water rose to a height of 21 feet above the curb as measured in a pipe. This well is situated at the base of the bordering hill slopes, and the curb is several feet higher than that of other wells situated well out upon the valley floor. Among the latter, that of Christian Baker had a head of 30 feet; others are said to have heads as low as 10 feet.

It is reported that the head of wells on the upland between Wapsipinicon River and Buck Creek has distinctly lowered, in some wells as much as 10 feet, and this decrease has been attributed to the flowing wells of the adjacent valley.

The midsummer temperature of the wells flowing under greatest pressure, and hence least warmed in their pipes, is about 47° F.

Up the valley from Tripoli water rises nearly to the surface but does not overflow. The only well near Tripoli of which a section has been obtained shows alluvial sand and stony clay to 60 feet, underlain by 4 feet of sand from which water rises within 5 feet of the surface. Another well, $2\frac{3}{4}$ miles to the north, in the NW. $\frac{1}{4}$ sec. 18, T. 93 N, R. 12 W., found no blue stony clay but passed directly from 10 feet of yellow clay into gravel which became more and more coarse, till at 53 feet, the bottom of the well, its pebbles were larger than hen's eggs.

Buried channel of "Bremer River."—A ground-water province of special interest is defined by a deep preglacial buried valley which traverses the county from northwest to southeast through Douglas, Warren, Jefferson, and Maxfield townships. (See fig. 3.) Here numerous wells, from 200 to 273 feet deep, end in drift, thus failing to reach the rock floor of the ancient valley. The depth in rock to which the valley was cut is at least 220 feet, as shown by the elevation of outcrops $2\frac{1}{2}$ miles distant. In the southern part of the county the ancient fluvial floor lies at least 160 feet below the rock bed of Cedar River at Waverly, or at an elevation less than 765 feet above sea level.

The drift is heavy on both sides of this buried valley and particularly so on the east side, where few wells reaching rock are reported. The facts at hand warrant the belief that the valley is at least as wide as is that of the upper Iowa in Allamakee County, this valley being selected for comparison because it is a preglacial Iowa valley that is situated in the driftless area. The spacing of the deeper wells demands a width of at least $1\frac{1}{2}$ miles, and no data are at hand which negative an estimate of twice that width. Wells, by no means the deepest of the area, which enter rock encounter either the dry shales of the Maquoketa or a thin bed of Niagara dolomite. Beyond doubt at least the medium portion of the channel was cut in the Maquoketa shale, and in this weak rock a wide valley is to be expected.

As the valley floor is made for the most part of dry shale, wells which fail to find water in the drift are compelled to go to an exceptionally great depth to the limestones of the middle part of the Maquoketa or even to those of the Galena and the Platteville. The large majority of wells in this "deep country," as drillers term it, find water in the sand and gravel associated with the drift.

In Douglas Township the few wells reported which are referable to the channel find little or no sand so far as known, the channel here

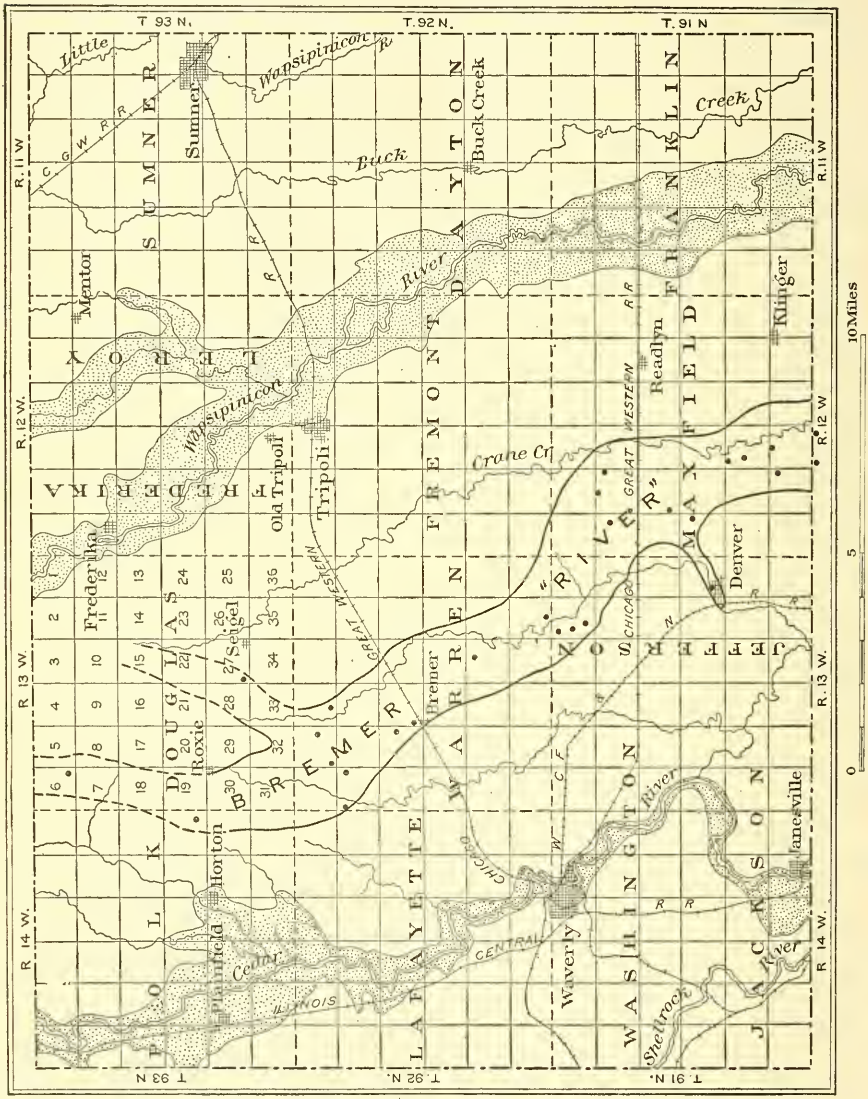


FIGURE 3.—Map of artesian field of Wapsipinicon River and of buried channel of Bremer River.

apparently being filled with blue stony clay. Two wells were compelled to go deep into rock for water, one in sec. 27 to 337 feet and one in sec. 6 to 266 feet. Both wells passed through the upper shale of the Maquoketa and found water in limestones referred to the middle Maquoketa, the shale in the first well being 87 feet thick overlain with 10 feet of Niagara dolomite, and in the second 60 feet thick overlain with drift.

In at least the northern part of Warren Township no continuous and heavy bed of sand is found in the channel, although a number of wells find water-bearing sands and gravels in the drift amply sufficient for farm supply. Thus in sec. 5 three wells find water-bearing sand at depths of 236, 150, and 92 feet, and in sec. 4 a well entering rock at 180 feet was compelled to go to 287 feet before obtaining a supply. In sec. 17 a well which enters the Niagara at 212 feet passes through 100 feet of shale (upper Maquoketa) before finding water at its base at 317 feet below the surface, no gravels or sands being here reported from the drift.

Where the channel crosses the northeast corner of Jefferson Township, wells find the stony clays of the Kansan (together with those perhaps of the Nebraskan) more than 200 feet in thickness. Here a water bed of sand and gravel is entered at about 200 feet and in one well was penetrated to a depth of 15 feet.

In Maxfield Township the channel seems to reach its greatest depth. Along it none of the deeper wells reach rock. The drill here passes through from 230 to 260 feet of yellow and blue clay before reaching water-bearing gravels whose depth is quite unknown. In some of these wells water rises to within 50 feet of the surface.

A little outside of the channel, in sec. 8 of Maxfield Township, two wells failed entirely to find water sands either in or beneath the drift, which here consisted of stony clays 190 and 170 feet thick. In the first well the drill entered limestone (Niagara), 3 feet thick, immediately below the drift, and thence passed through 300 feet of shale, the entire Maquoketa. Entering then the Galena limestone it was necessary before finding water to penetrate for 191 feet, making the total depth of the well 684 feet. In the second well on this section the drill passed through 285 feet of the Maquoketa shale and penetrated the Galena limestone 10 feet, the well being unfinished at date of writing.

The buried channel of "Bremer River" thus seems to differ from many similar "deep countries" in the absence of thick, continuous, and hence reliable water-bearing sands. The sinking of a well in this belt is therefore as much of an experiment as anywhere else in Iowa. The drill may strike water in one of the scattered lenses of sand within 100 feet or may be compelled to go 200 feet and more to the main water-bearing sand. Even this may fail, and the drilling, if continued, must be carried at least to the limestones of the middle Maquoketa and possibly even deep into the Galena. Fortunately, wells are uncommon in which water is not found in gravels within at least 270 feet of the surface.

CITY AND VILLAGE SUPPLIES.

Denver.—Waterworks at Denver (population, 224) were built in 1907 with supply from a well 132 feet deep. The log of the well is as follows:

Log of city well at Denver.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, yellow	18	18
Clay, blue	70	88
Quarry rock to water	28	116

Water is pumped to an elevated tank and thence distributed through 1,200 feet of mains. There are three fire hydrants. The house supplies are still obtained from wells which differ greatly in depth to rock and in depth at which water is found in rock. The drift gravels may or may not furnish an adequate supply. A buried channel, connecting with that of Bremer River, which runs a few miles east of the town, has largely cut away the Devonian and Silurian limestones, and wells in places may pass from the drift into dry Maquoketa shale. The following wells illustrate the various conditions:

Log of Clausing's well, one block from Main Street.

	Thickness.	Depth.
	Feet.	*Feet.*
Drift	66	66
Gravel and sand	10	67
Drift	86	162
Shale, blue (Maquoketa)	248	410

The Clausing well was a failure, but another well sunk on the same lot secured water in gravel at 90 feet.

Log of well on Main Street, a block from Clausing's well.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, yellow	12	12
Clay, blue, pebbly	30	42

Log of Henry Bauman's well, three blocks east of Clausing's well.

	Thickness.	Depth.
	Feet.	*Feet.*
Drift	120	120
Limestone	4	124
Shale, red, soft	8	132
Shale, blue	88	220

This well was a failure, but, the drill being moved 16 feet away, a successful well was secured with the following log:

Log of second Bauman well.

	Thickness.	Depth.
	Feet.	*Feet.*
Drift	120	120
Limestone (water bearing)	40	160

Frederika.—Frederika (population, 149) is situated on a rock bench covered with a veneer of alluvial sand and gravel 10 to 20 feet thick. Wells obtain water from the Devonian limestones at a depth of from 35 to 45 feet from the surface.

A hole drilled for the Pioneer Oil Co. in 1903, by L. Wilson & Co., of Chicago, Ill., was carried to a depth of 1,025 feet. The surface elevation at the hole is about 1,050 feet above sea level.

The strata penetrated are shown by the following section, based on the driller's log:

Record of strata in deep drill hole at Frederika.

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene	38	38
Devonian and Silurian (112 feet thick; top, 1,012 feet above sea level):		
Shale, blue	14	52
Shale, yellow	20	72
Limestone, blue	31	103
Shale, yellow	47	150
Ordovician:		
Maquoketa shale (166 feet thick; top, 900 feet above sea level)—		
Shale, blue	85	235
Limestone	65	300
Shale, blue	16	316
Galena limestone to Platteville limestone (349 feet thick; top, 734 feet above sea level)—		
Limestone, brown	51	367
Limestone, white	23	390
Limestone, dark gray	90	480
Limestone	97	577
Shale	23	600
Limestone	25	625
Shale, blue	32	657
Gumbo	8	665
Ordovician—Continued.		
St. Peter sandstone (52 feet thick; top, 385 feet above sea level)—		
Sandstone	52	717
Prairie du Chien group (308 feet thick; top, 333 feet above sea level)—		
Limestone, brown (Shakopee)	121	838
Sandstone (New Richmond)	45	883
No record	142	1,025
Limestone, brown (Oneota)	....	1,025

Plainfield.—Open and driven wells supply Plainfield (population, 288), which is situated on the terraces of the flood plain of Cedar River.

Readlyn.—At Readlyn (population, 227), wells drilled to a depth of 80 to 125 feet enter rock at about 80 feet. Drillers report the following succession of deposits:

Log of wells near Readlyn.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, yellow	60	60
Clay, blue	10	70
Clay, yellow to rock	10	80

Sumner.—The town of Sumner (population, 1,404) is supplied by an artesian well 1,770 feet deep, drilled by J. P. Miller & Co., of Chicago, in 1902. The well is 10 inches in diameter to 120 feet, 8 inches to 234 feet; 6 inches to bottom; casing to 730 feet. The curb is 1,054 feet above sea level and the head is 144 feet below curb. Water in the middle Maquoketa at 260 feet rose to 18 feet below curb; the temperature of this water was 51° F. Water was also found in the Galena at 420 to 660 feet, and in the Oneota at 1,086 feet, the lower waters heading 144 feet below curb. The well yields 200 gallons per minute with pump cylinder 204 feet below curb.

The strata penetrated are indicated by the following section of the city well at Sumner:

Record of strata in Sumner city well.

	Feet.
Pleistocene (128 feet thick; top, 1,054 above sea level):	
Sand and gravel, yellow	40
Gravel, coarse; pebbles in sample up to 3 inches diameter	41
Till, glacial, stony clay, drab; sandy at 90 feet; 7 samples	50–120
Devonian or Silurian (22 feet thick; top, 926 feet above sea level):	
Limestone; largely drab, fine grained, of Wapsipinicon type	128
Limestone, hard, light buff; of rapid effervescence; 2 samples	135–140
Limestone and shale; limestone, light, buff, of rapid effervescence; shale, drab; 2 samples	150–160
Ordovician:	
Maquoketa shale (220 feet thick; top, 904 feet above sea level):	
Shale, blue green, plastic, calcareous; 5 samples	170–220
"Hard rock" in driller's log at	230
Drift, sand, and gravel	235
Limestone, light blue gray; earthy luster, mottled, of rapid effervescence in cold dilute HCl, with much chert of same color; 4 samples	250–280
Limestone, soft, semicrystalline, gray; rapid effervescence; cherty; 1 sample containing crinoid stem; 3 samples	290–310
Shale; light blue green, calcareous; 5 samples	320–360
Galena limestone to Platteville limestone (344 feet thick; top, 684 above sea level):	
Limestone, blue gray; of rapid effervescence; 3 samples	370–390
Shale, calcareous, drab; 2 samples	400–410
Limestone, cream colored, soft; in thin flakes	410–420

Ordovician—Continued.

Galena limestone to Platteville limestone—Continued.

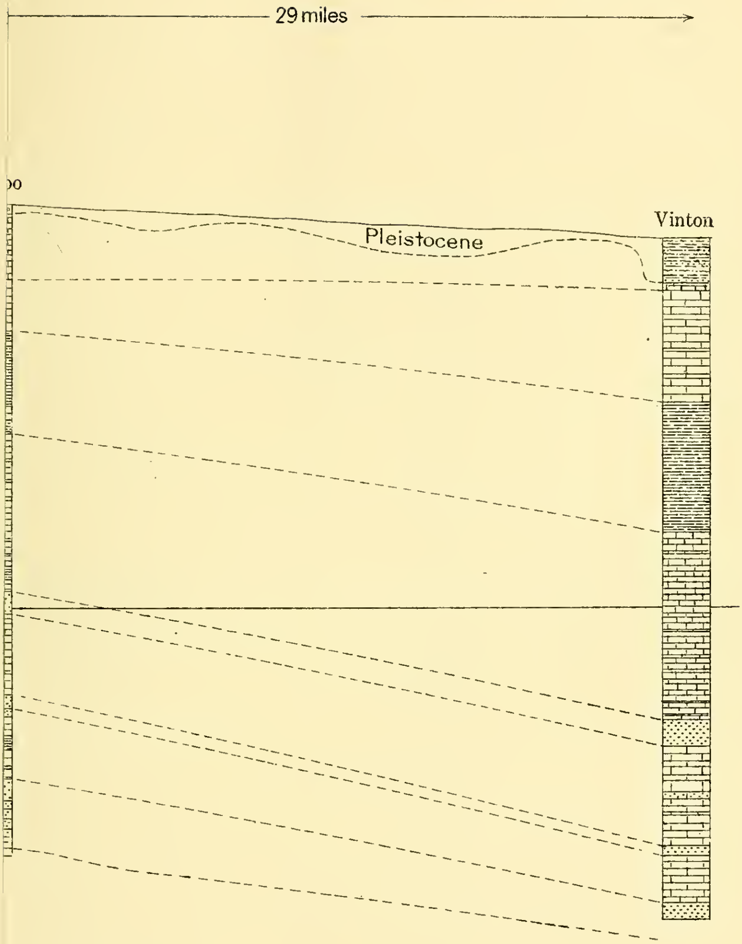
	Feet.
Limestone, light and dark gray; soft earthy luster; rapid effervescence; 21 samples	430–610
Limestone, dark blue, highly fossiliferous; 2 samples	640–650
Shale, bright green, plastic, slightly calcareous; 3 samples (probably Decorah shale)	660–668
Limestone, mottled gray, fossiliferous; rapid effervescence; 5 samples	678–710
Shale, bright green; highly fossiliferous at 665 and 710 feet; fragments with bits of characteristic fossil brachiopods, etc., occur in almost all the drillings from below	710–714
St. Peter sandstone (66 feet thick; top, 340 feet above sea level):	
Sandstone, of clean, white, quartz sand; grains well rounded, rather fine; at 720 feet some limestone chippings in the drillings; 5 samples	720–770
Prairie du Chien group:	
Shakopee dolomite (140 feet thick; top, 274 above sea level):	
Dolomite, white, gray, and light buff; in places cherty, crystalline; 7 samples	780–850
Dolomite, cream colored; much quartz sand in drillings	860
Dolomite, pink, arenaceous; with minute rounded grains of crystalline quartz; 2 samples	870–880
Dolomite, light buff and pinkish; 3 samples	890–910
New Richmond sandstone (40 feet thick; top, 134 feet above sea level):	
Sandstone and dolomite; drillings chiefly fine grains of quartz sand, but with chips of light-gray dolomite; 2 samples	920–930
Sandstone, fine grained, white; grains well rounded	940
Sandstone, white, and dolomite, gray	950
Oneota dolomite (200 feet thick; top, 94 feet above sea level):	
Dolomite, white or light gray; in places saccharoidal, in places with white chert; at 980 feet drillings contain considerable sand; 13 samples	960–1,080
Sandstone; of white clean quartz, grains well rounded; moderately fine	1,090
Dolomite, white and light-gray and buff; siliceous residues of finely divided quartzose matter; at 1,150 feet finely arenaceous; 3 samples	1,120–1,150
Cambrian:	
Jordan sandstone (120 feet thick; top, 106 feet below sea level):	
Sandstone, fine grained, white; grains of clear quartz, well rounded; 2 samples	1,160–1,170
Sandstone, as above, but coarser, largest grains 1 millimeter in diameter	1,180
Sandstone; 3 samples	1,210

	Feet.
Cambrian—Continued.	
Jordan sandstone—Continued.	
Indecisive; at 1,236 feet highly calcareous shale resembling Maquoketa; at 1,230 and 1,240 limestone, clearly Galena or Platteville and fallen in the boring; considerable quartz sand may have fallen from above but is the only material in samples in which the drill apparently could have worked; 3 samples	1,230–1,240
Sandstone, fine, white; Galena or Platteville limestone in the drillings; 2 samples	1,260–1,270
St. Lawrence formation (460 feet thick; top, 226 feet below sea level):	
Dolomite, highly siliceous; minute angular particles of crystalline quartz; in places green grains of glauconite; 13 samples	1,280–1,425
Shale, reddish, slightly calcareous	1,430
Shale, green slightly calcareous; 3 samples	1,440–1,460
Shale, green, fossiliferous, practically noncalcareous; minutely quartzose; 5 samples	1,480–1,520
Shale, bright and light green, highly arenaceous; minute grains of quartz; glauconiferous	1,530–1,550
Sandstone, gray, fine grained; glauconite grains	1,560
A few water-worn fragments of shale	1,570
Chiefly rusted chips of iron, from a fallen slush bucket, cut up by the drill	1,580
Sandstone, gray, fine grained	1,600
Shale, dark and bright green; minutely arenaceous and glauconiferous; 20 samples	1,610–1,620
Sandstone, fine grained; some greenish argillaceous material; dried blocks set after pouring from slush bucket are readily friable	1,630
Shale, light green, finely arenaceous, slightly calcareous, plastic	1,640
Marl, green, greenish yellow, or greenish gray; highly arenaceous with almost impalpable quartz grains; calcareous and argillaceous; glauconite present in round dark-green grains; some samples easily friable when dried, others more clayey and somewhat tenacious; 9 samples	1,660–1,740

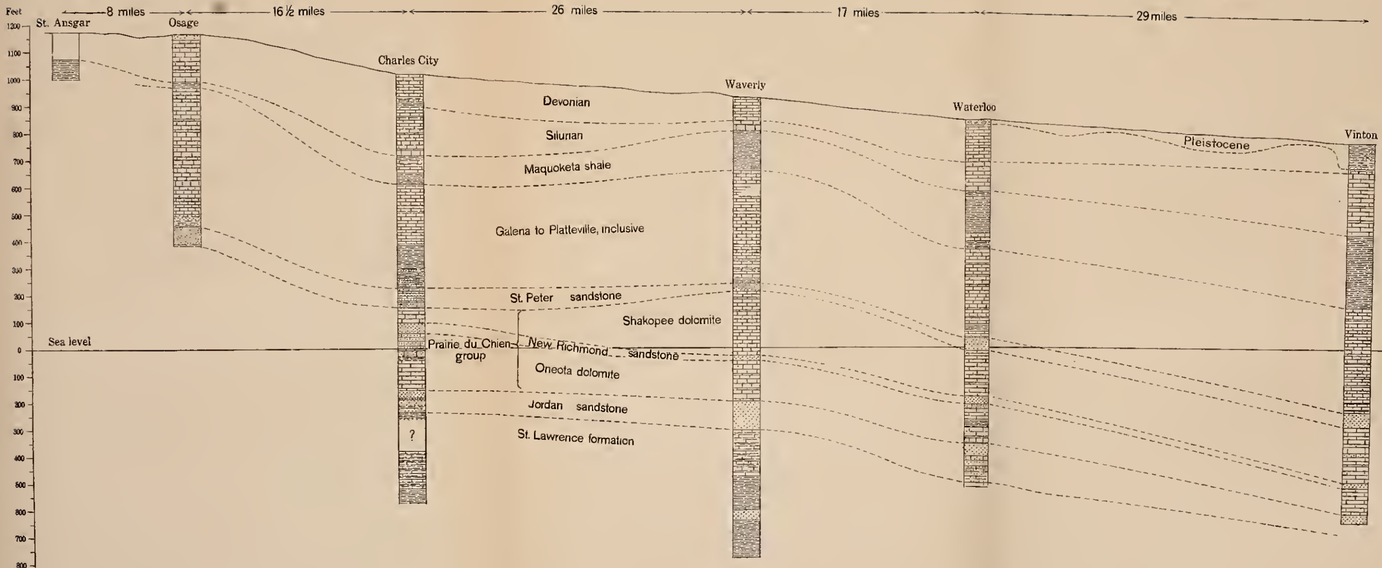
The water is distributed through 2½ miles of mains to 92 taps and 14 fire hydrants under 50 pounds pressure.

Tripoli.—The town of Tripoli (population, 755) is supplied from a well 113 feet deep, said to be capable of furnishing at least 70 barrels an hour. Water is distributed from a tank (capacity, 2,000 barrels) set on posts 90 feet high. There are 6,000 feet of mains, 16 fire hydrants, and 50 taps. Most wells in the village find water in gravel resting on bedrock.

Waverly.—The city of Waverly (population, 3,205) is supplied by an artesian well 1,720 feet deep, drilled in 1899 by J. P. Miller & Co., of Chicago. (See Pl. VII.) The well is 12 inches in diameter to a



THE NORRIS PETERS CO., WASHINGTON, D. C.



GEOLOGIC SECTION BETWEEN ST. ANSGAR AND VINTON, IOWA
By W. H. Norton

THE NORRIS PETERS CO., WASHINGTON, D. C.

depth of 15 feet, 10 inches to 100 feet, 8 inches to bottom, and is cased to a depth of 100 feet. The curb is 930 feet above sea level. The head was not tested, but the natural flow is 225 gallons per minute. Water was found at a depth of 730 feet (in the St. Peter), at 840 to 900 feet (in the Shakopee, first flow), and at 1,120 to 1,200 feet (in the Jordan). The temperature is 53° F.

The strata penetrated are shown by the following table:

Record of strata in city well at Waverly (Pl. VII, p. 272).

	Feet.
Devonian (70 feet thick; top, 930 feet above sea level):	
Limestone; buff, earthy	20
Limestone; light buff, earthy	30
Limestone; dense, hard, brittle, brownish drab and light buff, of finest grain and conchoidal fracture; rapidity of effervescence in cold dilute HCl indicated a very slight percentage of magnesium carbonate; facies of Wapsipinicon limestone	40
Limestone; as above, with a few chips of flint and some of light-yellow arenaceous limestone	50
Limestone; light buff, earthy, rapid effervescence	60
Silurian:	
Niagara dolomite (50 feet thick; top, 860 feet above sea level)—	
Dolomite or magnesian limestone; gray; earthy luster	70
Dolomite or magnesian limestone; in coarse chips, with flakes of bluish-white subtranslucent cryptocrystalline quartz	80
Dolomite or magnesian limestone, yellow gray; in fine sand	90
Dolomite; in large chips, gray; earthy luster, with cryptocrystalline silica	100
Dolomite or magnesian limestone, soft, blue, subcrystalline	110
Ordovician:	
Maquoketa shale (150 feet thick; top, 810 feet above sea level):	
Shale, blue; with small nodules of pyrite and fine sand of bluish limestone chippings	120
Limestone, soft, blue, saccharoidal, of brisk effervescence, pyritiferous	130
Shale, calcareous, bluish or greenish; 13 samples	140–260
Galena limestone to Platteville limestone (420 feet thick; top, 660 feet above sea level):	
Limestone, mottled, light and dark drab, fine saccharoidal, magnesian	270
Flint, light drab; in large chips; with blue-gray limestone, of rapid effervescence	280
Limestone, blue, gray; of rapid effervescence; soft, argillaceous, with considerable flint; 3 samples	290–320
Limestone, white, light gray and cream colored; in thin flakes; rather soft, somewhat argillaceous; luster earthy; effervescence rapid; 16 samples	360–590
Shale, green; with some fine chips of limestone	600

Ordovician—Continued.

Galena limestone to Platteville limestone—Continued. Feet.

Limestone, soft, earthy, nonmagnesian, light gray, fossiliferous 610

Limestone and shale; the latter green; two samples for this depth, one of limestone and one of shale, may represent the interval between 610 and 630 feet 620

Shale, green; in angular chips, with some chips of light-gray limestone, as above 630

Limestone, soft, earthy; with much green shale; 3 samples 640–660

Shale, green, bright, plastic; large pieces of dried clay cleaned from drill; 2 samples 670–680

St. Peter sandstone (30 feet thick; top, 240 feet above sea level):

Sandstone, white, soft; grains of pure quartz, moderately well-rounded and rather fine; 3 samples 690–710

Prairie du Chien group:

Shakopee dolomite (240 feet thick; top, 210 feet below sea level):

Dolomite, gray, cherty; with chips of white saccharoidal sandstone and much quartz sand 720

Dolomite, hard, crystalline, light gray and cream colored; in chips with much quartz sand; 3 samples 740–780

Dolomite, light, yellow gray; in chips mingled with much white sand 790–920

(Drillings said to have washed away because of overflow at 840 feet.)

Dolomite, white, crystalline, cherty; with much moderately fine quartz sand; 2 samples 930–940

Dolomite, cream colored 950

New Richmond sandstone (20 feet thick; top, 30 feet below sea level):

Sandstone, white, fine grained, calcareous cement; in small chips, with some pink dolomite and grains of sand 960

Dolomite, light gray, cherty, arenaceous 970

Oneota dolomite (150 feet thick; top, 50 feet below sea level):

Dolomite; mostly in clean sand and chips, vesicular, white, gray, pink; some cherty; 13 samples.... 980–1,120

Cambrian:

Jordan sandstone (110 feet thick; top, 200 feet below sea level):

Sandstone, white, soft; of clear quartz, grains rounded, general size of grains of last sample about 0.5 millimeter in diameter; 3 samples 1,130–1,150

Sandstone; drillings apparently consist in part of angular sand of light yellow dolomite, effervescing freely in hot HCl. Under the microscope it is seen to consist of minute angular grains of limpid crystalline quartz with calcareous cement; much of the drillings consists of rounded grains of white sand; 2 samples 1,160–1,170

	Feet.
Cambrian—Continued.	
Jordan sandstone—Continued.	
Sandstone; quartz, moderately fine and well rounded, with chippings of gray dolomite	1,180
Sandstone, calciferous; 2 samples	1,190–1,200
Sandstone, fine grained, white	1,210
Sandstone, calciferous; with some flakes of dolomite; 2 samples	1,220–1,230
St. Lawrence formation (480 feet thick; top, 310 feet below sea level):	
Dolomite, highly siliceous; with finely divided quartzose matter of angular particles, somewhat arenaceous; with bright green grains of glauconite; 4 samples	1,240–1,270
Chert and dolomite and siliceo-calcareous shale	1,280
Dolomite, highly argillaceous and siliceous	1,290
Dolomite, gray, siliceous; silica in form of minute angular crystalline particles constituting a large part of the rock; some green grains of glauconite; 5 samples	1,300–1,340
Shale, bluish green, slightly calcareous; 4 samples	1,410–1,440
Shale, pink, buff, and green, noncalcareous	1,450
Shale, blue green, somewhat indurated, noncalcareous; 8 samples	1,460–1,530
Sandstone; rather coarse grains, drillings contain clayey admixture and dolomite chips	1,540–1,580
Shale of various colors; yellow and dark-green set thickly with grains of red; arenaceous, with small, partly rounded quartz grains	1,590
Shale, blue green; with considerable red shale, probably from above; 9 samples	1,600–1,720

The water is pumped to a tank with a capacity of 60,000 gallons, and distributed through 8 miles of mains to 52 hydrants and 350 taps. Domestic pressure is 70 pounds, and fire pressure 125 pounds.

The excellent artesian supply has largely displaced the house wells of the town. Wells sunk before its introduction found water at varying depths. On the river terrace of Sturtevant's addition driven wells were used 15 to 20 feet deep. On the high hills of the first ward wells were sunk through loess and drift nearly 100 feet to rock. On the east side of the river a former channel of the Cedar is sounded by wells, which on the bottom lands of the fourth ward descend between 90 and 100 feet in river sand throughout, showing that the old rock floor lies scores of feet below the present rock-cut channel of the river through the town.

Waverly Junction.—At Waverly Junction (population, 80) wells range in depth from 30 feet (driven) to 100 feet (drilled). Rock is entered at 30 to 40 feet below the surface.

WELL DATA.

The following tables give data of typical wells in Bremer County:

Typical wells in Bremer County.

Owner.	Location.	Depth.	Depth to rock.	Head above or below curb.	Remarks (logs given in feet).
T. 93 N., R. 14 W. (POLK).		*Feet.*	*Feet.*	*Feet.*	
R. P. Black	NE. ¼ SE. ¼ sec. 3	75	40	....	
M. Carrier	SE. ¼ NE. ¼ sec. 4	139	115	124	Said to be flowing stream at bottom.
T. 93 N., R. 13 W. (DOUGLAS).					
J. Neuendorf	NE. ¼ SE. ¼ sec. 2	200	190	....	
J. H. Beam	NE. ¼ NW. ¼ sec. 3	200	170	....	
C. Zwanziger	SE. ¼ SE. ¼ sec. 6	266	200	....	Blue clay, 200; soft rock and shale (upper Maquoketa), 60; hard limestone (middle Maquoketa) 6.
Republic Creamery	NW. ¼ SW. ¼ sec. 9	180	178	....	
A. Biarmann	SE. ¼ SW. ¼ sec. 26	111	100	....	Creek bottom.
H. Winzenberg	SW. ¼ SW. ¼ sec. 27	220	49	....	Yellow clay, 30; blue clay, 19; limestone (Niagara), 10; shale (upper Maquoketa), 87; "sandstone" (perhaps sharp yellow sand cut from colomite of middle Maquoketa), 20.
L. Burgman	SW. ¼ SE. ¼ sec. 17	65	....	−10	
D. Moler	NW. ¼ NW. ¼ sec. 35	196	170	....	First rock struck a soapstone (shale) at 20; then 6 of gray rock containing water.
J. S. Leamon	1 mile SE. Dickey post office.	....	200	....	
T. 93 N., R. 12 W. (FREDERIKA AND PART OF LEROY).					
M. Collins	SW. ¼ sec. 5	100	80	....	
J. N. Johnson	SE. ¼ SW. ¼ sec. 6	53	13	....	
M. Mowatt	NW. ¼ NE. ¼ sec. 8	105	55	....	
J. Pinkerton	NE. ¼ NE. ¼ sec. 8	72	52	....	
W. J. Meier	SE. ¼ NE. ¼ sec. 8	100	92	....	
M. O. Connell	NW. ¼ NE. ¼ sec. 9	80	60	....	
F. Wolfgramm	NW. ¼ NW. ¼ sec. 16	97	91	....	
C. L. Rima	SE. ¼ SW. ¼ sec. 18	53	13	....	
F. Schultz	SE. ¼ NE. ¼ sec. 31	103	....	....	Yellow clay, 12; blue clay, 86; sand, 5; ends in sand.
C. F. Schwem	NW. ¼ NW. ¼ sec. 32	87	60	....	Yellow clay, 10; blue clay, 24; sand, 16; blue clay, 10; rock, 27.
C. E. Falcher	NW. ¼ NE. ¼ sec. 22	146	136	....	Upland. Yellow clay, 12; blue clay, 63; old ill-smelling soil, 20; blue clay, 41; rock, 10.
H. J. Pelton	NW. ¼ SE. ¼ sec. 1	190	....	−60	Upland. Yellow and blue clay; struck 25 feet of soft jumping clay, 156; water-bearing sand to bottom.
T. McConnell	NW. ¼ NE. ¼ sec. 3	73	....	−10	Close to East Wapsipinicon bottoms.
J. Leach	NE. ¼ NE. ¼ sec. 3	112	....	−40	All clay to water-bearing gravel at bottom.
I. H. Fay	NW. ¼ sec. 11	(?)	100	....	
F. H. Friedman	3 miles NE. Tripoli	230	....	+2	Ends in water-bearing sand; yields 10 gallons per minute.
John McQueeny	NW. ¼ NE. ¼ sec. 18	283	200	−50	Divide. Drift, 200; shale (upper Maquoketa), 60; lime rock (middle Maquoketa), 23.
A. Schmidt	NE. ¼ NW. ¼ sec. 18	222	220	....	Divide. Drift clays, 135; quicksand (fine dark gray), 60; blue clay, 25; soft shale (Maquoketa), 2.
W. B. Barnes	NW. ¼ NW. ¼ sec. 18	158	....	+4	Near foot of hill by Mentor Creek. Blue clay, 96; quicksand and wood, 60; coarse gravel and water, 2
E. Webster	NE. ¼ sec. 19	49	....	....	Water in gravel.

Typical wells in Bremer County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Head above or below curb.	Remarks (logs given in feet).
T. 93 N., R. 11 W. (SUMNER AND PART OF LEROY).					
		Feet.	*Feet.*	*Feet.*	
P. O'Connell	NW. ¼ NE. ¼ sec. 8	310	170	−80	High prairie. Yellow clay, 15; blue clay, 155; limestone, 140.
Creamery	SE. ¼ SE. ¼ sec. 5	128	116		
J. M. Jenks	SE. ¼ SE. ¼ sec. 9	153	147		
F. C. Krause	NE. ¼ NE. ¼ sec. 10	195	194		Blue clay, 194; limestone spalls, 1.
C. Shophonster	SW. ¼ SW. ¼ sec. 14	141	136		All clay to rock.
J. M. Jenks	NW. ¼ NW. ¼ sec. 15	120			Ends in 6 feet of sand.
H. Friend	SE. ¼ NE. ¼ sec. 17	116	112		
G. Hammetter	SW. ¼ sec. 21	138			Blue clay, 132; sand, 6.
T. 92 N., R. 14 W. (LAFAYETTE AND PART OF WASHINGTON).					
T. McCartney	SW. ¼ SW. ¼ sec. 2	56			
W. S. Grover	SE. ¼ NE. ¼ sec. 3	130	100		
W. Blasier	SW. ¼ NW ¼ sec. 4	(?)	29		Bottoms of Cedar River.
H. S. Bunth	NE. ¼ NE. ¼ sec. 10	(?)	130		Upland.
C. A. Kingsley	NW. ¼ sec. 17	80	80		Yellow clay, 15; blue clay, 65; white limestone, 80.
W. M. Colton	SE. ¼ NE. ¼ sec. 20	102	30		On upland. Drift, 30; limestone, 25; soapstone, blue soft (Independence shale member), 30; limestone, 17.
B. Bennett	SE. ¼ SW ¼ sec. 20	138	70		Yellow clay, 10; blue clay, 60; limestone, 44; shale gray (Independence), 10; limestone, 14, containing water.
E. Chase	NW. ¼ SW. ¼ sec. 21	130	30		Drift, 30; limestone, 50; limestone and shale, the latter in several beds 4 or 5 feet thick (Independence), 40; limestone, 10.
J. H. Bowman	Sec. 29	136	90		
J. Boglston	SE. ¼ NE. ¼ sec. 31	112	60		
M. Boglston	NW. ¼ sec. 32	112	70		
Wm. Cook	SW. ¼ SW. ¼ sec. 36	136	75		Drift, 75; limestone (Devonian), 45; shale (Independence), 2; limestone, 14.
T. 92 N., R. 13 W. (WARREN).					
L. Ladage	SW. ¼ SE. ¼ sec. 4	287	180		Water lowered on drilling of Wixenburg well, 2 miles north.
J. Wilkins	SW. ¼ NW. ¼ sec. 5	150			Ends in water-bearing gravel.
J. Alcock	SW. ¼ SW. ¼ sec. 5	92			Do.
Job Simmons	SE. ¼ NE. ¼ sec. 5	236			Not much sand in well.
W. B. Ingersoll	SW. ¼ SW. ¼ sec. 7	80			
L. Armstrong	NW. ¼ NW. ¼ sec. 7	201	196		
T. E. McCoy	SW. ¼ SE. ¼ sec. 7	385	(?)		
F. Pothast	SE. ¼ SE. ¼ sec. 17	317	212		Drift, 212; limestone, 5; shale, 100.
F. C. Pothast	SW. ¼ SW. ¼ sec. 16	352	210		Drift, 210; limestone, 5; shale, 135; sandstone with water, 2.
F. Lageshulte	NE. ¼ NE. ¼ sec. 17	236			All in drift.
H. S. Hoover	SW. ¼ SW. ¼ sec. 18	190	185		
Bremer County farm.	NW. ¼ SE. ¼ sec. 24	130	105	−30	
F. Kohagen	NW. ¼ NE. ¼ sec. 27	240			
M. Sharp	SE. ¼ NW. ¼ sec. 31	130	70		
Chas. Gors	SE. ¼ sec. 32	148	60		No shale.
M. Bentradt	SE ¼ NW. ¼ sec. 32	141			
W. T. Weideman	SE. ¼ SW. ¼ sec. 35	128			Bottoms of quarter section run. Blue clay, 128 feet; sand.
S. Clausing	SW. ¼ NW. ¼ sec. 36	120	(?)		Flowing well.
T. 92 N., R. 12 W. (FREMONT).					
C. F. Davies	SE. ¼ SE. ¼ sec. 6	30	12		Lowland, about 2¼ miles from an outcrop of Niagara limestone.
H. Hennings	NE. ¼ NE. ¼ sec. 19	100	100		
Miller	NE. ¼ SE. ¼ sec. 4	89	84		No sand worth mentioning; water in rock.
A. D. Chapin	NE. ¼ sec. 23	110	100	−30	Yellow clay, 7; blue clay. 93. limestone, 10.

Typical wells in Bremer County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Head above or below curb.	Remarks (logs given in feet).
T. 92 N., R. 11 W. (DAYTON).		*Feet.*	*Feet.*	*Feet.*	
C. Seehase	SE. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 8	195	190		Divide between Wapsipinicon River and Buck Creek.
J. C. Sell	SW. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 14	171			Divide between Buck Creek and Little Wapsipinicon; ends in sand.
H. Nuss	SW. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 24	183			Ends in sand.
I. Leverton	NE. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 25	150	145		Yellow clay, 30; blue clay, 115; limestone rock, 5.
C. Schwahn	NE. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 27	130			Ends in sand.
N. Mersch	SW. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 28	148		−30	Ends in sand. Yellow clay, 20; blue clay, 126; sand, 2; typical of wells in this and adjacent sections.
Wm. Franklin	SW. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 30	109	90	− 9	West bank of Wapsipinicon Valley.
Geo. Watts	SW. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 31	128	120	− 8	West bank of Wapsipinicon Valley. Yellow clay, 40; blue clay, 80; hard gray limestone, 8. Water at 128.
F. Pobler	NW. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 33	150			All clay to water-bearing sand at bottom.
T. 91 N., R. 13 W. (JEFFERSON AND PARTS OF WASHINGTON AND JACKSON).					
Washington Creamery	SW. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 5	104	81	−90	
F. Soldwisah	NW. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 6	136	90		
Hans Christian	SW. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 7	95	25		
M. Sinot	SW. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 7	65	40		
Chicago Great Western Ry. (E. N. Perry).	NW. $\frac{1}{4}$ sec. 7	120	45		Yellow clay, 10; blue clay, 35; limestone, 75.
Wm. Henning	SW. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 8	327	156		Blue clay, 156; limestone, 75; shale (Maquoketa), 96. Well unsuccessful; on another part of same farm water was found in drifts and at 150 feet.
L. Cory	SE. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 17	92	60		High hill.
Geo. Baskins	NE. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 30	214	29		Drift, 29; limestone (Devonian and Silurian), 87; shale (upper Maquoketa), 95; sandstone, 3.
J. Lewis	SE. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 30	(?)	80		
H. A. Knief	NW. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 2	214			Ends in sand, all blue clay above sand.
W. H. Knief	SW. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 2	214			Do.
John Knief	SE. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 2	220			Blue clay, 210; sand, fine gray and black, with some wood at 10.
Wm. Baskins	NW. $\frac{1}{4}$ sec. 4	110	100		
W. Farris	SE. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 23	132	63		Loess and yellow till, 22; blue clay, 41; limestone, 69.
Julius Wille	NE. $\frac{1}{4}$ sec. 25	122	122		High hill.
M. E. Bloeser	NE. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 26	82	82		Soft yellow clay, 13; blue clay, 69; rock at 82.
H. Walter	NW. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 27	90			
G. B. Briden	NE. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 33	120	40		Drift, 40; rock, 80.
M. Farrington	NE. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 35	122	110		Yellow clay and gravel, 30; sand at 30; blue clay, 80; rock, 12.
John Dornbush	1 mile N. and 1 mile W. of Denver.	95		−76	Yellow clay, 20; blue clay, 25; limestone, 50.
T. 91 N., R. 12 W. (MAXFIELD).					
M. Gauske	NW. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 1	158	118		Yellow clay, 20; blue clay, 98, to rock.
H. Olendorf	SW. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 11	95	80		
Geo. Knief	SW. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 21	80		−10	A few feet above level of flood plain of Crane Creek.
Fred Knief	SW. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 22	50			Ends in sand.
J. P. Ottrogge	SE. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 23	100			Do.
J. P. Ottrogge	NW. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 24	100			
P. O. Klinger	NE. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 35	90			

Typical wells in Bremer County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Head above or below curb.	Remarks (logs given in feet).
T. 91 N., R. 12 W. (MAXFIELD)—Con.		*Feet.*	*Feet.*	*Feet.*	
H. W. Meggerhoff	NE. ¼ SE. ¼ sec. 14	86			Yellow clay, 30; blue clay, 40; sand and gravel, 16.
J. Kolling	NW. ¼ sec. 20	60		−35	Yellow clay, 13; blue clay, 47.
H. Poock	SE. ¼ NE. ¼ sec. 32	273		−73	All blue clay to bottom, where water was found in sand and gravel.
T. 91 N., R. 11 W. (FRANKLIN).					
B. Bierie	SW. ¼ SW. ¼ sec. 7	240	230	−30	Drift clays, 200; "yellowish substance between rock and clay," 30; solid limestone with water, 10.
J. H. Rohrson	NE. ¼ SW. ¼ sec. 7	275		−24	Clay, 200; sand, gray, very fine, dry, 70; gravel and sand with water, 5.
G. Vander Walker	NW. ¼ NE. ¼ sec. 19	130			Ends in sand.
Orrin Station	NE. ¼ NE. ¼ sec. 13	123	98	−40	Yellow clay, 40; blue clay, 58, to rock; water in rock.
R. Rundle	NE. ¼ SE. ¼ sec. 12	128	100	−30	Clay, 100, to rock; water in rock.
Shippy and Harwood.	NE. ¼ NE. ¼ sec. 12	98	90		Yellow clay, 50; sand, 10; blue clay, 30, to rock.
Haas Kahler	SW. ¼ SW. ¼ sec. 1	140	120		Yellow clay, 30; sand, 10; blue clay, 80, to rock; water in rock.
Wm. Mundt	SW. ¼ NW. ¼ sec. 1	130	100		Drift clays, 80; gray sand with muddy water, 20; rock, 30.
J. T. Nuss	NW. ¼ NW. ¼ sec. 1	120	103		Yellow clay, 30; blue clay, 58; sand, 15; limestone, 17.
Chris. Nieland	SW. ¼ SE. ¼ sec. 2	112	108		Yellow clay, 30; blue clay, 78, to rock; water in rock, no sand in well.
D. Kerns	NE. ¼ SE. ¼ sec. 26		160		
T. 91 N., R. 14 W. (PARTS OF WASHINGTON AND JACKSON).					
G. W. Bowman	NW. ¼ NW. ¼ sec. 5	112	75		High ground.
Bowman Bros	SE. ¼ NE. ¼ sec. 4	112	80		
Geo. Moody	NE. ¼ NE. ¼ sec. 9	136	90		Hill.
E. Taylor	SW. ¼ NW. ¼ sec. 11	90	60		
Geo. Curtis	NE. ¼ sec. 13	45	45		Sand, 20; yellow clay, 25.
Chicago Great Western Ry. (J. Carry).	NE. ¼ sec. 12	89	60		
A. S. Mores	NE. ¼ SE. ¼ sec. 1	126	90		Yellow clay, 25; blue clay, 65; limestone, 36.
C. M. Barber	NW. ¼ NW. ¼ sec. 1	151	80		
Allen Sewall	NE. ¼ SW. ¼ sec. 21	126	70		
O. Babcock	NE. ¼ NW. ¼ sec. 22	126	100		
D. Lehman	SE. ¼ NW. ¼ sec. 28	70	40		
School No. 1	NE. ¼ SW. ¼ sec. 34	40			

Typical wells in the Wapsipinicon Valley artesian field, Bremer County.

Owner.	Location.	Depth.	Head.	Remarks (logs given in feet).
T. 93 N., R. 11 W. (SUMNER AND PART OF LE ROY).		*Feet.*	*Feet.*	
W. B. Barnes	NW. ¼ sec. 18	156	4	Blue clay, 60, fine soft quicksand with some wood at bottom; coarse gravel and water.
William Kuker	SW. ¼ sec. 31	140	− 4	Ends in gravel.
Hiram Lease	NE. ¼ sec. 13	120		Overflows.

Typical wells in the Wapsipinicon Valley artesian field, Bremer County—Continued.

Owner.	Location.	Depth.	Head.	Remarks (logs given in feet).
T. 93 N., R. 12 W. (LE ROY).		*Feet.*	*Feet.*	
J. Playman	SW. ¼ sec. 25	85	2½	Near East Wapsipinicon; diameter, 4½ inches.
Louis Testorff	NW. ¼ sec. 26	110	12	95 feet to rock, has now ceased to flow. On East Wapsipinicon.
John Barbknecht	NW. ¼ sec. 28	64	− 5	
Bertha Gericke	NW. ¼ sec. 18	53	− 6	Yellow clay, 10, then gravel which grew coarser to bottom.
Fred Hahn	NW. ¼ sec. 21	16	− 9	
F. H. Friedman	3 miles NE. of Tripoli	230	2	Valley ends in sand and gravel. Flows 10 gallons per minute.
T. 92 N., R. 11 W. (DAYTON).				
William Kuker	NW. ¼ sec. 6			
Jacob Umbrose	SW. ¼ sec. 7			
Christian Buhr	SE. ¼ sec. 18		30	
D. W. Buhr	SW. ¼ sec. 20			
W. C. Gode	SE. ¼ sec. 20	110		Water jetted 15 feet from top of 3-inch pipe.
P. Wynkoff	SE. ¼ sec. 30	75	6	Yellow clay, 10; sand and gravel, 30; blue clay, 25; limestone, 10.
N. Traufler	NE. ¼ sec. 29	121		
O. A. McCumber	NE. ¼ sec. 31			
Robert Watts	SW. ¼ sec. 31	103	10	10 or 12 feet above valley floor. Sand, 4; yellow clay, blue clay; limestone at 82; water in rock near bottom.
T. 92 N., R. 12 W. (FREMONT).				
A. P. Chapin	SE. ¼ sec. 13			
C. C. Cook	NE. ¼ sec. 1			Temperature, 47° F.
J. J. Cook	SE. ¼ sec. 1	120	21	About 10 feet above Wapsipinicon bottoms. Diameter, 5⅝ inches. Temperature, 47.3° F. Sand, 8; blue clay, 94; cemented gray gravel, 18.
J. Y. Hazlett	SE. ¼ sec. 24			
A. Countryman	SW. ¼ sec. 1			Hillside. Flows only when Cook's well is shut off.
T. 91 N., R. 11 W. (FRANKLIN).				
W. Benzow	SE. ¼ sec. 5			
Carl Balte	NW. ¼ sec. 9			
Charles Peck	NE. ¼ sec. 7			
Peter Watrine	NW. ¼ sec. 27	100		
George Meier	NE. ¼ sec. 5	100		
Anthony Schmeltzer	SW. ¼ sec. 22	93		Hillslope; has now ceased to flow; drilled about 1875.
William Green	NW. ¼ sec. 6			
Albert Judish	NW. ¼ sec. 8			
Frederick Hartman	SE. ¼ sec. 8	100		
Eugene Hemfseed	NE. ¼ sec. 8			
F. H. Schroeder	SE. ¼ sec. 8			
Henry Fuhr	NE. ¼ sec. 17	92	4	Hillside, 20 feet above Wapsipinicon bottoms. Diameter, 5 inches; drilled in 1903.
William Beal	SE. ¼ sec. 17	98	12	Diameter 2 inches; elevation, 9 feet above Wapsipinicon River. Temperature, 48° F. Loam, 2; sand, 28; blue stony clay, 67¾; gravel, ¼.
B. F. Call	SW. ¼ sec. 15	102		Hillside. Well just overflowed.
J. W. Rommell	NE. ¼ sec. 20	71	10	Diameter, 5 inches. Temperature, 49° F. Flow, 2 gallons through ¾-inch pipe. Yellow sand and clay, 20; blue clay, 51; gravel.
Leopold Leistikow	SW. ¼ sec. 20	107	36	Temperature, 47.3° F. Runs 30 gallons per minute through 1½-inch pipe plugged into square iron rod.
George Rommell	NW. ¼ sec. 21	92	4	Temperature, 49.5° F. Flows 1¾ gallons per minute through ½-inch pipe.
J. Campbell	NW. ¼ sec. 21			
Louis Fettkether	NW. ¼ sec. 29			
H. Leistikow	NW. ¼ sec. 29	113		Temperature, 49° F. Drill lifted when water was struck at base of blue till at 113 feet.
H. Leistikow	NW. ¼ sec. 29			Temperature, 49° F. Now a feeble flow.
Charles Liebert	NW. ¼ sec. 29			Formerly used for carp ponds.
M. E. Perry	NE. ¼ sec. 32	100		
Grove Hill Creamery	NW. ¼ sec. 22	106	− 6	Slope.
Carl Hagenow	S. ½ sec. 6	138	−20	30 feet above river. Ends in gravel.
Henry Tiedt	NE. ¼ sec. 18			

BUCHANAN COUNTY.

By M. F. Arey.

TOPOGRAPHY.

Topographically Buchanan County does not differ greatly from the other parts of the Iowan drift prairie. The inequalities in its surface are a little more pronounced in the southern half than in the northern, for the stream courses trend southward.

Wapsipinicon River crosses the county from northwest to southeast. Its principal tributaries in the county, the Little Wapsipinicon, Otter, Harter, and Pine creeks, enter from the northeast. Buffalo Creek, which joins the Wapsipinicon in Jones County, flows for about 25 miles of its course in the eastern part of Buchanan County. Tributaries of the Maquoketa drain almost all of Madison and Fremont townships, in the northeast corner; Spring, Lime, and Bear creeks, branches of the Cedar, drain the southwest corner.

GEOLOGY.

The indurated rocks in Buchanan County are everywhere covered by drift, which attains a maximum thickness in section 4, Buffalo Township. Well records indicate that the underlying rock surface is very uneven, partly owing to irregularities in the original deposits and partly to preglacial erosion.

Over about 190 square miles of the northeastern portion of the county the drift rests on Silurian rocks, the Niagara dolomite. Calvin,[1] in his report on the geology of Buchanan County, describes the Niagara here as a "coarse, granular, vesicular, dolomite, interbedded at certain localities with large quantities of chert." In the remaining areas the drift rests on the Wapsipinicon and Cedar Valley limestones (Middle Devonian).

The Wapsipinicon, which underlies an area of about 140 square miles in the central part of the county, mainly east of Wapsipinicon River, comprises a lower member (Independence shale member), consisting of dark shale alternating with the beds of limestone, and a much thicker and more widespread upper member of brecciated limestones. The lower shale member is ill defined, but it undoubtedly has an important effect in determining the underground water conditions west of the area assigned to it on the geologic map.

The Cedar Valley limestone, which underlies an area of about 240 square miles in the west and southwest portions of the county, is in large part soft, earthy, and somewhat porous, and on exposure weathers quite readily. The middle beds are firmer and carry much less water.

[1] Ann. Rept. Geol. Survey Iowa, vol. 8, 1898, p. 216.

UNDERGROUND WATER.

SOURCE.

The ground-water supplies of Buchanan County are obtained from the Buchanan gravel, which lies beneath the alluvial deposits in the stream valleys and forms local upland deposits; from the Kansan drift; from the sand, gravel, or broken rock underlying the Kansan drift; and from the more or less porous beds of the Devonian and Silurian limestones.

A supply of good water ample to meet all existing demands is found in every part of the county, but in some localities wells must be sunk to a depth of more than 200 feet. The deepest wells are in localities where the drift material is deepest.

Forty or fifty years ago all the water needed for use in the home or for stock, aside from that afforded by springs and surface streams, was obtained from dug wells, which, in the valleys of many of the larger streams, commonly ended in the Buchanan gravel. The water was plentiful and usually was considered wholesome, but was likely to taste of iron, and such wells were liable to become polluted with organic matter washed from the surface. Fortunately improved drainage facilities have rendered the supply somewhat uncertain in many places, compelling a resort to drilled wells ending in the underlying rock. On the open prairie some of the early settlers obtained water by wells ending in the upland phase of the Buchanan gravel, or, more commonly, in the pockets or streaks of gravels in the Kansan drift. Nearly all of these wells were abandoned long ago.

The layers of sand, gravel, or broken rock underlying the Kansan drift afford a plentiful supply of excellent water, but the water-bearing material is variable. In many places it comprises a bed of sand or gravel from 1 foot to 12 feet thick; in others it is a layer of fragmentary rock mingled with geest or till. In many wells this layer affords the first water, but when the supply obtained is insufficient the driller is compelled to continue into the rock, where second or third flows invariably give ample supplies. So variable, however, is the reported depth to water in rock that it is impossible to refer the source of supply to any particular beds.

In the area immediately underlain by the Niagara dolomite the drift is in many places thin, and most of the wells obtain water in the rock. The wells range in depth from 100 to 400 feet, and the distances in rock have an equally wide range.

DISTRIBUTION.

In the SW. ¼ sec. 1, Washington Township, a well 100 feet deep ends in gravel just above the rock. Northwest of the drift well 1½ miles a well 110 feet deep is 30 feet in rock. A few rods east of the drift well another well 110 feet deep is only 10 feet in rock. A hundred rods southeast of this, in Washington Township, a well 104 feet deep is only 4 feet in rock, and another, in Bryan Township, a little east of the last, is 123 feet deep, 23 feet in rock.

Calvin[1] reports a well in section 22, Buffalo Township, 152 feet deep, ending at the rock in a bed of gravel. In 1898 this well furnished a constant stream of water 1 inch in diameter; it is now reported as no longer flowing.

In the area in which the drift is immediately underlain by the Wapsipinicon limestone wells range in depth from 45 feet (as at Independence) to 136 feet.

A well in the NE. ¼ sec. 34, Washington Township, is 73 feet deep and is in rock for 70 feet. Rock outcrops in many places for 15 to 20 miles not far from the banks of the river and nearly parallel with it.

In a well in the NE. ¼ sec. 36, Washington Township, rock was found 20 feet from the surface. The well is 136 feet deep, the last 40 feet being chiefly in a gritless clay called "soapstone" by the well driller—undoubtedly the Independence shale member of the Wapsipinicon limestone. The well ends in a flinty rock—the Niagara—a good water bearer in all this region. In SE. ¼ sec. 36, a well 80 feet deep, 72 feet in rock, ends in the "soapstone," although, of course, the water comes from the rock just above it.

In the area immediately underlain by the Cedar Valley limestone rock wells range in depth from 85 to 220 feet, and penetrate rock from 5 to 170 feet. North of Wapsipinicon River in this area water is obtained in the Buchanan gravel and accurate data for rock wells are not available.

In Westburg Township, in the SW. ¼ sec. 23, a well 220 feet deep, 140 feet in rock, must reach nearly if not quite to the Independence shale member of the Wapsipinicon. In Sumner Township a well near the center of section 19 is 155 feet deep, the last 15 feet being in gravel. No rock occurred anywhere. Another, in the NE. ¼ sec. 22, is 100 feet deep, the last 20 feet being in rock. This well possibly is in the area underlain by the Wapsipinicon. In Homer Township two wells are reported—one in the north half of section 3 is 85 feet deep, 5 feet being in rock; the other in the SW. ¼ sec. 23 is 95 feet deep, 15 feet being in rock. In Jefferson Township, in the NE. ¼ sec. 2, a well 220 feet deep, 170 feet in rock, undoubtedly ends at the top of the Independence member of the Wapsipinicon.

SPRINGS.

Springs are not very numerous in Buchanan County, and most of those found are seep from the drift material. In the SW. ¼ sec. 6, Westburg Township, however, on G. W. Young's farm near the border

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[1] Geology of Buchanan County: Iowa Geol. Survey, vol. 8, 1898, p. 253.

of Spring Creek Valley, a large fissure spring of excellent water emerges at the base of a long, gradual slope 75 feet or more high. No rock outcrops in its immediate vicinity, but the lower beds of the Cedar Valley limestone are exposed in two quarries a mile to the northeast, and it is probable that the water comes from a gravel layer just above the Independence shale member of the Wapsipinicon limestone.

A large spring of good water is reported within the corporate limits of Jesup, on the place of J. D. Land; another is reported on the farm of Mrs. Joseph Patten, 2 miles northeast of Jesup. Others are reported at Winthrop, on the land of W. H. Eddy, R. L. Wright, R. W. Adams, and Mrs. A. Mulford; and at Rowley, on land of Theo. Hirsh and Robert Eldridge. An old resident of the county asserts that springs are diminishing in importance throughout the county, many no longer being serviceable.

CITY AND VILLAGE SUPPLIES.

Independence.—The public well at Independence (population, 3,517) is on Second Street NW., 525 feet west of the river and 10 feet above its level. It is really a cluster of driven wells supplying a common reservoir from which the water is pumped. The first wells were put down in 1886 and improved in 1906.

The wells end on the rock at a depth of 45 feet and obtain water from the Buchanan gravel. When highest the water from a depth of 35 feet stands within 8 feet of the surface; when lowest, within 16 feet. The strainer is 6 feet long. The temperature of the water taken in August was 50° F. and does not vary greatly. A compound duplex waterworks pump is used. The maximum yield is 600 gallons per minute, and the supply has not perceptibly varied. The water is soft. The cost of the wells was $2,000 and of the pumps $6,000. The water is used for fire protection and for all general purposes, supplying homes, schools, railroads, canning factory, and the State hospital for the insane. The daily average demand is 400,000 gallons.

In Rush Park, three-fourths of a mile west of the city well, a well to the Buchanan gravel yields an ample supply of water at a depth of 29 feet. One-half mile west of the Rush Park well a well 77 feet deep, 7 feet in rock, obtains an abundance of water; less than one-fourth of a mile west of this is another well about 112 feet deep, of which 12 feet is in rock. Most of the differences in these wells are due to difference in surface elevation.

The possibility of obtaining an artesian water supply at Independence for the hospital for the insane was considered some years ago at the request of the State board of control, and forecast was made by W. H. Norton substantially as follows:

Independence is 921 feet above sea level (Chicago, Rock Island & Pacific Railway track). After passing the hard limestones of the Devonian the drill will pass into the heavily bedded Niagara dolomite, where water will probably be found in channels opened by solution and will rise to a level of 25 feet or less below the surface. At about 280 feet the drill will enter the plastic Maquoketa shale, here probably somewhat more than 200 feet thick. The Galena dolomite, Decorah shale, and Platteville limestone will then be traversed, their aggregate thickness being estimated at 350 feet. In these terranes the drill may strike water-bearing crevices. The St. Peter sandstone, recognized by its whiteness, should be reached about 850 feet below the surface or about 70 feet above sea level. The water from this sandstone will not overflow at the surface and will probably not rise to the level of the water in the formations above. A well to be used for city or institutional supply should be sunk to a total depth of about 1,420 feet. Such a well would tap the water veins of the Prairie du Chien group (Shakopee, New Richmond, and Oneota) and the Jordan sandstone. The drills should not go below the beginning of the glauconiferous shales underlying the Jordan except on expert advice. These deeper waters will also fail to reach the surface. As in all this part of Iowa, artesian water at Independence will be of good quality.

A flowing well situated on a slope in the NE. ¼ sec. 1, Jefferson Township, 6½ miles southwest of Independence, owned by J. E. Cook and R. E. Leach, of Independence, was drilled in 1897. It is 6 inches in diameter throughout and enters rock, but neither the depth to rock nor the total depth could be ascertained. The water rises 2½ feet above the surface. A decrease in the supply is attributed to bad casing. The water is used for all farm purposes.

Jesup.—The public well of Jesup (population, 697), is 312 feet deep, but the depth in rock is not known. The water is abundant and of good quality.

Winthrop.—The well owned by the town of Winthrop (population 529) starts 100 feet above the level of Buffalo Creek. It is 8 inches in diameter at the top, 5 inches at the bottom, and is 400 feet deep, entering the rock at the depth of 193 feet. The water bed is in rock, undoubtedly the Niagara dolomite. Water was also found at the top of the rock and at 260 feet. The casing is 8 inches for 198 feet and 5 inches for 61 feet. Water stands constantly at 120 feet from the surface and is pumped by a gasoline engine at the maximum rate of 35 gallons a minute. The supply has not diminished. The well cost $600 and the pump $200. The water is used for all domestic purposes.

CHICKASAW COUNTY.

By O. E. Meinzer.

TOPOGRAPHY AND GEOLOGY.

The surface of Chickasaw County is part of the Iowan drift plain, which is well drained when compared with the areas covered with the younger Wisconsin drift and but slightly dissected when compared with the areas where the older Kansan drift lies at the surface. Numerous small streams cross the county, flowing southeastward in more or less parallel courses.

Over most of the county the deposits of glacial drift form a mantle for the most part 100 to 200 feet thick, though in some places it is still thicker and in others, as along Cedar and Little Cedar rivers in Chicaksaw and Bradford townships and along Little Turkey River in Utica Township, where postglacial erosion has been effective, it is entirely lacking. The bedrock consists of limestone, probably all of Devonian age. Its surface, as shown by well sections, is irregular—not unlike the rugged rock surface found farther east in the State, where the glacial drift is absent.

UNDERGROUND WATER.

SOURCE.

The water supply is derived from alluvial and outwash deposits, from glacial drift, from Devonian limestone, and from older limestones—probably Niagara or those belonging to the Maquoketa shale. Water could also be obtained from still deeper formations of limestone and sandstone.

The alluvial and ancient outwash gravels are found at the surface, chiefly in the valleys. As they commonly occur in low areas and rest upon impervious clays, they are usually saturated with water which they surrender freely to very shallow wells and hence are utilized largely.

Most of the wells in the county obtain water from the glacial drift—either from the upper layer, which is loosely aggregated and somewhat pervious, or from deeper sand and gravel beds which are in fact alluvial and outwash deposits that have been buried beneath bowlder clay. Many wells also penetrate the limestone, the ratio between the number of drift wells and rock wells in different localities varying with the thickness of the drift cover.

The wells in Chickasaw County may be grouped in four classes—driven wells, open wells, drilled drift wells, and drilled rock wells. A well of the first class consists merely of an iron pipe with a sand point driven (usually by hand) to a depth seldom exceeding 25 feet into sand and gravel where these materials lie at or near the surface.

Such wells are very inexpensive and they furnish much of the supply in the villages located near streams where alluvial and outwash deposits are best developed. Shallow open wells were the principal reliance of the early settlers, but they have generally proved unsatisfactory, both as to quantity and quality of water, and have been largely abandoned for deeper wells. Most of the drilled wells derive their water from sand or gravel in the glacial drift. If the sand is fine it tends to come into the well with the water, in which event it should be cased out and drilling should be continued. In all parts of the county some wells extend into the limestone where large and permanent yields of good water are obtained. Experience shows that it is poor economy to stop the drill before limestone is reached unless the supply coming from the drift is entirely satisfactory. In depth the drilled wells range from 50 to 330 feet. Their average depth is perhaps between 125 and 150 feet.

In many of the rock wells and deep drift wells the water rises nearly to the surface, and where the altitude is especially low may overflow. An example is afforded by a well on the farm of D. W. Lowry, a mile north of Fredericksburg. This well is 94 feet deep, ends in sand, originally had a head of more than 15 feet, and at present flows about 3 gallons a minute.

SPRINGS.

Springs are found along the principal streams, especially where the latter have cut through to limestone. In general, however, the county is a level prairie without springs of any consequence.

CITY AND VILLAGE SUPPLIES.

Fredericksburg.—The village well at Fredericksburg (population, 588) is 271 feet deep, the last 10 feet of which are in limestone. Its diameter is 6 inches at the top and 4 inches at the bottom, and the casing extends to rock. The water stands 6 feet below the surface, or about 1,070 feet above sea level. The water is pumped to an elevated tank connected to a short system of mains and is used chiefly for fire protection.

Nashua.—At Nashua (population, 1,102) the supply for the public waterworks is taken from Cedar River and is pumped by water power. The system comprises 2 miles of mains, 29 fire hydrants, and 162 taps.

New Hampton.—The city well at New Hampton (population, 2,275) is 235 feet deep, the last 100 feet being in limestone. (See Pl. V, p. 238.) The well is 10 inches in diameter at top and 8 inches at bottom, and it is cased to rock. The water is hard but otherwise of excellent quality and stands 40 feet below the surface, or 1,140 feet above sea level. The well is pumped at about 35 gallons a minute and is reported to have been tested at 125 gallons. The water is raised into an elevated tank from which it is distributed through $2\frac{1}{4}$ miles of mains to 22 fire hydrants and 198 taps. The daily consumption is estimated to be only 12,000 gallons, although about 500 people, or one-fifth of the population, are reported to be supplied and the water is also used in the locomotives of the Chicago Great Western Railway.

According to W. H. Norton, a deep well at New Hampton would probably obtain a moderate amount of water from the St. Peter sandstone, which here lies about 750 feet below the surface, and from the overlying limestones. A more bountiful supply, however, would be obtained by sinking the well to a depth of 1,250 or 1,350 feet, at which depth the shales of the St. Lawrence formation should be reached, beyond which drilling will be unprofitable. Owing to the high elevation of the town (1,159 feet above sea level) a flow need not be expected.

CLAYTON COUNTY.

By W. H. Norton.

TOPOGRAPHY.

Like other counties of the extreme northeastern part of Iowa, Clayton County comprises many geologic formations and has a diversified topography. Measured from the highest divides to the flood plain of the Mississippi, the maximum relief is 650 feet. The massive ridge that divides the valleys of Turkey and Yellow rivers attains an elevation of 1,185 feet between Luana and Monona. The prominent secondary ridge which extends southward between Turkey and Mississippi rivers gradually declines in height from 1,160 feet above sea level near National to 1,060 feet at Garnaville, and to 1,000 feet west of Guttenberg. The wedge-shaped ridge dividing the Turkey from its affluent, the Volga, reaches a height of 1,250 feet above sea level. South of the Volga the upland reaches the same elevation.

The upland south of the Volga is deeply dissected as far west as Strawberry Point and Edgewood, where it passes into undulating prairie. Here, in the southwest portion of the county, lies an area of Iowan drift in strong topographic contrast to the remainder of the county. Old valleys have been filled and the surface has been molded to gentle constructional sags and swells.

The topography of the remainder of the county is due to long-continued and deep erosion. The northern townships and a belt about 8 miles wide along Mississippi River are included in the driftless area. But outside the small area of Iowan drift the older drift forms little more than a veneer and its topographic influence is generally quite negligible. The topography of the entire county outside of the Iowan drift plain, therefore, is that of the driftless area. The ancient base plain of erosion to which this area had been reduced has been uplifted to more than 1,000 feet above sea level. It has been deeply dissected by its master streams and their numerous tributaries. Nowhere are tabular areas of any width left on the divides as remnants of the ancient erosion level. The flanks of the broad interstream areas have been carved to a maze of steep branching and rebranching spurs. The summits have been worn to broad-shouldered, gently rounding crests, which have been utilized as the sites of towns and villages and followed by the railways and the more important roads. On these ridges ground water necessarily stands far below the surface, as it is held only by friction and capillarity above the drainage levels of the adjacent valleys; wells are deep and windmills are everywhere.

GEOLOGY.

The Pleistocene deposits comprise the loess, the Iowan drift, the Kansan drift, which extends over a large portion of the county, and the blue-black Nebraskan drift, the first deposit of the ice sheets that invaded Iowa. The loess is a fine yellow silt or dust deposit, which mantles the driftless area and the Kansan drift with a maximum observed thickness of about 20 feet. Well records seem to indicate that the loess has a thickness considerably greater than 20 feet in places, but it can seldom be discriminated from other Pleistocene deposits. The drift rests on residual deposits derived by long preglacial weathering of the rocks. Where that rock was limestone the deposits consist of red cherty clay; where it was Maquoketa shale the residual material is clay or "soapstone" differing little in composition from the original shale but softer and reddened by the oxidation of its iron constituents.

The Niagara, the youngest of the rock formations in the county (Pl. V, p. 238), is everywhere a buff dolomite, as a rule cherty and heavily bedded, cutting under the drill to a sharp limestone sand. Like other dolomites of the county it is liable to be called "sand rock" by the driller, but the cuttings are readily distinguished from the rounded quartz grains of true sandstone by their form and by their brisk effervescence in hot concentrated hydrochloric acid.

The Maquoketa, a variable formation, including clay shales 90 to 100 feet, cherty dolomitic beds 30 feet, and basal shales and impure limestones 60 to 180 feet thick, lies beneath the Niagara. The shaly beds are known as mud rock or soapstone by many of the drillers, or, where somewhat harder, as slate. The Maquoketa forms the bedrock over the uplands of Garnavillo Ridge and of Monona Ridge west of Girard Township. In many sections the limestones are dark and more or less argillaceous.

The Maquoketa shale rests on the Galena limestone, the term as here used including the entire body of limestone lying between the Maquoketa and the Decorah shale, which, however, may be locally absent. Beneath the Decorah is the Platteville, consisting of limestone with a shale bed at its base. The Galena limestone has been changed in whole or in part into dolomite. The thickness of the dolomitized portion may reach 200 feet, but the depth to which dolomitization has extended varies greatly. Where dolomitized, the rock is hard, buff, and vesicular, cutting under the drill to yellow sparkling sand or brownish crystalline sand; where undolomitized, both the Galena and the Platteville comprise commonly light-colored, rather soft limestones that are broken by the drill to flaky chips. The total thickness of the Galena, Decorah, and Platteville at Elkader measures 285 feet. The combined thickness of the Decorah and Platteville is 50 to 60 feet. The three formations constitute the bedrock over a large part of the upland of the county.

Drillers distinguish as "oil rock" a brown petroliferous shale which is found in many places by the drill and which outcrops near the base of the Platteville; occasionally they report an oily scum in the water when the drill is working in this shale.

The Platteville is underlain by the St. Peter sandstone, a white rock made up of rounded grains of pure quartz, so little cemented that where quarried in the county for glass sand it is readily broken up by the pick and a stream of water from the hose. Even at Picture Rocks, below McGregor, where the sand is highly colored and partly cemented by films of the iron oxides deposited by ground water on the grains, the stone is so friable that it is difficult to obtain specimens of any size. The observed thickness of the sandstone in the county ranges from 40 to 85 feet. The St. Peter is not always recognized by the drillers. Thus it is said to be absent in the narrow wedge-shaped tongue of upland separating the Turkey from the Mississippi near their junction; at a depth corresponding to the horizon of the St. Peter, however, there is reported a "river sand," which may be assumed to be the upper layers of the St. Peter; it underlies a shale, which is probably the basal shale of the Platteville.

Next below the St. Peter is the Prairie du Chien group, comprising the strata formerly known as the "Lower Magnesian limestone," and consisting of an upper dolomite (Shakopee), an intermediate sandstone (New Richmond), and a basal dolomite (Oneota). The total observed thickness measures 230 feet. It outcrops only north of Guttenberg along the Mississippi bluffs and for 4 miles or less up the valleys of the tributary creeks. The dolomites of the Prairie du Chien group are hard, light gray or white, and in many places are cut by the drill into fine sharp limestone sand. They may be distinguished by the driller by their lithologic character and also by their position between the St. Peter and the Jordan sandstones. The New Richmond sandstone is inconstant, but quartz sand is not uncommon in the dolomite, either as interbedded layers or as disseminated grains.

The Jordan sandstone, the lowest rock outcropping in the county, is made up of pure quartz and is generally of coarse grain. In some layers the grains are firmly cemented with lime carbonate; in others they are incoherent and show little interstitial matter. At McGregor the Jordan is so soft as to be readily excavated with the spade for cellars and vaults in the hillsides. Here it rises 70 feet above the level of Mississippi River, though 2 miles below the city it sinks from sight below the flood plains of the stream. It outcrops only along the bases of the river bluffs in the northeastern townships, but it underlies the entire county and the waters stored in its pervious layers are accessible to the drill.

UNDERGROUND WATER.

SOURCE.

Gravels at the base of the loess locally yield sufficient water for house supply. Gravels lying between the Kansan and Nebraskan tills and probably at other horizons furnish a supply on the prairie areas of the southwestern part of the county, but are little drawn upon elsewhere. In an area of especially thick drift stretching from the southwestern part of Grand Meadow Township northeastward nearly to Postville many wells less than 100 feet deep draw water from drift gravels lying beneath 25 or 30 feet of yellow clay (loess and oxidized Kansan) and then pass into blue till (either unoxidized Kansan or Nebraskan), beneath which sands and gravel are again found on rock, or water is found in broken limestone or residual flints beneath heavy drift.

About 160 feet of the lower portion of the Niagara outcrops in the southern townships of the county and on the ridge separating the Volga from Turkey River. In this area water is found above the impervious shales of the underlying Maquoketa. On the more level ground of the Iowan plain the entire body of limestone may be saturated with water and yield a good supply to wells that enter the rock a few feet. Thus at Strawberry Point the city supply is obtained from wells drilled only 35 feet into the Niagara dolomite. Here, as in many places in the southwestern part of the county, the porous and creviced limestone forms a reservoir in which waters descending from the heavy overlying drift have accumulated.

Outside the dissected area covered by the Kansan drift the Niagara forms escarpments on the summits of the ridges and is drained out for a considerable distance back of these outcrops.

The limestone beds in the Maquoketa furnish an important water supply to villages and farms located on the outcrops of the formation. The water held in the median limestones of the Maquoketa between the upper and lower shales of that formation is under good head, at National rising within 40 feet of the curb.

The Galena and Platteville limestones hold large stores of water in crevices and porous beds, the chief horizons being just above the Decorah shale and above the basal shale of the Platteville. They are utilized by many farm wells in the areas of their outcrops and they form a very important supply on uplands capped with the Maquoketa shale or Niagara dolomite. At Farmersburg water from the Galena rises within 40 feet of the surface.

The head of the water in the Galena, Maquoketa, and Niagara is considerably higher than that in the underlying St. Peter, so that as the drill enters the St. Peter the upper waters often flow through it, and the water in the tube falls. Although the St. Peter water may not stand high in the well, the supply is copious, permanent, and of excellent quality and is assured to any well in any part of the county which reaches its level.

The St. Peter sandstone is the lowest formation reached by wells. It is utilized in the northern townships, in the townships adjacent to Mississippi River, and even in the western and central townships as far south as Highland and Cox Creek townships. The dip of the strata carries the sandstone increasingly deeper south and west from its outcrops along the Mississippi, so that on the ridges of the western part of the county between Turkey and Volga rivers it is entered by wells at depths of about 600 feet.

The waters in the underlying Jordan have not yet been tapped in Clayton County. They are, however, everywhere accessible.

FLOWING WELLS.

In the valley of Turkey River, from Elkader down to Motor, wells sunk into the St. Peter sandstone obtain flowing water. At the fair-grounds at Elkader the St. Peter is reached about 110 feet below the water level of Turkey River, or about 610 feet above sea level; at the James Russell estate farm (sec. 26, Boardman Township) it was reached about 100 feet below the river level; and at Fritz Freitag's, still farther down the valley, at about the same depth. At Motor, 4 miles in straight line southeast of Elkader, the St. Peter is 155 feet below the river, or approximately 525 feet above sea level. The head of water, from 40 to 60 feet above the river, encourages drilling at other points in the area. Statistics of these wells are given in the appended table:

Statistics of flowing wells in the Turkey River valley.

Owner.	Location.	Year completed.	Depth (feet).	Diameter at bottom (inches).	Casing (feet).	Elevation of curb (feet).	Head above curb (feet).	Head above sea level (feet).	Natural flow (gallons per minute).	Pumping capacity (gallons per minute).	Depth to rock (feet).	Depth to St. Peter sandstone (feet).
City of Elkader (2 wells).	Between High Street and river.	1896	186	9 7	70	[a]740	20	760	[b]35	[b]500	([c])	155
Elkader Fair Ass'n.	Elkader	......	167	....	......	[d]20	....	......	......	......	70	130–135
James Russell estate.	Sec. 26, Boardman Township.	1905	161	5	[e]75	[d]30	28	753	35	......	75	128
Fritz Freitag	Sec. 25, Boardman Township.	......	155	....	......	[d]26	34	760	......	......	20	122
Louis Klinck	NE. ¼ sec. 6, Read Township.	1906	196	4	[f]135	[d]17 [a]697	40	737	......	......	50	172

[a] Above sea level.
[b] Both wells.
[c] Surface.
[d] Above Turkey River.
[e] Of 5-inch.
[f] Of 3 and 2 inch.

If the head of the St. Peter water is the same up valley as at Elkader flowing wells should be obtained at water level in the river as far as the south line of section 22, Marion Township. As the head should increase somewhat upstream, wells in the St. Peter may yield flows as far even as the Fayette County line. Down the valley from Elkader flows can probably be obtained from the St. Peter at very moderate depths along the entire valley to its mouth. The large number of springs, the use of open and driven wells tapping alluvial sands and gravels, and the use for stock of the never-failing water of the spring-fed river no doubt have prevented the exploration of the deeper water beds; but the St. Peter sandstone, with its inexhaustible supplies, should be found within 200 feet below the valley floor at any point from Elkader to the Mississippi.

It is highly probable that in the valley of the Volga flows from the St. Peter can be obtained from Osborne to the mouth of the stream. The exact depth can not be definitely predicted, as the depth to the St. Peter is variable, and local changes or reversals of the dip are hidden from view. The data for prediction include an assumed uniform southwestward dip, the elevation of the summit of the St. Peter at Clayton at 776 feet above sea level, and the elevation of the same horizon at about 600 feet above sea level 14 miles west-southwest of Clayton; these give a dip of about 12.5 feet to the mile. If the same line be extended 10 miles west-southwest from Elkader to the Volga at the mouth of Deep Creek, the elevation of the summit of the St. Peter at the latter point is found to be 125 feet lower than at Elkader, or 475 feet above sea level. As the level of the river is here 800 feet above sea level, the St. Peter would be found about 325 feet below the surface. If the water of this sandstone had no higher head on the Volga than at Elkader, it would fall short of reaching the surface by about 40 feet. The fact that the head of the St. Peter waters increases westward gives ground for hope that as far up valley as Volga flowing wells may be obtained. If a similar section from Clayton to Motor is taken and the data are used to calculate the water prospects in the Volga Valley at Mederville, where the level of the river is 710 feet above sea level, the St. Peter should be encountered at 485 feet above sea level, or 225 feet beneath the stream level. The head above the river here should be equal to that at Elkader.

SPRINGS.

The springs of Clayton County are exceptionally numerous and large, and come from several well-marked geologic horizons.

The St. Peter, exposed in a narrow strip along the bluffs of the Mississippi from Guttenberg north, gives rise to oozes and springs where its edges outcrop. The largest springs of the county issue from the base of the Galena limestone. The limestone is creviced and even cavernous; definite channels have been formed by solution by ground water moving down the dip, along the floor of the impervious Decorah shale, to outlets along the valley sides. The same sequence of soluble limestone and underlying shale gives rise to the springs of the limestones of the middle Maquoketa and those at the base of the Niagara. Where, as is often the case, these formations are cut by valleys above their bases, these underground streams issue high above the bottom lands in lateral ravines and can be led down to village or farm under considerable head, with power adequate for many utilities. Springs are thus found along the entire course of the Mississippi and along the principal creeks whose valleys have been cut in rock.

CITY AND VILLAGE SUPPLIES.

Clayton.—The village of Clayton (population, 145) utilizes two springs issuing from limestone about 75 feet above the level of Mississippi River, leading the water through one-half mile of mains down the principal street. There are six hydrants from which most of the houses obtain their supply.

Elkader.—The water supply of Elkader (population, 1,181) is drawn from two flowing wells, 182 and 184 feet deep, 25 feet apart, situated on the bank of Turkey River. They pump 500 gallons a minute. A reservoir nearly 300 feet above the town affords ample pressure. There are 2 miles of mains, 28 hydrants, and 200 taps.

If for any reason the city supply should become insufficient it may be greatly increased by drilling to the top of the St. Lawrence formation, which here should be found 600 or 700 feet below the surface at the city water works.

Guttenberg.—The water supply of Guttenberg (population, 1,873) is obtained from a dug well on the bank of Mississippi River. The water is liable to be contaminated by sewage, which passes readily downward through the sandy alluvium of the river terrace on which the town is built. Water is pumped to a reservoir, giving a gravity pressure of 105 pounds. There are 36 hydrants and 4 miles of mains.

The elevation at the corner of Herder and First streets is 630 feet above sea level, and an artesian supply might readily be obtained by drilling a well to the Jordan sandstone. The summit of the St. Peter outcrops near the town at the base of the bluffs bordering the Mississippi. The thickness of the St. Peter is variable, but a maximum of 85 feet may be assumed. The Prairie du Chien group, which underlies it, is probably at least 230 feet thick—the maximum thickness where it is exposed along the river bluffs in this vicinity. At 315 feet from the surface the Jordan sandstone should be struck; a well 500 feet deep should draw the available water from this horizon.

As the town is situated well out over an ancient channel of the Mississippi, the drill will first pierce 100 or 150 feet of river sands and gravels. The St. Peter sandstone will therefore be cut out, and the bed in which the water-tight casing should be securely packed will be the Shakopee dolomite. If shaly beds in the Prairie du Chien are competent to form a cover for the Jordan sandstone the well should flow under moderate pressure.

If a well to the Jordan sandstone should not yield sufficient water by natural flow the supply might be increased by installing an air lift, by sinking other wells to the Jordan, or by deepening the well to the Dresbach or underlying Cambrian sandstones and tapping the water horizons which supply the McGregor wells.

McGregor.—The water supply of McGregor (population, 1,259) is drawn from a well 502 feet deep. Water is pumped to a reservoir affording a pressure of 110 pounds. There are 24 hydrants and 2 miles of mains.

The first artesian well at McGregor was drilled at the head of Main Street, about 60 feet above the lower part of the town, where the deep wells were afterward sunk. The water reached the surface but did not overflow. The well was about 500 feet deep and ended in sandstone.

City well No. 2 (Pl. V, p. 238), completed in 1877, is in the City Park and supplies one of the finest fountains in the State. This well is 1,006 feet deep, 6 to 3 inches in diameter, and is cased with 4-inch copper to a depth of 40 feet. The curb is 632 feet above sea level; the water rises 62 feet above curb. The flow is 630 gallons a minute. Water was found at a depth of 317 feet and in all sandstone beds below to the bottom of the well. At a depth of 520 feet salt water was found in 4 feet of white sandstone. The temperature of the water is 54.5° F.

City well No. 3, completed in 1890, is not now used. This well is 520 feet deep and 6 inches in diameter; 3-inch casing extends to 215 feet and is packed at the base with rubber gasket. The curb is 618 feet above sea level, and water originally rose 20 feet above curb. In 1895 the head was below curb. Water comes from a depth of 303 feet. Its temperature is 52° F.

The log of this well shows sandstone with white rolled grains at 250 feet, dolomite from 400 to 415 feet, and white sandstone with well-rounded grains from 450 to 520 feet.

City well No. 4, put down in 1898 by S. Swanson, of Minneapolis, s 502 feet deep and 12 to 8 inches in diameter; 12-inch casing extends to 70 feet and 9-inch casing to 200 feet. The curb is about 618 feet above sea level. Water originally rose a foot above the curb, but six months later it stood below the curb. The tested capacity shows that it is sufficient for the city.

No records of the wells at McGregor are available except that afforded by a few samples described below from cursory examination.

Description of samples from city well No. 4, at McGregor.

	Depth in feet.
Gravel	35
Sand, yellow, and gravel of pre-Cambrian rocks	50
Sandstone, fine grained, yellow	60
Sandstone; as above, but coarser	70
Dolomite, dark bluish, drab, and lighter drab crystalline	74–97
Sandstone, yellow; with yellow dolomitic powder	95
Dolomite, bluish drab, arenaceous; in angular flakes and in sand.	97–143
Shale, light blue	143–158
Sandstone, calciferous, or dolomite, arenaceous, light-gray	160
Shale, fine, greenish	158–220
Shale, light green	185
Sandstone, light gray, medium coarse; grains well rounded, far from uniform in size	305
Sandstone, pure white, medium coarse; grains well rounded, similar in facies to St. Peter	350
Sandstone; as above but fine-grained	400
Sandstone; as at 350	415
Sandstone, light gray, calciferous, very fine	444

J. Goedert's well at McGregor has a depth of 294 feet and a diameter of 6 inches. The curb is 622 feet above sea level and the original head was 22 feet above curb. The well was completed in 1889.

The following carefully kept record of one of the early deep wells at Prairie du Chien, Wis., illustrates the geologic section at McGregor. This record[1] has been modified by assigning the lithologic subdivisions

[1] Wisconsin Geol. Survey, vol. 4, 1882, p. 61.

given in the log as originally published to the appropriate geologic subdivisions, and by adding a column showing the depth, in feet, to the bottom of each lithologic unit. The lithologic descriptions have also been transposed, to accord with present survey practice. Another well at Prairie du Chien was sunk to a depth of 1,040 feet without reaching crystalline rocks.

Strata in well at Prairie du Chien, Wis.

	Thickness.	Depth.
[Pleistocene (old channel of Mississippi River 147 feet thick; top, 627 feet above sea level):]	*Feet.*	*Feet.*
1. Sand and gravel	147	147
[Cambrian:]		
[St. Lawrence formation (115 feet thick; top, 480 feet above sea level):]		
2. Clay, fine, light blue	$\frac{1}{6}$	$147\frac{1}{6}$
3. Limestone, hard, arenaceous	2	149
4. Grit, blue	6	155
5. Shale, bluish green, argillaceous	107	262
[Dresbach and underlying Cambrian strata (697 feet penetrated; top, 365 feet above sea level):]		
6. Sandstone, white, friable; alternating with hard streaks [Dresbach]	118	380
7. Grit, blue	35	415
8. Slate rock	65	480
9. Sandstone, reddish and yellow ochery	6	486
10. Shaly rock	24	510
11. Sandstone, white [carrying brine]	4	514
12. Slaty rock	75	589
13. Sandstone	310	899
14. Sandstone, red	45	944
15. Conglomerate; white waterworn quartz pebbles	5	949
16. Sandstone, coarse	10	$959\frac{1}{6}$]

Monona.—The water supply of Monona (population, 792) is furnished by two deep wells and a spring. The wells are owned by F. L. Wellman, are 27 feet apart, are under one roof, and supply the Chicago, Milwaukee & St. Paul Railway as well as the town. They were completed in 1885. One is 437 feet deep and the other is 448 feet. The wells are 6 inches in diameter and are cased for 20 feet. The curb is 1,216 feet above sea level and the head 226 feet below the curb. The combined capacity is 70 gallons a minute. The temperature is 51° F. The water is lowered full depth by continuous pumping.

The water is pumped to a tank affording a pressure of 40 pounds, which is considered insufficient by the town officials. There are 3 miles of mains, 100 taps, and six hydrants.

North McGregor.—An artesian well, 585 feet deep, belonging to the town of North McGregor (population, 588), is used for fire protection.

The well is 6 inches in diameter and is cased 180 feet to rock; the original head was about 17 feet above the curb. The temperature is 52° F. In 1904 the flow ceased, but was restored with head of 10 feet by recasing.

Driller's log of North McGregor city well.

	Depth in feet.
Dolomite, reddish	300
Sandstones, white	350
Sandstone, grayish white	392
Sandstone, white, pure, medium coarse; rolled grains of similar facies to St. Peter	420
Sandstone, white, fine-grained	423

Strawberry Point.—The water supply for Strawberry Point (population, 1,052) is obtained from two wells, 160 feet deep and 10 feet apart, penetrating 125 feet of drift and 35 feet of the underlying Niagara dolomite. Water is distributed from a standpipe 110 feet high with a capacity of 800 barrels. There are six hydrants and one-half mile of mains.

The sinking of deep wells is not recommended at either Strawberry Point or Edgewood, as the high elevation above sea level of these towns (Strawberry Point 1,217 feet and Edgewood 1,165 feet at Chicago, Milwaukee & St. Paul Railway tracks) makes it impossible to obtain a flowing well. The St. Peter sandstone should be found at about 350 feet above sea level, judging from its steep dip of more than 18 feet to the mile from Elkader to Manchester; the Prairie du Chien and the Jordan lie about 500 feet deeper; to reach these waters wells at Edgewood must be sunk to a depth of 1,315 feet from the surface and at Strawberry Point to about 1,365 feet. The water in the St. Peter sandstone would stand several hundred feet below the surface.

Minor supplies.—Information in regard to water supplies in the smaller villages and the typical wells used through the county is presented in the following tables:

Village supplies in Clayton County.

Town.	Nature of supply.	Depth.	Depth to water bed.	Source of supply.	Head above or below curb.	Depth to rock.	Springs.
		Feet.	*Feet.*		*Feet.*	*Feet.*	
Edgewood	Wells	12- 16	12		6-8		
Farmersburg	Drilled wells	50-160		Galena to St. Peter.	−40	30	Small.
Froelich	Drilled wells and cisterns.	100-200		Limestone	50- 75 100-175	10-25	Large and small.
Littleport	Driven wells	15		Gravel			Large.
Luana	Drilled wells	70-100	60- 90	Limestone	60-70	40	Large and small.
National	do	50- 80	75	do	−45	20	Small.
Volga	Dug and driven wells.	10-100	15	Sand and gravel.	−10		

WELL DATA.

The following table gives data of typical wells in Clayton County:

Typical wells in Clayton County.

Owner.	Location.	Depth.	Depth to rock.	Depth to water supply.	Source of supply.	Head below curb.	Remarks (logs given in feet).
T. 91 N., R. 3 W. (MALLORY).							
		Feet.	*Feet.*	*Feet.*		*Feet.*	
L. W. Flenniken	NW. ¼ SE. ¼ sec. 21.	180	40	50	Clay	140	500 feet above river. Diameter, 6 inches.
J. H. Brown	NW. ¼ sec. 28	589	29	580	Slate rock.	400	500 feet above river. Clay, 29; limestone (Niagara); 200; shale (Maquoketa), 200; limestone (Galena), 160. Yields 3 gallons per minute. Diameter, 5 inches.
T. 91 N., R. 6 W. (CASS).							
Hugh Middleton	Near Strawberry Point.	265	65	....	Limestone	....	Drift, 65; limeetone, 200.
R. M. Peck	SW. ¼ sec. 28	237	80	140	....	180	Diameter, 6 inches.
W. C. Barnhart	Sec. 21	70	24	65	....	55	Do.
T. 92 N., R. 6 W. (SPERRY).							
F. E. Ambrose	NW. ¼ sec. 14	146	31	145	Limestone	31	Water at about 55. Diameter, 6 inches.
T. 93 N., R. 6 W. (HIGHLAND).							
C. Duff	Sec. 20	56	25	....	Sandstone	30	Valley. Diameter, 6 inches.
Henry Baars	SW. ¼ NE. ¼ sec. 36.	665	....	....	....	415	Yellow clay, 15; rotten yellow sandstone (Niagara), 20; blue shale, 205; limestone, 350; shale, 10; limestone, 35; clear sandstone, St. Peter, 30. About 545 above sea level.
John Rinkerts	1 mile west of Baars.	527	....	....	do	....	
T. 92 N., R. 5 W. (COX CREEK).							
Henry Jennings	Sec. 5	120	100	110	....	100	Diameter, 5 inches.
Town	Volga	25	....	20	Gravel	20	Flood plain of Turkey River. Diameter, 3 feet.
L. Beute	SW. ¼ NE. ¼ sec. 11.	515	....	....	....	265	Struck St. Peter sandstone.
Henry Leubke	SE. ¼ NW. ¼ sec. 4.	589	....	....	Sandstone	349	Yellow clay, 60; shale, 140; limestone, 371; shale, green, 8; St. Peter sandstone, 10. About 521 above sea level.
T. 95 N., R. 6 W. (GRAND MEADOW).							
Charles Shultz	SW. ¼ SW. ¼ sec. 21.	165	160	160	"Loose flint" residual.	....	Yellow clay, 20; quicksand, 140; loose flint (residual), 5.
T. Gordon	Sec. 6	66	....	....	Gravel	....	Blue-black till from 40 to 60, gravel below.

Typical wells in Clayton County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Depth to water supply.	Source of supply.	Head below curb.	Remarks (log given in feet).
T. 94 N., R. 6 W. (MARION).		*Feet.*	*Feet.*	*Feet.*		*Feet.*	
....	NE. ¼ SW. ¼ sec. 16.	150	....	....	....	115	Ravine; all limestone from curb.
....	SW. ¼ NW. ¼ sec. 4.	75	20	....	....	57	Sand rock at 20; ends in blue clay.
....	NW. ¼ NW. ¼ sec. 11.	115	80	....	Sandstone	20	Yellow clay, 40; blue till, 40; sandstone, 35.
Mrs. Bowder........	NW. ¼ NW. ¼ sec. 18.	237	60	....	Limestone	225	Ridge. Drift, 60; blue shale, 100; sand rock, 77.
W. Houg........	NW. ¼ NW. ¼ sec. 23.	120	....	....	....do.....	100	Ridge. "Sandstone" brown, 50; shale, blue, 50; limestone, 20.
T. 95 N., R. 4 W. (GIRARD).							
J. Smyzer........	3½ miles east of Monona.	404	....	....	....	....	To sandstone, 288.
J. W. Tewes........	NW. ¼ NE. ¼ sec. 17.	405	45	....	Sandstone	375	Water in St. Peter sandstone; temp. 48° F. Diameter, 6¼ inches.
T. 92 N., R. 2 W. (PART OF JEFFERSON).							
Peter Burr........	SW. ¼ SW. ¼ sec. 29.	370	33	370	Sandstone	359	Clay, 33; limestone, 222; St. Peter (shale and sand, clean sand at bottom), 115. Water at bottom of St. Peter in large supply.
A. E. Schroeder....	NW. ¼ SW. ¼ sec. 7.	275	40	180–225	Limestone on shale.	185	Loess, 40; limestone, 185; shale blue, fossiliferous, 6; limestone, 39; shale, blue, 4; St. Peter sandstone, 1.
Gustav Ditmar.....	NW. ¼ SE. ¼ sec. 30.	275	40	270	On shale..	215	Limestone, 230; shale, 5. Water in shale (large supply).
L. Mueller........	NW. ¼ NE. ¼ sec. 31.	257	40	254	Limestone	167	All limestone below 40.
N. Niehause........	NE. ¼ SW. ¼ sec. 33.	367	....	....	....	349	Curb about, 940 above sea level. Clay, 40; limestone, 250; shale, 10; light-colored sand from 340 to 342; limestone from 342 to 360; shale, blue, 7; footing in reddish sand and gravel.
T. 92 N., R. 3 W. (PART OF JEFFERSON).							
William Ball........	NE. ¼ NE. ¼ sec. 28.	403	30	....	Limestone	183	Oil rock at 380; water above oil rock; a weak vein.
P. J. Schmidt......	N. ½ SE. ¼ sec. 15.	120	80	120	....	60	Clay, 80; slate, 20; brown hard rock, 20.
T. 93 N., R. 5 W. (BOARDMAN).							
....	SE. ¼ sec. 8.....	449	40	....	....	244	Divide. Yellow clay, 40; soapstone, 40; slate with water, 20; soapstone, limestone, St. Peter, at 435.

Typical wells in Clayton County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Depth to water supply.	Source of supply.	Head below curb.	Remarks (log given in feet).
T. 93 N., R. 5 W. (BOARDMAN)—Con.		*Feet.*	*Feet.*	*Feet.*		*Feet.*	
George Cassuth	SE. ¼ NW. ¼ sec. 21.	219	30	215	Slate		Yellow clay, 24; sand with a little water, 4; yellow clay, 2; soapstone, 35; slate with water, 15; soapstone, 20; limestone to 219.
T. 93 N., R. 4 W. (READ AND PART OF GANAVILLO).							
S. Schmidt	SE. ¼ SE. ¼ sec. 7	398	20		Sandstone	344	Ridge. Yellow clay, 20; limestone, 210; soapstone, 70; slate, 30; shell, 8; hard limestone, 40; blue soapstone, 5; St. Peter sandstone, 15. About 611 above sea level.
T. 95 N., R. 5 W. (MONONA).							
—— Selder	Luana	80			Gravel	?	Water-bed gravel below blue-black till.
T. 91 N., R. 4 W. (ELK).							
	Sec. 33	213	92				
T. 91 N., R. 2 W. (MILLVILLE).							
John Minger	SW. ¼ NE. ¼ sec. 15.	233	45		Hard rock.	188	Hill.
J. S. Graykill	NW. ¼ NE. ¼ sec. 23.	266				246	Insufficient supply.
John Patrick	NW. ¼ SE. ¼ sec. 23.	66			Rock	18	
William Smith	NW. ¼ NE. ¼ sec. 15.	220				200	Large supply.
A. Brockman	SE. ¼ NW. ¼ sec. 10.	30			Sand		Dug well on bottoms.
J. Beeker	NW. ¼ NW. ¼ sec. 16.	290	40		Limestone	268	Footing in shale (Platteville).
L. Troester	S. ½ sec. 7	90	30		do	30	60 feet solid Galena limestone; house well.
J. T. Collins	NW. ¼ NE. ¼ sec. 17.	140				100	Loess, 30; blue clay, 70; black hard slate from 117 to 140.
E. Smith	NE. ¼ SW. ¼ sec. 36.	225	30				Loess, 24; red flint (residual), 6; limestone, 188; slate, 7.
A. Andrus	SE. ¼ SW. ¼ sec. 26.	330	30			205	Drift, 24; red flint, 6; soft limestone, 110; light-colored limestone, 185; shale, 5.
P. Hellas	SW. ¼ SW. ¼ sec. 26.	500					
T. 95 N., R. 1 W. (BUENA VISTA).							
J. Hafel	SW. ¼ SW. ¼ sec. 20.	255				215	Shale, 120; limestone, 60; oil rock; water in limestone below oil rock.

Typical wells in Clayton County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Depth to water supply.	Source of supply.	Head below curb.	Remarks (log given in feet).
T. 95 N., R. 6 W. (Buena Vista)—Continued.		*Feet.*	*Inches.*	*Feet.*		*Feet.*	
—— Hafel	NW. ¼ SE. ¼ sec. 20.	243	38				Limestone from 38 to 235; shale, 5; fine soft sandstone of white quality, 3; water at 170.
Frank Nagel	NW. ¼ NE. ¼ sec. 20.	280	30	275	Limestone	250	All limestone; water in crevice.
R. Meuth	NE. ¼ sec. 21	230	30	220		200	Loess; residual red flints; limestone to 220; black rock hard, in chips, with water, 10.
A. Weeks	SE. ¼ sec. 22	220	30			180	Clay, 30; limestone, 130; dark rock, 60.
Charles Wales	NW. ¼ NW. ¼ sec. 31.	167		70		75	Under bluff; light-colored clay, 60. black slate, 10' dark limestone' 30; oil rock, 5, limestone, 1; oil rock with black-jack, 5; limestone with pockets of blackjack, 38; glass rock, 18; strong vein.

DELAWARE COUNTY.

By W. H. Norton.

TOPOGRAPHY.

The topography of Delaware County is somewhat complex. In the northern part lies a rugged upland of loess-covered Kansan drift, dissected in interglacial time by the headwaters of streams tributary to Turkey River. A similar tract of maturely dissected Kansan extends from Earlville and Delhi south along Maquoketa River, and other insular patches of upland occur in Richland and Coffin Grove townships.

Bordering or surrounding these areas of rugose uplands lies the plain of Iowan drift, its fairly level surface diversified with low, ice-molded swells of stony clay and glacial gravels.

GEOLOGY.

Three drift sheets are represented in the county. The Iowan drift sheet, the uppermost of the three, is comparatively thin. The lowest, the Nebraskan, is revealed in wells where an old soil bed (Aftonian) separates the basal stony clay from the overlying Kansan drift. The Nebraskan and the Kansan tills together make up the great bulk of the drift deposits of the county. The loess, a yellow silt, too fine for sand and too coarse for clay, is spread as a blanket over the dissected surface of the Kansan uplands.

In well records it is very difficult to distinguish the different deposits of the drift. Even the pebbleless, soft yellow loess may not be set apart from the brighter yellow, hard, and stony Kansan drift on which it lies, although their discrimination on the spot is extremely easy. In the contents of the slush bucket it is hardly possible for the driller to distinguish the oxidized Iowan drift from the still more highly oxidized Kansan till, and yet more difficult to separate the blue unoxidized Kansan from the blue Nebraskan drift on which it rests. In places, however, the Kansan till is covered with old, rusted glacial gravel (Buchanan), which separates it from the Iowan drift. In some places this gravel has been left heaped in hills; in others it underlies low plains or occurs as outwash in the river valleys.

The basement rocks underlying the county belong to three formations. The youngest are Devonian limestones, which are supposed to lie beneath the heavy cover of drift over an area comprising about 7 square miles in the extreme southwestern part of the county. Next in age is the Niagara dolomite, which forms the bedrock over nearly the entire county. It outcrops in many sections and, where concealed from view by the mantle of drift, is discovered beneath it by the drill. The lowest rock exposed is the Maquoketa, a bluish, plastic shale, which outcrops in the deep valleys of Elk Creek and Little Turkey River and is reached by wells in different parts of the county. (See Pl. VI.)

UNDERGROUND WATER.

SOURCE AND DISTRIBUTION.

Drillers in Delaware County, as in other counties of eastern Iowa, report a general lowering of the surface of permanent ground water during the last two or three decades, leaving dry or inadequate the drift sands which in earlier years were sufficient to the needs of the population. Twenty years ago on the Iowan drift plains about Manchester ground water stood within 50 to 75 feet of the surface and wells of that depth sufficed; at present most wells in that area exceed 100 feet and penetrate the rock. In many wells which have not gone dry a distinct lowering of water has been noticed, amounting to as much as 20 feet.

Exceptions to the present insufficiency of the drift strata may be noted where drift sands are unusually thick, as in buried river channels, where they are unusually extensive overlying the rock, and where outwash sands whose upper surface lies little above the level of a river are well supplied with water from higher ground adjacent. Thus on the east side of Honey Creek, from Manchester nearly to

Millheim, driven wells in sand are used. An ancient bed of the Maquoketa at Rockville, filled to a depth of 80 feet with sand, supplies farm wells in that locality. At Manchester, where Maquoketa River now flows over a bed of rock, a wide ancient channel, 100 feet deep and filled with sand, lies but two blocks from the river banks and is utilized for many house wells. At Sand Springs also wells are sunk through sand to a depth of 75 feet, where they reach the Niagara dolomite, and obtain water that rises within 1 foot of the surface. On the prairie southwest of Petersburg wells still find water in glacial gravels overlying rock. A belt of exceptionally thick drift passes east of Ryan through Hazel Green and into southwestern Milo Township. Several wells reported from this belt show drift from 200 to 240 feet thick, and each of these wells enters rock for a few feet, probably to secure attachment for the casing.

The drift over most of the northwestern part of the county is chiefly of a hard blue stony clay or till, with included sand veins 4 to 6 feet thick. In places it is 15 feet thick, but at present it does not afford a supply of water adequate for the ordinary farm. Most of the wells are sunk to the underlying rock.

Over much of the county, especially in the northern and eastern portions, where the Niagara approaches or reaches the surface, water is found at varying though usually moderate depths in the country rock.

In the southeastern part of the county wells commonly find water above the base of the Niagara and the summit of the underlying impervious Maquoketa shale. Northwest of Monticello few wells exceed 80 or 100 feet. As the Niagara in the southeast townships attains a thickness, according to some well sections, of 160 to 200 feet, wells not infrequently find water at depths of 80 and 100 feet at a greater or less distance above the floor of the shale. Six miles southeast of Delhi a well entered the Niagara at 40 feet; at 200 feet it encountered loose, caving, shelly rock; and at 280 feet it struck a mud-rock shale, both the caving rock and shale being referable to the Maquoketa. The mud-rock shale was penetrated to a depth of 120 feet, the total depth of the well being 400 feet. The boring was abandoned before it reached the Galena limestone, and a new well, located 50 feet from the first, found plenty of good water on the shale.

In Delhi Township, occupied largely by an area of Kansan drift, the thickness of the drift varies from practically nothing to 240 feet and wells find water in the subjacent limestone at depths of 60 to 225 feet from the surface of the ground.

In the northeastern townships of the county much the same conditions prevail as in the southeastern. Wells 100 feet deep draw water from glacial sands on the Iowan prairie southwest of Petersburg, where rock is reached as a rule. In Colony Township, in an area of well-dissected Kansan drift mantled with loess, blue Kansan till is heavy and wells find water in the subjacent limestone.

The Maquoketa shale, brought up toward the north and east, by the general southwestward dip of the strata, outcrops at Rockville and in the valleys of Little Turkey River and Elk Creek. Hence the depth of wells in the Niagara decreases toward Dubuque and Clayton counties. In northern Colony and Elk townships the deepest wells penetrate the Maquoketa shale and resemble those described in the adjacent parts of Clayton County.

In the four northwestern townships no wells are reported as reaching the Maquoketa, all finding water either in Niagara dolomite at different depths or, less commonly, in the sands and gravels of the drift. Wells seldom exceed 160 feet in depth, although some are as deep as 265 feet, penetrating the Niagara to 200 feet.

In the southwestern townships the drift thickens toward the south and west. The deep drift east of Ryan, due probably to a buried channel, has already been noted. To the east of this "deep country," as the drillers term it, the rock rises to the surface at Maquoketa River. A mile west of the buried channel rock approaches within 50 feet of the surface of the Iowan drift plain. In southern Prairie Township wells are drilled from 70 to 100 feet and more in the Niagara dolomite after passing through from 80 to 120 feet of drift. In Adams Township the same conditions prevail, except that in the southwest corner of the township the bedrock belongs to the Devonian system.

The deeper Ordovician and Cambrian sandstones lie too far below the surface to be reached with profit, except for the water supply of the largest towns. It is from these affluent sources that the supply of Manchester is drawn, the artesian well of that city being 1,870 feet in depth. (See Pls. VI and VIII.)

SPRINGS.

Delaware County is favored with many large springs in all parts except the southwestern, where the country rock is deeply blanketed with drift and the area has suffered but little dissection.

A well-marked spring horizon occurs in the Niagara dolomite below the base of the Pentamerus zone, which lies 150 feet above the summit of the Maquoketa shale along Elk Creek. From this horizon issue the copious springs which supply Spring Creek in southern Delaware and northern Milo townships, and the waters of which are utilized by the large fish hatchery of the United States Bureau of Fisheries near Manchester. Other large springs from the same horizon occur near Hopkinton, near Millhein, and at different points in Honey

Creek and Delaware townships along the valleys of the creeks tributary to the Maquoketa. In Richland Township many springs issue from the same beds at the base of the picturesque limestone cliffs north of Forestville known as the "Devil's Backbone."

A still lower horizon is at the contact of the pervious and creviced Niagara dolomite with the Maquoketa shale. The underlying impervious bed of shale collects the water descending through the limestone and leads it down the dip to outlets where valley and ravine have trenched the strata. Dissolving little by little the rock through which it seeps, the ground water has developed a system of passageways in the transition beds overlying the shales and issues from its trunk conduits in powerful springs. The many springs along Elk Creek and its numerous branches in Elk and Colony townships emerge at this horizon.

A few examples of these fine springs must suffice. The spring of L. Schnittjer, sec. 26, Delhi Township, issues with a temperature of 52° F. from the Niagara. The water is lifted to a convenient level for domestic use and the watering of stock by a hydraulic ram—a device also used by other farms in the vicinity. The Silver Spring Creamery, Delhi, uses two springs issuing from the Niagara dolomite at the bottom of a ravine. Like most of the springs of the county the water carries no sediment, and its flow and clearness are not affected by storms or wind. The water flows through the creamery, where it is used for all purposes. The temperature is stated to be about 50° F. Big Spring, sec. 3, Colony Township, issues from the base of the Niagara, as does the spring of J. D. Chase, of Greely, which flows from 100 to 120 gallons a minute. From the same horizon issues the spring of J. C. Odell, sec. 16, Elk Township, whose discharge is 10 barrels or more a minute and whose water is carried by a flume 40 rods long and develops 30 horsepower. It is utilized to run a gristmill. The temperature is stated to be 48° F.

CITY AND VILLAGE SUPPLIES.

Earlville.—Earlville (population, 552) draws its water supply from a well and uses it chiefly for fire protection. The pressure is 39 pounds, and there are 11 hydrants and 1 mile of mains.

Hopkinton.—Water for Hopkinton (population, 797) is obtained from a drilled well 83 feet deep and 8 inches in diameter. Water is found in the Niagara dolomite, which the well enters at 30 feet. The Maquoketa shale was reached by the well. Water rises within 40 feet of the surface and is lowered but 5 feet under pumping. It is pumped by gasoline engine to a tank, which supplies a gravity pressure of 55 pounds. There are 3,300 feet of mains and 7 fire hydrants.

Manchester.—The supply for Manchester (population, 2,758) is drawn from an artesian well 1,870 feet deep. (See Pls. VI, VIII.)

The well is 10 inches in diameter to 260 feet, 7 inches to 890 feet, and 6 inches to 1,650 feet. A 7-inch casing extends from 260 to 890 feet, and a 5-inch casing from 1,300 to 1,650 feet. The curb is 926 feet above sea level and the head is 14 feet below the curb; with the Niagara waters cased out the head is 150 feet below curb; the present head is the same. The tested capacity was originally 200 gallons a minute and is now 250 to 300 gallons a minute from depths of 1,200 to 1,296 feet (Jordan). No water was found below 1,500 feet. No repairs have been made. The temperature after 10 hours' pumping was 48° F. The well was completed in 1896 by J. P. Miller & Co.

Previous to the completion of this well the water supply of Manchester had been an excellent spring, situated near the business portion of the town on the banks of Maquoketa River. A reservoir excavated in solid Niagara rock receives the water of the spring, and to develop the flow to the utmost several wells of moderate depth have been drilled within it. As the water was insufficient to supply the increasing population of the town, it was wisely decided to sink an artesian well, and a site was selected adjoining the reservoir and some 24 feet higher than the water in it.

While the drilling was in progress to at least a depth of 1,400 feet, water stood in the shaft at about 14 feet from the surface, and there were indications that this height was due to the influx of water from the spring. When water-bearing strata were reached at 1,200 feet and below, and the well was cased to 260 feet, the water dropped to 150 feet from the surface. On removing the upper casing to a depth of 260 feet, the water again rose within 14 feet of the curb, and on the final pumping test of the well the spring adjacent nearly ceased flowing. The well, therefore, receives a supply of water from the Niagara dolomite from the same source as that of the spring. The St. Peter is cased out, if the record is correct, and it is not known whether or not it is water bearing. The main flow seems to come from the Jordan sandstone, from 1,200 to 1,296 feet. Below 1,500 feet it is reported that no water was found—a remarkable fact, as the drill penetrated the entire thickness of the Dresbach sandstone.

The lower flow alone was tested with a pump throwing 75 gallons a minute for 24 hours without lowering the water. On the final test of all waters with a pump throwing from 160 to 200 gallons per minute from a 7-inch pipe 200 feet deep, the water soon sunk to 33 feet from the surface and there remained during the entire test of 20 consecutive hours.

The pumping cylinder is now set 200 feet below the surface in the well and the engines also pump from the spring reservoir. When the deep-well pump is in operation no water flows from the spring and the reservoir is drained. When the pump of the spring is working at its maximum the pump of the deep well jerks as if sucking air.

The spring alone supplies about 40,000 gallons a day. The deep well pumps from 250 to 300 gallons a minute all day without difficulty. In this connection should be noted the abnormally low temperature of the water pumped from the deep well after 10 hours' pumping and some 20 minutes after the pumping from the spring had ceased. Without question the well receives from the Niagara a large amount of water of low temperature.

Record of strata in city well at Manchester (*Pl. VI, p. 258; Pl. VIII, p. 352.*)

	Thickness.	Depth.
Silurian:		
Niagara dolomite (225 feet thick; top, 926 feet above sea level)—	*Feet.*	*Feet.*
Dolomite, buff, 6 samples	140	140
Dolomite, blue gray, highly cherty, 6 samples	60	200
Dolomite, blue gray, cherty, pyritiferous, slightly argillaceous	25	225
Ordovician:		
Maquoketa shale (205 feet thick; top, 701 feet above sea level)—		
Shale, blue, gray green, and drab; 18 samples	145	370
Magnesian limestone or dolomite, dark drab, subcrystalline, somewhat argillaceous, in flakes; 2 samples	14	384
Shale, blue and gray green; 7 samples	46	430
Galena limestone to Platteville limestone (354 feet thick; top, 496 feet above sea level)—		
Limestone, magnesian, dark drab, argillaceous	10	440
Limestone, light gray; earthy luster; briskly effervescent; 16 samples	106	546
Dolomite, light yellow gray, subcrystalline; stained with ferric oxide in minute rounded spots; much of the superior limestone in small fragments	10	556
Limestone, light and darker blue gray; generally rather soft; earthy luster; in flakes and chips; 20 samples	142	698
Shale, bright green, fossiliferous, containing *Orthis perveta* Conrad, *Strophomena trentonensis* W. and S. and Bryozoa (Decorah shale)	5	703
Limestone, light blue gray, fossiliferous	8	711
Limestone, light blue gray, earthy to crystalline; 11 samples	66	777
Shale, green, somewhat calcareous	7	784
St. Peter sandstone (33 feet thick; top, 142 feet above sea level):		
Sandstone, with small chips of limestone, in which no embedded grains are noticed	3	787
Sandstone, as above, but free from admixture; 4 samples	30	817
Prairie du Chien group—		
Shakopee dolomite (65 feet thick; top, 109 feet above sea level)—		
Dolomite, buff and gray; angular sand, mostly quartz sand, probably from above; 3 samples	18	835
Dolomite, light gray	42	877
Dolomite, slightly arenaceous	5	882
New Richmond sandstone (49 feet thick; top, 44 feet above sea level)—		
Dolomite, highly arenaceous, grains rounded and some enlarged by crystalline facets; 2 samples	11	893
Dolomite, gray, arenaceous; some light-drab shale	6	899
Dolomite, arenaceous; some highly arenaceous shale; 2 samples	19	918
Sandstone, calciferous	3	921
Dolomite, gray, arenaceous, with argillaceous powder	10	931
Oneota dolomite (275 feet thick; top, 5 feet below sea level)—		
Dolomite, gray; 8 samples	54	985
Dolomite, light gray, arenaceous; 3 samples	24	1,009
Dolomite, gray; arenaceous from 1,100 to 1,103 feet; 27 samples	170	1,179
Dolomite, arenaceous, gray	5	1,184
Dolomite, highly arenaceous, or sandstone, calciferous; 4 samples	22	1,206
Cambrian:		
Jordan sandstone (90 feet thick; top, 280 feet below sea level)—		
Sandstone, white; grains rounded and ground, with considerable diversity in size; 7 samples	50	1,256
Shale, highly arenaceous and calcareous	4	1,260
Sandstone, as at 1,256; 5 samples	36	1,296
St. Lawrence formation (242 feet thick; top, 370 feet below sea level)—		
Dolomite, gray; some sand, probably from above	20	1,316
Sandstone, calciferous, or highly arenaceous dolomite	15	1,331
Dolomite, light yellow gray	5	1,336
Dolomite, gray; in fine sand mixed with considerable quartz sand; 2 samples	10	1,346
Dolomite, light gray; in clean chips; a little sand from above	10	1,356
Dolomite, as at 1,346; 2 samples	16	1,372
Marl, arenaceous, argillaceous, and calcareous; in fine green-gray powder; 6 samples, all of a pulverulent powder, seen under the microscope to be composed of minute angular particles of quartz, dolomite, and chert, with much argillaceous material; glauconiferous	153	1,525
Sandstone, fine grained; in greenish-yellow powder; argillaceous	13	1,538

Record of strata in city well at Manchester—Continued.

	Thickness.	Depth.
Cambrian—Continued.		
Dresbach sandstone and underlying Cambrian strata (332 feet thick; top, 612 feet below sea level)—	*Feet.*	*Feet.*
Sandstone, white; grains fine and rounded	22	1,560
Sandstone; greenish argillaceous material mixed with drillings	13	1,573
Sandstone, fine; light buff from ferruginous stain	6	1,579
Sandstone, fine	19	1,598
Sandstone, coarser; uniform rounded, smooth-surfaced grains of limpid quartz	13	1,611
Sandstone, white	79	1,690
Sandstone, yellow, glauconiferous; said to be argillaceous	25	1,715
Shale, light blue, arenaceous, calcareous, somewhat glauconiferous	155	1,870

The water is pumped to a standpipe (capacity, 105,750 gallons) and distributed under domestic pressure of 50 pounds and fire pressure of 80 to 110 pounds, through 6 miles of mains, to 38 fire hydrants and 350 taps.

Ryan.—The water supply of Ryan (population, 511) for fire protection is drawn from a drilled well 258 feet deep, which enters rock at 90 feet. Water was found at 150 feet and rises within 60 feet of the surface. The capacity of the well is 150 gallons a minute. Water is distributed from an air-pressure tank under pressure of 60 pounds. There are 400 feet of mains and five hydrants.

Minor supplies.—Information concerning the water supplies of the smaller communities in the county is presented in the following tables:

Village supplies in Delaware County.

Town.	Nature of supply.	Depth.	Depth to water bed.	Head below curb.	Source of supply.
		Feet.	*Feet.*	*Feet.*	
Compton	Driven and drilled wells	12-150		10-20	
Delhi	Drilled wells	75-100		65-80	Niagara dolomite.
Dundee	Wells	40-250	70-100	20-40	Do.
Greely	Drilled wells	70-200	90		Do.
Masonville	Deep wells	65-140	90-140	50-100	Do.
Oneida	Wells	50-125	60		Do.
Sand Springs	Driven and drilled wells			1	Sand.
Thorp	Drilled and dug wells	15-100			Niagara dolomite.

WELL DATA.

The following table gives data of typical wells in Delaware County:

Typical wells in Delaware County.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head below curb.	Remarks (logs given in feet).
T. 87 N., R. 6 W. (Dams).						
		Feet.	*Feet.*		*Feet.*	
T. Williamson	4 miles north of Coggon.	305	55		55	20 feet away a well sunk to 160 feet found no water, rock being struck at 108 feet.

Typical wells in Delaware County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head below curb.	Remarks (logs given in feet).
T. 87 N., R. 6 W. (DAMS)—Contd.		*Feet.*	*Feet.*		*Feet.*	
W. Montgomery	4 miles north and 1 mile east of Coggon.	108	108			108 feet to water bed.
R. Platten	4 miles northeast of Coggon.	140	80			
T. Henderson	4½ miles northeast of Coggon.	68	68		18	68 feet to water bed.
A. Swidle	Silver Creek	70	30			70 feet to water bed.
Charles Beny	Northwest of Ryan	350	200+			Sandy soil, 2; clays to 6; soil, 8; Niagara, buff dolomite, 130; limestone, nearly white, 20; blue shale, Maquoketa, 40.
	S. ½ sec. 35	207	20			207 feet to water bed.
	NE. ¼ NE. ¼ sec. 23.	130	120			Mostly blue clay to rock.
	SW. ¼ SW. ¼ sec. 1.	160				All in drift.
	SW. ¼ NW. ¼ sec. 35	280	120			
T. 87 N., R. 5 W. (HAZEL GREEN).						
William Porter	3 or 4 miles east of Ryan.	262	260		110	
	NW. ¼ SW. ¼ sec. 28	205	200			High ground. Mostly blue clay to rock.
G. Abbey	NE. ¼ NE. ¼ sec. 32.	160	155			Somewhat lower ground than last.
	NE. ¼ SE. ¼ sec. 28.	242	240		40	Much lower ground than last two.
T. 87 N., R. 4 W. (UNION AND PART OF SOUTH FORK).						
James O'Neil	Southwest of Hopkinton.	200	80	Niagara dolomite.		All blue clay to rock.
T. 87 N., R. 3 W. (PART OF SOUTH FORK).						
Charles Root	NW. ¼ sec. 18	200	10			
Jacob Land	Northeast of Sand Springs.	125	65			
—— Mauser	2½ miles south of Worthington.	208	16			
	NW. ¼ NE. ¼ sec. 1.	162	20			Sand, 20; limestone, 140; shale, 2.
T. 88 N., R. 5 W. (MILO).						
	NE. ¼ NE. ¼ sec. 29.	215	214			High ground.
	SW. ¼ SW. ¼ sec. 28	190		Gravel		Lower ground. Ends in gravel 60 feet lower than the preceding and following.
—— Haynes	NW. ¼ NW. ¼ sec. 33.	210	200±			Nearly all in drift.
	NW. ¼ NW. ¼ sec. 32.	145	130			
	NW. ¼ NW. ¼ sec. 30.	70	50			Low ground.
	SW. ¼ SW. ¼ sec. 19	60	60		15	Low ground; clay from top to rock.
Charles Thorpe	7 miles south of Manchester.	180	150			Blue clay to rock.
	SW. ¼ SW. ¼ sec. 2.	85	15			
T. 88 N., R. 6 W. (PRAIRIE).						
	NW. ¼ NW. ¼ sec. 24.	160	90			
Lee M. Smith	4 miles southwest of Manchester.	100	80	Limestone		Blue clay to rock.

Typical wells in Delaware County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head below curb.	Remarks (logs given in feet).
T. 88 N., R. 6 W. (PRAIRIE)—Contd.						
		Feet.	*Feet.*		*Feet.*	
Sherman Harris....	6 miles southwest of Manchester.	121	101	....	....	Blue clay to rock.
....	NE. ¼ SE. ¼ sec. 19.	185	180	....	....	High knoll; nearly all blue clay to rock.
....	NE. ¼ SE. ¼ sec. 6.	120	118	....	....	
T. 88 N., R. 4 W. (DELHI).						
....	NE. ¼ sec. 18......	125	65	....	....	
....	SE. ¼ NE. ¼ sec. 19.	185	....	....	165	
....	NW. ¼ SW. ¼ sec. 29	204	50	....	....	
....	NE. ¼ SW. ¼ sec. 31.	220	100	....	200	
....	NW. ¼ NW. ¼ sec. 22	65	35	....	....	
....	SE. ¼ NW. ¼ sec. 22.	165	100	....	....	
....	SE. ¼ SE. ¼ sec. 14.	214	100+	....	....	
....	S. ½ sec. 14........	150	140	....	....	
....	W. ½ sec. 13.......	168	15	....	148	
....	SE. ¼ NW. ¼ sec. 24.	225	40	....	150	
George Morris......	E. ½ sec. 23........	141	46	....	....	Bottom of ravine. Log feet: Drift or alluvium, 46; dolomite (Niagara), 75; "shell rock" described also as a "blue clay" (Maquoketa).
T. 88 N., R. 3 W. (NORTH FORK).						
Mrs. Georgian......	Rockville..........	80	....	Sand and gravel..	....	Maquoketa bottoms. All sand and gravel.
Frank Kerns.......	2½ miles south of Dyersville.	160	12	....	....	Surface deposits, 12; limestone, 100; Maquoketa shale, 48.
—— Harris..........	2 miles south of Dyersville.	130	10	Limestone.......	....	Surface deposits, 10; limestone, 119; shale, 1.
N. Felters..........	2 miles northwest of Worthington.	320	90	.....do...........	....	Ridge; drift, mostly blue clay, 90; limestone, 70; shale, 150; limestone, 10.
T. 89 N., R. 5 W. (DELAWARE).						
West Side School..	Manchester.........	105	101	....	....	All blue clay to rock.
....	SW. ¼ NE. ¼ sec. 23.	75	50	Limestone.......	....	Blue clay to rock.
School well..........	Manchester.........	302	104	....	....	Sand to rock; Maquoketa shale struck at 220 feet from surface; ends in shale.
....	SW. ¼ NW. ¼ sec. 15	61	60	Sand.............	....	Sand to rock.
....	SE. ¼ SE. ¼ sec. 31.	92	90	....	....	All blue clay to rock; on low ground; would overflow years ago in wet seasons.
....	Center of sec. 22...	160	....	Gravel...........	....	
T. 89 N., R. 6 W. (COFFINS GROVE).						
....	SE. ¼ SE. ¼ sec. 21.	110	102	....	....	
....	Center of sec. 21...	80	72	....	....	Ravine.
....	SE. ¼ SE. ¼ sec. 15.	160	130	Limestone.......	....	Till to rock; a few streaks of quicksand.
....	SW. ¼ SE. ¼ sec. 3..	130	122	....	....	Sand to thin clay, overlying rock; one sand well in locality.

Typical wells in Delaware County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Sources of supply.	Head below curb.	Remarks (logs given in feet).
T. 89 N., R. 6 W. (COFFINS GROVE)—Continued.						
		Feet.	*Feet.*		*Feet.*	
....	NE. ¼ SE. ¼ sec. 4..	120	90	Limestone.......	....	Clays, 90; shell rock, 10; solid rock, 20.
....	NW. ¼ NW. ¼ sec. 30	132	130	....	....	
Charles Thorpe.....	9 miles west of Manchester.	140	....	Gravel...........	80	All blue clay to gravel.
Do.............	8 miles northwest of Manchester.	120	100	Limestone.......	....	
John Robinson.....	6 miles northwest of Manchester.	102	80	....	....	
T. 89 N., R. 4 W. (ONEIDA).						
D. B. Bushnell.....	5 miles east of Manchester.	137	20	....	....	
T. 89 N., R. 3 W. (BREMEN).						
....	1½ miles northeast of Earlville.	100+	....	Sand............	....	Nearly all sand.
Henry Leschy......	2½ miles southwest of Petersburg.	100+	....	Gravel...........	....	All sand and gravel.
—— Groffman......	5 miles west of Dyersville.	99	....	Sand............	....	Flowing well from sand under blue till.
—— Nachmann....	.....do..........	119	....	.....do..........	....	Do.
Henry Goertz......	4 miles west of Dyersville.	85	....	.....do..........	....	High prairie; nearly all blue till.
Henry Lichtenberg	3½ miles northwest of Dyersville.	206	25	Limestone.......	126	High ground. Drift, 25; limestone, 181.
T. 90 N., R. 4 W. (ELK).						
A. B. Holbert......	Greeley...........	265	{ 60 105 }	....	....	Diameter, 6 inches.
T. 90 N., R. 3 W. (COLONY).						
....	Sec. 19............	206	....	Sand............	....	Ends in sand under heavy pebbly blue till.
T. 90 N., R. 6 W. (RICHLAND).						
—— Wood.........	NW. ¼ NE. ¼ sec. 26	130	100	....	....	Yellow clay, 8; blue clay, 92.
W. H. Sherwin.....	Near Forestville...	131	30	....	....	
Allix Schaufner....	Schaufner.........	380	250	....	....	
....	4 miles southeast of Strawberry Point.	230	230	Sand............	....	Blue till, 215.

DUBUQUE COUNTY.

By W. H. NORTON.

TOPOGRAPHY.

The topography of Dubuque County is composite. The eastern part, rising 600 feet and more above Mississippi River, which flows along its eastern border, was deeply gashed by the tributaries of the master river during the long periods preceding the glacial epoch, and the hills and valleys thus developed have been accented by erosion since that time. The western part of the county, because of distance from the main channels of erosion, was perhaps not so deeply and thoroughly dissected in preglacial time, and it has been blanketed with sheets of glacial stony clays deposited by successive ice sheets from the northwest. Its valleys have thus been partly or wholly filled and the sharp erosion profiles characteristic of the eastern driftless portion of the county have been blurred or quite obliterated.

The youngest drift present, the Iowan, forms two long lobes, one occupying the summit of the ridge reaching from Dyersville to Epworth, the other stretching from Worthington southeastward down John Creek Valley. These are areas of gently undulating prairie with a local relief on the more level portions of not more than 40 or 60 feet in a square mile.

The remainder of the western and southern part of the county is occupied by older drift, the Kansan. Here the relief depends on two factors—the degree to which the preglacial rock-cut valleys were filled with drift, and the degree to which the drift has been removed by streams since its deposition. The time since the deposit of the Kansan drift has been long enough to permit a well-marked and fully developed drainage system to be initiated or restored. Streamways are incised below the upland crests to a depth of 150 feet about New Vienna and to more than 200 feet at Mellary. So broad, however, are the valleys that the local relief in places may not exceed 80 or 100 feet in a square mile.

The Kansan drift extends as far east as Bankston and Centralia and southeast to the Jackson County line. It reaches the edge of the main body of upland underlain by the Niagara dolomite, but fails to follow out upon the long spurs which render the escarpment of this upland so strongly digitate. The remainder of the county lies in the driftless area.

In this area broad flat-floored valleys have been opened by the larger streams, such as the Little Maquoketa. It may be noted that adjacent to the Mississippi there has been developed a wide upland, now maturely dissected, standing about 240 feet above the river and about the same distance below the Niagara upland to the west. This upland is underlain by the Maquoketa shale, and upon it are located the towns of Asbury, Julian, Ricardsville, and Key West. The origin of the upland, which is wholly comparable to that developed on the St. Peter along upper Iowa River in Allamakee County, need not here be discussed. Whether it is due to cliff recession of the overlying Niagara or is a peneplain uplifted and dissected it is of no special importance in the water supply of the county.

GEOLOGY.

The following geologic formations are present in Dubuque County:

- Quaternary:
  - Alluvium.
  - Loess.
  - Iowan drift.
  - Kansan drift.
  - Aftonian soil.
  - Nebraskan drift.
- Silurian:
  - Niagara dolomite.
- Ordovician:
  - Maquoketa shale.
  - Galena dolomite.
  - Decorah shale.
  - Platteville limestone.
  - St. Peter sandstone.
  - Prairie du Chien group.
    - Shakopee dolomite.
    - New Richmond sandstone.
    - Oneota dolomite.
- Cambrian:
  - Jordan sandstone.
  - St. Lawrence formation.
  - Dresbach sandstone and earlier Cambrian strata.

The following hypothetical geologic section is based on the scanty and in places conflicting data supplied by the records of the deep wells of Dubuque. (See Pl. VI, p. 258.) The thickness of the Galena dolomite is obtained by measurement of its outcrop.

General geologic section at Dubuque.

	Thickness.	Elevation of stratum.
Galena dolomite to Platteville limestone:	*Feet.*	*Feet.*
Dolomite	237	+ 550
Limestone, bituminous shale, green shale	46	+ 504
St. Peter sandstone:		
White sandstone, water bearing	58	+ 446
Prairie du Chien group:		
Dolomites (Shakopee and Oneota), arenaceous in places, New Richmond sandstone perhaps at 376 feet, with some shaly beds	310	+ 136
Jordan sandstone:		
Sandstone, water bearing	95	+ 41
St. Lawrence formation:		
Dolomites and shales; dolomites to sea level, shales, red marls, arenaceous and glauconiferous	179	− 138
Dresbach sandstone:		
Sandstone, water bearing	221	− 359
Unnamed Cambrian strata:		
Shales	121	− 480
Sandstone, water bearing above	768	−1,248

The lowest formation exposed to view in the county, the St. Peter sandstone, outcrops at several places near Spechts Ferry at the base of the bluffs bordering the Mississippi. In these places the normally loose white sandstone has been discolored and hardened by iron compounds leached from the rocks above. The drill, however, everywhere throughout the county finds the St. Peter in its normal phase—a soft friable sandstone of round clear grains of quartz.

The Platteville limestone overlies the St. Peter and appears along the Mississippi as far south as Eagle Point, Dubuque. It consists of a basal shale (the Glenwood shale of the Iowa State Survey), overlain by limestones, some magnesian and some fossiliferous, blue and brittle, and cut by the drill into flaky chips. Bituminous brown shales may be interbedded with these limestones. Above the Platteville lies the Decorah shale, a highly fossiliferous plastic shale with lenses of limestone. The Decorah is succeeded in ascending order by the Galena dolomite, which as now defined includes all from the summit of the Decorah shale to the base of the Maquoketa shale. The entire body of the Galena may be dolomitized, as at Dubuque, or more or less of the body of rock may have escaped the process and remain in its original nonmagnesian or slightly magnesian state. Where dolomitized, the Galena is porous and cavernous. It is the lead-bearing rock at Dubuque, where its thickness reaches 237 feet. The Galena forms the bedrock over a considerable area in the immediate vicinity of the streams in the northwestern part of the county.

The Maquoketa consists in Dubuque County of 50 feet of friable shale with earthy limestones overlain by 150 feet of plastic blue shale. These impervious and dry rocks immediately underlie a large upland area in the eastern part of the county (p. 313). The shale is well known to drillers throughout the county. The progress of the drill is retarded in this formation by the fact that the drill hole must be washed out every 2 or 2½ feet.

The uppermost geologic formation of the county and the most extensive in its outcrops is the Niagara—a buff dolomite, in many places cherty, especially toward the base. It underlies the superficial deposits west and south of the conspicuous sinuous line of cliffs of the Niagara escarpment. As rock, the Niagara closely resembles the dolomitized Galena and could hardly be told from it by the cuttings of the drill, although the Niagara tends in color to blue-grays and to lighter buffs rather than to the darker buff of the Galena. The two formations are readily distinguished by their surface distribution and by the thick shale which parts them.

The drift sheets of the county are three. The oldest, the Nebraskan, is separated from the overlying Kansan by the interglacial Aftonian deposits, consisting of old forest beds representing an interval during which soils accumulated and forests grew on the older glacial ground moraine. Both the Kansan and Nebraskan drift sheets are tough blue stony clays, although superficially the Kansan is deeply reddened by long weathering. The lobes occupied by the thin sheet of Iowan drift have already been mentioned. (p. 313).

The loess, a yellow or ashen silt or dust deposit, mantles everywhere the eroded surface of the Kansan and the driftless area.

UNDERGROUND WATER.

SOURCE AND DISTRIBUTION.

With the wide range of formations exposed in Dubuque County the number of horizons at which ground water may be found is exceptionally large.

The drift water beds consist of different sands and gravels either separating different drift sheets, inclosed within the stony clay of an individual drift sheet, or resting immediately on bedrock. The upper interglacial gravels have long since been left behind by the gradual lowering of the ground water since the country was opened to cultivation. Drillers state that no water is now found between the yellow and blue clays, and the seepages at the base of the loess have also gone dry. Only the basal sands of the drift supply stock wells at present, and these sands carry little water except where the drift is of considerable thickness. Drift wells drawing their water from this source are naturally most numerous on the slightly dissected Iowan drift plains. Thus about Worthington wells are commonly from 100 to 120 feet deep and "just about reach rock;" on the Farley lobe of the Iowan drift wells are reported as supplied from gravels 135 and 160 feet below the surface and covered chiefly by blue till. The depth of wells in drift is affected by the varying thickness of this glacial deposit, due in part to the preglacial relief of the country. A strip of "deep country" is reported in Taylor Township, extending from southeast to northwest and running out northwest of Epworth, the drift here being 100 feet and more in thickness. West of Bankston rock may be covered with 70 feet of drift within 1,000 feet of its outcrops. In Epworth rock is reached at 35 feet in places on the low ridge at the west end of town, whereas at the east end the drift is 135 feet deep. In places, as on the ridges about Farley, drillers report a stiff unctuous clay 5 or 6 feet thick, resting on rock. This is probably the red residual clay to be looked for on ancient weathered limestone surfaces, and to the driller it is a far less desirable formation than the water-carrying glacial gravels that in many places rest directly on the rock.

The Niagara is the chief water bed of the county in the southern and western parts. The well records give no section of the formation as more than 135 feet, although the measured outcrops give a thickness of somewhat more than 200 feet. No special horizons within this thick body of dolomite have been noted at which water can be expected. Where local conditions permit its ready drainage, as on the long spurs along its border, water will be found, if at all, only at its base; back from the margin, where, owing to lack of dissection, ground water stands high and the larger part of the dolomite is water-logged, water may be found wherever the drill encounters a crevice or an especially porous layer.

Even far within the border of the Niagara the drill may occasionally fail to strike such a crevice or porous bed and may reach the base of the formation and enter the Maquoketa shale without having found a water supply. If the well is continued it should be with the full understanding that this shale is dry throughout its thickness of 200 feet and more, and it may be necessary to drill some distance into the Galena before finding a good water bed. Wells in the Niagara are reported which thus reached a total depth of 400 and even of 500 feet.

On the ancient weather terrace or peneplain developed on the Maquoketa shale about Dubuque, wells do not find water until they reach the basal portion of the Maquoketa, consisting of earthy non-plastic layers, or the upper thin-layered beds of the Galena.

In the northeastern parts of the county water is found in the Galena and Platteville at depths depending on the height to which these bodies of dolomite and limestone are locally water-logged and on the success of the drill in striking a water vein. At Linwood, Dubuque, a well which entered the Galena at 40 feet found water within 145 feet of the surface of the ground. Another well at Linwood in the Roman Catholic cemetery was sunk to 312 feet, some water being found at 190 feet. On the bluffs at Dubuque the ground-water level stands about 150 feet below the surface, lowering, however, toward the river, as seen in the Fourteenth Street mine. In this area a number of wells, about 100 feet deep, are used for cesspools, the contents discharging freely into the ground water, from which house wells in the same district are supplied. Northeast of Sherrills Mound, an outlier of the Niagara, wells run about 200 feet in depth, finding their supply in the Galena and Platteville.

The St. Peter, the lowest water bed except those of the deep artesian wells of Dubuque, is tapped only near Mississippi River in the northeastern portion of the county. Thus, on the Peru bottoms the 160-foot well of William Cavanaugh (SW. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 35, T. 90 N., R. 2 E.) struck light-yellow water-bearing sandstone 6 or 7 feet thick, beneath 154 feet of alluvial quicksand and gravel.

The alluvial deposits outside of the broad flood plains of the Mississippi are so small in extent that they hardly need mention. An interesting belt of country where water is obtained in river deposits is that of the Couler Valley, which extends northwest from the city of Dubuque to Sageville. In this ancient abandoned river channel driven wells furnish sufficient water for household and ordinary farm uses. The deep well at the works of the Dubuque Malting Co. shows that the alluvium in this valley is 117 feet thick. At Eagle Point, Dubuque, the well of Amos Baily, on the flood plain of the Mississippi, was sunk through 160 feet of alluvium before striking rock, the total depth of the well being 170 feet.

SPRINGS.

The two best-marked spring horizons in Dubuque County are at the summits of the Maquoketa shale and of the Decorah shale. At both these horizons ground water is arrested in its descent by an impervious floor of shale and finds way to open air wherever the basal strata of the limestones are trenched by the channels of surface drainage. The large quantity of water gathered and the easy solubility of the limestones, which permits the opening of passageways of considerable size, give rise to copious springs. Along each of these horizons the spring may not mark the exact line of junction of two formations; it may lead out through talus cloaking the hillside to issue from this loose rock waste at some lower level than the summit of the shale; or it may issue at some higher level than the shale, owing to the devious windings of the subterranean passages dissolved in limestone.

Of less importance is the Niagara dolomite. Springs are found issuing from its crevices along the North Fork of the Maquoketa.

These water beds are cut by the valleys of the streams in almost every section of the northeastern part of the county, and springs are correspondingly numerous. The perennial flow of the Little Maquoketa is due to its supply by springs issuing from the summit of the Maquoketa shale, which takes its name from its outcrops along this stream. On the other hand, the next stream to the south, Catfish Creek, which drains the plain developed in the Maquoketa shale, goes dry each year for lack of springs within its catchment area, although this area is large enough to give rise to torrential and destructive floods from the run-off of heavy rains.

Among the more important of the springs of the county may be mentioned that at Washington Mills, which issues at the exact contact between the Niagara and the Maquoketa; a large spring near Rochester; one in sec. 4, Georgetown Township; and the springs issuing along the bluffs of the Mississippi which supply the villages of Spechts Ferry and Waupeton.

CITY AND VILLAGE SUPPLIES.

Cascade.—Cascade (population, 1,268) pumps water from a spring issuing from the Niagara dolomite to a tank with a capacity of 20,000 gallons. The amount used daily is 70,000 gallons. The gravity domestic pressure is 56 pounds and the fire pressure 100 pounds. The system comprises 1 mile of mains, 52 taps, and 15 fire hydrants.

Dubuque.—The city of Dubuque (population 38,494) is supplied with water from artesian wells from which 4,000,000 gallons daily are pumped to a reservoir and distributed under gravity pressure of 45 pounds. There are 63 miles of mains, 363 fire hydrants, and 3,300 taps. (See pp. 318 and 319.)

Near Dubuque the chief water beds are the Dresbach and earlier Cambrian sandstones, the St. Peter sandstone, Prairie du Chien group, and Jordan sandstone being of minor importance. Wells about 1,000 feet in depth tap all reservoirs except those below the Cambrian shale underlying the Dresbach sandstone, and wells 1,300 feet or more in depth reach the stores found in the Cambrian sandstone underlying this shale. If the conditions reported at the deepest well of the Linwood Cemetery prevail throughout the field, no water need be expected below 1,650 feet.

The head of the water of the lower sandstone of the Cambrian just described seems somewhat higher than that of the Dresbach sandstone, as seen in the well of the Key City Gas Co., where the two waters are kept apart.

The first deep wells drilled at Dubuque were put down about 1,000 feet, tapping the Jordan and the Dresbach sandstone. They had a static level of more than 700 feet, heading a little more than 100 feet above the lower ground of the city. Thus the well of the Butchers Association is reported to have headed at 740, the Julien House well at 724, and the well of the Steam Heating Co., drilled in 1884, at 704 feet above sea level. The enormous discharge of the 10-inch well drilled in 1888 by the waterworks company at Eighth Street reduced very generally the head of the other wells, and later wells from 900 to 1,300 feet in depth showed a distinctly lower static level (Schmidt well, 645 feet above sea level; Chicago, Milwaukee & St. Paul Ry. well, 683 feet above sea level). The latest well of this class, that of the gas company, had a static level of 667 feet above sea level.

Of the deeper wells tapping the lower sandstone of the Cambrian the initial head of the Linwood Cemetery well was 742 feet above sea level, but in 1900 this had declined to 661, and the Sixth Avenue well at Eagle Point showed an initial head of but 647 feet.

The use of compressed air in several wells has caused a sudden loss of pressure in neighboring wells, and this lowering of static level may be expected to widen in area and increase in amount.

In 1905 several old wells still held their waters up to from 630 to 645 feet above sea level, and the Julien House well and the gas company well showed heads respectively of 685 and 667 feet above sea level. In 1908 the wells reporting in response to letters of inquiry showed heads not exceeding 625 feet above sea level, except in one or two doubtful cases.

The early failure of some of the wells points to defective or deteriorated casings, but the general loss of head, a loss in several wells sudden and coincident with the completion of new wells of great capacity on low ground or with the installation of air lifts in other wells, finds its cause in a general lowering of static level due to overdraft. For this condition there is no remedy except the partial one of restriction of outflow so far as possible. Wells in plants not in operation should be closed, and lateral escape of waters through defective casing and through channels opened in the rock where the well is not cased should be prevented by keeping all wells effectively cased to the chief aquifers.

The Butchers' Association well has a depth of 1,000 feet and a diameter of 8 inches to the bottom; it is cased to 300 feet. The curb is 607 feet above sea level. The original head was 133 feet above the curb and the head in 1896 was 41 feet above the curb. The original flow was 580 gallons a minute. No record of the present head and discharge has been obtained. Water was first tapped at a depth of 600 feet and gradually increased to the bottom. The temperature is 56.5° F. The well was completed in 1887 by J. P. Miller & Co., of Chicago.

The Lorimer House well has a depth of 1,057 feet and a diameter of 5 inches. The curb is 652 feet above sea level. The original head was 57 feet above the curb and the head in 1896 approximately at curb. The original flow of 400 gallons a minute had ceased in 1906. The well was drilled by J. P. Miller & Co., of Chicago. It has not been in use since 1892.

The Julien House well had an original depth of 896 feet but was deepened in 1898 to 1,660 feet. Its diameters are 12, 6, and 5 inches, cased originally to 212 feet. The curb is 615 feet above sea level. The original head was 109 feet above curb; head in 1896, 97 feet above the curb; head in 1905, 70 feet above the curb. The original flow was 480 gallons a minute. The well was drilled in 1872 by J. P. Miller & Co., of Chicago.

Before the well was deepened the flow had ceased. The sinking of the city wells had no influence on the flow, but the first night that the air compressor was set working in the city well, about 11 blocks away, the Julien House well discharged about 2 bushels of sand.

Driller's log of Julien House well at Dubuque.

	Thickness.	Depth.
	Feet.	*Feet.*
Loose material	210	210
Sandstone	160	370
Marl	66	436
Sand, marl, and limestone mixed	50	486
Sandstone	60	546
Limestone	105	651
Marl, red	40	691
Shale, sandy	46	737
Marl, red	7	744
Sandstone	141	885

The Linwood Cemetery well No. 1 has a depth of 1,765 feet. Its curb is approximately 776 feet above sea level and its original head was 23 feet below the curb. The well is now pumped with a cylinder 200 feet below the curb.

The Linwood Cemetery well No. 2 has a depth of 1,954 feet and a diameter of 8 inches to 1,000 feet and 6 inches to bottom; casing to 1,025 feet. The curb is 706 feet above sea level. The original head was 36 feet above curb; head in 1896, 1(?) foot above curb; head in 1900, 45 feet below curb. The original flow was 40 gallons a minute; flow in 1896, 20 gallons a minute; well now pumped. Water from a depth of 100 feet rose nearly to the surface. The first rock flow was at about 1,250 feet and gradually increased until drill reached a depth of 1,650 feet, below which no water was found. The well was completed in 1891 by J. P. Miller & Co., of Chicago.

This well is sometimes obstructed by a "fibrous sediment" which may be Crenothrix and which is removed by churning an iron rod in the tube. At times this treatment has doubled the diminished flow.

The J. Cushing factory well has a depth of 965 feet and a diameter of 7 inches to 60 feet, 5 inches to 190 feet, and 4 inches to bottom; cased to bottom. The curb is 642 feet above sea level. The original head was 31 feet above the curb and the head in 1896 at curb. Water comes from 600 feet and lower. The temperature is 60° F. The well was completed in 1888 by J. P. Miller & Co., of Chicago.

The Packing & Provision Co.'s well has a depth of 955 feet and a diameter of 8 and 6 inches; cased to 200 feet. The curb is 607 feet above sea level. The original head was 55 feet above the curb; head in 1896, 50 feet above curb; head in 1905, 23 feet above curb. The original flow was 340 gallons a minute; the present tested capacity, with pump cylinder 16 feet above curb, is 90 gallons a minute. The well was completed in 1889 by J. P. Miller & Co., of Chicago.

The Consumers' Steam Heating Co.'s well has a depth of 802 feet and a diameter of 4 inches. The curb is 617 feet above sea level.

The original head was 87 feet above curb and the head in 1896 at curb. The original flow of 260 gallons a minute had ceased in 1896. The water comes from depths of 353, 480, and 780 feet. The well was completed in 1884 by J. P. Miller & Co., of Chicago.

Driller's log of Steam Heating Co.'s well at Dubuque.

	Thickness.	Depth.
	Feet.	*Feet.*
Depth to rock [alluvium]	165	165
Sandstone	6	171
Sand and shale	5	176
Limestone, white	128	304
Limestone, gray	42	346
Sand and lime [inspection of the tube shows that this includes a cherty limestone, perhaps arenaceous, a gray limestone, and lowest a brown cherty, arenaceous limestone]	135	481
Sandstone, brown	20	501
Marl, yellow	3	504
Sand and lime	10	514
Sandstone	62	576
Lime	18	594
Marl, red	87	681
Shale, sandy, green	64	745
Marl, red	10	755
Sandstone, cream yellow	47	802

The Schmidt brewery well (W. Weiss Beer Co.) has a depth of 886 feet and a diameter of 8 to 6 inches; 8-inch casing to 80 feet, 5-inch casing to 120 feet. The curb is 630 feet above sea level. The head in 1896 was 15 feet above curb; the present head is below curb; water rises nights and Sundays. The well now pumps 35 gallons a minute with the cylinder set 16 feet below curb. The water comes from depths of 500 feet, 700 to 800 feet (main flow), and below. The well was completed in 1891 by J. Bicksler, of Dubuque.

Record of strata in Schmidt brewery well at Dubuque.

	Depth in feet.
Sand and gravel	25
Sand, yellow	30
Sand, reddish	56
Dolomite, buff; aspect of Galena	60–65
Limestone, dark bluish gray and buff	80
Limestone, magnesian, or dolomite; dark drab, mottled with lighter color; in small angular fragments, residue after solution large; argillaceous, siliceous, and pyritiferous; three samples	100–114
Sandstone, white, moderately coarse; grains rounded, smooth, and comparatively uniform in size	126
Dolomite, light yellow gray, nearly white, with much sand in drillings	140
Sandstone, as at 126 feet	156
Dolomite; drillings chiefly chert	189
Dolomite, gray, highly cherty at 250 feet	210–250
Sandstone, white, many grains faceted; some dolomite chips in drillings	254
Dolomite, light buff, in fine sand, with chert and quartz sand	258

	Depth in feet.
Sandstone, white, with calcareous cement	267
No samples	267–426
Dolomite, buff, cherty	426
Dolomite, brown; chippings splintery; mostly of flint with some of drusy quartz	430
Sandstone, cream yellow, moderately fine, calciferous as shown by dolomitic and cherty material in drillings; three samples	465–474
Dolomite, buff; in fine sand, with some quartz sand	478
Sandstone, light reddish yellow, fine, calciferous	535
Dolomite, in fine buff sand and gray chips	581–584½
Shale, highly arenaceous, glauconiferous; in chips which pulverize into reddish yellow powder at 632 feet and reddish brown at 636 feet, quartzose material, microscopic and angular	632–636
Dolomite, highly arenaceous, glauconiferous; in fine brown angular sand at 724 feet and in coarser sand at 726 feet	724–726
Sandstone, yellow; grains moderately fine, the larger rounded and smoothed	730
Sandstone, pure, white; grains rounded, moderately fine	841

The Bank and Insurance Building well had a depth of 973 feet, but was deepened in 1900 to 1,380 feet. Its diameter is 8 to 4½ inches. The casing extends to 150 feet, and also covers 50 feet of shales below 200 feet. The curb is 638 feet above sea level. The original head was 10 feet above the curb; the present head is 3 feet above curb (water pumped to tank on roof). The original flow was 120 gallons a minute, which increased in 1900, after deepening, to 125 gallons a minute. The first flow was at a depth of about 900 feet. Temperature, 61° F. Date of completion, 1894; drillers, J. P. Miller & Co., Chicago.

The E. Hemmi dairy well has a depth of 973 feet. The curb is 627 feet above sea level. It was completed in 1895 (?).

This well stopped flowing on the starting of the air compressors of the malting company. It is now pumped by a windmill.

The Dubuque Brewing & Malting Co.'s well has a depth of 999 feet, but was deepened in 1904 to 1,165 feet. Its diameter is 8 to 6 inches. The curb is 624 feet above sea level. The well was completed in 1895 by J. Bicksler, of Dubuque, and was deepened and recased to 450 feet in 1904 by J. P. Miller & Co., of Chicago. No definite facts are obtainable as to head and discharge. The original flow was received in a reservoir from which it was pumped throughout the brewery. The flow ceased when the air compressors of the city wells were in use, and an air compressor was installed to pump the well, whose capacity was estimated at 150 gallons a minute. The repairs made by deepening and recasing the well in 1904 are reported as having been very beneficial, but the increase in flow or pressure is not stated. In 1908 the head was 6 inches above the curb, the flow being increased by the use of the air compressor.

Driller's log of Dubuque Malting & Brewing Co. well.

	Thickness.	Depth.
	Feet.	*Feet.*
[Surface material]	117	117
Limestone	33	150
Sandstone	75	225
Limestone	225	450
No record	533	983
Shale	45	1,028
Marl, red	2	1,030
Sandstone	135	1,165

The Key City Gas Co.'s well has a depth of 1,310 feet and a diameter of 10 inches to bedrock (116 feet), 8 inches to 562 feet, 6¼ inches to 1,070 feet, and 5 inches to the bottom; casing, 10 inches to 116 feet and 4 inches from curb to 1,118 feet. The curb is 619 feet above sea level. The original head was 48 feet above curb; head in 1905, 48 feet above curb. The original flow was 400 gallons a minute. Water comes from depths of 1,000, 1,118, and 1,310 feet. Temperature, 60° F. The well was completed in 1900 by J. P. Miller & Co., of Chicago. The waters of the higher water beds rise through the outer casing and those of the lower through the inner. The lower waters have the higher head, but the difference is variously reported. It is stated that on the completion of the well the flow of other wells in the city was diminished and some of the shallower wells ceased to flow. In 1905 the two flows had become mingled through corrosion of casing.

Driller's log of Key City Gas Co.'s well at Dubuque.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface material	67	67
Limestone, shelly	49	116
Limestone or shale	34	150
Shale, sandy	320	470
Shale, red, and caving rock	75	545
Limestone	100	645
Shale	45	690
Sandstone	295	985
Shale, sandy	115	1,100
Rock, hard and soft streaks	210	1,310

The Chicago, Milwaukee & St. Paul Railway wells are two in number, each with a depth of 1,263 feet. The curbs are 607 feet above sea level. The original heads were 76 feet above curb; heads in 1905, 28 feet above curb. The well No. 1 was completed in 1898; it flowed 60 gallons a minute.

City well No. 1, Eighth and Pine Streets, has a depth of 1,310 feet and a diameter of 10 inches; casing, 400 feet. The curb is 607 feet above sea level. The original head was 46 feet above the curb; head in 1905, 23 feet above curb; head in 1908, 3 feet above curb. The original flow is unknown, but the flow in 1908 was 100 gallons a minute. The water came from depths of 500 and 1,310 feet. Date of completion, 1888.

The Eagle Point north city well has a depth of 1,308 feet and a diameter of 12 inches; 12-inch casing to 400 feet. The curb is 625 feet above sea level. The original head was 24 feet above curb, and the head in 1905, 20 feet above curb. The flow in 1905 was 300 gallons a minute; flow in 1908, 230 gallons a minute; capacity under air compressor acting at 300 feet in depth, 805 gallons a minute. The first flow came from 800 feet. The well was completed in 1899 at a cost of $2,600.

The Eagle Point south city well has a depth of 1,306 feet and a diameter of 12 inches to 900 feet, 8 inches to bottom; casing, 8 inches to 1,000 feet. The flow in 1905 was 265 gallons per minute, and in 1908, 120 gallons a minute; capacity under the air compressor, 290 gallons a minute. The head was the same as that of the north well. Date of completion, 1899.

The Eagle Point Sixth Avenue city well has a depth of 1,927 (or 1,908) feet and a diameter of 4 inches; 4-inch casing to 450 feet. The original head was 22 feet above curb; head in 1905, 11 feet above curb. The original flow was 135 gallons a minute. Temperature, 61° F. The well was completed in 1900.

The use of the air compressor in the north well stops the flow of the south well; in 1905 its use in the north and south wells reduced the flow in the Sixth Avenue well to one-third its normal discharge; the effect on the distant Eighth Street well is said to be slight.

An unpublished log of the waterworks well at Galena, Ill., is here presented for comparison with the logs of wells at Dubuque.

Driller's log of well of waterworks at Galena, Ill.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface material	65	65
Limestone	95	160
Sand, white, water, first flow (St. Peter)	105	265
Marl, red	40	305
Sandstone, white, water	222	527
Limestone, sandy	80	607
Shale, sandy	28	635
Limestone, sandy	50	685
Sand, white, water	28	913
Sand and limestone	12	925
Sand, white, water	645	1,570

Dyersville.—The water system of Dyersville (population, 1,511), owned by the city, obtains its supply from a 5-inch drilled well, 384 feet deep, entering rock at a depth of 2 feet. Water heads 150 feet from the surface. The chief water bed was found at 136 feet in Niagara dolomite. Water is pumped by gasoline engine to a tank, whence it is distributed under gravity pressure of 45 pounds through $1\frac{1}{6}$ miles of mains. There are 30 taps and 20 fire hydrants.

The St. Peter sandstone should be struck at about 260 feet above sea level, or 681 feet below the surface, and the Jordan at about 150 feet below sea level or about 1,090 feet below the surface. A well sunk to 250 feet below sea level, that is, to about 1,100 feet from the surface, should give a supply ample for the town so long as the well is kept in good repair. The water from the deeper beds may be expected to stand about 150 feet below the curb, but the upper waters, which will be found in the Niagara, Galena, and Platteville limestones, will come much higher and increase the head. The cylinder of the pump should be placed low enough to draw on the deeper waters after the upper limestone waters, which will be less in amount, have been pumped off.

Minor supplies.—Information concerning the supplies of some of the smaller places is contained in the following table:

Village supplies in Dubuque County.

Village.	Nature of supply.	Depth of wells.			Depth to water bed.	Depth to rock.	Head.	Springs.
		From—	To—	Common.				
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Bernard	Wells	80	600	120	100	12		None.
Durango	Cisterns and wells.	30	135	130			−20	Large and small.
Epworth								
Farley	Drilled wells	60	120			15		
Peosta	do	18	535	150		25	−15 −30	Small.
Spechts Ferry	Springs							
Placid		24	315	120	120	300 135	−16 −80	
Waupeton	Springs							
Sageville				100				
Worthington	Drilled and open wells.	30	60	60	60	25	−15 −30	Small.

WELL DATA.

The following table gives data of typical wells in Dubuque County:

Wells in Dubuque County.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head.	Remarks (logs given in feet).
T. 88 N., R. 1 E. (VERNON).						
		Feet.	*Feet.*		*Feet.*	
Mrs. King	NW. ¼ NE. ¼ sec. 13	135				High ground.
Peter Broessel	SW. ¼ SW. ¼ sec. 7.	200			−160	
J. McMahon	SW. ¼ SE. ¼ sec. 12.	400				Dolomite, Niagara, 60; Maquoketa shale and Galena limestone, 340.

Wells in Dubuque County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head.	Remarks (logs given in feet).
T. 90 N., R. 2 E. (PERU).		*Feet.*	*Feet.*		*Feet.*	
John Coultis	1½ miles southwest Spechts Ferry.	150				
T. 89 N., R. 1 W. (IOWA).						
	Tivoli, sec. 8	140	66	Limestone		Yellow clay, 10; blue clay, 56; limestone, 74.
	Bankston	175				Drift and Niagara dolomite to Maquoketa shale, 175 feet.
Clement Meyer	SW. ¼ NE. ¼ sec. 33	160	13			Rather high ground.
L. H. Fangmann	NE. ¼ SW. ¼ sec. 8.	160		Gravel		All sand to gravel.
C. Fangmann	NE. ¼ SE. ¼ sec. 8	208	70	Limestone		Yellow clay to rock.
	Kidder	86	20	On shale		Low ground near creek. Reddish sand and clay, 20; limestone, 20; shale, 46.
Keller	4 miles northwest of Epworth.	160				Ridge; Maquoketa shale penetrated, 60.
T. 88 N., R. 1 W. (TAYLOR).						
—— Bennett	1 mile north of Epworth.	112				Mostly sand; limestone, 5.
Geo. Freeman	4 miles southwest of Epworth.	155		On shale	− 95	Yellow clay, 30; blue clay, 60; limestone, 40; shale, 25.
Aug. Krogmann	SW. ¼ SE. ¼ sec. 7.	500				High hill. Drift, 60; limestone, 100; shale, 340. No water.
Geo. Graham	1½ miles southeast of Graham.	450	66			Ridge. Yellow clay, 40; blue clay, 26; limestone, 110; shale (Maquoketa), 254; hard gray limestone, 12; shale, 8.
—— Harns	East end of Epworth.	187	135	Limestone		Drift, nearly all sand, 135; Niagara dolomite, 52.
M. M. McDermott	1½ miles south of Epworth.	115		Gravel		Yellow clay, 20; blue clay, 87; gravel, 8.
—— Quirrin	Sec. 11	250	190			
N. Bradfield	Sec. 12	140	135		−100	Blue till from 40 to 135.
T. Smith	Sec. 22	83	65			Black drift into wood above rock.
J. Haly	Sec. 34	195	190			Mainly yellow till and sandy material to rock with some "black clay."
Geo. Banerich	SW. ¼ NE. ¼ sec. 31	220	85	Limestone		Drift, 85; Niagara dolomite, 135.
T. 88 N., R. 2 W. (DODGE).						
	2 miles northwest of Farley.	135		Gravel		Nearly all blue clay to gravel.
—— Martin	1½ miles west of Farley.	160		do		Blue clay to water bed.
J. N. Crapp	Sec. 11	102	102		− 66	Mainly yellow till.
F. Funke	Sec. 9	154	117		− 54	67 feet of blue-black till on rock.
Aug. Coopman	2 miles south of Dyersville.	300	6			High ground. Drift, 6; Niagara dolomite, 100; Maquoketa shale, 194; ends in shale.
Town	Worthington	56	30	Limestone	− 18	Diameter, 5⅝ inches. Depth to water supply, 50.
T. 90 N., R. 1 W. (CONCORD).						
John Frietmann	NE. ¼ NE. ¼ sec. 16	164		Sand and gravel.		Blue stony clay to water bed.
Nicholas Smith	SE. ¼ SE. ¼ sec. 32.	200				Reached Maquoketa shale.
T. 88 N., R. 2 E. (TABLE MOUND.)						
C. Ehrsam	NW. ¼ sec. 18			Sand and Gravel.		Valley. Mostly soft quicksand; rock not reached.

Wells in Dubuque County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head.	Remarks (logs given in feet.
T. 89 N., R. 1 E. (CENTER).		*Feet.*	*Feet.*		*Feet.*	
....	Centralia..........	250	....	....	....	Drift and loess, 30; blue shale, 220.
P. Erschen........	.....do............	220	....	....	−190	
A. Hollins........	.....do............	120	....	....	− 40	
H. Calahan.......	Sec. 7............	416	....	....	−398	Altitude, 1,150 feet; 32 feet of drift.
....	.....do............	112	60	Limestone	....	Yellow and blue clay, 60; limestone, 12.
T. 89 N., R. 2 W. (NEW WINE).						
—— Mayberry....	2½ miles northwest of Farley.	92	32	.....do........	− 52	Yellow clay, 12; blue clay, 20; limestone, 60.

FAYETTE COUNTY.

By W. H. NORTON.

TOPOGRAPHY.

As Fayette County lies near the margin of the driftless area, it includes two types of topography, each of which exercises a certain control over the distribution of ground water. The northeastern part of the county—the area lying east and north of West Union and Fayette—is a land of hills, some of which are 400 feet high, carved by streams from an upland about 1,200 feet above sea level. Here the Kansan drift is thin and the topography of preglacial time is not effaced or even masked. Over the remainder of the county the preglacial hills and valleys have been deeply buried beneath drift, and the latest ice sheet to invade the region, the Iowan, has molded the surface to a gently undulating prairie. In this prairie region ground water stands high, feeding the streams of the shallow valleys with oozes along their banks; in the rugged country of the northeastern part ground water stands low and must be sought by wells at levels approximating those of the bases of the hills, where it issues in copious springs.

The divide between Volga and Turkey rivers reaches an elevation of 1,280 feet above sea level; the lowest valley floors descend to 775 feet above sea level. The two areas are roughly sketched in any road map of the county. In the dissected area the crooked highways follow around hill and up winding valley and along the sinuous ridge tops; on the prairie of the younger drift they adhere to the section lines undeviatingly.

The broad, flat valleys of the streams of the dissected area form a topographic type of special interest in this investigation. Their width, which commonly reaches a mile along Volga and Turkey rivers is an expression of an advanced stage of development due not only to their great age but also to the weak rock, the Maquoketa shale, in which they have been worn.

GEOLOGY.

Pleistocene drift deposits mantle the entire county. In the hilly northeastern part they are thin and almost negligible from the present viewpoint, but over the prairies of the county they are thick. The great bulk of the drift belongs to the earlier drift sheets, the Nebraskan and the Kansan. The Iowan drift forms a veneer on the older drift over about two-thirds of the county. Outside of the Iowan area the stony clays of the drift are mantled with a fine yellow silt called loess.

The well driller does not distinguish between these superficial deposits, nor is their discrimination easy in the contents of the slush bucket. Yet valuable data may be obtained by noting the depth at which the gritless yellow loess passes into the ashen loess beneath it or into the sands which in a few places underlie it, or into the brighter-yellow stony clay of the weathered Kansan. The place and thickness of the sand beds which locally intervene between the Kansan and the Nebraskan should also be noted. At the same horizon (Aftonian) will be found in places old soils, deposits of peat, and forest beds, whose dark and ill-smelling products are recognized at once. The driller should also note the depth at which the weathered reddish or yellow Kansan passes into the blue unoxidized and tougher stony clay of the unweathered basal portion of that drift.

Several members of the Devonian system, differing lithologically one from another, are exposed in different places in the central and western parts of the county, as in the deep railway cut at Fayette, but their discrimination matters little in this investigation.

The Niagara dolomite (Silurian) appears in the cliffs along the valley of Turkey and Volga rivers and forms the bedrock in parts of Illyria, Dover, Auburn, Union, and Westfield townships. Covered by heavy drift, it is supposed to underlie the southern townships. The rock is for the most part a buff dolomite, although beds of gray nonmagnesian limestone occur locally. The measured outcrops do not exceed 70 feet.

Because of its impervious shales, the Maquoketa (Ordovician) exerts a strong influence on the distribution of ground water. The formation includes a basal member nearly 100 feet thick, made up of shales and clayey limestones, a middle member about 50 feet thick composed of cherty magnesian limestones, and an upper member, a plastic bluish shale, whose thickness may reach 125 feet. These beds form the surface rock over Clermont and most of Dover townships, and over the northeastern part of Auburn Township. They form the bedrock of the valley floor of the Volga to 3 miles north of Lima, of Turkey River to its junction with Crane Creek, and of Otter Creek to a point within 2 miles of West Union.

The 70 feet of the upper beds of the Galena (Ordovician) exposed in the county are nondolomitic limestones, light gray in color, and may be recognized by the driller by these characteristics, as well as by their position immediately beneath the easily determined base of the Maquoketa shale. They outcrop only along the valley of Turkey River and its tributaries above Clermont.

UNDERGROUND WATER.

SOURCE AND DISTRIBUTION.

In the northeastern part of the county water is obtained chiefly in the bedrock. The drift is thin, and the loess seldom affords a large or permanent supply. Wells encounter, immediately above the rock, a stratum of residual flints several feet thick, but this stratum does not form a water bed, as the flints are set in impervious red residual clay. In Clermont and much of Pleasant Valley townships, where the Maquoketa shale forms the country rock, water may be found above the blue upper shale of that formation, but generally the drill must go to the limestones of the middle Maquoketa, or even into the Galena and Platteville limestones underlying the heavy shales of the lower Maquoketa. As the thickness of the Maquoketa is estimated at not less than 250 feet, it is not surprising that some of the deeper wells of the area are 400 feet deep.

On the high uplands of the northeastern townships, where the Niagara dolomite forms the country rock, water is commonly found at moderate depths, but even here in a few wells the drill fails to strike water in the Niagara, and wells are reported which go to the middle Maquoketa. One west of Wadena passed through 80 feet of "sand rock" (Niagara), 155 feet of "soapstone" (upper Maquoketa), 15 feet of "dark shale in chips," and 32 feet of limestone (middle Maquoketa), finding water in the beds last named.

The wide valley floors of Turkey and Volga rivers form a distinct province where shallow wells tap the abundant water of alluvial sands and gravels.

In the remainder of the county the chief water beds are (1) sands and gravels of glacial origin, interbedded with stony clays or overlying the rock at different depths from the surface, and (2) Devonian and Silurian limestones. In the southeastern part of the county, in Fairfield, Smithfield, Putnam, and Scott townships, water is found in the basal glacial gravels and in the Niagara dolomite. Wells vary in depth with the thickness of the drift and with the depth in the

Niagara at which a water-bearing crevice or porous layer may be encountered.

The data at hand suggest that the drift ranges in thickness commonly from 70 to 150 feet. Near Scott, however, some wells find water in glacial sands resting on rock at a depth of 170 feet. Four miles west and 1 mile north of Arlington the same water-bearing sands lie in places about 200 feet from the surface. About 4 miles southwest of Arlington the average depth to rock is 150 feet, most wells here finding water on the rock or a few feet below the rock surface. Near Taylorsville some wells are sunk about 60 feet below the rock surface. On the high ridge north of Brush Creek ground water in the limestone stands low and wells may need to go through 150 feet or more of rock before obtaining a supply.

In the southwestern townships the drift is of considerable thickness, although at Fairbank, Maynard, and Randalia the rock approaches close to the surface or outcrops. In Oran and Fremont townships a common range of from 50 to 125 feet is indicated by our reports, wells seldom exceeding 150 feet in depth. At Westgate rock is reached at 80 feet and from Oelwein west to Little Wapsipinicon River wells footing in keel rock are said to range from 75 to 100 feet in depth. In Jefferson Township the drift is thicker than in Oran, and wells which here find water in its basal sands or in the upper layers of the underlying rock commonly exceed 100 feet. At Oelwein on the hills house wells are about 145 feet deep and foot in rock, 5 feet being sufficient for reservoir and anchorage for casings. On the other hand, in the northwestern part of the city rock lies at 30 feet. At the Roman Catholic Church a well penetrated sand for 60 feet, whereas wells not 100 feet distant on either side struck rock within 3 feet of the surface. This narrow bed of sand runs half a mile southwest to Otter Creek. The steepness of the rock walls of this buried channel is shown by the fact that at a house in the town the excavation for the cellar encountered rock at 4 feet, and a well 5 or 6 feet from the house wall penetrated sand for 60 feet.

In Harlan, Center, and Banks townships wells find water in basal sands and gravels or immediately below the rock surface in the Devonian limestones. In Banks township the drift apparently runs deep and a thickness of 187 feet is reported at one locality. A short distance southeast of Randalia rock comes to the surface, though immediately at the village it is 90 feet below ground About Maynard stock wells run to depths of from 40 to 100 feet, and are commonly drilled from 5 to 10 feet in rock.

In the northwestern part of the county, which is comprised within the limits of the Iowan drift plain the general conditions are the same as in the central and southwestern parts.

A few flowing wells from Pleistocene sands overlain by stony clays are reported from the county but no provinces were found of sufficient importance to deserve investigation. These flows occur on low ground on a branch of Turkey River in Windsor Township and at one or two points along Otter Creek north of Oelwein, and on the Little Wapsipinicon.

SPRINGS.

Springs are numerous and many of them are copious in the northeastern part of the county along the valleys of Volga and Turkey rivers. A well-marked horizon occurs at the base of the Devonian, whence some large springs issue near Fayette. A still larger contribution of spring water is made by the rocks at the summit of the Maquoketa shale, for this impervious clay leads the ground water along its surface to open air wherever it is cut by streamways. At Wadena, on Turkey River, several springs issue on the hillsides, that of William Sargent being said to be 80 feet above the village. The water of one of these springs has been piped to the village, but no use has been made of them for power. In most of the part of the county covered with Iowan drift springs are few and small.

CITY AND VILLAGE SUPPLIES.

Arlington.—At Arlington (population, 678) water obtained from a well is pumped to a tank supplying pressures of 35 to 45 pounds. There are 2,400 feet of mains.

Fayette.—The public supply of Fayette (population, 1,112) is drawn from two 8-inch wells 65 feet deep, situated at the edge of town on the banks of Volga River. Their joint capacity is said to be 500,000 gallons a day, but a run of the pumps for not more than 1½ hours a day is sufficient to meet present demands. Water stands 15 feet below the surface, and is drawn down to 17½ feet by pumping a few minutes. The driller's log of the wells is as follows:

Log of well at Fayette.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and sand	30	30
Limestone, gray, hard	32	62
Sandrock	3	65

The sandrock in which the well ends is probably a coarse-grained magnesian limestone of the Niagara; the limestone above corresponds with the Wapsipinicon limestone of the Devonian.

Water is distributed by direct pressure with domestic and fire pressures of 80 and 100 pounds respectively. There are 1,300 feet of mains and four fire hydrants.

The summit of the Niagara dolomite at Fayette (elevation, 902 feet) is exposed along Volga River near the water line. The formation here is probably not more than 75 feet thick. A deep well would pass through the Niagara into the Maquoketa shale, which is here about 200 feet thick and includes middle dolomitic beds that may carry water under a sufficient head to overflow at the surface. Still more water will probably be found in the 300 or 350 feet of the Galena and Platteville limestones, which underlie the Maquoketa. The St. Peter sandstone should be reached about 625 feet below the surface. This estimate, based on the thickness of the formations, is believed to be more accurate than one based on the assumed uniform dip of the St. Peter from Elkader to Sumner, which would bring the St. Peter at Fayette about 470 feet below the surface.

The lower waters can not be expected to overflow, although they may rise near the surface. A well or wells sunk to the depth of about 675 feet will probably obtain sufficient water for a public supply, but the far more abundant stores of the Prairie du Chien and the Jordan may be reached by sinking the well 500 to 550 feet deeper.

Hawkeye.—At Hawkeye (population, 510) the public supply is pumped from a 6-inch well to a tank 100 feet high and thence distributed through 1 mile of mains. There are nine fire hydrants. The well is 180 feet deep and is cased to rock which it enters at 160 feet.

Oelwein.—The water supply for Oelwein (population, 6,028) is drawn from four wells, 7 inches in diameter and 72 feet deep, connected and pumped with a vacuum pump. The capacity of the wells is somewhat less than 240 gallons a minute, as by pumping at this rate the water is lowered from a head of 12 feet below the surface to 25 feet below it, and the pumps begin to pound. The wells are located in the northeastern part of the city on a level with the railway station. Rock was entered at 16 feet, and the main water bed was found in a seam at 40 feet. The wells are adjacent to a deep well drilled for the city but never used. On testing the deep well with a cylinder set at 150 feet and pumping 250 gallons a minute, the water in the four wells was drawn down below the vacuum pump, the water in the deep well lowering in corresponding measure. The water in the deep well now rises and falls with that of the four wells, according as the vacuum pump is in action or at rest.

Water is distributed from a standpipe (capacity, 96,000 gallons) under a pressure of 60 to 75 pounds. There are 8 miles of mains, 55 fire hydrants, and more than 600 taps. The amount used daily exceeds 200,000 galons.

The deep well was drilled for the city some years since by J. F. McCarthy, of Minneapolis, but nothing can be learned about it except its depth, 1,000 feet, and its head, 15 feet below the curb. If the dip of the strata in this area is uniform between the nearest deed wells on either side of Oelwein, this well hardly more than reached the base of the St. Peter sandstone. Whatever the supply of this well may have been, the capacity would doubtless have been increased by drilling deeper to the Jordan sandstone.

Westgate.—A supply used for fire protection at Westgate (population, 232) is obtained from a 6-inch well, 98 feet deep. Rock is entered at 80 feet. The water bed is limestone at 85 feet, and the head is 30 feet below the curb. Water is pumped by gasoline engine to a tank 90 feet high, with a capacity of 600 barrels, and is thence distributed through 1,000 feet of mains. There are three fire hydrants. Other drilled wells 20 to 150 feet deep find rock at 80 feet and water at 35 to 40 feet that heads 10 feet below curb.

West Union.—Four wells, 68 to 70 feet deep, situated at the base of the north bluff of Otter Creek, supply West Union (population, 1,652) with about 100,000 gallons of water a day. The head of the water is sufficient to carry it over the curb, but overflow is prevented by closing three of the wells with cement. The wells are drilled almost wholly in limestone and are evidently closely related to the strong springs of this district, which issue from the lower beds of the Devonian limestone. The temperature of the water is about 51° F.

Water is pumped by a compound duplex steam pump to a standpipe, from which it is distributed with a domestic pressure of from 40 to 80 pounds through 5 miles of mains to 30 fire hydrants and 375 taps. The fire pressure is 110 pounds. It is improbable that the city will need to seek a deeper water supply for many years, but such a supply is obtainable in the St. Peter sandstone, which should be found about 550 feet below the surface, or in the Jordan, whose base must be at about 1,150 feet. Water may be looked for in very moderate amounts in the Prairie du Chien group and the Jordan sandstone. The water from these deep sandstones would probably stand 100 feet or more below the surface.

Minor supplies.—Information concerning the water supplies of the smaller villages is presented in the following table:

Village supplies in Fayette County.

Town.	Nature of supply.	Depth of wells.	Depth to water bed.	Depth to rock.	Head above or below curb.	Volume of springs.
		Feet.	*Feet.*	*Feet.*	*Feet.*	
Alpha	Wells	20-40			16-30	
Brainard	Drilled wells and springs.	60				Small.
Clermont	Wells and springs	40-350	80-100			
Donnan	Bored and drilled wells.	20-120	120		15	Do.
Douglass	Wells and ponds	30-130	100	50	12-60	Large and small.
Eldorado	Drilled wells	40			20	Small.
Elgin	Wells			16-60	30	
Illyria	Drilled wells	90-312	138	40	70-175	Medium.
Lima	Wells	20-60	40-60		165-210	Small.
Maynard	do	30			20	
Randalia	Driven and bored wells.	12-125		90	20	
Waucoma	Wells	20-100				Do.

WELL DATA.

The following table gives data of typical wells in Fayette County:

Typical wells of Fayette County.

Owner.	Location.	Depth.	Depth to rock.	Depth to water supply.	Source of supply.	Head above or below curb.	Remarks (logs given in feet).
T. 92 N., R. 10 W. (FREMONT).							
		Feet.	*Feet.*	*Feet.*		*Feet.*	
Fred Barle	5 miles southeast of Sumner.	145	139	....	Limestone	−115	
——— Dieperkoph	do	155	149	....	....	....	
Town	Westgate	98	80	85	Limestone	− 30	Used for fire protection only. Diameter, 6 inches.
J. I. Minckler	2 miles southwest of Westgate.	60	....	....	Sand	+ 25	A little clay on top; then all sand to bottom. Diameter, 5 inches.
T. 91 N., R. 10 W. (ORAN).							
G. L. Egan	NE. ¼ sec. 5	84	20	84	Limestone	+ 5	Valley of Little Wapsipinico River. Supplies water for fishponds. Yields 15 gallons per minute from 5-inch pipe.
Peter Kanten	SE. ¼ SE. ¼ sec. 10	55	45	....	Yellow limestone.	....	
Edward Dundell	8 miles west and 1 mile north of Oelwein.	70	67	....	Limestone	....	All clay to rock.
Chicago Great Western Railway.	1 mile west of Oelwein.	120	116	....	....	....	Do.
Do	6 miles west of Oelwein.	64	60	....	....	....	
John Gerken	NW. ¼ sec. 9	100	48	40	Limestone	− 21	Diameter 6 inches.
T. 91 N., R. 9 W. (JEFFERSON).							
——— Barr	SE. ¼ NE. ¼ sec. 23.	140	138	....	....	....	All blue clay to rock.
Oelwein town wells.	....	145	140	....	....	− 60	Hill.
Do	Northwest part of town.	....	30	....	....	....	
Catholic Church	Oelwein	60	....	....	Sand	....	All sand; wells not 100 feet distant on either side; strike rock in 3 feet.
Richard Swartz	SE. ¼ NE. ¼ sec. 8	110	....	....	do	....	Clay, 60; sand, 20; clay.
Julius Tallman	3 miles northwest of Oelwein on Otter Creek.	80	....	80	do	....	Overflows.
——— Platt	1 mile east of Oelwein.	102	100	....	....	....	
Creamery	At Craft's, east of Oelwein.	70	....	....	Gravel	....	Blue clay, 50; sand, 20.
Frank Cragin	2 miles east of Oelwein.	40	38	....	Sand	− 20	Sand, 2; yellow clay, 10; sand, 26; limestone, 2.
T. 92 N., R. 9 W. (HARLAN).							
——— Barnes	SW. ¼ NW. ¼ sec. 26.	120	118	....	....	− 60	Yellow clay, 10; blue clay, 50; quicksand, 25; dark clay and sand, 33; limestone, 2.

Typical wells of Fayette County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Depth to water supply.	Source of supply.	Head above or below curb.	Remarks (logs given in feet).
T. 92 N., R. 9 W. (HARLAN)—Con.		*Feet.*	*Feet.*	*Feet.*		*Feet.*	
G. Beuzer	NE. ¼ NE. ¼ sec. 13.	40	32		Limestone	− 15	A good stock well on low ground.
—— McMaster	NW. ¼ NW. ¼ sec. 15.	80	70				
Do	1 mile north of preceding.	150	145				Clays, 60; quicksand, 15; brownish sand and clay, 50; quicksand, 20; limestone, 5.
	SW. ¼ SW. ¼ sec. 36.	130					Drift clays, 100; sand, 30.
T. 91 N., R. 8 W. (SCOTT).							
Peter Kraft	NW. ¼ SW. ¼ sec. 14.	160	158	158	Limestone		Clay, yellow, 15; clay, blue, 105; dark soft muck without grit, 30; sand and gravel on rock.
—— Puffet	SE. ¼ SE. ¼ sec. 15.	175	175				High ground; yellow and blue clay, 155; sand 20.
Frank Sherman	SW. ¼ SE. ¼ sec. 9.	180					Ends in rock.
	Sec. 15	171		170	Sand	− 36	Dry blue clay 170; sand, 1.
T. 92 N., R. 8 W. (SMITHFIELD).							
Stephen Payne	NW. ¼ SW. ¼ sec. 20.	150	142				Clays, 80; yellow fine sand, 25; blue clay, 37; limestone, 8.
Jesse Paul	SW. ¼ SW. ¼ sec. 21.	130	127				Clays, 45; quicksand, 82; limestone, 3.
Charles Smith	SW. ¼ SW. ¼ sec. 22.	160	155				Clays, 40; sand, 115; limestone, 5.
—— Turner	SE. ¼ SE. ¼ sec. 33.	150	148				Mostly clay to rock.
	SW. ¼ SW. ¼ sec. 34.	150			Sand		Clays, 135; sand 15. Not strong.
W. B. Stevenson	SW. ¼ sec. 26	114	114		Sand and gravel on rock.		Diameter, 5 inches.
J. J. Bogert	NE. ¼ sec. 27	218	160			− 90	58 feet of limestone. Diameter, 6 inches.
	NE. ¼ NE. ¼ sec. 24.	100	20			− 60	Blue clay, 20; limestone and clay, 40; limestone, 40.
	SE. ¼ SE. ¼ sec. 21.	205	205	200	Sand	−100	Blue clay with thin streaks of sand, 4 inches thick, 200; white sand, 5. Level prairie.
H. H. Smith	4 miles southwest of Arlington.	265	200	260	Crevice in rock.		Diameter, 5 inches
T. 91 N., R. 7 W. (PUTNAM).							
W. C. Gundlach	SE. ¼ sec. 31	73	70	70		− 2	Sand, 10; gravel, 3; blue clay, 57; rock, 3. Casing tapped so that well flows to tank on lower ground. Yields 2½ gallons per minute from 6-inch pipe.

Typical wells of Fayette County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Depth to water supply.	Source of supply.	Head above or below curb.	Remarks (logs given in feet).
T. 92 N., R. 7 W. (FAIRFIELD).		*Feet.*	*Feet.*	*Feet.*		*Feet.*	
....	NW. ¼ sec. 5	100	80	....	Limestone	....	Blue clay, 80; blue limestone, 20.
....	NE. ¼ NW. ¼ sec. 5.	150	40	....	Crevice in limestone.	−146	Drift, 40; limestone with crevice, 110.
....	NW. ¼ NW. ¼ sec. 6.	204	....	....	....	....	Yellow clay, 20; blue clay, 20; limestone, 60; "sandrock," 9.
George Clough	Sec. 22	153	90	....	....	− 65	Diameter, 5 inches.
T. 93 N., R. 7 W. (ILLYRIA).							
W. Flanegan	NE. ¼ NE. ¼ sec. 29.	312	30	....	Limestone	−247	Hill. Yellow clay, 30; "sandrock," 80; soapstone, 155; shale, dark, in chips, 15; limestone, 32.
Alexander Peters	SW. ¼ NE. ¼ sec. 11.	140	40	....	Sandstone	−100	Yellow clay, 40; limestone, 60; "sandrock," 40. High ridge.
....	NE. ¼ SW. ¼ sec. 25.	60	18	....	....	....	Volga River bottoms.
....	NW. ¼ NE. ¼ sec. 25.	75	50	....	....	....	Volga River bottoms, about 20 feet above river. All sunk to rock.
....	NW. ¼ SW. ¼ sec. 4.	140	90	....	Limestone	−100	Yellow clay, 40; blue till, 50; limestone, 50.
T. 93 N., R. 8 W. (WESTFIELD).							
J. Orr	SW. ¼ NE. ¼ sec. 21.	147	....	....	....	....	Ridge. No water obtained. Yellow clay, 30; blue clay, 50; limestone, 62; yellow porous limestone, 5.
....	NE. ¼ NW. ¼ sec. 22.	212	....	....	....	−192	High ground. Yellow clay, 16; blue clay, 44; rock and clay, 1; gray limestone, 149; "sandrock," 2.
Peter Graft	3 miles northeast of Fayette.	200	40	190	....	....	Yellow clay, 40; limestone, 150; soapstone, 10.
—— Bars	NW. ¼ SW. ¼ sec. 24.	288	30	280	....	−180	Drift, 30; limestone, 100; shale, blue, caving, 150; unknown, drilling washed out, 8.
—— Whitely	SE. ¼ SE. ¼ sec. 26.	205	80	200	....	−183	Yellow clay, 20; blue clay, 60 (at 45 feet old black soil, ill-smelling, 5); limestone, 120; "sand rock," 5.
....	NE. ¼ NE. ¼ sec. 5.	65	....	....	"Sandrock"	....	Drift, 5; limestone, 60. High level prairie.
....	NW. ¼ NW. ¼ sec. 7.	100	80	....	Limestone	− 30	Blue clay, 80; limestone, 20.
....	NW. ¼ SW. ¼ sec. 19.	45	....	....	do	....	All limestone; plenty of water.
—— Dye	SW. ¼ SW. ¼ sec. 32.	160	160	....	do	....	Yellow clay, 15; blue clay, 35; limestone, 110.
—— Badger	Sec. 20	130	....	....	....	....	Drift, mainly yellow till, 30; rock, 100.

Typical wells of Fayette County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Depth to water supply.	Source of supply.	Head above or below curb.	Remarks (logs given in feet).
T. 93 N., R. 9 W. (CENTER).		*Feet.*	*Feet.*	*Feet.*		*Feet.*	
Creamery	Randalia	300					
Clarence Moulton	NW. ¼ NW. ¼ sec. 20.	140	135		Limestone		Yellow clay, 10; blue clay, 70; quicksand, 55; limestone, 5.
T. 93 N. R. 10 W. (BANKS).							
J. J. Cavlin	NE. ¼ NE. ¼ sec. 26.	190	187				Nearly all blue clay; a little sand on rock. Ridge.
T. 94 N., R. 7 W. (PLEASANT VALLEY).							
	SE. ¼ SE. ¼ sec. 31.	135	80				Yellow and blue clay, 80; "sandrock," 55.
John Brackin	SW. ¼ NE. ¼ sec. 18.	130	40	127	"Sandrock."	− 93	Yellow clay, 30; blue till, 10; residual flints, 12; limestone, 40; "sandrock" dark brown, soft, 38.
Canning Factory	Elgin	125	30		Limestone	− 45	Sand, 30; blue soft limestone, 10; "sandrock," 15; limestone, 70.
T. 94 N., R. 8 W. (UNION).							
	Sec. 10	250					Drift, 134; shale, 100; limestone, 16.
T. 94 N., R. 9 W. (WINDSOR).							
John Wagner	Sec. 18	46		46	Limestone	+ 2	Diameter, 6 inches.
	N. ½ NE. ¼ sec. 18.	20				+	Flows strong stream.
——— Muldownay	Sec. 35	110					Water from sand under blue till.
T. 95 N., R. 7 W. (CLERMONT).							
Wilkes Williams	SE. ¼ sec. 24	36		25	Shale	− 10	Starts in upper Maquoketa shale. Diameter, 6 inches.
	SE. ¼ SE. ¼ sec. 13.	401	40		Galena or Platteville limestone.	−390	Loess, 10; drift, 30; shales and limestones, 361. Diameter, 6½ inches.
William Garvry	SE. ¼ SE. ¼ sec. 17.	270	50	250	Limestone	−210	Hill. Yellow clay, 25; blue till, 25; residual flints, 8; blue limestone, 100; "sandrock," 40; limestone, 52; "slate," 20.
Creamery	Clermont	42	0		do		

HOWARD COUNTY.

By O. E. Meinzer.

TOPOGRAPHY AND GEOLOGY.

The greater part of Howard County shows the gently undulating Iowan drift plain, all parts of which have a competent drainage, though the streams have not yet cut deep valleys. In the northeast, however, the Iowan drift is absent and a strong erosion topography has been developed. In large areas near the western border, and especially in Jamestown Township, the total thickness of glacial drift is more than 200 feet and in certain localities it is more than 300 feet; farther east it becomes much thinner, and near the northeast corner the valleys are incised in bed rock which is extensively exposed. Owing to the irregularities of the rock surface, radical differences in the thickness of the drift may be found in wells at points not far apart and at practically the same level.

In the outcrops in the northeast, Devonian limestone is seen to rest on the Maquoketa shale, and this in turn on Galena limestone. As the strata are known to dip gently toward the southwest, it is probable that the Maquoketa and the Galena pass to greater depths in this direction and that the indurated limestone which is everywhere found immediately below the drift is as a rule Devonian in age.

UNDERGROUND WATER.

SOURCE.

The water supply is derived from the glacial drift and the underlying limestone formations. The bulk of the drift is impervious bowlder clay which yields no water, but at certain levels are irregular beds of porous sand or gravel, which are generally charged with water under pressure. The limestone is compact and impervious, but contains fissures and solution passages that were probably produced by preglacial weathering. These open spaces are filled with water, which is delivered freely to wells that connect with them. In the areas of deepest drift most of the wells end in sand and gravel, but elsewhere the majority enter rock. Many wells end in saturated beds of fine sand that persistently rises with the water. In such wells both water and sand should be cased out and the drilling should be carried into the limestone if necessary.

The drilled wells vary greatly in depth. In the area of thick drift many good wells are less than 100 feet deep; on the other hand, wells between 200 and 300 feet deep are not uncommon. In the northeastern part of the county, where the water level is depressed by the presence of deep valleys, it may be necessary to drill several hundred feet into the rock in order to procure satisfactory supplies.

FLOWING WELLS.

In the valley of upper Iowa River, west and north of the village of Chester, a group of 12 or more flowing wells lie near or north of the State line. They range in depth from 80 to 100 feet and are supplied from gravel beneath a layer of impervious clay. The valley has been cut slightly below the level at which the water stands in the drilled wells on the adjoining upland plain, but not deeply enough to impair the clay layer in its function as a confining bed. Hence, in wells drilled in the valley the water rises to nearly the same height as in the upland wells or slightly above the valley level, thus giving rise to flows which range from a mere dribble to 30 or 40 gallons a minute. Indeed, in several of these wells the artesian pressure is so slight that the flow is noticeably affected by changes in atmospheric pressure. A 65-foot flowing rock well was also reported southwest of Cresco in the NE. ¼ sec. 11, T. 98 N., R. 12 W.

Wherever the drift is continuous and but little dissected it seems to play a double part, receiving the rain water and in some way transmitting it to the deeper porous deposits and eventually to the crevices of the limestone, and yet acting in general as a confining bed. Thus, if at any point in the western part of the county a hole is drilled through the dense blue bowlder clay, the underlying sand, gravel, or rock is invariably found to be filled with water, which rushes into the drill hole and rises under artesian pressure. As already stated, entirely different conditions prevail in the northeastern area, where the drift sheet is dissected and the upper pervious formations are drained into the valleys, thereby giving rise to springs but at the same time depressing the water level far below the upland surface. This difference is well shown along upper Iowa River as it flows from the area of deep drift into a rock valley. That the influence of the outcrops is effective as far up as Chester seems to be indicated by the fact that flowing wells are obtained in the valley above the village but that attempts to secure them in the valley below the village have generally failed.

Enough is known in regard to the head of water from the deep beds to make it certain that flows can not be obtained by deep drilling at Cresco, Lime Springs, or Chester, and that the water would remain far below the surface. Even where large supplies are required it does not seem advisable to drill more than a few hundred feet into rock.

CITY AND VILLAGE SUPPLIES.

Cresco.—The public water supply at Cresco (population, 2,658) is obtained from two wells drilled into rock, the one ending at a depth of 196 feet and the other at a depth of 396 feet. The waterworks include a standpipe with a rather extensive system of mains. It is estimated that about 75,000 gallons of water are consumed daily.

The Chicago, Milwaukee & St. Paul Railway well is 1,045 feet deep, and its curb is 1,298 feet above sea level. It was completed in 1878, but has been abandoned; no satisfactory supply was found.

Record of strata[a] in Chicago, Milwaukee & St. Paul Railway well at Cresco.

	Thickness.	Depth.
	Feet.	*Feet.*
Alluvial deposit and shales	42	42
Limestone (Devonian, Maquoketa, and Galena)	494	536
Shale, gray (Decorah)	40	576
Limestone (Platteville)	25	601
Shale, calciferous, gray (Platteville)	36	637
Sandstone (St. Peter)	65	702
Limestone (Shakopee)	115	817
Sandstone (New Richmond)	10	827
Sandstone, calciferous (Oneota)	160	987
Sandstone (Jordan)	58	1,045

[a] Based on driller's log.

WINNESHIEK COUNTY.

By W. H. Norton.

TOPOGRAPHY.

The important topographic features of Winneshiek County are for the most part due to the deep incision of valleys in an ancient uplifted base-level of erosion now marked by the general accordance of level of the summits of the existing ridges and divides. The edges of a large number of formations, some water bearing and some dry, are thus exposed along the valley side. The maximum relief is not far from 600 feet. The Cresco-Calmar ridge rises to a height of 1,269 feet above sea level, and the high ridges north of upper Iowa River reach a height of 1,360 feet above sea level a short distance west of Hesper. The flood plain of upper Iowa River on the eastern boundary of the county descends to 760 feet.

The divides separating the trunk streams and those intervening between their tributary valleys are broad-shouldered, well-rounded ridges, carved by storm water into a multitude of branching and rebranching ravines. The summits of the main divides are gently rolling, but as the trunk streams are approached the incision of the deepening valleys becomes sharp and precipitous bluffs mark the outcrop of the stronger strata.

In the western part of the county the drift sheets laid down by ancient glaciers are sufficiently thick to mask in part the erosion topography and to form the gently undulating plain of Jackson, Sumner, and Orleans townships, in which erosion has been least and deposition greatest.

Although the principal streams of the area have reached maturity, the valley floors have not been widened sufficiently to give them importance for agriculture or as sites for towns.

GEOLOGY.

The geologic formations, from lowest to highest, exposed to view in the county are the following:

1. The Jordan sandstone, a coarse soft sandstone, outcropping only in the eastern part of the county in small areas at the base of the bluffs along Bear and Canoe creeks. About 50 feet of the upper beds of the formation are exposed.

2. The Prairie du Chien group, consisting of (*a*) the Oneota dolomite, a body of light-buff or whitish dolomite, 150 feet thick; (*b*) the New Richmond sandstone, about 24 feet thick; and (*c*) the Shakopee dolomite, a dolomite resembling the Oneota, graduating downward by arenaceous beds into the New Richmond and ranging from 50 to 80 feet in thickness. The Prairie du Chien group is exposed only in the northeastern parts of the county, forming the country rock over most of Highland Township and the eastern part of Pleasant Township and extending up the valley of the upper Iowa as far as Freeport.

3. The St. Peter sandstone, soft and incoherent, white (except where stained with iron by infiltrating waters) without well-defined bedding or lamination, composed of grains of clear quartz, well smoothed and rounded. The sandstone comes to the surface in a narrow belt along the bluffs of the upper Iowa and its tributaries as far west as Freeport. The thickness of the St. Peter in its outcrops is about 60 feet.

4. The Platteville limestone, Decorah shale, and Galena limestone. The lowest of these formations, the Platteville limestone, succeeds the St. Peter sandstone; it includes a basal shale (the Glenwood shale of the Iowa State Survey), about 15 feet thick and in places sandy, forming a transition bed to the St. Peter sandstone, and an upper bed of limestone about 25 feet thick. The Platteville is overlain by the Decorah shale, a calcareous greenish shale 30 feet thick, containing interbedded limestone layers, named from its excellent exposures in the "Dug-Way" at Decorah. The Decorah shale is in turn overlain by the Galena limestone, about 225 feet thick, which in this county is mostly nondolomitic but which, in counties to the south and east, consists chiefly or wholly of massive dolomites. These three formations (Platteville, Decorah, and Galena) form the country rock from Hesper west to the Howard County line and thence southeast to Nordness. They cap the ridges lying between upper Iowa River and Canoe Creek and those extending south of the upper Iowa from Decorah to Washington prairie.

5. The Maquoketa shale, which includes a lower shaly limestone 70 feet thick, a plastic blue shale 15 feet thick, dolomites and limestones 40 feet thick, and an upper blue shale 120 feet thick. The Maquoketa for the most part outcrops south and west of upper Iowa

River. It forms the bedrock over most of the southeastern townships, occupies the long spur leading from the high Calmar-Ridgeway divide to the upper Iowa Valley, and also the valley of Turkey River on the western side of this ridge.

6. The Niagara dolomite, which occurs in a few small outliers in Washington Township near the Fayette County line, with a maximum thickness of 75 feet.

7. The Devonian limestone, which forms the surface rock in Jackson and parts of Sumner, Lincoln, Orleans, and Fremont townships and in a narrow belt capping the Cresco-Calmar ridge as far east as Calmar.

8. Pleistocene deposits, including drift sheets and loess. Two drift sheets have been recognized within the county. The lowest, the Kansan, is a stony clay occurring in patches chiefly on the uplands in the eastern part of the county; the upper, the Iowan, is a thin stony clay covering the western third. Between these two stony clays occurs the interglacial Buchanan gravel. The loess, a yellow loam, mantles uplands and valley slopes outside of the area of the Iowan drift and attains in places a thickness of 20 feet.

UNDERGROUND WATER.

SOURCE.

The wide range of geologic formations exposed within the county affords an unusually large number of water beds. The lowest of these is the Jordan sandstone, from which springs rise at Highlandville and elsewhere in the northeastern townships, and to which some of the deeper wells may penetrate.

The St. Peter sandstone is entered by the deeper wells in the same townships and affords a pure and plentiful supply, although with a low head requiring a long lift.

The Galena and Platteville contain very important water beds, especially in their lower limestones, which in the Galena rest on the Decorah shale, and in the Platteville rest on the shale member to which the Iowa State Survey has given the name Glenwood. Over the eastern part of the county they furnish inexhaustible supplies under a head sufficient to bring their water close enough to the surface to be easily pumped by the wind engines commonly employed.

The limestones of the Maquoketa shale supply some springs and wells. The heavy shales of this formation are dry but serve a most useful purpose in collecting descending ground water above their impervious upper surface either in overlying limestones or in the superficial deposits of the drift.

The different drift clays with their interbedded sheets of sand and gravel and the sandy layers forming the base of the loess afford a supply often sufficient for house wells, and in the southwestern part of the county where the drift is thickest, for stock wells also.

DISTRIBUTION.

As the water beds of the county are so numerous and the topographic relief is so great it is difficult to define any water provinces without going into extensive detail. Even the township is too large a unit to permit exact description.

In general terms it may be said that on the ridges of the north-central part of the county, from Nordness to Hesper and to the northeast corner of the county, wells find water at the base of the Galena where its waters are held by the underlying Decorah shale. Where this supply is not tapped, because the well may fail to strike a water channel, the St. Peter sandstone, from 60 to 100 feet deeper, is the next source. Water in the Galena has a higher head than the water in the St. Peter, rising within 70 feet of the surface or even nearer, according to the local relief. Water in the St. Peter rises only a few feet above the water bed; its supply, however, is large.

In the extensive area underlain by the Maquoketa shale water is found in the limestones interbedded with the impervious shales of that formation. Thus at Calmar, where the drift at the Chicago, Milwaukee & St. Paul Railway roundhouse is 65 feet thick, water was found at 90 feet in limestone above the first bed of shale, and at 160 feet in limestone below the same bed of shale. Some water was also struck on the rock at 65 feet. The Maquoketa waters rise within 100 feet or less of the surface.

Exceptionally it is necessary to go for large supplies to the chief water beds of the Galena above the Decorah shale or even to the St. Peter. First water was reached at Calmar at 520 feet, and second water at 605 feet below the surface.

On the high ground between Calmar and Decorah farm wells commonly obtain water in the upper limestones of the Maquoketa at 75 to 100 feet below the surface, the superficial clays here being from 20 to 40 feet in thickness. Water sufficient for farm wells is not now found in the drift and all wells enter rock.

On the ridges about Ossian some wells find water in the upper few feet of the country rock, but many are compelled to go several hundred feet deeper to tap the deeper limestones of the Maquoketa, and even, exceptionally, to descend to the Galena. The diversity and complexity of the conditions are illustrated within the narrow limits of the village of Ossian, where some good house wells obtained water within 30 feet of the surface; several wells go down for 100 to 300 feet; and one reaches a depth of 735 feet.

In the ravines and in the valleys of the creeks, ground water stands naturally nearer to the surface, and where the country rock is limestone, may be found in rock wells 35 to 40 feet deep.

On the plain of Iowan drift in the southwestern townships water may locally be found in glacial sands and gravels, although not infrequently it must be sought in the underlying Devonian limestones.

SPRINGS.

Winneshiek County is one of the most favored in the State in the number of its springs and in their generous supply of pure water. In the eastern part of the county springs are found along each valley and ravine, furnishing a perennial supply to the clear running creeks. The chief source is immediately above the Decorah shale. Waters descending by sink holes and through the creviced and cavernous Galena limestone are gathered into definite courses and issue in large springs where these waterways are trenched by the ravines.

Among the best-known springs from this horizon are Union Springs, on the farm of Beard Bros., west of Decorah. Strong springs issuing on both sides of a ravine unite in a swift-flowing creek a rod wide, which at one time was utilized to run a feed mill. The August temperature of the water is 47.3° F.

Mill Spring, on the side of upper Iowa River at Decorah, is a powerful spring with an August temperature of 48°, issuing from the summit of the Decorah shale well up the steep valley side, thus giving considerable water power, which in past years has been utilized to run a sawmill. At the west of the present debouchure and about 20 feet above the river a heavy deposit of brownish soft porous travertine has been laid down by the calcareous waters. Another noteworthy spring from this horizon is Cold Spring, a few miles northwest of Bluffton.

A large cavern, which gives exit to a characteristic underground stream from the Galena limestone is situated in sec. 34, Glenwood Township. The mouth of the cave is described as a pointed arch 40 feet high and 60 feet wide.

Most notable, however, is the Decorah ice cave, formed in part by the enlargement of a master joint and in part by the creep of the massive Galena over the underlying shale. This cavern shows the peculiar phenomenon of ice forming on its walls in spring and early summer and melting in late summer and early autumn, the walls remaining dry and bare in late autumn and winter. The solution of this interesting problem throws some light on the movements of ground water in the miles of crevices in the Galena. The freezing temperature reached by the underground air in early winter is maintained until late in the summer. Moisture from the surface is sealed out by frost during the winter, but ice begins to freeze on the cold walls of the cave as soon as the ground thaws enough in spring to permit the entrance of water from above. The ice remains until after the cold dense air has slowly passed from the great labyrinth of underground passages through the opening and has been replaced by warmer air. By this time the summer is well advanced, and as the rainfall is slight the walls remain relatively dry until the freezing temperature is again reached.

Another spring horizon is at the summit of the shale forming the basal part of the Platteville limestone (Glenwood shale of Iowa State Survey), but the springs therefrom are comparatively small.

The Jordan sandstone affords springs under hydrostatic pressure where it is cut by the valley of Bear Creek from Highlandville east to the county line. Owing to the local northerly dip of the strata the springs occur on the south side of the valley.

Springs issue also from the limestones of the Maquoketa, as in sec. 1, Jackson Township.

The base of the Niagara forms a still higher horizon, and supplies a number of springs in Washington Township.

CITY AND VILLAGE SUPPLIES.

Calmar.—At Calmar (population, 849) the waterworks are owned by the municipality. Water is obtained from a well 364 feet deep and distributed, at a pressure of 50 pounds, from an elevated tank with a capacity of 2,000 barrels. There are 16 hydrants, 1 mile of mains, and 75 taps.

Well No. 1 of the Chicago, Milwaukee & St. Paul Railway at Calmar has a depth of 1,223 feet and a diameter of 6 inches from 70 to 860 feet and 5 inches to bottom; no casing. The curb is 1,261 feet above sea level and the head 150 feet below the curb. The pumping cylinder, 3¾ inches in diameter, is 374 feet below curb. The tested capacity is 80 gallons a minute. The well was completed in 1880 by W. E. Swan, of Andover, S. Dak.

Record of strata in deep well No. 1 at Calmar (Pl. V, p. 238).

	Thickness.	Depth.
	Feet.	*Feet.*
No record	70	70
Ordovician:		
Maquoketa shale (146 feet thick; top, 1,191 feet above sea level)—		
Limestone	76	146
Shale	10	156
Limestone	35	191
Shale, gray	25	216
Galena limestone to Platteville limestone (392 feet thick; top, 1,045 feet above sea level)—		
Limestone (Galena)	305	521
Shale, green (Decorah)	47	568
Limestone (Platteville)	30	598
Shale (Platteville)	10	608
St. Peter sandstone (67 feet thick; top, 653 feet above sea level)—		
Sandstone	67	675
Prairie du Chien group (325 feet thick; top, 586 feet above sea level)—		
Limestone (Shakopee)	98	773
Sand and limestone mixed (New Richmond)	47	820
Limestone (Oneota)	180	1,000
Cambrian:		
Jordan sandstone (120 feet thick; top, 261 feet above sea level)—		
Sandstone	120	1,120
St. Lawrence formation (103 feet penetrated; top, 141 feet above sea level)—		
Limestone	103	1,223

Well No. 2 of the Chicago, Milwaukee & St. Paul Railway at Calmar has a depth of 365 feet and a diameter of 10 inches, cased to 66 feet. Its curb is 1,252 feet above sea level and its head 65 feet below the curb. It finds water at 65, 90, and 160 feet. The pump cylinder, 5¾ inches in diameter, is set 100 feet below surface. The tested capacity is 115 gallons a minute and the temperature 48.5° F. The well was completed in 1904 by J. F. McCarthy, of Minneapolis.

The two railway wells are 50 feet apart, and while well No. 2 was being drilled the water of well No. 1 was turbid.

Driller's log of deep well No. 2 at Calmar.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, yellow	30	30
Clay, blue	35	65
Limestone, soft	53	118
Soapstone, soft	9	127
Limestone, soft	33	160
Shale	28	188
Limestone, hard	60	248
Shale	62	310
Limestone, hard	48	358
Shale	2	360
Limestone, hard	5	365

Decorah.—Decorah (population, 3,592) is supplied from wells. The well in common use is situated in the valley of Dry Run, about 8 feet above the level of the creek. Its diameter is 15 feet and its depth 40 feet. The water bed is gravel, rock not being entered. Water stands 15 feet below the surface and is lowered 12 feet by pumping. The maximum yield is 468 gallons a minute, the water being pumped by a suction pump run by electric motor.

For emergencies there are also used eight 4-inch drilled wells 30 feet deep, located on the bottoms of upper Iowa River, about 8 feet above water level and pumped by steam. The water bed is gravel and the capacity of the wells is 240 gallons a minute. Water is pumped to a reservoir and distributed under gravity pressure of 110 pounds. There are 60 hydrants and 6½ miles of mains. The consumption is 160,000 gallons daily.

The Artesian Well & Water Co.'s well at Decorah has a depth of 1,600 feet and a diameter of 6 inches. Its curb is 877 feet above sea level. It was completed in 1877. This well is reported to have struck water at about 28 feet and to have held it at that level until the drill reached a depth of 1,600 feet, when the water disappeared and the drill was lost. The contractors clamed that they were working in granite and abandoned the well. It is very improbable, however, that crystalline rock was struck at the depth mentioned. Those who observed the drilling found reason to believe that the rising water was carried off laterally through a crevice in a limestone.

Certainly the normal head of the deep artesian water should give at Decorah on low ground a flow under a good head. But lateral escape would need to be guarded against, both through crevices and probably also through the St. Peter, whose water here is under no great pressure.

The elevation at the Chicago, Rock Island & Pacific Railway depot at Decorah is 862 feet above sea level. The green Decorah shale outcrops and the St. Peter sandstone probably lies within a few feet of the bottom of upper Iowa River. Five or six hundred feet is an ample estimate of the distance to the Jordan sandstone and the stores of artesian water which it contains. Besides, more or less water should enter the drill hole through crevices and sandy layers of the limestones which intervene between the St. Peter and the Jordan. To tap the aquifers of the Dresbach and earlier Cambrian sandstones, which supply the wells of McGregor, Lansing, and New Albin, a well should be sunk to about 1,200 feet below the surface.

Ossian.—At Ossian (population, 749) the well of E. V. Gilbert has a depth of 730 feet and a diameter of 8 inches to 400 feet and 6½ inches to bottom. Its curb is 1,258 feet above sea level and its head 300 feet below curb. Water comes from 680 feet and lowers 100 feet when pumped about 47 gallons per minute. The well was completed in 1903 by F. F. McCarthy, of Minneapolis.

Log of E. V. Gilbert well (*Pl. V, p. 238*).

[Supplied by owner.]

	Thickness.	Depth.
	Feet.	*Feet.*
Surface, white limestone, blue shale, and blue rock	590	590
Sandstone, dry		590
Unreported	90	680
Sandstone, in thin layers	18	698
Sandstone, coarse	7	705
Limestone, white	25	730

This section, showing the occurrence of two sandstones at the level of the St. Peter, is comparable with the section of the city well at Postville. The upper sandstone falls in place with the summit of the St. Peter at both Postville and Calmar, but the second, nearly 100 feet below the top of the first, is low for the base of the St. Peter. Unfortunately no samples nor any detailed log exist of this most interesting well.

Public supplies are obtained from bored and drilled wells and small springs. The wells range from 40 to 500 feet in depth, reaching rock at 20 feet. The water heads 40 feet below the curb.

Minor supplies.—The following table gives statistics of miscellaneous village supplies in Winneshiek County:

Village supplies in Winneshiek County.

Village.	Nature of supply.	Depth.	Depth to rock.	Depth to water bed.	Head below curb.	Volume of springs.
		Feet.	*Feet.*	*Feet.*	*Feet.*	
Bluffton	Open wells and springs	15–50			15	Large.
Castalia	Drilled wells	175–200	60			
Canoe	Open wells and springs	15–35	35		10	Do.
Canover	Drilled wells	60–145	30		40	Large and small.
Frankville	do	65–200		40	80	Small.
Fort Atkinson	Wells	60		40	20	
Freeport	Open and driven wells	10–50		20–30	8	Do.
Hesper	Drilled wells	35–80	10		25	Large.
Highlandville	Springs and drilled wells	35–67	15		20	Do.
Nordness	Wells	100–300	50	175	65	Large and small.
Ridgeway	Wells and cisterns	50–400		100		

WELL DATA.

The following table gives data of typical wells in Winneshiek County:

Wells in Winneshiek County.

Owner.	Location.	Depth.	Diameter.	Depth to rock.	Depth to water supply.	Source of supply.	Head below curb.	Remarks (logs given in feet).
T. 100 N., R. 9 W. (BURR OAK).								
		Feet.	*In.*	*Feet.*	*Feet.*		*Feet.*	
Alvin Rollins	NE. ¼ sec. 14	172	6	12	160	Limestone	72	
Do	SE. ¼ sec. 11	285	5	13	265	St. Peter	265	
L. W. Bennett	NE. ¼ sec. 13	70	6		60	Gravel	40	
T. 98 N., R. 10 W. (LINCOLN).								
O. O. Rue	SW. ¼ sec. 36	96	4	30	90	Limestone on shale.	26	15 feet above Turkey River.
H. L. Wernark	SW. ¼ sec. 35	60	6			Sand		
	Ridgeway, at station.	80		45–50				Blue clay at 20.
	1 mile south of Ridgeway.	101		40				
T. 99 N., R. 9 W. (BLUFFTON).								
John Sexton	Sec. 32	187	6	50	162	Soft rock	50	10 feet above level of Tenmile Creek. 167 feet of casing. Yields 2½ gallons per minute.
T. Nelson	NW. ¼ sec. 20	276	6	40	270	Limestone		300 feet above Oneota River. Lowered 50 feet by pumping. Yields 4 gallons per minute. Temperature, 50° F.
W. E. Hoyt	NE. ¼ sec. 28	100	6	18	95		64	Temperature, 48°F.
T. 98 N., R. 9 W. (MADISON).								
B. T. Barfoot	SE. ¼ sec. 19	108	5	30			80	
Do	Sec. 19	200		33				

Wells in Winneshiek County—Continued.

Owner.	Location.	Depth.	Diameter.	Depth to rock.	Depth to water supply.	Source of supply.	Head below curb.	Remarks (logs given in feet).
T. 100 N., R. 7 W. (HIGHLAND).								
		Feet.	*In.*	*Feet.*	*Feet.*		*Feet.*	
Julius Selmes	3 miles east of Hesper.	177	6	20	147	Sandstone	147	
T. 100 N., R. 8 W. (HESPER).								
Frank Darington	4 miles southeast of Hesper.	224	6	20	194	do	194	
Charles Casterton	4 miles north of Locust.	107	6	15	69	do	69	
T. 96 N., R. 9 W. (WASHINGTON).								
	Fort Atkinson	100	6		80		80	
T. 96 N., R. 8 W. (MILITARY).								
Anthony Bore	Ossian	224			60			
	do	735		100				Yellow clay, 35; blue till, 61; yellow clay, 4; limestone; shale; limestone, 300.
Public school	do	134		60			15	
	NE. ¼ SE. ¼ sec. 19.	187		28				
John Collins	SW. ¼ SW. ¼ sec. 8.	198		40		Limestone	80	Water in white limestone underlying shale.
	NE. ¼ NE. ¼ sec. 3.	220		40			50	Surface clays, 40; limestone, 25; blue shale with limestone, 124; white limestone, 31.
	NE. ¼ NW. ¼ sec. 23.	396		48	370	Limestone	330	Yellow clay, 15; blue clay, 33; limestone, 22; shale (Maquoketa) with interbedded limestone layers, 115; white limestone, 211.
T. 96 N., R. 7 W. (BLOOMFIELD).								
	SE. ¼ NE. ¼ sec. 19.	180		32				
T. 98 N., R. 8 W. (DECORAH).								
O. P. Rocksvold	SW. ¼ NW. ¼ sec. 14.	508	6½	20	500	Sandstone	380	Clay, 20; limestone, 200; St. Peter, 70; magnesia, 90; Cambrian or Oneota, 117; Cambrian sand, 13. Water also at 175.

CHAPTER IX.

EAST-CENTRAL DISTRICT.

INTRODUCTION.

By W. H. Norton.

The east-central area fronts on the Mississippi; it comprises the 12 counties of Benton, Cedar, Clinton, Iowa, Jackson, Johnson, Jones, Linn, Muscatine, Poweshiek, Scott, and Tama. The great Cambrian and Ordovician aquifers lie within moderate distances of the surface and dip southwestward. Their waters show increasing mineralization with increasing depth and distance from the area of supply, but are by no means unpotable.

From Monticello to Homestead the dip averages 10 feet to the mile for the St. Peter sandstone and 12 feet to the mile for the Jordan sandstone. In the western part of the area the southwestward dip of the St. Peter is 9.4 feet to the mile from Vinton to Grinnell. (See Pl. VIII.) In the eastern part of the district the St. Peter dips 4 feet to the mile, from Sabula to Vinton (Pl. IX), but the greatest dip is southward, as shown by the outcrops of the Devonian and Silurian rocks in the southeastern counties. Although the dip of the St. Peter from Maquoketa southwestward to Tipton is but 6.8 feet to the mile (Pl. X, p. 374), the southward dip from Maquoketa to Davenport is 11.5 feet to the mile, and from Green Island to Davenport 12.6 feet to the mile. This southward dip is due in part to an upwarp in the eastern portion of the area whose axis seems to run through or near Stanwood. The base of the Maquoketa shale at Stanwood (Pl. XI, p. 382) is 150 feet above the level at which it would be found if the dip of the strata were uniform from Clinton to Cedar Rapids. Both base and summit of this formation are lower at Clinton than at Stanwood, 50 miles west. From Cedar Rapids west to Belle Plaine the dip of the Maquoketa is 6.3 feet to the mile and of the St. Peter 5.5 feet to the mile. (See Pl. XI.)

In the eastern part of the district the country rock—that is, the rock at the surface or immediately underlying the drift—is of Silurian age; in a wide belt passing through the central part the country rock is Devonian; in the western and southwestern parts, including Tama, Poweshiek, and parts of Iowa and Johnson counties, the country rock is Mississippian. In the areas where the country rock is Silurian and

Devonian the water of these formations may be allowed to mingle with that of the deep aquifers without impairing the quality of the latter, but the Mississippian waters are usually charged heavily with sulphates, and their effect on the deeper waters is plainly indicated by the analyses of the waters of deep wells in the western counties. The Silurian rocks also appear to become gypseous in the western counties, and here their waters may increase the sulphate content of the water from deep wells.

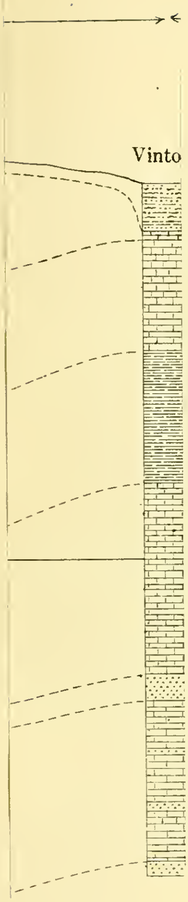
To the south and west the aquifers lie deeper and their waters are more highly mineralized, but in all parts of this district the Cambrian and Ordovician rocks furnish potable water.

The chief water beds are the St. Peter, Shakopee, New Richmond, Oneota, Jordan, and Dresbach and subjacent Cambrian sandstones. (See Pl. I, in pocket.) Artesian water may also be found in the Galena and Platteville, as at Davenport, Wilton, and Grinnell; in the Niagara, as at Homestead; and in the Devonian, as at Cedar Rapids, Vinton, and Belle Plaine. But none of the aquifers above the St. Peter is dependable, and all contracts for artesian wells should provide for drilling to the base of the Jordan sandstone.

The lowest water beds—the Dresbach sandstone and the subjacent sandstones of the Cambrian—lie within the limits of profitable drilling along Mississippi River and yield copious supplies of excellent water at Clinton and Davenport. At Anamosa and at Tipton drilling was carried far into these terranes, but no information as to their water beds is available. At Cedar Rapids the first well drilled by the city water company found, either in these terranes or possibly in a higher water bed below the Oneota, a strongly corrosive water, on account of which the well was plugged just above the vein. Wells drilled later were stopped above this zone.

As a rule, throughout the east-central district abundant water may be found without drilling as deep as the Dresbach, and it is recommended that the drill be stopped at the top of the St. Lawrence formation, or at least at the top of the glauconiferous shales of that terrane. In towns of the Mississippi Valley, however, where the higher formations are overdrawn, wells should be carried to the Dresbach and the first sandstone underneath it.

In the extreme southwestern part of the district deep artesian wells are not recommended for the smaller upland towns on account of the expense of drilling and the difficulty in casing out the poorer upper waters. Thus, in southwestern Poweshiek County the St. Peter lies about 750 feet below sea level; in towns situated 1,100 or 1,200 feet above sea level, therefore, drilling would have to be carried to a depth of 1,850 or 1,950 feet in order to reach that formation.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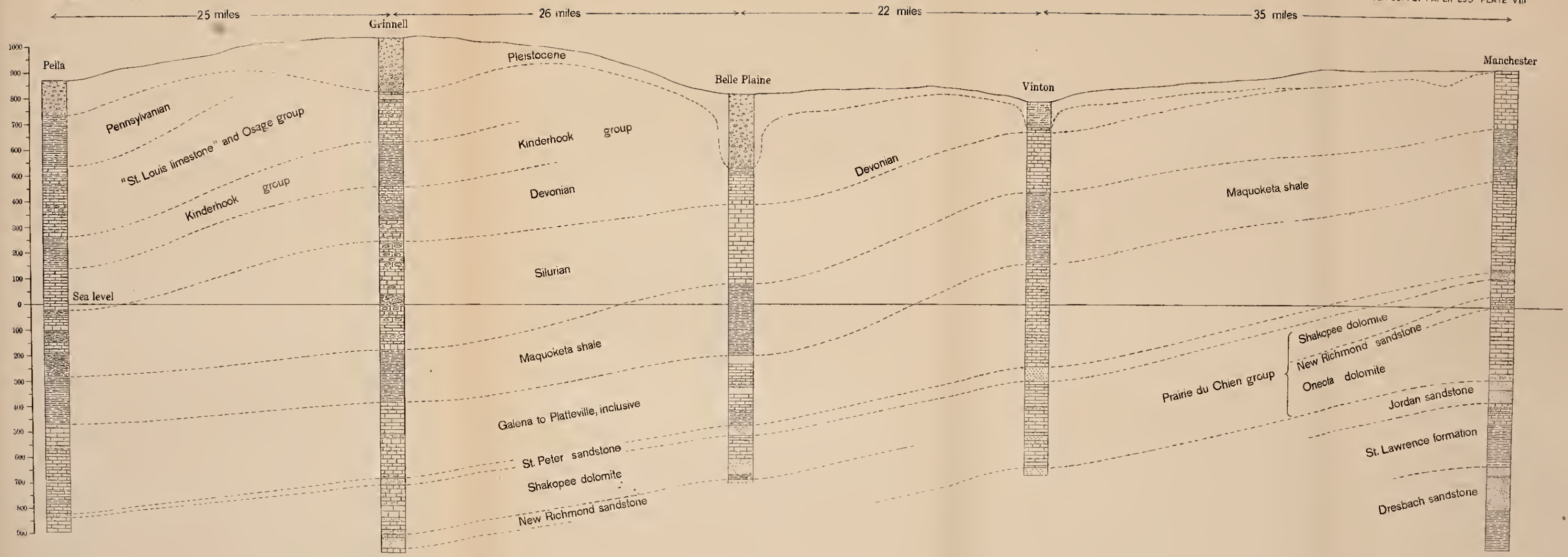


GEOLOGIC SECTION BETWEEN MANCHESTER AND PELLA, IOWA
By W. H. Norton

BENTON COUNTY.

By Howard E. Simpson and W. H. Norton.

TOPOGRAPHY.

Benton County comprises a portion of the undulating prairie plain characteristic of north-central Iowa. Topographically, however, it is divisible into two strikingly contrasted areas coinciding with the surface areas of two drift sheets of different age—the Kansan and the Iowan. The Kansan drift area, embracing about 40 square miles in the southwest corner of the county, shows a mature drift plain, thoroughly drained by streams flowing in deep valleys on broad flood plains. The Iowan drift area, comprising the rest of the county, is a very gently undulating plain, broken by few well-defined stream channels and containing many undrained depressions and small marshy meadows and sloughs, the remnants of glacial lakes and ponds. The marked topographic contrast is ascribed by Savage to the fact that "The surface features over one portion of the area have been developed through the destructive processes of erosion; those over the other part of the region have been molded by the constructive agency of ice".[1]

The southwestern third of the county drains chiefly through Prairie Creek to Iowa River, which barely crosses the corner of the county.

The larger portion of the area drains to Cedar River, which flows across the northeast corner, The divide between Iowa and Cedar rivers passes northwest and southeast through Rogerville and Van Horne.

GEOLOGY.

The surface of Benton County is drift covered except in the broad valleys of Cedar and Iowa rivers and their larger tributaries, whose flood plains range in width up to 2 miles or more and are covered with alluvium. Three drift sheets are represented—the Iowan, Kansan, and Nebraskan. Between the Iowan and the Kansan occurs in places the interglacial Buchanan gravel, and beneath the Kansan drift the interglacial Aftonian gravel. Loess is also present in places above the drift. Throughout most of the county the drift is underlain by Middle Devonian sediments. In a small area in the extreme southwest corner, however, the drift rests on Mississippian shale (Kinderhook group). The Middle Devonian rocks are represented chiefly by the Cedar Valley limestone, which shows a maximum thickness of more than 80 feet and by the Wapsipinicon limestone, which is exposed along Cedar River and its tributaries, Pratt and Prairie creeks.

[1] Savage, T. E., Geology of Benton County: Ann. Rept. Geol. Survey Iowa, vol. 15, 1905, p. 132.

As a rule the indurated rocks lie in conformable parallel beds dipping slightly to the south, this arrangement being modified only by a few slight and unimportant folds. The formations underlying the Devonian are indicated by the geologic sections (Pls. VII, VIII, IX), and by the well sections on pages 359, 363.

UNDERGROUND WATER.

SOURCE AND DISTRIBUTION.

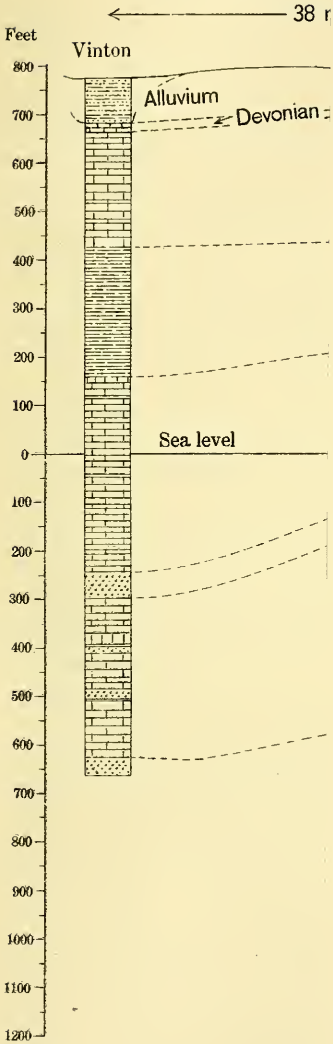
Water is obtained from the Buchanan gravel, the Iowan and Kansan drift, the Aftonian gravel, the Devonian limestones, and from deeper artesian aquifers.

In the broad valleys of Cedar and Iowa rivers and their chief tributaries water is obtained chiefly by sand points driven 25 to 30 feet into the Buchanan gravel, which underlies the alluvium at no great depth and overlies the bowlder clay of the Kansan drift. Bored wells of about the same depth, in which the water stands not far from the river level, are also common. A few wells in the Buchanan gravel yield flows, as is illustrated by the 30-foot bored well, on the farm of A. D. Seeley 1 mile southwest of Benton, and by the well owned by Joseph Kerling, near the foot of the river bluff in the NW. ¼ sec. 13, T. 85 N., R. 9 W., the water of which tastes slightly of iron and gives the brownish-yellow stain characteristic of iron-bearing waters. The water ordinarily is wholesome, though it is liable to pollution owing to the easy access of organic matter from the surface. The Buchanan gravel is found locally on the uplands but there it affords an uncertain source of water.

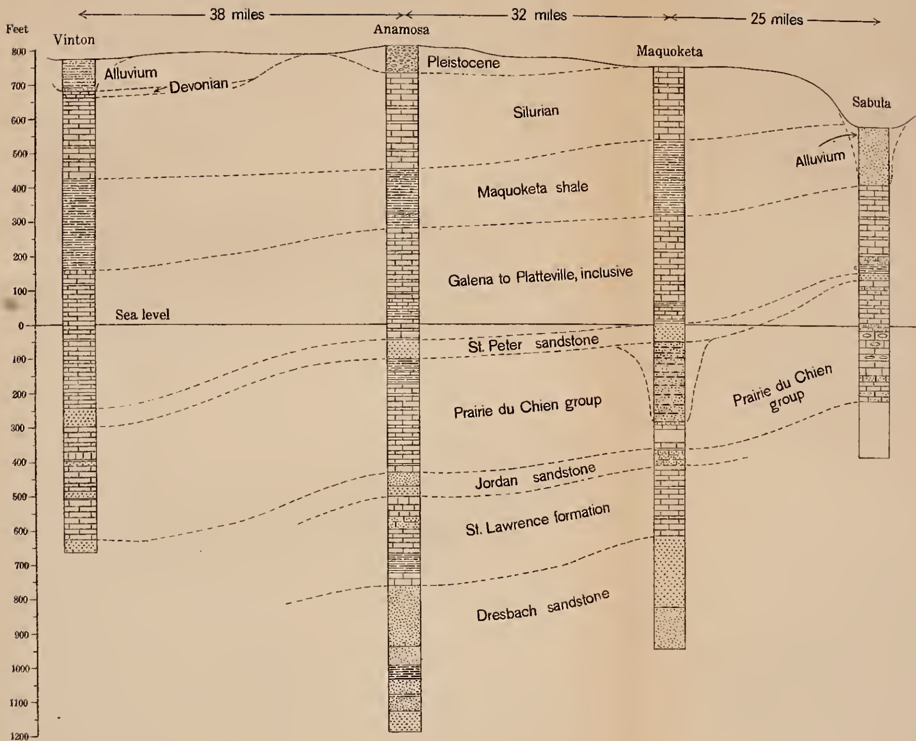
A few fine springs issue from the upper limestone outcrops along the bluffs. A very large spring is on land owned by J. E. Wychoff, in the NW. ¼ sec. 9, T. 85 N., R. 9 W.

The most common source of water supply in this county is the Iowan and Kansan drift, whose combined thickness ranges from 50 to 300 feet. It is difficult to discriminate these two drift sheets in ordinary shallow wells, but the Iowan is so thin that it is certain that most of the wells in the Iowan region pass through it and end in the Kansan, in which pockets and lenses of sand and gravel afford small but fairly constant supplies of good water.

On the upland prairie in the northeast corner of the county, north and east of the Cedar River valley, water is obtained chiefly by means of shallow dug wells, some of which draw from sand and gravel lenses in the drift, but more from the porous gravelly beds lying beneath the till and resting on the Cedar Valley limestone. The limestone is reached at depths ranging from 30 to 150 feet and in most places yields a bountiful supply of excellent water. A few wells penetrate the Cedar Valley limestone for a short distance and find in it a good supply of hard water.



38 r
Feet
Vinton
800
700
600
500
400
300
200
100
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
Alluvium
Devonian
Sea level



GEOLOGIC SECTION BETWEEN SABULA AND VINTON, IOWA
By W. H. Norton

THE NORRIS PETERS CO., WASHINGTON, D. C.

In the creek valleys shallow wells easily obtain water near the surface of the ground. South and west toward Cedar River the drift is thinner, and, as bedrock is nearer the surface, rock wells are more common. The well on the farm of William Pitts, in the NW. ¼ sec. 1, T. 85 N., R. 10 W., where water is obtained in limestone at a depth of 76 feet, the drift being 46 feet deep, is fairly typical.

Southwest of the Cedar River valley, except in the Belle Plaine artesian basin, bedrock is buried beneath a mantle of drift ranging in thickness from 100 to 300 feet. Most of the wells derive their waters from the sandy layers of the drift but a few enter the Cedar Valley limestone to obtain a more permanent supply. Near Cedar River the surface is deeply trenched by the valleys of tributary creeks in whose banks or bluffs the Devonian limestone outcrops.

In Taylor Township, southwest of Vinton, the better and deeper wells are about 125 feet deep and draw water chiefly from gravel at the base of the drift. At the county farm 1½ miles southeast of Vinton, a drilled well 175 feet deep obtains water in the Cedar Valley limestone and supplies a small system of waterworks, the water being distributed by compressed air.

In Canton Township, where the limestone is near the surface, stock wells on uplands range in depth from 50 to 300 feet, and obtain water from the overlying gravel or from the limestone itself.

A few good springs occur in the broken uplands near the larger streams. One owned by W. J. White, 1½ miles northwest of Shellsburg, affords a fair perennial supply for stock. A spring 1½ miles northeast of Shellsburg, owned by Allen Primer, yields a water strongly mineral.

At Garrison bored and dug wells 25 to 50 feet deep are common. Throughout Jackson and Monroe townships, farm wells are ordinarily 200 to 400 feet deep and draw hard water from limestone.

The wells of Homer, Big Grove, and Eden townships obtain water from gravel beds below the till and from the rock immediately beneath them. The water is as a rule good and soft.

In the vicinity of Keystone the common dug wells range in depth from 20 to 30 feet and draw moderate supplies from Kansan drift. On the lower ground, near the streams, a good supply of water for stock is usually found in sandy soils within 8 or 10 feet of the surface. Larger and more permanent supplies are obtained by means of drilled wells, most of which obtain an abundant supply in gravel beds about 100 feet below the surface. One well, however, 2 miles west of Keystone, enters limestone at 250 feet below the surface.

The Aftonian gravel, which underlies the Kansan drift at a depth ranging from 100 to 300 feet in the southwestern part of the county, furnishes the waters for the Belle Plaine artesian basin. This gravel occupies the preglacial Iowa channel, which extends across the extreme southwest corner of the county and, though by no means continuous, is found in many of the deep drift wells of the central and southern parts of the county.

BELLE PLAINE ARTESIAN BASIN.

The Belle Plaine artesian basin [1] includes practically all of Iowa Township and a small portion of Kane Township in Benton County, somewhat larger areas in the adjacent portions of Tama and Iowa counties, and a small corner of Poweshiek County. It embraces a little more than 100 square miles and occupies a portion of the valley of Iowa River, across which it cuts diagonally at Belle Plaine. The axis of the basin is more nearly north and south than that of Iowa River and their intersection here appears but a coincidence. The basin is 6 or 7 miles wide and the northeast margin, so far as Benton County is concerned, extends from about 2 miles north of Irving southeast to Luzerne and thence south to the county line. Topographically the area includes some of the high rolling uplands margining the Iowan drift, the more subdued Kansan plain, and the low, flat alluvial valley of Iowa River.

The district became famous by the outbreak of the "Jumbo" well in 1886. A brief history of the "Jumbo" well is given by W. H. Norton,[2] who says:

> The notoriety of "Jumbo" was strictly that of a member of the criminal classes, and began with his resistance to control and lasted only until his final imprisonment. Six artesian wells had previously been drilled in the drift at Belle Plaine. In depth they varied from 210 to 301 feet, and the common head of their water was from 3 feet below the surface to 45 feet above it, according to the lie of the ground. * * * The seventh well, "Jumbo," was drilled on lower ground than any of the others and reached the water-bearing stratum of sand and gravel at 193 feet.
>
> Local historians of the well, which they please to term "the eighth wonder of the world," state that the beginning of trouble lay in the fact that the driller attempted to use the force of the flow in reaming out the 2-inch bore, which he had put down for want of a larger drill, to 3 inches, the dimension specified in the contract. This task the water speedily accomplished in the unindurated clays and sands, but not stopping there went on and soon enlarged the bore to over 3 feet in diameter. Through this shaft the water boiled up in a fountain 5 feet in height—the press reports giving several hundred feet as the height of this fountain were exaggerated—flooding streets and yards and covering them with sand. It is estimated that from 500 to 1,000 carloads of sand were discharged from the well. The quantity was certainly so great that only with the greatest effort could the ditches be kept open to carry off the water. Gravel and small pebbles of northern drift were thrown out, and some pieces of fossil wood 2 and 3 feet long. The maximum flow of water was variously estimated at from 5,000,000 gallons to 9,000,000 gallons per diem. Two weeks after the well was drilled Chamberlin calculated its discharge at 3,000,000 gallons for the same period.

[1] Much of the information contained in this brief account is derived from Mosnat's excellent report on the artesian wells of the Belle Plaine area (Ann. Rept. Iowa Geol. Survey, vol. 9, 1899, pp. 521-562). This report contains a large number of well sections and a table giving data for nearly 200 flowing and nonflowing wells in the basin.

[2] Norton, W. H., Artesian wells of Iowa: Ann. Rept. Iowa Geol. Survey, vol. 6, 1897, pp. 350-351.

The enormous flow rapidly drew down the head of the other wells until it sank beneath the surface.

The attempts to case and control the well continued from August 26, 1886, the date when water was struck, to October 6, 1887, when the task was successfully accomplished.

During this time the well, 193 feet deep, devoured, as local historians tell us, 163 feet of 18-inch pipe, 77 feet of 16-inch pipe, 60 feet of 5-inch pipe, an iron cone 3 feet in diameter and 24 feet long, 40 carloads of stone, 130 barrels of cement, and an inestimable amount of sand and clay.

It may be of interest to add that in 1906 the entire flow was carried underground by an ordinary 3-inch tile drain and that many teams pass daily over the former well site.

Water is obtained in the Belle Plaine area by wells ranging in depth from 90 to 360 feet, depending on location, elevation, and nearness to the middle of the basin. Not all wells in the area yield flows. The flowing wells are most numerous and the head is greatest in the southwest corner of the county on the flood plain of Iowa River in the vicinity of Belle Plaine. To the east and north the head gradually lowers until, on the higher uplands toward Keystone and Van Horn, water is found only at such depths and with such low head that its recovery is difficult. The driller's log of the "Jumbo" well and the interpretation given by Mosnat[1] as typical of all the flowing wells on low ground is as follows:

Record of strata in "Jumbo" well, Belle Plaine.

	Thickness.	Depth.	Interpretation.
	Feet.	*Feet.*	
6. Soil with humus	4	4	Recent.
5. Sandy clay	12	16	Loess.
4. Gravel and sand	8	24	Loess.
3. Yellow clay	13	37	Weathered Kansan till, or loess.
2. Blue clay, with layers or pockets of sand and gravel and occasional hard bowlders.	172	209	Kansan till.
1. (a) Leaves and wood of an old forest bed; (b) Gravel and sand, water bearing at	......	209	Aftonian interglacial stage.
0. Nebraskan till.			

These strata, down to No. 1, do not differ from the usual soil, loess, and Kansan till, except in thickness. Stratum No. 1, which yields the water, is typical of Aftonian interglacial beds found in many places in the State. The old forest bed in the upper portion is generally reported as about 2 feet thick, and in this district overlies the gravel of the Aftonian—the aquifer proper. The thickness of the gravel bed ranges from 2 feet to more than 46 feet, the maximum being unknown as wells do not pass through it where it is thickest. This gravel bed grades upward into fine sand, the thinner deposits being in places entirely of sand.

[1] Ann. Rept. Iowa Geol. Survey, vol. 9, 1898, p. 530.

The aquifer is thicker in the middle of the basin than at the sides. Cross sections worked out by Mosnat show conclusively that the aquifer and the underlying Nebraskan or sub-Aftonian drift sheet lie within an old preglacial valley cut fully 200 feet into the Devonian limestones and shales and that the aquifer dips about 3½ feet per mile southward. The new valley has since been filled by the later drift, on which a new drainage system, independent of the old channels, has been superposed. Unfortunately, the artesian water of the Belle Plaine area is unsuited for general household purposes or for use in boilers or in manufacturing processes on account of the large amounts of calcium and magnesium sulphates and other salts it contains. For watering stock, however, it furnishes an abundant and inexpensive supply, warm in winter, cool in summer, and perennially flowing. It is used on every farm on which it is available.

CITY AND VILLAGE SUPPLIES.

Atkins.—As Atkins (population, 250) is 583 feet above sea level, the drill may be expected to reach the Maquoketa shale about 250 feet above sea level. Possibly some water may be found both in the Devonian and in the Silurian limestones. The dry Maquoketa shale is between 250 and 290 feet thick. It is underlain by the Galena and Platteville limestones, in which some water beds may be discovered. The St. Peter sandstone, with its assured supply of good water, in this area probably lies about 300 feet below sea level. Any drilling should be carried 300 or 400 feet deeper still in order to tap the large supplies of the Prairie du Chien group and the Jordan sandstone. The depth of a successful well would thus probably be about 1,300 feet.

Belle Plaine.—City well No. 1 (Pls. VIII, XI), at Belle Plaine (population, 3,121), has a depth of 1,503 feet, and a diameter of 10 inches to 215 feet, 8 inches to 503 feet, 6 inches to 1,300 feet, 5 inches to bottom of well. Its curb is 810 feet above sea level, and its original head 34 feet below the curb; after three months' use the head was 20 feet below the curb. Pump cylinders are set at 63 and at 174 feet below surface; pumping capacity, 100 gallons a minute. The well was completed in 1907.

Water was first found in the Aftonian gravel at a depth of 214 feet. This flow, estimated at 2,000 gallons a minute, gave much trouble and made it impossible to drive the 10-inch casing to bed-rock. A second flow, estimated as at least 75 gallons a minute, was struck at 316 feet from the surface at the base of a blue calcareous shale. An analysis shows that this water contained 149 grains of solids to the gallon, including more than 60 grains of scale-forming salts; magnesium sulphate amounted to nearly 13 grains to the gallon and calcium sulphate to nearly 18 grains. On the advice of W. H. Norton, drilling was continued and water was found in the Galena at a depth of 1,140 feet and in the St. Peter at 1,280 feet, within 30 feet of the predicted depth. The principal water bed is reported at 1,486 feet.

Ten-inch casing was put down to 215 feet, but it could not be driven to rock. An 8-inch casing was put down to the first limestone, found at 315 feet, and bedded in it without packing. As the water burrowed under this pipe, a 6-inch pipe was inserted to 174 feet, and within this a 5-inch pipe was placed whose base was packed with lead at 503 feet. No casing was inserted below this last depth. The total cost of the well, including pumps and the pipes connecting with the reservoir, was $4,200. It was drilled by the J. P. Miller Artesian Well Co., of Chicago. A complete record of the well was not kept, but some drillings were saved.

Record of strata in deep well at Belle Plaine (Pl. VIII, p. 352; Pl. XI, p. 382).

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene chiefly; no samples	283	283
Devonian (142 feet thick; top, 527 feet above sea level):		
Shale, blue, hard, calcareous, siliceous, pyritiferous; in small chips	12	295
Shale, greenish, in concreted masses; 2 samples	20	315
Limestone, light yellow gray, rather soft; dull luster; in small flaky chips; rapid effervescence; 6 samples	60	375
No sample	10	385
Limestone, drab, hard, microscopically quartzose; with much light-blue chert; 3 samples	40	425
Silurian:		
Niagara dolomite (305 feet thick; top, 385 feet above sea level)—		
Dolomite, blue gray, mottled, slightly vesicular; with a little chert; 5 samples	42	467
Dolomite, buff, in crystalline sand	8	475
Dolomite, blue, argillaceous	21	496
Dolomite, buff, in sand	3	499
Dolomite, blue gray, hard, siliceous; 3 samples	26	525
Dolomite, blue gray, subcrystalline, compact; some shale at 545 feet; 7 samples	60	585
Dolomite, white, minutely arenaceous	10	595
Dolomite, gray, in crystalline sand; 3 samples	30	625
Dolomite, blue, and white chert; 4 samples	48	673
Dolomite, white, granular; cherty; with some greenish shale	2	675
Dolomite, gray; 2 samples	30	705
Dolomite, gray, with much white chert; 3 samples	25	730
Ordovician:		
Maquoketa shale (290 feet thick; top, 80 feet above sea level)—		
Shale, blue, drab; 24 samples	240	970
Shale, brown-drab; 2 samples	20	990
Shale; drab at 990 feet; greenish below; 3 samples	30	1,020
Galena limestone to Platteville limestone (260 feet thick; top, 210 feet below sea level)—		
No samples	20	1,040
Limestone, highly argillaceous; in light-gray concreted powder and meal; residue cherty and minutely quartzose; effervescence slow	10	1,050
Limestone; in white concreted powder; effervescence slow; 6 samples	60	1,110
Limestone; in fine meal, argillaceous residue of minute particles of mottled chert	10	1,120
Shale, drab	10	1,130
Limestone as at 1,110 feet	10	1,140
No samples	20	1,160
Dolomite, buff, some chert; in sand; 2 samples	20	1,180
No samples	10	1,190
Dolomite, with chert	10	1,200
Limestone, gray, granular; rapid effervescence	10	1,210
Limestone, argillaceous, in light-gray concreted powder and meal; rapid effervescence; highly arenaceous at 1,260 and 1,270 feet; with minute grains of quartz; 7 samples	70	1,280
St. Peter sandstone (40 feet thick; top, 470 feet below sea level)—		
Sandstone, white, grains well rounded, up to 0.8 millimeter in diameter; some fragments of green shale; 3 samples	40	1,320

Record of strata in deep well at Belle Plaine—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Ordovician—Continued.		
Prairie du Chien group (183 feet thick; top, 510 feet below sea level)—		
Dolomite, light yellow-gray, argillaceous; in concreted powder	20	1,340
Dolomite, light yellow-gray; highly arenaceous; grains of sand rounded, some sharp with secondary enlargements; 2 samples	30	1,370
"Sandrock;" no samples	100	1,470
Marl, in powder and small white fragments; slow effervescence; highly siliceous, with microscopic quartz; 2 samples	20	1,490
Sandstone; grains rounded; up to 0.8 millimeter in diameter; clean, slightly yellow from rust films on grains.		

Analysis of rock in Belle Plaine city well at 555 feet.[a]

$CaCO_3$	53.89
$MgCO_3$	43.84
$CaSO_4$	.47
SiO_2	1.04
Fe_2O_3	.13
Al_2O_3	.46
H_2O	.18
	100.01

Blairstown.—The town of Blairstown (population, 532) depends for fire protection on cisterns and private wells and hand pumps. A small private system, owned by Mrs. M. L. Kirk, supplies 20 families with satisfactory water pumped by a 2½ horsepower gasoline engine from a drilled well, sunk 101 feet deep into "rock sand", into two small elevated tanks from which it is distributed by half a mile of mains. Most of the Blairstown wells are dug or bored in the drift 15 to 30 feet. In some wells gravel is found overlying the hard, shelly limestone at a depth of 100 to 120 feet. H. Lipe, in the western part of town, has a 130-foot well which obtains water in sand below the "blue clay." A few sandy layers occur in yellow clay above but contain little water.

The stockyards well evidently penetrates limestone of the Kinderhook group at 120 feet and it is reported to draw water from that stratum. The section follows:

Log of stockyard well, Blairstown.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and yellow clay (loess)	7	7
Clay, blue (Kansan)	80	87
Soapstone (Kinderhook)	33	120

Keystone.—Keystone (population, 412) is on an upland prairie. The town water supply is drawn from a large dug well 68 feet deep, in the bottom of which is a drilled hole extending down to 130 feet, all in

[a] Made in chemical laboratory of Cornell College, Mount Vernon, Iowa.

the drift. The water is drawn from several layers of sand and gravel. It stands 50 feet below the surface, but its level is quickly lowered by pumping.

The water is forced into an elevated tank holding 1,200 barrels, and gives a pressure of about 45 pounds in the business part of town. The water is chiefly used for fire protection, less than 100 barrels being used daily for other purposes. The water is considered to be of good quality. Under agreement with the Chicago, Milwaukee, & St. Paul Railway, the town may use water from the railway well in case of fire or other emergency. The railway system uses a large open well which is on the lower ground apparently than the town well and has an abundant supply.

Luzerne.—At Luzerne (population, 160) the shallow town well is 8 feet in diameter and 25 feet deep. Most of the inhabitants, however, used bored wells, from 15 to 35 feet deep, which furnish an abundance of good, hard water.

Mount Auburn.—At Mount Auburn (population, 228) water for domestic use is commonly obtained from bored drift wells ranging in depth from 20 to 55 feet. Throughout Cedar and Bruce townships the stock wells range in depth from 100 to 250 feet, entering limestone at 75 to 150 feet. These wells furnish a good supply of hard water standing 50 to 100 feet below the surface. They are generally pumped with windmills. In St. Clair Township the deep wells are from 120 to 400 feet deep.

Shellsburg.—Shellsburg (population, 527) is situated on the bottom and north side of the valley of Wildcat Creek. The public water supply is owned by the town and is obtained from an open well, 24 feet deep and 14 feet in diameter, dug on the hillslope. The surface deposits of sandy alluvium, about 5 feet thick, pass into fine white sand, which merges into a bed of coarse gravel. This gravel overlies the limestone and is saturated with water. The well is bricked and cemented to the bottom, which is in open gravel. Normally it is about half full of water, but the level is lowered rapidly by pumping until it stands only 2 or 3 feet above bottom, where it remains constant with the pump drawing 40 gallons a minute.

The water is forced into a steel tank (capacity, 13,800 gallons), in which an air pressure of 40 pounds is maintained. In case of fire 240 gallons a minute can be delivered under 80 pounds pressure. The water is apparently wholesome, though little is used except for fire protection, on account of the ease with which water can be obtained from the gravels by a dug well. In the lower parts of the town drive points are successfully used to draw water from the same source.

Urbana.—The town of Urbana (population, 306) has no public supply. The shallow wells are dug to rock at a depth of 30 to 50 feet and find "sheet water" in gravel. A few of the better wells are drilled from 100 to 300 feet, and for the most part find the most satisfactory supply in the limestone at about 150 feet. As this water stands 30 to 50 feet below the surface, a source in common with that of shallower wells is indicated.

The well at the Urbana creamery is typical of the better drift wells. Water is obtained from a bed of sand and gravel underlying the blue clay of the Kansan drift and overlying the bedrock at a depth of 180 feet. J. G. Waitman found water at 100 feet under similar conditions in the NE. ¼ sec. 3, T. 86 N., R. 9 W.

Van Horne.—Van Horne (population, 444) is situated on the crest of the divide between Cedar and Iowa rivers. Fire protection is obtained from two large open wells 25 feet deep. The water usually stands 5 to 10 feet from the top and is pumped by hand. At the electric light plant a well 20 feet deep was dug to obtain water for boiler feed. The water was fairly satisfactory, producing little scale though leaving a heavy white sediment. As the supply was, however, insufficient, a hole 6 inches in diameter was drilled to a depth of 795 feet and cased to rock at 264 feet. The driller's record follows:

Driller's log of well at Van Horne.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and yellow clay	30	30
Clay, blue	234	264
Limestone, white	456	720
Shale (Maquoketa), dry; stopped in shale	75	795

The Chicago, Milwaukee & St. Paul Railway dug 136 feet and drilled 111 feet to find water in the rock. The ground-water level is very low. Wells 200 to 300 feet deep are nearly all in drift.

Vinton.—The city of Vinton (population, 3,336) owns two deep flowing wells, 400 feet apart. One, 1,287 feet deep, was drilled by W. N. Casey & Son in 1889; the other, 1,425 feet deep, was sunk by A. K. Wallen in 1892. (See Pls. VII, VIII, IX.) Both are 6 inches in diameter and the initial head was 28½ feet above curb (800½ feet above sea level); the flow of the first was 62 gallons per minute, of the second 50 gallons a minute. The temperature of their waters is the same—56° F. In well No. 1 sulphurous water, rising within 8 feet of the surface, was obtained at a depth of 125 feet; water-bearing strata were also penetrated at depths of 950, 1,230, and 1,280 feet. The casing in this well was carried to a depth of 620 feet. The strata penetrated in these wells are indicated in the following sections:

Record of strata in city well No. 1 at Vinton (Pl. VII, p. 272; Pl. VIII, p. 352).

	Thickness.	Depth.
	Feet.	*Feet.*
Quaternary:		
Alluvial and drift deposits in ancient river valley	115	115
Devonian (20 feet thick; top, 665 feet above sea level):		
Limestone; hard and compact, nonmagnesian, light cream color; fracture subconchoidal	20	135
Silurian:		
Niagara dolomite (215 feet thick; top, 645 feet above sea level)—		
Limestone; magnesian, light buff, porous, subcrystalline	15	150
Limestone; powder, pinkish, argillaceous, cherty; contains some magnesia; associated with some dark clay and light nonmagnesian limestone	18	168
Limestone; powder, white, nonmagnesian, pyritiferous, with white chert and some rounded grains of quartz	82	250
Dolomite; hard, compact, subcrystalline, yellowish in color, with white chert, inclosing centers of gray flint	15	265
Dolomite, powder, white	10	275
Dolomite; bluish gray, subcrystalline, with gray flint	10	285
Clay, light green	5	290
Sandstone, very fine, white; grains angular	5	295
Dolomite; chips soft, light gray, porous, subcrystalline, with a little dark-gray flint	55	350
Ordovician:		
Maquoketa shale (269 feet thick; top, 430 feet above sea level)—		
Shale, green calcareous	25	375
Shale, fine, bluish, calcareous; soluble portion magnesian	167	542
Magnesian limestone or dolomite; chips hard, brown, subcrystalline, ferruginous.	23	565
Shale, light and dark gray	9	574
Shale, light bluish, calcareous	45	619
Galena and Platteville limestones (401 feet thick; top, 161 feet above sea level)—		
Limestone; powder, light gray; argillaceous; contains some magnesia	111	730
Limestone; powder, cream colored; contains some magnesia	30	760
Limestone; as above	47	807
No sample	13	820
Limestone, gray	15	835
Limestone, soft gray; chips minute	65	900
Limestone, bluish gray, nonmagnesian; chips minute	75	975
Limestone, rather soft, fine-grained, compact, light gray, nonmagnesian; chips thin, flaky	45	1,020
St. Peter sandstone (55 feet thick; top, 240 feet below sea level)—		
Sandstone, with fragments of limestone	20	1,040
Sandstone; clean quartz, grains rounded, of moderate and nearly uniform size; vitreous, limpid; surface ground	35	1,075
Prairie du Chien group (212 feet penetrated; top, 295 feet below sea level)—		
Chert, white; with white dolomite, and greenish slatelike shale	5	1,080
Dolomite; chips subcrystalline, minutely porous, medium dark gray, with much chert	15	1,095
Dolomite; powder, fine, white	5	1,100
Dolomite; chips white and light gray, fine-grained, subcrystalline, with some chert	25	1,125
Dolomite; hard, medium dark gray, and softer white	50	1,175
Sandstone; with considerable dolomite, grains of silica light colored, varying widely in size, largest being about 0.9 millimeter in diameter	15	1,190
Dolomite; chips white and light gray, fine-grained, subcrystalline, with some chert	85	1,275
Chert with minute calcareous fragments	10	1,285
Sandstone; grains mostly rounded, varying considerably in size, largest about 1 millimeter; also considerable dolomite	2	1,287

Driller's log of city well No. 2 at Vinton (Pl. IX, p. 354).

	Thickness.	Depth.
	Feet.	*Feet.*
Surface material	100	100
Limestone, white	200	300
Clay, tough, blue	320	620
Limestone, brown	200	820
Limestone, light gray	150	970
Sandstone, St. Peter	50	1,020
Sandstone, brown	200	1,220
Sandstone, light (water-bearing)	20	1,240
Sandstone, coarse, brown	170	1,410
Sandstone, white, coarse (water-bearing)	30	1,440

The agreements of the log of well No. 2 with the record and drillings of well No. 1 are more marked than the discrepancies. In log No. 2 the Niagara is not discriminated; the top of the Maquoketa is 50 feet higher than in the record of well No. 1; the Maquoketa is 52 feet thicker, and the Middle Ordovician limestones (Galena and Platteville) are as much thinner; the Shakopee dolomite is called "brown sandstone," the drillers not distinguishing the fine sand of angular drill-cut fragments of dolomite from true siliceous sand—a common error. The St. Peter has the same thickness in both sections, but it is placed 50 feet higher in log No. 2. The thin sandy layer at 1,175 feet in well No. 1 was overlooked in well No. 2. The sandstone at 1,220 feet in well No. 2 is identical with the basal sandstone of well No. 1, and is referred to the New Richmond; "brown sandstone" at 1,240 feet of well No. 2 is taken to be the Oneota dolomite, and the white water-bearing sandstone at 1,410 feet the Jordan sandstone.

In 1909 the flow from the wells had almost ceased. The casings of black iron had become so deeply corroded in 19 years of use that they were drawn with great difficulty, and on the north well it was considered necessary to use several shots of high explosives. By exceptional good fortune the drill hole was not completely wrecked and the work of repairing the two wells was then intrusted to other hands and was carried forward to successful completion. Both wells were recased with 5-inch standard galvanized casing to 612 feet—that is, through the Maquoketa shale. In making the repairs it was found that the first flow was at about 600 feet, near the base of the shale just mentioned. The second flow of 13 gallons per minute was from near the summit of the St. Peter sandstone, at 1,270 feet. On completion the flow from each well measured 27½ gallons a minute, with a head of 6 feet above the surface of the ground. An air compressor was installed in one well at a depth of 173 feet below the surface and yields 162 gallons a minute. The other well is allowed to flow into the cement-lined cistern holding 2,000 barrels, constructed some years before the repairs were made, but the flow of this well is small when the air lift is at work in the adjacent well. The inefficiency of the supply before the repairs were completed compelled the introduction of a second system for which the water was taken from a well 20 feet in diameter and 32 feet deep dug in the sand and gravel 60 feet from Cedar River and fed from the underflow. On hard pumping the water level was lowered rapidly, and it was supposed that at such times the well drew directly through the sands from the river, the water level in well and river ordinarily being the same. Into this well a feed pipe used only in emergencies led directly from the river. A separate pump forced the water from this well into a distinct set of mains and supplied the railroad, several factories, and the street sprinklers. This part of the system consumed about 60 per cent of total amount pumped daily.

While the repairs on the wells were in progress and entire dependence was placed on the shallow well and river, a considerable epidemic of typhoid fever broke out in the city. The city supply is now drawn entirely from the two artesian wells.

Another valuable flowing well 6 inches in diameter and reported as 2,000 feet in depth, drawing its supply from the deeper artesian sources, is located about 2 miles west of Vinton on W. P. Whipple's farm.

About one-third of the population of Vinton is supplied from shallow private wells sunk in the drift. Such wells in so large a town are very liable to be polluted by water entering from the surface.

The Iowa State College for the Blind has a well 160 feet deep, which has not been used for several years because in one summer it failed. The college uses more than 2,500,000 gallons annually from the city supply.

A well owned by C. Fee was drilled many years ago in prospecting for oil. The depth is variously reported as about 2,000 and near 3,000 feet. The water still flows with a head 4 or 5 feet above the curb.

WELL DATA.

The following table gives data of typical wells in Benton County:

Typical wells of Benton County.

Owner.	Location.	Depth.	Depth of rock.	Source of supply.	Head.	Remarks (logs given in feet).
T. 83 N., R. 11 W. (UNION).						
		Feet.	*Feet.*		*Feet.*	
John Holler	Van Horne	795	264	Limestone		Insufficient, abandoned. Soil, 4; yellow clay, 26; blue clay, 234; white limestone, 456; greenish shaly limestone, 75; incomplete at 795.
T. 85 N., R. 9 W. (PARTS OF POLK AND BENTON).						
Joseph Kisling	4 miles southeast of Urbana.				8	Cedar River bottoms.
T. 85 N., R. 10 W. (PARTS OF TAYLOR AND HARRISON).						
State College for Blind	Vinton	160				Failed one summer, unused.
W. M. Pitts	Sec. 1	76	46	Limestone		
T. 84 N., R. 9 W. (CANTON).						
M. White	NW. ¼ sec. 11	40	15	do	− 12	Fine hard water.
Milton Richey	NE. ¼ sec. 20	307		Gravel (z)	−147	
William Hatfield	SW. ¼ sec. 21	120		Gravel	− 60	
James Rife	SW. ¼ sec. 11	130	2	Limestone		Plenty of hard water.

Typical wells of Benton County—Continued.

Owner.	Location.	Depth.	Depth of rock.	Source of supply.	Head.	Remarks (logs given in feet).
T. 82 N., R. 11 W. (Le Roy).						
		Feet.	*Feet.*		*Feet.*	
Stockyards	Blairstown	130	130	Shale	− 20	"Water crevice in dark slate rock."
C. E. Case	NW. ¼ sec. 27	450				Scanty supply.
H. Lipe	SE. ¼ sec. 28	92	(*a*)	Sand		Plenty of good water.
T. 85 N., R. 11 W. (Jackson).						
J. Alchorn	SE. ¼ sec. 25	220	140	Limestone		
Joseph Kline	NE. ¼ sec. 6	149		do		
William Baldridge	SE. ¼ sec. 1	202		do		
T. 84 N., R. 10 W. (Eden).						
N. D. Boneshel	SE. ¼ sec. 23	130	130	Gravel	− 90	To limestone.
C. E. Bean	SE. ¼ sec. 19	200	198	Top limestone.		
John Powers	NE. ¼ sec. 5	125	(*b*)	Gravel		
T. 84 N., R. 11 W. (Big Grove).						
A. W. White	NW ¼ sec. 2	130	(*b*)	do		
T. M. Anderson	NE. ¼ sec. 1	240	(*b*)	do		
T. 83 N., R. 10 W. (Eldorado).						
Jacob Schlotterbeck	NW. ¼ sec. 10	400		Limestone		Several holes abandoned.
Adam Kranz	SW. ¼ sec. 11	220	200	do	−120	
E. S. Thompson	SW. ¼ sec. 29	480				
T. 83 N., R. 9 W. (Fremont).						
A. H. Fawcett	SE. ¼ sec. 3	250	(*a*)	Gravel		Strong well.
T. M. Gregor	SW. ¼ sec. 35	250	(*a*)	Sand		Plenty of water.
T. 82 N., R. 10 W. (St. Clair).						
William Reissers	SE. ¼ sec. 28	140	(*a*)	do		
Charles Parschl	NE. ¼ sec. 34	250	(*a*)	do		

a No rock; drift. *b* No rock.

CEDAR COUNTY.

By W. H. Norton.

TOPOGRAPHY.

Cedar County is an area of low relief; its highest and lowest elevations differ by only about 325 feet. The strongest topographic contrasts are presented by the uplands of Kansan drift and the Iowan drift plains. The latter comprise two lobate areas. One stretches across the northern tier of townships, its southern boundary coinciding pretty closely with the line of the Chicago & North Western Railway, which chose the even surface and low levels of the plain in preference to the rugged Kansan upland. The second lobe enters the county from the west along the left bank of Cedar River and extends nearly to Tipton.

The Kansan upland varies in relief according to the degree of its dissection. In Farmington Township its nearly level divides are scored by only the faintest erosion channels; in Fairfield Township it is a gently rolling prairie; but bordering Cedar River in Rochester and Cedar Valley townships it has been cut to a maze of the steepest of hills.

GEOLOGY.

The rocks of the county fall into two general divisions. The Niagara, a buff dolomite, forms the bedrock over the northern and eastern parts, and Devonian limestones of differing lithologic characteristics underlie the southeastern part. (See Pls. X, XI.)

The drift sheets appearing on the surface are the Kansan and the Iowan; a third drift sheet, the Nebraskan, is in places found beneath the Kansan and separated from it by old soils and forest beds (Aftonian) and outwash sands.

The loess, a yellow silt, destitute of pebbles, mantles the Kansan areas.

UNDERGROUND WATER.

SOURCE.

The ground-water supplies of Cedar County are, at present, drawn chiefly from deep-lying sources. The shallow wells which at an early date found plenty of water at the base of the loess in ashen silts and basal sands and in sands separating yellow and blue stony clays have been generally either abandoned or sunk deeper, because of both decreasing supply and increasing demands. On alluvial bottoms, such as the flood plains of the Cedar and some of the larger creeks, shallow wells still are adequate even for farm purposes.

Aquifers largely used are the sands and gravels associated with the drift. These water beds occur as discontinuous lenses in the Kansan and Nebraskan, as extensive sheets parting the stony clays of the drift, and in basal sands parting the Nebraskan till from rock. Sands, locally of great thickness, occur in the well-marked buried ancient river valley which traverses the county from north of Stanwood to the southeast corner. Though these sands are, as a rule, saturated with water, they are in many places too fine to to be a source of supply owing to the impracticability of screening them out with present methods. A very valuable water bed is that formed by the basal sands of the drift and the upper few feet of bedrock, broken and made pervious by preglacial weathering.

In the bedrock water occurs throughout the Niagara dolomite, where it accumulates in large quantities owing to the impervious floor of the Maquoketa shale on which the latter rests. Water is also found in the Devonian limestones of the southern and western parts of the county. In both limestones it occurs in channels dissolved by waters seeping along bedding planes and joints in porous layers.

DISTRIBUTION.

The areas of Iowan drift of the northern and northeastern parts of the county can hardly be set off from those of the Kansan drift as a distinct underground water province, for the Iowan drift forms but a veneer upon the older drift sheet and can not influence the distribution of ground water. The low relief of the Iowan allows ground water to stand high and to exude in swales and wet-weather ponds, but in only a few places is the water thus stored sufficient for farm wells. In places on the Tipton lobe sands store water sufficient for house wells.

A well-defined province is that of an ancient rock-cut channel deeply buried by the drift, which may be called "Stanwood channel," as it extends beneath the town of Stanwood. The surface of the ground gives no indication whatever of the topography of the rock surface lying 300 feet beneath. Enough deep wells have been drilled over this "deep country" to outline its general course, although they fail to define accurately either its gradient or its width. The channel (fig. 4) enters the county in Fremont Township and, curving sharply to the east, passes southeast to Stanwood. Trending thence southward, it passes east of Tipton and follows along the east side of Sugar Creek. About 2½ miles north of Lime City it turns to the southeast and near Durant joins the ancient buried valley, passing through Scott and Muscatine counties southward.

At Stanwood the rock floor of the channel is 544 feet above sea level, if correctly reported; 5 miles southeast of Stanwood rock was struck at 440 feet. In southwestern Scott County the floor of this channel is not higher than 400 feet above sea level.

In Cedar County the channel is aggraded with river sand beneath and glacial stony clays above. At Stanwood it is filled with sand to a height of 116 feet above its floor of rock. At Henry Britcher's place sand 144 feet thick is reported overlying rock. In some wells these sands are replaced by glacial pebbly clays and the work of the driller is much lightened. The sand is generally of fine grain, and that in one well is reported as so fine as to sift through a tobacco sack. It contains streaks and beds of coarser sand and even of gravel. It presents a serious problem for the driller, for though it is saturated, it is for the most part too fine for ordinary types of strainers and affords no ground for casing. The water which makes it a quicksand forms an inexhaustible reservoir, supplying the gravels at its base and the upper creviced layers of the bedrock.

No "deep country" is reported in Pioneer Township, and although the land is considerably diversified in relief, water is found generally

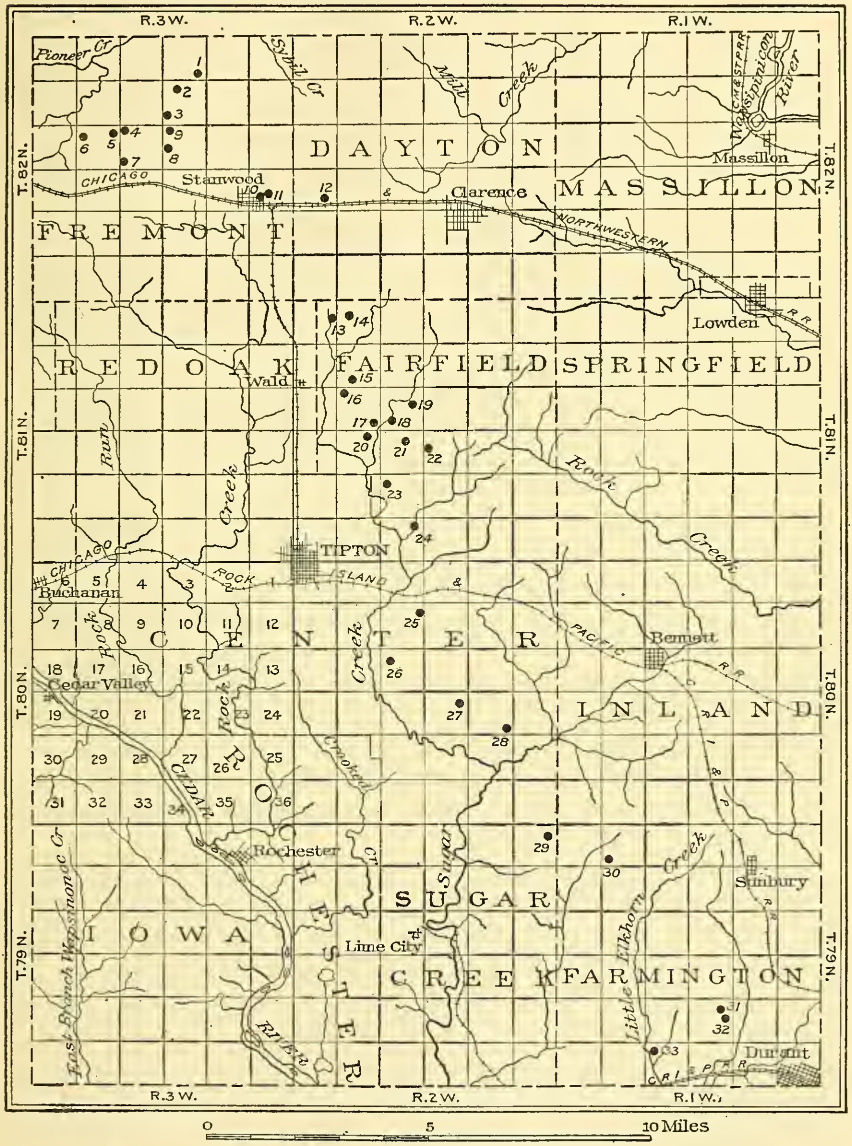


FIGURE 4.—Map showing location of wells (●) marking the position of the buried Stanwood channel Numbers on wells refer to table on p. 372.

from 80 to 100 feet from the surface in Niagara dolomite. In the northeastern part some wells are drilled as deep as 140 feet.

Outside the deep buried Stanwood channel wells in Fremont Township are of moderate depth. West of this channel rock is generally entered at from 80 to 100 feet. Northeast of Mechanicsville it comes within 30 to 50 feet of the surface and water is obtained in abundance by wells 80 or 90 feet deep. In secs. 21 and 28 rock lies lower than 150 and 170 feet below the surface of the gently-rolling Kansan upland, indicating here a branch of the Stanwood Channel. These wells, like many wells of the main channel, find water at top of the river sand with which these buried valleys have been deeply filled.

In the northern half of Dayton Township rock outcrops or is found near the surface. In the southern part the drift is deeper, reaching in places a depth of more than 125 feet. Wells commonly find water in the Niagara dolomite within 80 and 90 to 120 feet from the surface, the water rising within 40 feet of the curb.

On the loess-covered dissected Kansan upland west of Massillon, in Massillon Township, wells find water within 140 feet, in Niagara dolomite, which here comes within 80 or 90 feet of the surface. Loess is of unusual thickness and drift clays are thin.

On the high ridge north of Lowden, extending northwest and southeast through secs. 20–22, 25–28, 35, and 36, wells on the crests are from 150 to 180 feet in depth, finding water in gravels of the drift. In one well on this ridge rock was entered at 85 feet and water obtained in the Niagara, the depth of the well being 144 feet.

In Linn, Cass, and Red Oak townships rock lies near the surface, being rarely found more than 70 to 100 feet below it. Water is found chiefly in the Niagara at depths seldom exceeding 100 and 120 feet. At the large stock farm of Alexander Buchanan, a well was sunk to the very exceptional depth of 300 feet, of which 230 feet were in rock, presumably the Niagara.

Northwest of Tipton in Center Township rock underlies the Iowan drift plain at no great depth, and outcrops are not uncommon. Wells find plenty of water within 50 feet or less of the surface. In and about Tipton a greater depth of wells is rendered necessary by the deeper-lying rock. Thus at the fair grounds a well was sunk 201 feet, 105 feet being in rock. At A. Birks's, northeast of town, rock was entered at 175 feet, and the total depth of the well is 275 feet. At H. L. Huker's, on the east side of town, a well 197 feet deep found no rock. There seems to be here either a strong descent to the buried Stanwood channel, which lies east of Tipton, or perhaps to the channel of a tributary. Within the city limits the depth to rock ranges from 85 to 130 feet and water is found either immediately upon or in the rock.

Near the border of the Iowan drift house wells obtain water in the basal sands of the loess. The sands which part the blue and yellow tills also afford a moderate supply.

Over most of the southwestern part of Center Township wells find water in limestone, either Niagara or Devonian, within 80 to 130 and 140 feet of the surface. Here the bedrock is in few places covered with more than 80 feet of drift. In the eastern part of the township, beyond the belt of "deep country" of the buried Stanwood channel, the drift is from 80 to 130 feet thick, and wells commonly find water in the Niagara at depths of 100 to 150 feet.

Concerning Inland Township the facts at hand relate chiefly to wells in the northern part, where stock wells range from 100 to 170 feet, finding water in rock a few feet below its surface. The drift here is 60 to 170 feet thick.

In the maze of steep hills of the Kansan upland of the eastern part of Gower Township water is found in rock from 100 to 180 feet below the surface, the cover of loess and till being 70 to 100 feet thick. In the western part of the township the drift is 170 to 200 feet thick and several wells are 190 to 220 feet deep.

In Springdale Township the drift is deep, ranging generally from 100 to 180 feet. In the extreme northeast sections the drift is thinner, and at the village of Springdale rock is entered at 50 feet. The wells reported range in depth from 120 to 215 feet, water commonly being found in Devonian limestone.

In Iowa and Rochester townships the Devonian limestones appear at the surface or closely approach it. On the upland of Iowa Township rock is found at 40 to 80 feet. In some rock-cut buried valleys the rock lies as deep as 120 feet. In Rochester Township, though rock outcrops east of Rochester, it occurs as deep as 120 and 200 feet in the northeastern sections. The wells reported penetrate the limestones to depths ranging from 20 to 100 feet before finding sufficient water, and exceptionally wells are sunk in rock as much as 120 feet. Northeast of Springdale a well 200 feet deep is reported.

In Sugar Creek and Farmington townships, outside the course of the Stanwood channel, rock approaches within 40 and 59 feet of the surface between Sunbury and Durant and north of Lime City. Northeast of Lime City it lies from 90 to 125 feet below the surface, and one well, which may be on a tributary of the Stanwood channel, is reported to end in gravel at 325 feet. In the western part of Farmington Township the drift appears to be from 80 to 140 feet thick. Water is found in or on the rock, and wells, except in the buried channel, seldom exceed 130 feet in depth.

Wells in the Stanwood channel.

No.[1]	Owner.	Location.	Depth.	Depth to rock.	Remarks (logs given in feet).
	T. 82 N., R. 3 W. (FREMONT).		*Feet.*	*Feet.*	
1	L. Williams	SE. ¼ SE. ¼ sec. 3	154		Yellow clay, 30; blue clay, 100; sand, 24.
2	M. Rigby	NW. ¼ sec. 10	162		
3	L. Lehrman	SW. ¼ sec. 10	103		Blue clay, 90; dark fine sand, 13.
4	A. Pound	NW. ¼ sec. 16	216		Drift clays, 125; sand and gravel, 91. Water rises within 60 feet of surface.
5	John Foley	NE. ¼ sec. 17	257		
6	J. P. Hines	Sec. 17	197		Blue clay, 180; sand, 17.
7	R. A. Bardue	SW. ¼ sec. 16	210	180	Blue clay, 120; sand, 60.
8	George Melton	NW. ¼ SW. ¼ sec. 15	192		Drift clays with streaks of sand (one 7 feet thick), 180; sand, 12.
9	J. Ferguson	NW. ¼ NW. ¼ sec. 15	109		
10	Tile Works, Stanwood	SW. ¼ sec. 24	340	296	Yellow loess, 20; ashen loess, 7; green clay, 1; yellow, stony clay, 7; blue clay (Kansan), 65; sand with fragments of wood (Aftonian), 15; blue clay (Nebraskan), 65; sand, 116; shale (Maquoketa), 44.
11	H. S. Hoyman	NW. ¼ SE. ¼ sec. 24	250	220	
	T. 82 N., R. 2 W. (DAYTON).				
12	S. M. Davidson	SE. ¼ sec. 19	230	215	
	T. 81 N., R. 2 W. (FAIRFIELD).				
13	Henry Britcher	SE. ¼ NE. ¼ sec. 6	365	327	Yellow clay, 60; blue clay, 123; sand, 144; limestone, 12; blue soapstone, 6; limestone with water, 20.
14	O. T. Johnson	NW. ¼ sec. 5	250	220	Yellow clay, 30; blue clay, 50; fine, white sand; limestone, with water rising within 50 feet of surface, 30.
15	J. Monahan	SE. ¼ SW. ¼ sec. 8	185		
16	George Kinney	NW. ¼ NW. ¼ sec. 17	333	320	
17	N. and K. Lay	SE. ¼ sec. 17	240	180	
18	E. E. Heltebrielle	SW. ¼ sec. 16	295	293	
19	M. J. Fay	SW. ¼ NE. ¼ sec. 16	198	177	Yellow clay, 20; blue clay, 155; a little sand on rock.
20	N. Fay	NE. ¼ sec. 20	247	184	
21	T. Wingerd	NE. ¼ sec. 21	302	278	
22	Gus Peters	NW. ¼ sec. 22	298	233	Chiefly blue clay; not 10 feet of sand.
23	D. Moreland	NW. ¼ sec. 28	98		
24	F. H. Milligan	NE. ¼ sec. 33	250	248	Drift clays, 80; fine sand, 160; black clay (geest?), 8; porous limestone, 2. Water rises within 30 feet of surface.
	T. 80 N., R. 2 W. (PART OF CENTER).				
25	W. Stubblefield	NE. ¼ NE. ¼ sec. 9	302	220	Yellow clay 40; blue clay, 180; sand.
26	G. W. Gary	NW. ¼ sec. 16	304	302	
27	J. B. Carl	NE. ¼ sec. 22	200		
28	J. Helmer	SE. ¼ SE. ¼ sec. 23	300		
	T. 79 N., R. 2 W. (SUGAR CREEK; PART OF ROCHESTER).				
29	B. Ayres	NE. ¼ sec. 1	220		
	T. 79 N., R. 1 W. (FARMINGTON).				
30	John Rice	SW. ¼ SW. ¼ sec. 5	110		
31	C. H. Nienaber	NE. ¼ sec. 27	196		
32	Charles Fitzler	do	272		
33	Marx Hartz	NW. ¼ sec. 33	217		

[1] For position of wells see fig. 4.

CITY AND VILLAGE SUPPLIES.

Buchanan.—At Buchanan (population, 61) water is obtained from drilled wells 27 to 127 feet deep, a depth of 120 feet being very common. The water in the deeper wells rises within 70 feet of the surface. Springs furnish a small part of the water.

Clarence.—The water supply of Clarence (population, 662) is pumped from a well to an elevated tank giving a gravity pressure of 40 pounds. There are 2 miles of mains, 11 fire hydrants, and 100 taps. Many house wells, ranging in depth from 20 to 115 feet, are still used. These wells enter rock at 60 feet, and obtain their largest supplies at about 90 feet. The water of the deeper wells rises within 40 feet of the surface.

Durant.—At Durant (population, 720) the public supply is drawn from a well and pumped to an elevated tank, with a capacity of 600 barrels, supplying a gravity pressure of 46 pounds. There are 2 miles of mains and 24 hydrants. House wells ranging in depth from 40 to 50 feet and obtaining water in sand are used largely.

Lowden.—In Lowden (population, 584) water is obtained from wells that range in depth from 20 to 200 feet. A small amount is obtained from springs.

Mechanicsville.—At Mechanicsville (population, 817) water is pumped from wells into a tank, giving gravity pressure of 45 pounds. There are 4,400 feet of mains and 12 hydrants.

Springdale.—At Springdale (population, 125) wells range in depth from 75 to 150 feet.

Stanwood.—Open and drilled wells ranging in depth from 20 to 300 feet furnish water at Stanwood (population, 511). The depth to the water-bearing formation in the deeper wells is 120 feet, and water rises within 50 feet of the surface. A well 630 feet deep and ranging in diameter from 10⅝ to 8 inches was sunk at the Chicago & North Western Railway track in 1905. (See Pl. XI.) The elevation of the curb is 847 feet above sea level. Water was not found in adequate quantity and the well was abandoned in 1907. The record of this well based on driller's log follows:

Record of strata in railway well at Stanwood (Pl. XI, p. 382).

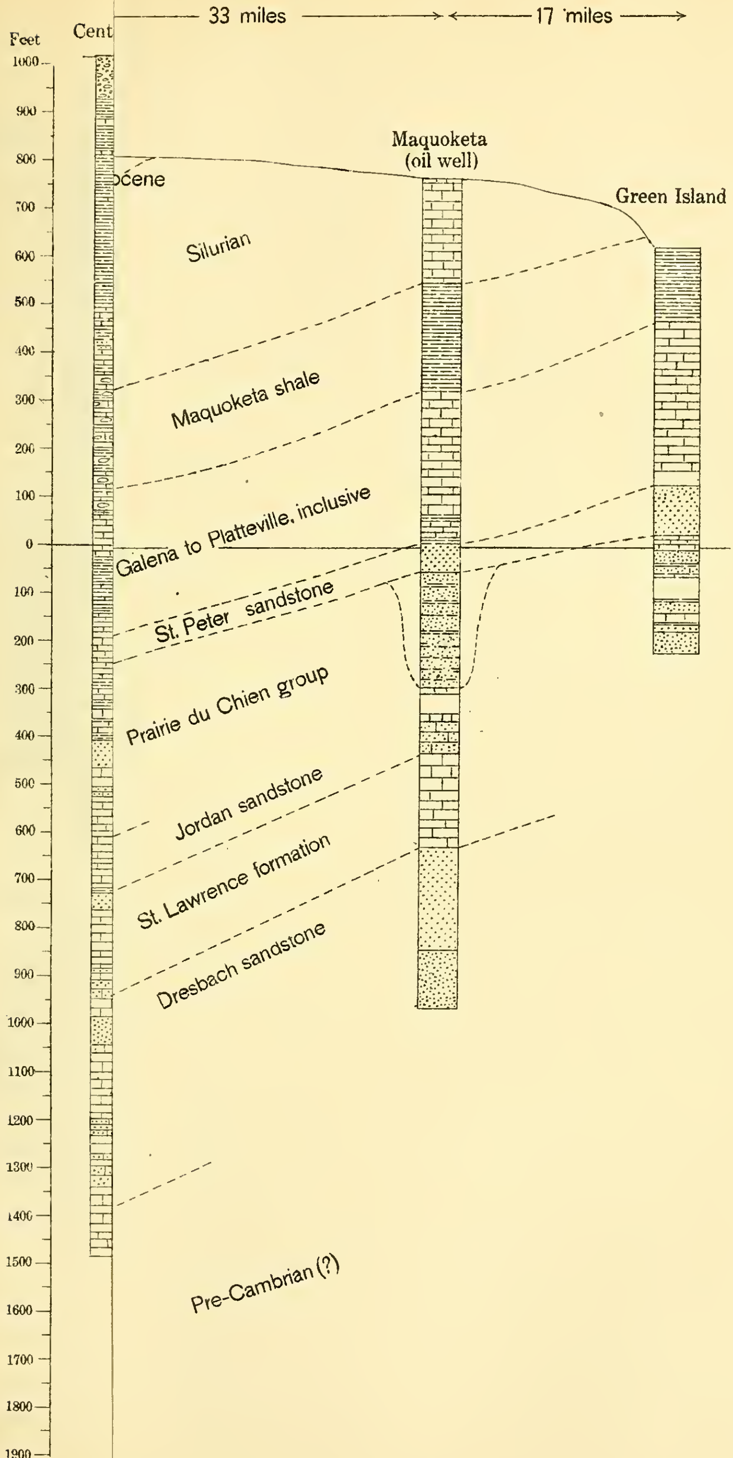
	Thickness.	Depth.
Pleistocene (300 feet thick; top, 847 feet above sea level):	*Feet.*	*Feet.*
Clay, yellow, soft	30	30
Clay, blue, soft	80	110
Clay, sandy, brown, hard	8	118
Clay, blue, soft	84	202
Sand and mud, soft; some blue and some yellow	98	300
Silurian:		
Niagara dolomite (70 feet thick; top, 547 feet above sea level)—		
Streaks of clay and limerock; had to be cased	20	320
Limerock, light colored, soft; a little water	50	370
Ordovician:		
Maquoketa shale (250 feet thick; top, 477 feet above sea level)—		
Shale, light blue, soft	250	620
Galena limestone (10 feet penetrated; top, 227 feet above sea level)—		
Limerock; gray, hard	10	630

Sunbury.—In Sunbury (population, 200) water is obtained chiefly from wells and cisterns. A small quantity is also obtained from springs.

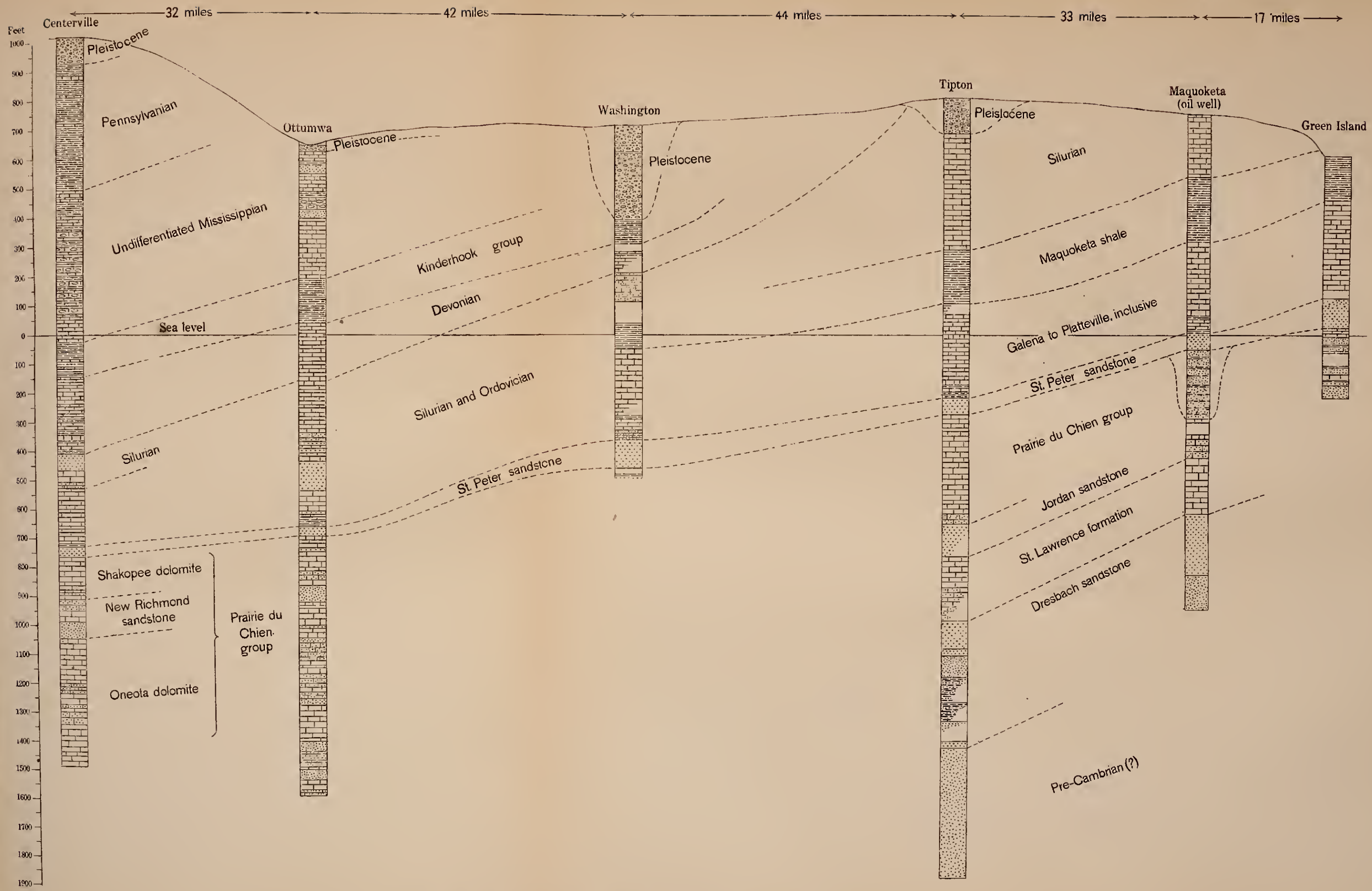
Tipton.—The water supply of Tipton (population, 2,048) is drawn from a well 2,696½ feet deep. (See Pl. X.) The diameter is reported as 8 inches. The well was originally cased to 120 feet and was recased in 1889 to 225 feet. The curb is 810 feet above sea level, and the original head was 65 feet below the curb. The present head is about 80 feet below the curb. The tested capacity of the well is 225 gallons a minute. The water beds are unknown, but the drillers, J. P. Miller & Co., of Chicago, reported no water found below 1,200 feet. The temperature is 57° F.

Record of strata in city well at Tipton (Pl. X, p. 374).

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene:		
Drift	135	135
Silurian:		
Niagara dolomite (365 feet thick; top, 675 feet above sea level)—		
Limestone and dolomite, light gray, hard; white chert at 135 feet; dolomite, buff, at 300 feet; limestone, soft, medium dark gray, argillaceous, slightly magnesian, at 445 feet	365	500
Ordovician:		
Maquoketa shale (200 feet thick; top, 310 feet above sea level)—		
Shale, greenish; 3 samples	100	600
Shale, gray green; in fine meal of argillo-siliceous particles, and grains of dolomite; some rather coarse imperfectly rounded grains of varicolored quartz	20	620
Shale, blue; in concreted powder	20	640
Shale, chocolate-brown, slightly bituminous	20	660
Dolomite, brown, argillaceous, earthy	20	680
Shale, blue	20	700
Galena limestone to Platteville limestone (330 feet thick; top, 110 feet above sea level)—		
Dolomite, buff and gray; 4 samples	40	740
Limestone, light buff, soft, magnesian	60	800
Limestone, soft, grayish white, argillaceous	50	850
Limestone, white, slightly magnesian	35	885
Limestone, light gray	15	900
Limestone, darker gray	50	950
Limestone, dark blue gray; fossiliferous, argillaceous	40	990
Shale, green (probably Decorah shale)	10	1,000
Limestone, dark blue gray, argillaceous	30	1,030
St. Peter sandstone (55 feet thick; top, 220 feet below sea level)—		
Sandstone, clean, white; grains rounded; 3 samples	40	1,070
Prairie du Chien group (377 feet thick; top, 275 feet below sea level)—		
Dolomite, gray; green shale in drillings	15	1,085
Dolomite; some sand in drillings	5	1,090
Marl, white, dolomitic, argillaceous, and minutely arenaceous	10	1,100
Dolomite, gray, buff, and in places white; cherty, especially toward the base; white powder at 1,300 feet; 17 samples	265	1,365
Dolomite and sand	35	1,400
Dolomite, light yellow	10	1,410
Dolomite with sand	40	1,450
Dolomite, gray; considerable sand	6	1,456
Cambrian:		
Jordan sandstone (118 feet thick; top, 652 feet below sea level)—		
Sandstone, calciferous; fine, light colored; rounded grains of quartz, some showing secondary enlargements; also many minute angular cuttings of white subcrystalline dolomite	6	1,462
Sandstone, buff; 2 samples	23	1,485
Sandstone, fine, white and light yellow; 2 samples	17	1,502
Dolomite, highly siliceous, white	3	1,505
Sandstone, fine grained, light yellow	10	1,515
St. Lawrence formation (222 feet thick; top, 770 feet below sea level)—		
Dolomite, yellow	65	1,580
Dolomite, dark gray	36	1,616
Dolomite, gray; in fine sand	34	1,650
Marl, blue gray	30	1,680
Shale, dark greenish, pyritiferous; much dolomite and chips of fine-grained, argillaceous sandstone	22	1,702
Marl, pink	38	1,740



THE NORRIS PETERS CO., WASHINGTON, D. C



GEOLOGIC SECTION BETWEEN GREEN ISLAND AND CENTERVILLE, IOWA

By W. H. Norton

THE NORRIS PETERS CO., WASHINGTON, D. C.

Record of strata in city well at Tipton.

	Thickness.	Depth.
Cambrian—Continued.		
Dresbach sandstone and underlying Cambrian strata (443 feet thick; top, 992 feet below sea level)—		
Sandstone, clean, white, saccharoidal; grains generally rounded but many faceted with secondary enlargements; largest grains 1 mm. in diameter	*Feet.* 62	*Feet.* 1,802
Sandstone, white, fine; 3 samples	88	1,890
Sandstone; in fine, siliceous powder	5	1,895
Sandstone, white; grains very fine, mostly angular	5	1,900
Marl, minutely arenaceous	10	1,910
Sandstone, fine, white; shale in drillings	15	1,925
Sandstone, buff, fine	25	1,950
Marl, siliceous and glauconiferous	15	1,965
Sandstone, pink; in minute angular fragments	25	1,990
Marl, siliceous and glauconiferous	5	1,995
Marl, pink gray; microscopically quartzose; glauconiferous	75	2,070
Marl, reddish; microscopically quartzose; glauconiferous	30	2,100
Sandstone, gray; in fine powder, consisting as seen under the microscope of angular particles of quartz; calcareous cement	50	2,150
Sandstone, buff, fine grained	10	2,160
Sandstone, fine white	50	2,210
Sandstone, white; grains of moderate size, mostly broken; some with secondary enlargements	10	2,220
Algonkian (?) (451½ feet penetrated; top, 1,435 feet below sea level):		
Sandstone, clean, pink; 2 samples	50	2,270
Sandstone, red and brown; 3 samples	70	2,340
Sandstone, moderately fine; grains broken, pink	20	2,360
Sandstone, fine, cream colored	5	2,365
Sandstone, pink; angular grains and grains with secondary enlargements	35	2,400
Sandstone, pink, fine; in angular cuttings, 2,420 and 2,430	30	2,430
Sandstone, light yellow	5	2,435
Sandstone, dark brown	40	2,475
Sandstone, terra-cotta red, fine	10	2,485
Sandstone, reddish; 2 samples	35	2,520
Sandstone, buff, fine	15	2,535
Sandstone, reddish	15	2,550
Sandstone, light purplish, fine	10	2,560
Sandstone, reddish brown, fine; 3 samples	25	2,585
Sandstone, dark reddish brown; grains angular, 2,600 and 2,610	25	2,610
Sandstone, purplish; 2 samples	15	2,625
Sandstone, red, pink, and brown, fine; grains broken; 15 samples	71½	2,696½

The water is pumped to a standpipe with a capacity of 27,000 gallons, affording a domestic pressure of 45 pounds. Direct pressure is 100 pounds. There are 3½ miles of mains, 46 fire hydrants, and 320 taps. The consumption averages 45,000 gallons a day.

West Branch.—Waterworks were installed at West Branch (population, 643) in 1906. The supply is from an 8-inch well, 65 feet deep, with a capacity of 100 gallons per minute. Pumping 13½ hours lowered the water to but 7 feet below the surface of the ground. The water bed is honeycombed limestone of Devonian age. Rock is entered at 6 feet. Water is pumped to a tank with capacity of 30,000 gallons, affording a gravity pressure of 103 pounds. There are 1¾ miles of mains and 23 fire hydrants. Village house wells range from 20 to 50 feet in depth.

WELL DATA.

Information concerning typical wells in Cedar County is presented in the following tables:

Typical wells in Cedar County.

Owner.	Location.	Depth.	Depth to rock.	Remarks (logs given in feet).
T. 81 N., R. 4 W. (PARTS OF CASS AND LINN).				
		Feet.	*Feet.*	
Charles Dodds	SE. ¼ sec. 25	50	25	
Mary Kauffman	SE. ¼ sec. 26	....	80	Nearly all blue clay; bowlders from 20 to 40.
B. Wilson	Sec. 30	73	50	Yellow clay, 20; blue clay, 30.
Charles Pfaff	SW. ¼ sec. 36	118	100	
Philip Hammond	NW. ¼ sec. 4	80	16	
C. Strother	Sec. 12	....	70	
Elmer Wallick	Sec. 16	120	36	
T. 81 N., R. 3 W. (RED OAK; PARTS OF CASS, LINN, CENTER).				
R. Stout	SW. ¼ sec. 18	120	100	Drift clays, 100; limestone, 10; greenish pipe clay (Carboniferous cavern filling) 10; limestone to bottom.
Alexander Moffitt	NW. ¼ sec. 6	98	40	
Alexander Buchanan	NW. ¼ sec. 18	300	70	
H. Shank	NE. ¼ sec. 7	65	35	
	SW. ¼ sec. 17	133	40	
E. H. Carl	Sec. 18	160	120	Yellow clay, 60; sand, 60.
T. 81 N., R. 2 W. (DAYTON).				
H. Dewell	Sec. 2	108	108	Yellow clay, 20; blue clay, 48; on paha hill.
George McLeod	Sec. 25	105	....	Blue clay, 20; pebbly hardpan overlying quicksand, 20; gravel, 65.
T. 80 N., R. 2 W. (PARTS OF CENTER AND ROCHESTER).				
W. W. Aldrich	Sec. 2	220	60	
D. R. Smith	Sec. 3	156	136	On rock was found "red granite," 3 inches thick, which cut drill and was dynamited.
G. Wingert	Sec. 4	109	80	60 feet of sand. Strong flow of gas encountered at 60 feet between clay above and sand; would blow off hat.
C. G. Wright	Sec. 5	160	110	
——— Swartzlander	Sec. 6	156	150	Yellow clay deep in this vicinity.
B. Sandy	NE. ¼ sec. 8	....	102	Yellow clay, soft, 45; blue clay, 55; pebbles, 2.
William Ford	Sec. 10	156	136	No sand.
J. Huddlestone	Sec. 12	100	73	Yellow clay, 10; blue clay, 63.
George Wilbur	Sec. 13	180	130	Yellow clay, 20; sand, 90.
C. W. Carl	Sec. 15	140	120	
H. L. Snider	Sec. 16	190	54	
E. D. Neirson	Sec. 21	140	70	Yellow clay, 35; blue clay, 35.
R. J. Goodale	Sec. 22	120	60	Yellow clay, 20; blue clay, 40.
Moses Brunker	Sec. 29	156	131	
Adam Birk	Sec. 31	275	176	Yellow clay, 20; blue clay with a very little sand, 156; solid log or limb of wood at 166; no dark soil; rock, 99.
P. Metz	Sec. 32	120	51	
J. Kropelin	Sec. 34	121	118	20 feet of sand on rock.
Fair Grounds, Tipton	SW. ¼ sec. 36	201	105	
T. 81 N., R. 2 W. (FAIRFIELD; PART OF CENTER).				
L. Haggerty	Sec. 9	170	110	
Johnson Spear	NW. ¼ sec. 16	198	177	
E. H. Carl	Sec. 18	146	120	
J. C. Casford	Sec. 21	150	....	Much sand and gravel.
Matt. Fell	Sec. 20	133	110	Yellow clay, 20; blue clay, 80; gravel, 10.
J. Kroeplene	Sec. 34	125	118	Nearly all sand and gravel to rock.

Typical wells in Cedar County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Remarks (logs given in feet).
T. 79 N., R. 1 W. (FARMINGTON).		*Feet.*	*Feet.*	
Charles Moorehouse	SW. ¼ sec. 5	110	....	Black soil, 10; blue clay, 40; sand, 40; gravel, 20.
J. F. Schroeder	Sec. 8	114	80	
Henry Steffen	Sec. 12	54	46	All yellow clay to rock.
William Miller	Sec. 16	132	132	Yellow and blue clays, 80; sand, 30; blue clay, 22.
Johann Klohn	Sec. 23	100	48	
T. 82 N., R. 3 W. (FREMONT).				
R. M. Carll	Sec. 2	190	160	Blue clay, 100; sand and gravel, 60.
P. Farrington	SE. ¼ sec. 4	120	120	Yellow clay, 24; blue clay, 64; sand, 14; muck, 10; blue clay and gravel, 8.
John Schwalpert	S. ½ sec. 8	87	40	
G. S. Burleigh	Sec. 9	146	....	Foot of Stanwood paha. Mostly blue clay; 3 sand beds.
J. Studer	NE. ¼ sec. 18	65	30	
H. B. Thomas	Sec. 20	93	93	Yellow clay, 20; blue clay nearly to rock; water in gravel on rock.
A. M. House	Sec. 21	111	105	
Alex. Caldwell	NE. ¼ sec. 28	168	....	On NW. ¼ NE. ¼, drift clays, 120; sand, 48. On SE. ¼ NE. ¼ rock was entered at 98, and the drill stopped at 118.
T. 80 N., R. 4 W. (GOWER).				
J. A. Armstrong	Sec. 4	120	100	Yellow and blue clay to rock.
A. H. Fisher	Sec. 9	220	180	Drift clays, 140; sand, 40.
T. W. Fitzpatrick	Sec. 13	180	75	Hill.
J. Tucker	Sec. 15	112	100	Yellow clay, 60; blue clay, 40.
B. Ellison	Sec. 27	190	160	
W. W. Totum	SE. ¼ sec. 36	135	95	Yellow clay, 20; blue clay, 75.
T. 80 N., R. 1 W. (INLAND).				
A. Dresselhouse	Sec. 3	138	106	8 feet of sand on rock.
M. Sparks	Sec. 4	140	140	Yellow clay, 40; blue clay, 45; sand, 5. Water on rock, head, 40 feet.
E. Bell	Sec. 7	172	165	Yellow clay, 50; blue clay, 50; quicksand, 40; blue clay to rock.
H. Wharton	Sec. 11	138	60	
T. 79 N., R. 3 W. (IOWA; PART OF ROCHESTER).				
J. S. Smith	Sec. 4	70	40	
E. Hanna	Sec. 4	160	60	
——— Hutchins	Sec. 5	102	80	
B. Ellison	Sec. 7	100	65	
C. D. Stottler	Sec. 9	100	60	
J. P. Stottler	Sec. 10	160	60	
B. Woods	Sec. 18	160	120	
——— Dufle	Sec. 21	70	40	Water in blue limestone.
W. Kennedy	Sec. 31	256	50	All yellow clay to rock.
H. Cress	Sec. 34	70	40	Water in blue limestone.
T. 80, R. 2 W. (PARTS OF ROCHESTER AND CENTER).				
A. Antons	Sec. 29	177	157	Yellow clay, 70; blue clay, 86; sand, 1, to rock. Hill.
Thomas Mathews	Sec. 29	202	102	First rock shelly limestone, 3; blue shale, 5; hard limestone, 96.
James Ross	Sec. 31	130	100	No sand; rock soft and shaly.
J. Fulbrider	Sec. 32	200	....	
T. 79 N., R. 2 W. (SUGAR CREEK; PART OF ROCHESTER).				
J. D. Ridenours	Sec. 5	200	60	From 110 to 120 feet "pipe clay" (shale) underlain by 4 feet of coal.
C. A. Ridenours	Sec. 7	50	20	
——— Ayers	Sec. 1	220	....	Soft blue clay, 50; sand and clay mixed, mucky, black, 100; clean fine sand resting on gravel, 70.

Typical wells in Cedar County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Remarks (logs given in feet).
T. 79 N., R. 2 W.—Continued.		*Feet.*	*Feet.*	
Isaac Riser	Sec. 1	245	....	Across road from Ayers. Clay, 50; muddy sand, 100; clean sand, 75; gravel, 20.
J. W. Rockhaltz	Sec. 4	....	45	Rock full of flint nodules from size of hickory nut to baseball.
Charles Kiser	Sec. 11	124	84	Yellow clay, 74; sand, 10.
T. 79 N., R. 4 W. (SPRINGDALE).				
E. Halloway	Sec. 3	213	110	Pipe clay from 125 to 131.
Samuel Thomas	Sec. 9	160	40	Yellow clay, 20; soft sandy blue clay, 20.
D. Sullivan	Sec. 19	....	160	Yellow and blue clay to rock.
—— Meredith	Sec. 19	....	120	60 feet of sand on rock.
D. Wiggins	Sec. 31	215	180	On belt of "deep country" which starts in west of West Branch and runs west of Downey.
T. 80 N., R. 3 W. (PARTS OF CENTER, ROCHESTER, IOWA, GOWER).				
O. P. Pratt	Sec. 10	80	30	
T. 82 N., R. 1 W. (MASSILLON).				
L. Vansickle	SW. ¼ sec. 4	112	82	Well unfinished. Loess, 60; ashen loess, 10; sand, 12, to rock. Hill.
J. S. Erbe	SE. ¼ sec. 14	120	....	Blue clay, 50; sand, 70. Hill.
Charles Kramer	SE. ¼ sec. 20	183	....	Water at 180; much sand.
Gustave Martens	SE. ¼ sec. 21	174	....	
E. Schleuter	NW. ¼ sec. 27	172	....	Yellow clay, 40; blue clay to bottom; water in streak of sand at 110.
T. 82 N., R. 4 W. (PIONEER).				
Louis Seever	NE. ¼ sec. 3	140	120	Yellow clay, 35; blue clay, 85; rock.
D. Foley	Sec. 21	143	....	Yellow clay, 30; blue clay, 110; river sand, 3.
Jacob Hammond	SE. ¼ sec. 32	80	50	
W. Bennett	SW. ¼ sec. 34	80	42	
W. Elliott	SW. ¼ sec. 35	88	30	
David Rhoudes	NE. ¼ sec. 36	130	70	

CLINTON COUNTY.

By W. H. NORTON.

TOPOGRAPHY.

The upland of the northeastern townships of Clinton County attains a height of 900 feet above sea level and is deeply and intricately dissected. The topography is that characteristic of the driftless area and the belt of Kansan drift immediately adjacent. The entire area of these townships has been reduced by long erosion to valley slopes.

The southern portion of the county consists of a gently undulating plain of Iowan drift, diversified, near the edges, with ridges and elongated hills of the older drift, capped with loess, and trending from northwest to southeast.

Wide alluvial plains occur not only along the Mississippi but also along the entire course of Wapsipinicon River (except a short rock-bound reach at Big Rock), and up the valley of Yankee Run. A broad strip of lowland known as the Goose Lake Channel, crossing the county from north to south, marks an ancient temporary channel of the Mississippi.

GEOLOGY.

The bulk of the Pleistocene deposits of Clinton County consists of the Kansan and the Nebraskan drift sheets, the Iowan drift forming but a veneer on the area allotted to it. The northern dissected Kansan upland is thickly covered with a pebbleless yellow silt or dust, the loess. The foundation rock on which the superficial deposits rest throughout most of the county is the Niagara dolomite; some deep-cut ancient valleys, however, are filled with drift which reaches to the Maquoketa, a blue plastic shale which outcrops along the base of the bluffs of the Mississippi as far south as Lyons.

UNDERGROUND WATER.

SOURCE AND DISTRIBUTION.

Clinton County offers a wide variety of water beds, including the alluvial plains with their shallow ground water, the glacial gravels associated with the different sheets of glacial drift, and the Niagara dolomite. Some of the deepest farm wells of the county tap still deeper horizons, in the Maquoketa shale and the underlying Galena dolomite. The artesian wells of Clinton pass through the Ordovician formations and tap the Jordan and Dresbach sandstones and deeper Cambrian strata.

In Sharon Township, on the Kansan upland, the drill strikes the Niagara dolomite at depths ranging from 70 to 120 feet and finds water within 150 feet of the surface. On the Iowan drift plain in the southern part of the township wells south of Lost Nation find water in glacial gravels less than 150 feet from the surface.

In the northeastern section of Brookfield Township, rock appears at the surface. Water is found in the Niagara at depths seldom exceeding 150 feet. A deep-buried river channel enters the northwestern part of the township from Jackson County, passes east of Elwood, and thence trends southwest. The lowest altitude recorded for the rock floor of this buried valley is 470 feet above sea level. This "deep country" passes through a well-dissected Kansan upland and several wells approach or exceed 300 feet in depth. Water is usually found in gravel before reaching rock, but in one or two wells drilling was continued to some depth in the Maquoketa shale.

In Bloomfield Township no well reported exceeds 175 feet in depth. Water is usually found in the Niagara, which is generally reached from 50 to 125 feet from the surface. Exceptional wells which failed to reach rock and disclose an ancient buried river channel are reported, one on the aggraded valley of Deep Creek (sec. 32), which passed through 144 feet of quicksand and struck rock 171 feet below the surface; and two wells in the hilly country north of Delmar (secs. 10 and 11), which reached 200 feet, passing mainly through blue stony clay.

In Waterford Township the scanty data at hand indicate that the Niagara is covered but thinly with drift in many places. Water is commonly found in this dolomite at depths of less than 150 feet. The Maquoketa underlies the Niagara at moderate depths; in sec. 3 it occurs not lower than 550 feet above sea level. At Brown, on Sugar Creek, an ancient channel was discovered by a well which passed through 199 feet of drift to the Maquoketa shale, whose summit is about 500 feet above sea level.

Most of the wells of Deep Creek Township find abundant water in the Niagara, which there lies 150 feet below the surface. In the marshy lowland known as Goose Lake channel, carved and partly aggraded by the Mississippi during one of the great invasions of the State by glacier ice, are many driven and open wells. A drilled well sunk in the channel in sec. 7 passed through 108 feet of alluvial clays and sands without reaching rock. The rock floor of the channel here lies less than 570 feet above sea level.

In Elk River, Hampshire, Spring Valley, and Lincoln townships wells commonly succeed in finding water in the Niagara within 50 to 180 feet from the surface. Sand wells prevail along the terraces of the Mississippi. The deepest are those which unfortunately fail to find water in the Niagara and are drilled into the Maquoketa shale, which emerges along the base of the bluffs at Lyons and other localities along Mississippi River and in the valley of Elk Creek. In these townships the depth to the Maquoketa—a matter of great importance to the driller—ranges from 100 to 250 feet. At Eagle Point Park the shale, which was found beneath 20 feet of loess and 140 feet of Niagara dolomite, was 200 feet thick. The well was sunk through the shale and penetrated 104 feet into the Galena dolomite, from which a small supply of water was obtained.

A well in Elk River Township, sec. 31, reached the shale after passing through 142 feet of drift and 100 feet of limestone and found some water in the shale after penetrating it to a depth of 157 feet.

In Center, Comanche, and Eden townships, which are supplied chiefly from the Niagara, few wells exceed 180 feet in depth. On the Sullivan farm, 1½ miles southeast of Bryant, a well 409 feet deep enters rock, probably the Galena, near the bottom. The alluvial sands of Goose Lake channel, a flat-floored valley from 1 to 2 miles wide, now occupied by Brophys Creek, supply many driven wells. Deep wells have been drilled in the channel and have failed to find the rock floor at depths even of 175 feet (485 feet above sea level). So far as reported only alluvial sands and clays occur in this channel. Driven wells furnish the supply on the Mississippi and Maquoketa flood plains of these townships.

Washington, Orange, Welton, and De Witt townships obtain their supplies from glacial gravels or, more commonly, from the Niagara dolomite. Few wells exceed 150 or 180 feet in depth or reach the Maquoketa shale. The succession which may be expected in deeper wells is shown by the log of the well of the Chicago & North Western Railway Co. at De Witt.

Log of well at De Witt (Pl. XI, p. 382).

	Thickness.	Depth.
	Feet.	*Feet.*
Drift	40	40
Limestone (Niagara)	220	260
Shale (Maquoketa) penetrated	7	267

Driven wells obtain water on the broad flood plain of Wapsipinicon River.

Liberty, Berlin, Spring Rock, and Olive townships draw their water supplies from alluvial and glacial sands and gravels and from the Niagara dolomite. The flood plain of Wapsipinicon River, which below Toronto is more than 3 miles wide, affords many wells 40 to 60 feet deep. The deeper wells drilled on the flood plain show a filling of the ancient rock-cut valley with 150 and 180 feet of glacial and alluvial deposits and reveal the rock floor at 525 feet above sea level south of Toronto and at 490 feet above sea level northeast of Big Rock. At places near Toronto the Niagara approaches or reaches the surface and affords a supply to wells at depths of 50 to 100 feet. Over the larger part of the area of these townships the drift is 70 to 120 feet thick, and wells find water at less than 150 feet from the surface in the upper strata of the Niagara. In places, however, the drift is far thicker, owing to the filling of preglacial valleys. Thus, north of Bliedorn several wells show drift exceeding 200 feet in depth. This buried valley evidently connects with the preglacial valley which extends from Nashville, in Jackson County, to a point south of Elwood. This channel perhaps makes southwest to the aggraded valley of the Wapsipinicon below Toronto, but the data at hand are not sufficient to trace it.

SPRINGS.

Springs are few in Clinton County, except in the northeastern part, where Elk Creek and its tributaries have opened their valleys to the base of the Niagara and have thus cut the waterways developed at that horizon near the summit of the impervious Maquoketa shale. Springs from the Niagara occur along Rock Run in Spring Rock Township and on the creek near Grand Mound and De Witt.

CITY AND VILLAGE SUPPLIES.

Clinton.—The water supply of Clinton (population, 25,577) is notable in that it is drawn entirely from five artesian wells (Pl. XI), which yield enough to meet the daily consumption of 2,000,000 gallons. The water from these wells is pumped into a reservoir with a capacity of 10,000,000 gallons and thence direct through 42 miles of mains with a domestic pressure of 60 pounds and a fire pressure of 100 pounds. There are 400 fire hydrants and 3,000 taps.

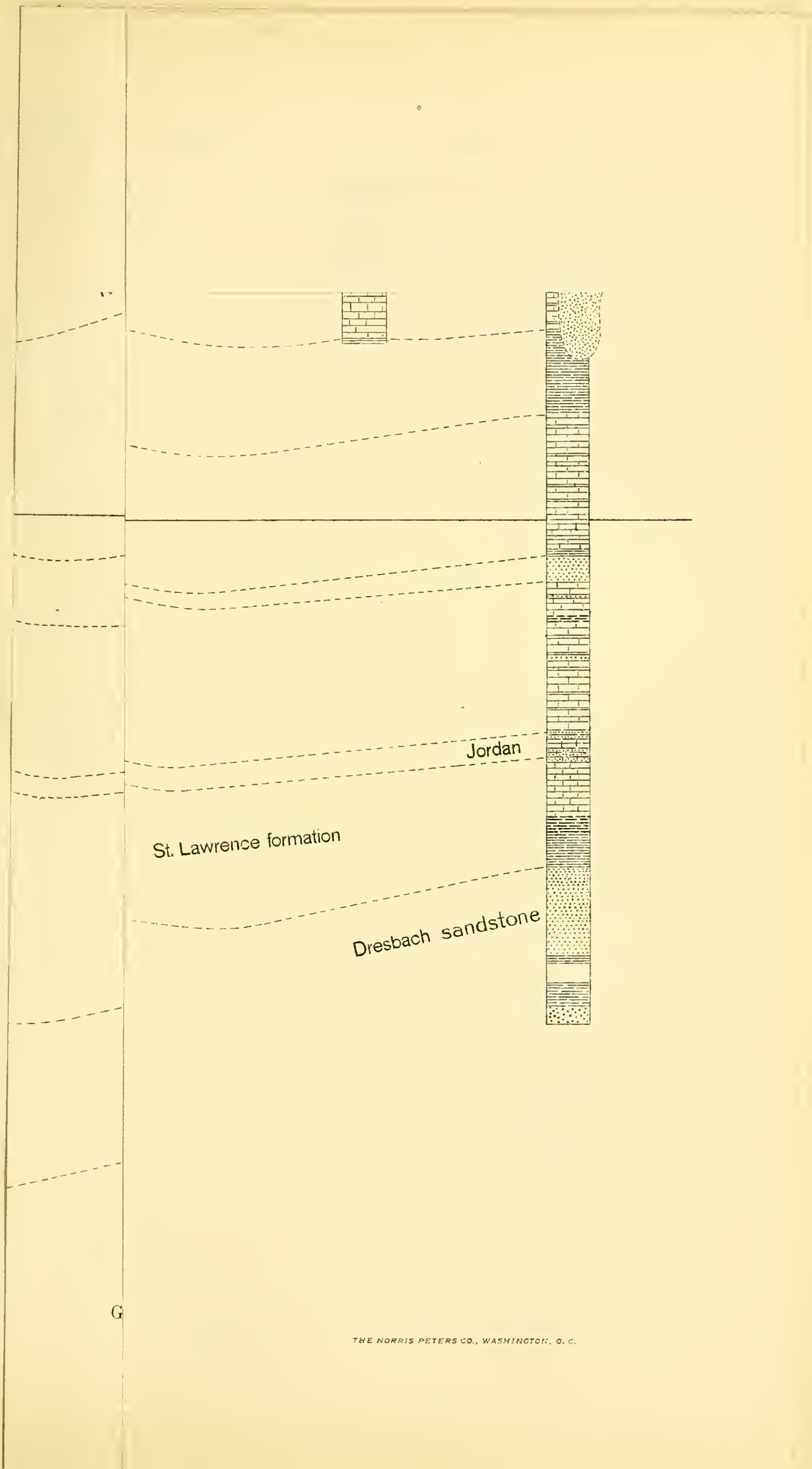
At Clinton the geologic horizon at the surface is somewhat below the summit of the Maquoketa shale, the shale appearing at the base of the bluffs, just north of Lyons, a town now incorporated into Clinton. Some of the wells, however, as for example that of the Clinton Brewery Co., find the lower layers of the Niagara and much of the upper part of the Maquoketa cut away by a preglacial channel of Mississippi River.

Water may be found in the Galena and Platteville limestones at numerous levels, but in such small amounts as to be negligible when compared with the large yields to be obtained from deeper terranes. The water in the St. Peter sandstone is now so overdrawn that no large yield can be expected from this formation. The Prairie du Chien group contributes a good deal of water from its creviced limestones and sandy beds to each of the Clinton wells.

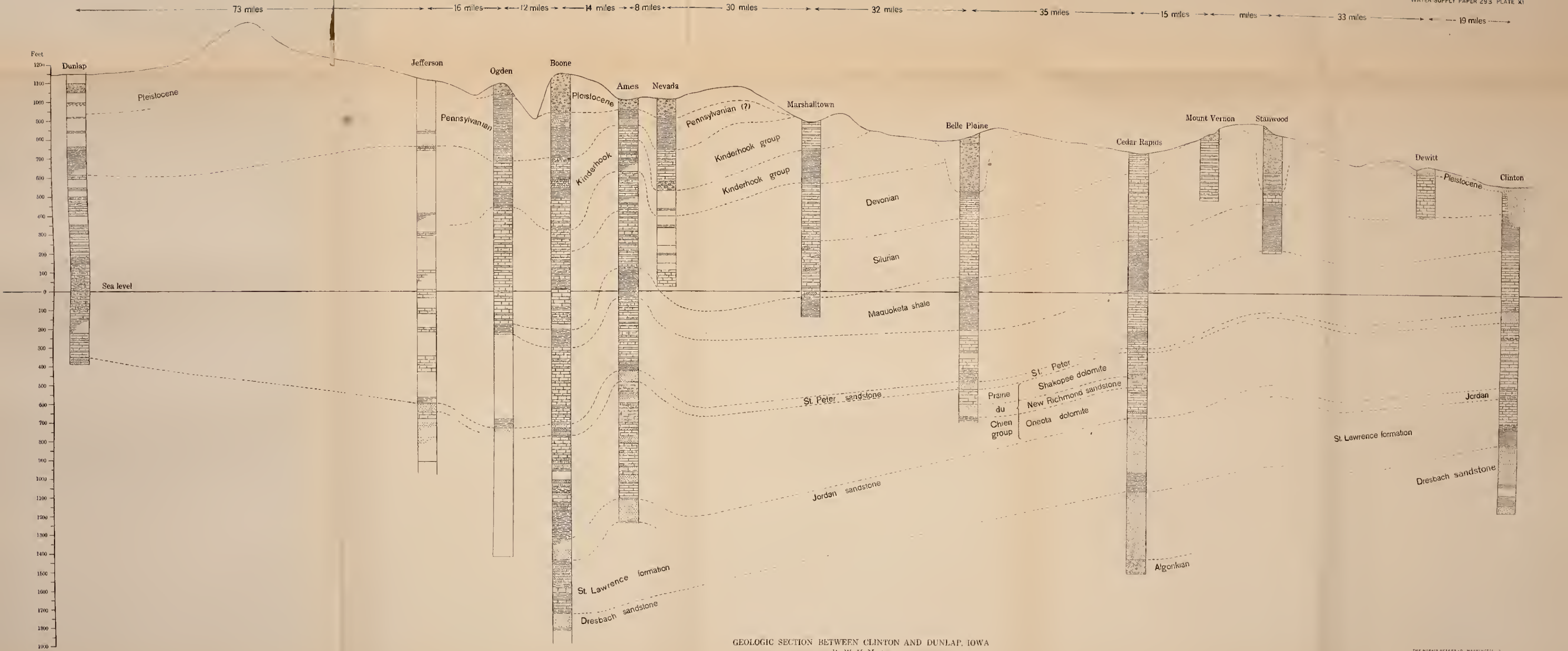
The main flow of all the Clinton wells except the deepest comes from the Jordan sandstone at depths ranging from 1,100 to 1,290 feet, and at present sufficient water for industrial plants can be obtained from this formation.

The Cambrian sandstones underlying the Dresbach, reached now by but three wells, yield far more generously than the upper water beds. Under present conditions they may be expected to furnish more than double the amount supplied by all the higher terranes combined, and in the future the proportion will naturally become still larger owing to the depletion of the upper beds. Fortunately the water of these Cambrian strata at Clinton is of exceptionally good quality and no fear need be felt that it will be salty or highly mineralized. To reach the first sandstone beneath the Dresbach it is necessary to go about 1,650 feet below the level of the Clinton plain. The second sandstone, whose summit is reached at about 1,700 feet, contains two water beds, one within the upper 100 feet, the other between 1,400 and 2,100 feet from the surface. As the overdraft, which has already brought the artesian head down to approximately the surface of the ground, increases, the higher terranes may in time be largely exhausted and the Dresbach and earlier Cambrian sandstones become the chief dependence for artesian water.

Waterworks well No. 1 has a depth of 1,400 feet and a diameter of 5 to 8 inches; casing, 135 feet, packed at base with rubber and lead. The curb is 588 feet above sea level. The original head was 44 feet



THE NORRIS PETERS CO., WASHINGTON, D. C.



GEOLOGIC SECTION BETWEEN CLINTON AND DUNLAP, IOWA
By W. H. Norton

above the curb and the head in 1896 was 35 feet above the curb. The original discharge was 500,000 gallons a day. Temperature, 64° F. The well was completed in 1886 by J. P. Miller & Co., of Chicago.

Waterworks well No. 2 has a depth of 1,246 feet and a diameter of 5 inches. The curb is 588 feet above sea level and the original head, 44 feet above the curb. The original discharge was 500,000 gallons a day. Temperature, 64° F. The well was completed in 1886 by J. P. Miller & Co., of Chicago.

Waterworks well No. 3 has a depth of 1,685 feet and a diameter of 8 inches to 1,200 feet and 6 inches to bottom; casing, to 135 feet, packed with lead. The curb is 588 feet above sea level. The original head was 44 feet above the curb and the original discharge 600 gallons a minute, measured on a weir. The first flow was from 335 feet; continuous flow from 1,050 feet; from 625 to 725 feet, 150 gallons a minute, 8-inch bore; from 1,025 to 1,150 feet, 400 gallons a minute, 8-inch bore; from 1,400 to 1,675 feet, 600 gallons a minute, 6-inch bore. Temperature, 63° F. The well was completed in 1890 by J. P. Miller & Co., of Chicago.

Waterworks well No. 4 at De Witt Park has a depth of 1,497 feet and a diameter of 8 inches to 1,279 feet and 5 inches to 1,300 feet; casing to 700 feet to cut off caving sands. The curb is 588 feet above sea level. The discharge was originally 600,000 gallons a day. Temperature, 63° F. The well was completed in 1893 by J. P. Miller & Co., of Chicago. The driller reports that the full flow was reached at 1,100 feet. The well ceased to flow and was disconnected from the waterworks system.

Waterworks well No. 5 has a depth of 1,763 feet and a diameter of 8 to 6 inches; 8-inch casing to 125 feet into shale, and 6-inch from 739 to 840 feet. The curb is 588 feet above sea level. A small flow began at 850 feet, and was followed by a considerable increase from 1,140 to 1,160 feet; at 1,230 feet, flow of 165 gallons a minute; at 1,295 feet, 200 gallons; at 1,613 feet, 238 gallons; at 1,710 feet, 266 gallons; and at 1,763 feet, 303 gallons. Temperature, 64° F. The well was completed in 1902 at a cost of $3,506 by J. P. Miller & Co., of Chicago.

Log of city well No. 5 at Clinton (Pl. XI, p. 382).

	Thickness.	Depth.
	Feet.	*Feet.*
Surface material	6	6
Limestone	125	131
Shale	227	358
Limestone	318	676
Shale	14	690
Sandstone	50	740
Shale	92	832
Limestone	308	1,140
Sandstone mixed with limestone	25	1,165
Limestone	155	1,320
Shale	93	1,413
Sandstone	252	1,665
Shale	55	1,720
Sandstone	43	1,763

This log shows the thickness of the Niagara dolomite (6 to 131 feet) and the entire thickness of the Maquoketa shale (131 to 358 feet), as the well was put down at one side of the preglacial channel of the Mississippi.

The thickness of the Niagara given in this log is corroborated by the logs of several other wells. The Dresbach sandstone of the brewing company well section is included in the sandstone reported from 1,413 to 1,665 feet in the city well No. 5. Apparently the shale at the bottom of the brewing company's well rests on a bed of sandstone, below which is a 55-foot bed of shale, which in turn rests on the water-bearing sandstone that was penetrated to a depth of 43 feet in the city well. The record of the city well shows an increase in flow of about 65 gallons a minute from this basal sandstone.

The waterworks well No. 6 has a depth of 2,101 feet and a diameter of 10 feet to rock, 15½ inches to 354 feet, 12½ inches to 870 feet, and 10 inches to bottom; casing to 364 feet; packing, lead. The curb is 588 feet above sea level and the head 14 feet above the curb. The first overflow was from the second Cambrian sandstone beneath the Dresbach. The discharge at 1,940 feet was 70 gallons a minute; on completion, 225 gallons. Temperature, 70° F. The well was completed in 1911 by J. D. Shaw, of Davenport, Iowa.

During the drilling of the well water from the upper artesian horizons stood 14 feet below the surface until the water bed of the second sandstone beneath the Dresbach was reached. The head of this bed is therefore now about 28 feet higher than that of the higher artesian sources. On the completion of this well the first drilled well of the Clinton Gas, Light & Coke Co. is said to have been raised 2 feet. It is reported by the officials of the Clinton Water Co. that the well of the Treitschler & Tiesse Malting Co. at Lyons began to overflow at the same time. On the other hand, no change was observed in the head of the wells of the Sugar Refining Co., the Clinton Paper Co., the Clinton Brewing Co., the Chicago & North Western Railway Co., the Fulton waterworks, and L. Iten & Sons. The officials of the Clinton Waterworks Co. are confident that on the completion of their new well the head of artesian water was lifted about 3 feet over an area extending 2,000 to 3,000 feet from their well. This implies an enormous leakage from the well and that the water from the second sandstone beneath the Dresbach, with its higher head, finds lateral escape through the higher water beds which feed the other wells and thus increases their head. The volume of water from the sandstones underlying the Dresbach must be immense to supply not only the flow of the well but also the enormous supposed leakage into the surrounding strata. It is the intention of the water company to test the well thoroughly with a current meter, ascertaining the places and amounts of leakage and then to case off the outlet strata above the Dresbach sandstone.

Record of strata in waterworks well No. 6 at Clinton.

	Thickness.	Depth.
	Feet.	*Feet.*
Alluvium	10	10
Silurian:		
Niagara dolomite (115 feet thick; top, 578 feet above sea level)—		
Dolomite, buff; 4 samples	115	125
Ordovician:		
Maquoketa shale (225 feet thick; top, 463 feet above sea level)—		
Shale, blue, plastic; 7 samples	225	350
Galena dolomite and Platteville limestone (350 feet thick; top, 238 feet above sea level)—		
Dolomite, gray and brown, crystalline; 8 samples	200	550
Limestone, brown, hard; rapid effervescence; 6 samples	143	693
Shale, dark green, fissile	7	700
St. Peter sandstone (50 feet thick; top, 112 feet below sea level)—		
Sandstone, white; rounded grains, fine	25	725
Sandstone and dolomite; sandstone, white, coarser than above; dolomite, gray (Shakopee?)	25	750
Prairie du Chien group—		
Shakopee dolomite (150 feet thick; top, 162 feet below sea level)—		
Dolomite, brown and gray; 5 samples	150	900
New Richmond sandstone (35 feet thick; top, 312 feet below sea level)—		
Dolomite and sandstone; color in mass, buff; all in fine sand; oolitic	25	925
Dolomite, arenaceous, cream colored and pink, cherty	10	935
Oneota dolomite (230 feet thick; top, 347 feet below sea level)—		
Dolomite, whitish; in fine sand; 2 samples	10	945
Marl; in finest argillo-silico-calcareous powder	5	950
Dolomite, whitish, cherty; some oolitic chert; 8 samples	50	1,000
Dolomite, light gray; 7 samples	165	1,165
Cambrian:		
Jordan sandstone (155 feet thick; top, 577 feet below sea level)—		
Sandstone, calciferous; or dolomite highly arenaceous; fine grains, moderately well rounded; some chips of dolomite; some fragments show quartz grains in dolomitic matrix	155	1,320
St. Lawrence formation (120 feet thick; top, 732 feet below sea level)—		
Dolomite, gray; in small chips	15	1,335
Marl, white; residue after solution, microscopic silica and clay	10	1,345
Dolomite, light gray; in sand and powder	10	1,355
Marl, pink, glauconiferous; microscopic quartzose and argillaceous residue after solution	1	1,356
Sandstone and dolomite; sandstone, dark red, argillaceous; of finest grain; dolomite, gray, glauconiferous	14	1,370
Sandstone, fine-grained; grains imperfectly rounded; glauconiferous with some hard fissile green shale	30	1,400
Shale, high arenaceous, glauconiferous, fine grained; in light-green flour	40	1,440
Sandstone, fine grained; grains imperfectly rounded, highly glauconiferous; in chips; and arenaceous red shale	5	1,445
Dresbach sandstone and underlying strata (656 feet penetrated; top, 852 feet below sea level)—		
Sandstone, white; larger grains reaching diameter of 1 millimeter	5	1,450
Sandstone, clean, white, fine grained quartz sand	5	1,455
Sandstone, pinkish; larger grains 1 millimeter, some reaching 1.5 millimeters	20	1,475
Sandstone, white, fine grained; 3 samples	35	1,510
Shale, drab, plastic	10	1,520
Shale, bright green, highly glauconiferous, arenaceous; driller's log gives shale from 1,510 to 1,550	30	1,550
Sandstone, light pink; larger grains 0.8 millimeter in diameter, well rounded	20	1,570
Sandstone, moderately fine, white	30	1,600
Sandstone, pinkish, glauconiferous	30	1,630
Shale, light green, fissile, glauconiferous; 2 samples	55	1,685
Sandstone, light buff; fine grained, hard	35	1,720
Sandstone, white; grains mostly below 0.5 millimeter in diameter	20	1,750
Sandstone; as above, but coarser; chips of arenaceous dolomite; 2 samples	50	1,800
Sandstone, white, moderately fine, at	....	1,840
Sandstone, white; larger grains, about 7 millimeters in diameter, moderately well rounded, fairly uniform; a few show secondary enlargements, at	....	1,880
Sandstone; grains less uniform; light pink at 1,910, buff at 1,925, at	....	1,925
Sandstone, white; grains moderately well rounded; larger 0.8 and 1 millimeter in diameter; well overflows from this water bed, at	....	1,940
Sandstone; as above; white and some buff or red from rusting of drillings; 7 samples, at	....	1,998
Sandstone, light buff; larger grains 1 millimeter in diameter, secondary enlargements; some hard green fissile shale, at	....	2,060
Sandstone, pink, moderately fine, at	....	2,065
Sandstone, darker buff; larger grains 1 millimeter in diameter, imperfectly rounded, at	....	2,101

The Chicago & North Western Railway well No. 1, located at the shops, has a depth of 1,159 feet and a diameter of 10 to 4 inches. The curb is 588 feet above sea level and the original and present head 12 feet above the curb. The tested pumping capacity is 500 gallons a minute. Temperature, 56.5° F. The well was completed in 1896 by J. P. Miller & Co., of Chicago. Owing to decrease in pressure and contamination of the water, it was recased in 1905 by inserting 30 feet of 8-inch, 72 feet of 5-inch, 315 feet of 4-inch, and 27 feet of 3-inch casing, and its flow was thereby increased.

The Chicago & North Western Railway well No. 2 at the South Clinton roundhouse has a present head of about 20 feet below the curb. The temperature of the water is 57° F. The well was drilled about 1900. It ceased to flow in July, 1908, on the completion of the new Clinton Sugar Refining Co.'s well; it regained its flow when the latter was closed. In the summer of 1910 an air lift was used on these two wells from a depth of 300 feet. The discharge from the two wells combined was 1,500,000 gallons a day.

The Clinton Gas, Light & Coke Co. well No. 2 has a depth of 1,605 feet and a diameter of 12 inches to 8 feet, 10½ inches to 35 feet, 8 inches to 853 feet, and 6¼ inches to bottom. Its curb is 579 feet above sea level and its head is 2 feet above the curb. The pumping capacity is 500 gallons a minute; temperature, 72° F. The well was completed in 1911 by H. W. Hambrecht, of Sterling, Ill.

Record of strata in Clinton Gas, Light & Coke Co.'s well No. 2.

	Thickness.	Depth.
River deposits:	*Feet.*	*Feet.*
Cinder filling	5	5
Loam, black	4	9
Sand	3	12
Clay, red	17	29
Sand	24	53
Gravel	12	65
Sand	4	69
Silurian:		
Niagara dolomite—		
Loose rock	1	70
Limerock	44	114
Ordovician:		
Maquoketa shale—		
Flint, yellow white, and blue and brown shale	121	335
Galena dolomite and Platteville limestone—		
Limerock	326	671
Shale	14	685
St. Peter sandstone—		
Sandstone	61	746
Prairie du Chien group—		
Shale	2	748
Cambrian:		
Jordan sandstone—		
Limerock	560	1,308
St. Lawrence formation—		
Shale	105	1,413
Dresbach sandstone—		
Sandstone	192	1,605

The chief water beds were at 550 feet (Galena dolomite, which furnishes the principal supply), at 800 feet (Shakopee dolomite), at 1,200 feet (Jordan sandstone), and at 1,500 feet (Dresbach sandstone).

The Treitschler & Tiesse Malting Co.'s well has a depth of 1,132 feet and a diameter of 8 to 5 inches; 8-inch casing to 150 feet; casing also between 700 and 800 feet. The original head was 3 feet above the curb, and the original flow 300 gallons a minute. Most of the water comes from 1,050 to 1,130 feet. Temperature, 60° F. The well was completed in 1897 by J. P. Miller & Co., of Chicago.

Driller's log of Treitschler & Tiesse Malting Co.'s well.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface	40	40
Limestone	80	120
Shale	200	320
Limestone	352	672
Shale	8	680
Sandstone	65	745
Limestone	387	1,132

Five years after the completion of the well an air lift was installed but shortly afterwards the brewery was closed and the well is not now in use.

The two wells of the Clinton Sugar Refining Co. have a depth of 1,226 feet and a diameter of 12 inches to 422 feet, 10 inches to 727 feet, 8 inches to the bottom; 10-inch casing to 422 feet; 8-inch casing from 666 feet to 747 feet. The curb is about 586 feet above sea level. The original flow was 191 gallons a minute and the tested pumping capacity 400 gallons a minute. The first flow was very slight, at 760 feet but markedly increased at 935 feet, gradually from 935 to 1,100 feet, and largely at 1,190 feet; no further increase was noted. Temperature, 62° F. The well was completed in 1908 by J. D. Shaw, of Sioux City, Iowa. The sinking of the wells seriously affected the supply of the well of the Chicago & North Western Railway Co. at the roundhouse at South Clinton.

Record of strata in well of Clinton Sugar Refining Co.

	Thickness.	Depth.
Silurian:		
Niagara dolomite (177 feet thick; top, 586 feet above sea level)—	*Feet.*	*Feet.*
Dolomite, buff and light cream color; in powder and fine sand; 6 samples	60	60
Dolomite, buff, subcrystalline; in small chips and coarse sand; 5 samples	40	100
Dolomite, very light gray, cherty; 7 samples	67	167
Dolomite, light blue gray, cherty; in fine chippings	10	177
Ordovician:		
Maquoketa shale (213 feet thick; top, 409 feet above sea level)—		
Shale; greenish gray to 340 feet; below, olive green gray and drab; 20 samples	213	390

Record of strata in well of Clinton Sugar Refining Co.—Continued.

	Thickness.	Depth.
Ordovician—Continued.		
Galena dolomite and Platteville limestone (335 feet thick; top, 196 feet above sea level—	*Feet.*	*Feet.*
Dolomite, yellow gray, crystalline; 9 samples	105	495
Dolomite, brown and gray, cherty; 6 samples	75	570
Dolomite, yellow gray and brown gray; two samples	25	595
Dolomite, light yellow, highly argillaceous, cherty	20	615
Dolomite, brown, blue gray and buff; three samples, from 625 feet some nonmagnesian, limestone chips; in drillings	30	645
Limestone, yellow, gray and blue gray, earthy, nonmagnesian; in flaky chips; seven samples	70	715
Shale, greenish drab; in molded masses	10	725
St. Peter sandstone (30 feet thick; top, 139 feet below sea level)—		
Sandstone, white, clean; rounded grains, attaining a diameter of 1 millimeter; 2 samples	20	745
Sandstone, white, fine; considerable diversity in size of grains	10	755
Prairie du Chien group—		
Shakopee dolomite (180 feet thick; top, 169 feet below sea level)—		
Dolomite, gray; some sand (first water)	10	765
Dolomite, gray; much quartz sand; 2 samples	35	800
Dolomite, gray, cherty; considerable sand	10	810
Dolomite, light gray; considerable sand and some bright green shale; 3 samples	25	835
Dolomite, light gray; clean of sand; in chips and sand; 6 samples	60	895
Dolomite, light gray; cherty, little quartz sand	10	905
Dolomite, brown gray; with oolitic white chert, 3 samples	30	935
New Richmond sandstone (20 feet thick; top, 349 feet below sea level)—		
Dolomite, highly arenaceous, cherty, whitish; 2 samples	20	995
Oneota dolomite (160 feet thick; top, 369 feet below sea level)—		
Dolomite, whitish, clean of sand; 3 samples	30	985
Dolomite, whitish, highly cherty	10	955
Dolomite, yellow gray, brown and buff, and blue gray; cherty at 995, 1,025, and 1,105 feet; 11 samples	120	1,115
Cambrian:		
Jordan sandstone (100 feet penetrated; top, 629 feet below sea level)—		
Sandstone, white, fine grained; grains show secondary enlargements, many grains fractured; some chips of light-buff dolomite	10	1,125
Dolomite, light buff; some rounded grains of quartz sand	10	1,135
Sandstone, white fine; secondary enlargements; a little dolomite	10	1,145
Dolomite, light buff, some sand; 2 samples	20	1,165
Sandstone, white, fine grained; secondary enlargements, some chips, show sand grains and calcareous and cherty matrix	10	1,175
Dolomite, light gray; some sand	10	1,185
Dolomite, blue gray and buff, cherty; oolitic chert at 1,185 feet; 2 samples	15	1,200
Dolomite, light gray, fine grained, and sandstone, some whitish marl	15	1,215

The well of the Excelsior Laundry Co. has a depth of 737 feet and a diameter of 10 to 8 inches. The head is 11 feet below the surface. Date of completion October 31, 1910; driller, M. P. Petersen, Madison, Wis. On the average there are pumped 20,000 gallons a day. Continuous pumping lowers the well 3 or 4 feet. No account of the water beds was kept, but as the well extends to or below the base of the St. Peter, it may be taken for granted that the supply is from that formation and from the Galena and Platteville limestones.

The well of Curtis Bros. has a depth of 1,150 feet and a diameter of 12 inches to 27 feet, 8 inches to 745 feet, and 6¼ inches to bottom; casing, 24 feet of 12 inch at top, 311 feet of 8 inch immediately below; 92 feet of 6¼ inch from 653 to 745 feet. The head is 3 feet below the surface. Driller, H. W. Hambrecht, Sterling, Ill. Date of completion, February 10, 1911. Temperature 60° F.

Record of strata in Curtis Bros. well at Clinton.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface deposit:		
Filling of sawdust	12	12
Clay	8	20
Silurian:		
Niagara dolomite—		
Lime, yellow, loose	7	27
Lime, yellow	33	60
Lime, white	12	72
Lime, blue	63	135
Ordovician:		
Maquoketa shale—		
Shale, blue and brown	203	338
Galena dolomite and Platteville limestone—		
Lime rock	335	673
Shale, green	14	687
St. Peter sandstone—		
Sandstone	58	745
Prairie du Chien group—		
Lime rock	410	1,155
Cambrian:		
Jordan sandstone—		
Sandy lime	8	1,163

The well of the Clinton Ice Co. has a depth of 1,561 feet and a diameter of 10 inches to 62 feet, $8\frac{1}{8}$ inches to 745 feet, and $5\frac{1}{8}$ inches to bottom. The head is 9 feet below the curb and the pumping capacity 75 gallons a minute. Temperature about 68° F. Date of completion, 1910; driller, H. W. Hambrecht, of Sterling, Ill.

Record of strata in Clinton Ice Co. well at Clinton.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface deposit:		
Filling	8	8
Clay	12	20
Silurian:		
Niagara dolomite—		
Lime, yellow	92	112
Lime, blue	10	122
Ordovician:		
Maquoketa shale—		
Shale, blue	150	272
Shale, brown	58	330
Galena dolomite and Platteville limestone—		
Limerock	90	420
Lime, brown	143	563
Shale, blue	123	686
St. Peter sandstone—		
Sandrock	52	738
Prairie du Chien group—		
Limerock	367	1,105
Sandrock	42	1,147
Limerock	33	1,280
Limerock, red	8	1,288
Limerock, brown	12	1,300
Cambrian:		
St. Lawrence formation—		
Shale	102	1,402
Dresbach sandstone—		
Sandrock	159	1,561

The paper company's well has a depth of 1,076 feet and a diameter of 8 to 6 inches; 6-inch casing to 84 feet. The curb is approximately 588 feet above sea level. The original head was 42 feet above the curb; head in 1896, 8 feet above curb; present head (1909), 2 feet above the curb. The original flow was about 200 gallons a minute. Temperature, 59° F. The well was completed in 1883 by J. P. Miller & Co., of Chicago. The well showed considerable loss of pressure within four years after its completion. As it had been closed nights and Sundays, it was thought that much of the water was forced by the pressure on the sides of the bore hole into crevices of the rock. In 1893 the well was reamed and another casing inserted. At the bottom of the first casing the rock was found so eroded by the water that the reamer dropped 7 feet. A casing was then put in to the depth of 160 feet, and packed with rubber, but without increasing the flow.

The well of C. Lamb & Son has a depth of 1,230 feet and a diameter of 5 inches; casing to 125 feet. The curb is 588 feet above sea level. The original head was 60 feet above curb; the present head is much lower, and the well ceases to flow when pumps are working on Sugar Refining Co. well, about 500 feet distant. Temperature, 59½° F. The well was completed in 1888 at a cost of $2,128 by J. P. Miller & Co., of Chicago. It has passed into the ownership of the National Papier Mâché Co., and is not now in use except as a drinking fountain.

L. Iten & Sons well has a depth of 1,180 feet and a diameter of 6¼ inches; casing, 200 feet. The curb is about 588 feet above sea level. The head is slight, flowing 75 to 100 gallons a minute. The first good flow was from 1,025 feet, and the next noticed was from 1,180 feet. Temperature, 62° F. The well was completed in 1907, at a cost of $3,000, by J. D. Shaw, of Sioux City, Iowa. This well flows from 9 p. m. to 10 a. m., and then the water sinks to about 1 foot below the curb.

The Clinton Brewing Co. well has a depth of 1,620 feet and a diameter 10 to 6 inches; 10-inch casing to 99 feet, 8-inch to 212 feet, 6-inch, to 300 feet. The head is 2 feet below the curb. Temperature, 62° F. The well was completed in 1907 by L. Wilson & Co., of Chicago. Although many deep wells have been drilled at Clinton, no adequate record of the strata penetrated was available until 1907, when this well was put down. Samples of the drillings were taken every 5 or 10 feet.

Record of strata in well of the Clinton Brewing Co.

	Thickness.	Depth.
Quaternary (205 feet thick; top, 588 feet above sea level):	*Feet.*	*Feet.*
Soil, black, sandy	3½	3½
Sand, coarse, gray	4	7½
Sand, light gray, fine	12	19½
Gravel	2½	22
Gravel and sand	13	35
Sand, gray, fine	4	39
Gravel and sand	½	39½
Gravel, coarse, well rounded, 2 samples	12½	52
Sand and gravel, yellow gray	14	66
Gravel, coarse; pebbles up to 2 inches in diameter	1	67

Record of strata in well of the Clinton Brewieg Co.—Continued.

	Thickness.	Depth.
Quaternary (205 feet thick; top, 588 feet above sea level)—Continued.	*Feet.*	*Feet.*
Sand, yellow gray, coarse	10	77
Clay, pink, friable, noncalcareous	½	77½
Gravel; pebbles reaching 1½ inches in diameter	19½	97
Clay, dark-colored slate, sandy	3	100
Clay, sand and gravel, yellow	10	110
Gravel, coarse	3	113
Sand, orange, medium fine	9	122
Gravel, coarse	3	125
Sand, light yellow	8	133
Gravel, coarse; with limestone pebbles 1½ inches in diameter	7	140
Sand, yellow, fine	20	160
Clay, light yellow, calcareous	2	162
Sand, yellow, fine	12	174
Clay, light yellow, calcareous	3	177
Sand, fine, yellow	4	181
Clay, yellow, hard, calcareous	2	183
Gravel, coarse	3	186
Sand and gravel	2	188
Gravel, coarse, with glaciated pebble	7	195
Sand and gravel, with fragments of granite bowlder	2	197
Clay, hard, yellow, calcareous	1	198
Sand, yellow, fine	7	205
Ordovician:		
Maquoketa shale (125 feet thick; top, 383 feet above sea level)—		
Shale, blue green; 2 samples	125	330
Galena dolomite and Platteville limestone (340 feet thick; top 258 feet above sea level:		
Dolomite, gray, crystalline; cherty from 435 to 450 and from 460 to 470 feet; 16 samples	170	500
Dolomite, gray, cherty	10	510
Dolomite, gray or light buff, vesicular at 510 feet; crystalline; 7 samples	55	565
Dolomite or magnesian limestone, brown, crystalline; with brown fossiliferous and bituminous shale	5	570
Shale, brown, highly bituminous and fossiliferous	5	575
Limestone, magnesian, brown	12	587
Limestone, magnesian, drab, subcrystalline; cherty at 600 feet; 4 samples	33	620
Limestone, blue gray, nonmagnesian, compact, fossiliferous, thin, laminated, in flaky chips; 4 samples	25	645
Limestone, light yellow gray, soft, earthy, fossiliferous, in thin flakes	5	650
Limestone, light blue gray, fossiliferous; rapid effervescence	5	655
Shale, brown, bituminous, in thin flaky chips; and limestone, compact, earthy; rapid effervescence	10	665
Shale, blue green, pyritiferous, flaky	5	670
St. Peter sandstone (60 feet thick; top, 82 feet below sea level)—		
Sandstone, white; largest grains 1 millimeter in diameter; 5 samples	55	725
Sandstone, light buff, fine grained, with angular sand of dolomite	5	730
Prairie du Chien group (345 feet thick; top, 142 feet below sea level)—		
Dolomite, gray; in chips; considerable sand	18	748
Dolomite, gray, slightly arenaceous	5	753
Dolomite, gray; with arenaceous laminæ; in chips	7	760
Dolomite, gray; with hard dark shale	15	775
Dolomite, gray; pyritiferous and blue gray at 783 feet; 2 samples	18	793
Sandstone; in detached rounded grains of moderate fineness, and dolomite in chips	7	800
Dolomite, light gray, compact; large cherty and argillaceous residue	10	810
Marl; in whitish powder, highly calcareous; large, argillaceous and arenaceous residue; grains diverse in size, but none coarse, imperfectly rounded	15	825
Dolomite, light gray to dark drab, crystalline, vesicular; in places cherty; 3 samples	70	895
Dolomite, light gray; in fine chips, with grains of quartz sand	8	903
Dolomite, light gray; in fine chips; sandstone in detached grains	8	911
Sandstone, light gray, calciferous, hard, fine grained; in chips	9	920
Dolomite, light gray and pink; cherty at 920 feet; 4 samples	45	965
Chert, white, and whitish dolomite; in chips	5	970
Dolomite, light yellow, cherty; in sand; 2 samples	20	990
Marl; in light-yellow powder; large residue of minute and microscopic angular flakes of cryptocrystalline quartz with some of crystalline quartz	10	1,000
Dolomite, light gray and blue gray; in places cherty and in places arenaceous; 8 samples	75	1,075
Cambrian:		
Jordan sandstone (65 feet thick; top, 487 feet below sea level)—		
Sandstone, light gray, calciferous, fine grained, glauconiferous; in chips; and dolomite, gray	15	1,090
Dolomite, light gray, arenaceous, quartz grains, fine, rounded	30	1,120
Sandstone, light gray, calciferous; in small chips and fine sand	20	1,140
St. Lawrence formation (255 feet thick; top, 552 feet below sea level)—		
Dolomite, buff, cherty; in sand; according to log cuttings flowed away between 1,130 and 1,240 feet	70	1,210
Dolomite, light brown, hard, crystalline; in chips	10	1,220
Dolomite; in chips, slightly siliceous and glauconiferous	10	1,230

Record of strata in well of the Clinton Brewing Co.—Continued.

	Thickness.	Depth.
Cambrian—Continued.		
St. Lawrence formation—Continued.		
Dolomite, pink, highly siliceous; with minute quartzose particles; glauconiferous; in chips	*Feet.* 10	*Feet.* 1,240
Dolomite, gray, siliceous; in chips, 3 samples	30	1,270
Dolomite, light pink, highly siliceous, with minute quartzose particles; glauconiferous	10	1,280
Marl, pink, calcareous; in powder and easily friable compacted masses; residue argillaceous and microscopically quartzose; glauconiferous	38	1,318
Shale, light blue, calcareous, plastic	77	1,395
Dresbach sandstone and underlying strata (225 feet penetrated; top, 807 feet below sea level)—		
Sandstone, light buff, friable; grains rounded; considerable diversity in size; largest 1 millimeter in diameter	15	1,410
Sandstone, white; grains, 0.25 millimeter in diameter	10	1,420
Sandstone, light yellow; grains well rounded; largest grains, 0.75 millimeter in in diameter	10	1,430
Sandstone, light yellow; fairly well rounded; larger grains 0.5 millimeter in diameter	10	1,440
"Sand rock;" cuttings washed away	162	1,602
Shale; cuttings washed away	18	1,620

The geologic section is continued 140 feet deeper by the log of city well No. 5 (p. 383).

The gas company well has a depth of 1,085 feet and a diameter of 8 to 5⅝ inches; casing, 6 feet to rock. The curb is 579 feet above sea level and the original and present head 35 feet above curb. It flows 230 gallons a minute. Water was found at 1,000 feet. Temperature, 59° F. The well was completed in 1901 at a cost of $1,800 by J. P. Miller & Co., of Chicago.

Delmar.—The water-supply system of Delmar (population, 548) includes wells of depths not reported, a standpipe, and 2,700 feet of mains with six fire hydrants. The pressure is 46 pounds. For the most part the town draws its domestic supply from drilled wells 30 to 250 feet deep, 100 feet being the most common depth. Wells enter rock at 90 feet and the largest supply is found at 100 feet.

De Witt.—At De Witt (population, 1,634) the water supply is drawn from two wells, 274 feet and 524 feet deep. (See Pl. XI.) The deeper well is 10 inches in diameter, enters rock at 40 feet, and finds water at 500 feet. Water stands 100 feet below the curb after long pumping and rises 10 feet when pumping ceases. The 274-foot well is 8 inches in diameter and finds its main supply at 270 feet. Water heads at 40 feet below the curb, but long pumping lowers it to 150 feet. The Maquoketa shale at De Witt is struck at about 260 feet from the surface, and the city well evidently passed entirely through it and found water in the Galena dolomite. It is regretted that no record of the well was kept showing the thickness of the shale.

If the city well or the well of either of the railway companies at De Witt should fail to yield enough water, recourse may be had to waters in the St. Peter sandstone, which lies 800 to 850 feet below the surface; its water will rise within easy pumping distance. Water will also probably be found in the limestones (Platteville and Galena) overlying the St. Peter but this can not be assured.

Grand Mound.—At Grand Mound (population, 428) the gravity system is employed, a pressure of 32 pounds being afforded by a standpipe. There are 13 fire hydrants, 55 taps, and 1 mile of mains. The supply comes from a well 6 inches in diameter and 87 feet deep. Rock is entered at 70 feet and water was found in the Niagara at 80 feet. Water heads 30 feet from the surface. The maximum yield by pumping is 1½ barrels a minute.

Wheatland.—The supply of Wheatland (population, 539) is drawn from a well and distributed from a tank by the gravity system through 1¼ miles of mains. There are 10 fire hydrants and 24 taps. A large part of the population is supplied by house wells which range in depth from 11 to 178 feet. The city well is 6 inches in diameter and 189 feet deep and enters rock at 14 feet. It is cased to 185 feet.

Minor supplies.—Information concerning supplies in the smaller communities is presented in the following table:

Village supplies in Clinton County.

Town.	Nature of supply.	Depth.	Depth to water bed.	Depth to rock.	Head below curb.	
					Shallow.	Deep.
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Brown	Wells	Below 200		10–50		
Bryant	Drilled wells					
Buena Vista	Wells	90–190	35–50	40–100	5	50
Charlotte	Drilled wells	32–120	100	24–160	20	30
Comanche	Driven wells	30–38			28	
Elvira	Drilled wells	50–100		25		40
Folletts	Driven and drilled wells	30–60	36		28	45
Goose Lake	Drilled wells	60–90				
Lost Nation	do	45–140	100	50–120	40	80
Low Moor	Open, driven, and drilled wells.	18–120			20	200
Malone	Drilled wells	30–120	100	40–60	25	50
Teeds Grove	Wells	16–100			115	15
Toronto	Drilled wells	40–125	100	60	35	40
Welton	do	13–25			13	

WELL DATA.

The following table gives data of typical wells in Clinton County:

Typical wells in Clinton County.

Owner.	Location.	Depth.	Diameter.	Depth to rock.	Depth to water-bed.	Water-bearing formation.	Remarks (logs given in feet).
T. 83 N., R. 1 E. (SHARON).		*Feet.*	*Inches.*	*Feet.*	*Feet.*		
Chicago, Milwaukee & St. Paul Ry.	Lost Nation	95		47		Limestone	Alluvium, 7; yellow clay, 40; limestone, 48.
W. Jaronsen	do	135		130			Soil, 3; yellow clay, 30; blue clay, 97; limestone, 5.

Typical wells in Clinton County—Continued.

Owner.	Location.	Depth.	Diameter.	Depth to rock.	Depth to water-bed.	Water-bearing formation.	Remarks (logs given in feet).
T. 83 N., R. 1 E. (SHARON)—Contd.		*Feet.*	*Inches.*	*Feet.*	*Feet.*		
M. Ales	2 miles north of Lost Nation.	152		80			Dark blue till on rock.
G. P. Teeple	Sec. 10	126		70			
J. G. Garder	NE. ¼ NE. ¼ sec. 34.	137					Creek bottom. Soil, 4; yellow clay, 4; very fine sand, 125; coarse gravel, 3.
J. Mulverhill	SE. ¼ sec. 6	140		70			Yellow clay, 35; blue clay, 35; limestone, 70.
Mrs. P. Pitch	SW. ¼ SW. ¼ sec. 31.	140		80			Upland. Fine red sand, 80; limestone, 60.
T. 83 N., R. 2 E. (BROOKFIELD).							
	NW. ¼ NE. ¼ sec. 5.	206				Gravel	Ridge.
J. W. Whitsell	Sec. 9	277		257			Upland. Soil 2; yellow clay, 40; blue clay, 215; limestone, 20.
J. Toskey	N. ½ NE. ¼ sec. 28.	329				Gravel	Base of bluff. Yellow bowldery clay, 37; blue clay, 100; quicksand, 115; blue clay, 75; coarse gravel, 2.
	SW. ¼ SE. ¼ sec. 4.	106				Sand	Mostly blue clay.
	SE. ¼ NW. ¼ sec. 9.	256		201		do	Sand 45 feet thick.
	NW. ¼ SE. ¼ sec. 9.	256		201			Yellow clay, 20; blue clay, 80; sand with some water, 1; blue clay, 80; sand and water, 20; rough hard blue clay without grit (Maquoketa shale), 55; ends in red gravel. Heads 156 feet below curb.
—— Benton	NW. ¼ sec. 22	268					About same as above; ends also in red gravel.
—— Anderson	SE. ¼ SW. ¼ sec. 15.	300					About same as above.
	¼ mile S. of Elwood on creek.	200				Gravel	Flowing well.
Hans Christianson	SE. ¼ SE. ¼ sec. 30.	501	3		480		Slope. Heads 40 feet below curb. Driller's log: Yellow till, 40; blue till, 310; sand, 50; greenish gray rock, hard, 101. Udden's record: Black soil, 4; yellow clay, 35; blue clay, 136; river sand, 25; blue clay, 100; soapstone, 100; blue shale, 100.
John Wirth	Sec. 29	306		300			
J. Anderson	NW. ¼ SW. ¼ sec. 14.	125		50			

Typical wells in Clinton County—Continued.

Owner.	Location.	Depth.	Diameter.	Depth to rock.	Depth to water-bed.	Water-bearing formation.	Remarks (logs given in feet)
T. 83 N., R. 2 E. (BROOKFIELD)—Continued.		*Feet.*	*Inches.*	*Feet.*	*Feet.*		
J. A. Anderson	SW. ¼ sec. 14	315		295			Yellow clay, 30; blue clay, 190; quicksand, 75; limestone, 20.
	SW. ¼ SW. ¼ sec. 1.	410		13			Hill. Drift, 13; limestone, 107; soapstone (shale), 290.
	NW. ¼ SE. ¼ sec. 34.	166		163			
	NE. ¼ NW ¼ sec. 9.	82		35			
	Sec. 4	85		70			Considerable blue till.
	Sec. 12	90		20			
E. S. Hiner	Sec. 22	188				Gravel	
Do	Sec. 23	63		45			
J. A. Hiner	Sec. 26	156				Gravel	Heads 73 feet below curb.
H. Schmidt	Sec. 36	100		70			
H. G. Scott	SE. ¼ SE. ¼ sec. 25.	110		50		Limestone	Yellow clay, 20; blue clay, 30; limestone, 60.
T. 83 N., R. 3 E. (BLOOMFIELD).							
Chicago, Milwaukee & St. Paul Ry.	Delmar	90		36		do	
	do	102		56			Ridge. Yellow clay, 15; blue clay, 41; limestone, 46.
	SE. ¼ SE. ¼ sec. 21.	130		126		Sand	Yellow clay, 25; blue clay, 97; sand with water, 4; limestone, 4;
	SW. ¼ SW. ¼ sec. 23.	107		95		Limestone	wood, between 50 and 60.
J. Dennis	S. ½ NW. ¼ sec. 31.	170		72		do	Black soil, 2; yellow clay, 40; blue clay, 30; limestone, 98.
E. A. Fitch	NW. ¼ sec. 32	175		171		Quicksand	Yellow clay, 27; quicksand, 144; limestone, 4.
D. Eckard	Sec. 10	200				Sand	
R. F. Rossiter	Sec. 11	200				Gravel	Mainly blue till.
W. McCloy	Sec. 12	184		80		Limestone	
T. 83 N., R. 4 E. (WATERFORD).							
	Brown Station	199		199			Surface deposits and soft blue clay, 30; blue till, 52; sand and gravel, 28; blue till, 22; pebbles, drab silt, 30; blue clay with pebbly streaks, 31; chocolate-colored clay, 6; Maquoketa shale.
Charles Frank	Sec. 11	130		+20			
——— Niehaus	Sec. 1	100				Sand and gravel.	Near-by wells, higher ground, reach rock at 50 feet.
J. Powers	Sec. 3	166		60		Limestone	Drift, 60; Niagara dolomite, 96; Maquoketa shale, 10.
M. Omara	Sec. 18	140		20		do	
W. Ward	Sec. 7	120		20		do	

Typical wells in Clinton County—Continued.

Owner.	Location.	Depth.	Diameter.	Depth to rock.	Depth to water-bed.	Water-bearing formation.	Remarks (logs given in feet).
T. 83 N., R. 4 E. (WATERFORD)—Continued.		*Feet.*	*Inches.*	*Feet.*	*Feet.*		
J. Reife	Sec. 8	190		30		Limestone	Drift, 30; limestone, 40; blue mucky shale, 40; limestone, 80.
Anton Tur	Sec. 8	160		6		do	Yellow clay, 6; limestone, 154.
	NE. ¼ SE. ¼ sec. 30.	140		16		do	
	SE. ¼ NE. ¼ sec. 29.	111		29		do	
T. 83 N., R. 5 E. (DEEP CREEK).							
Otto Kreuse	NE. ¼ SE. ¼ sec. 14.	175		50			Plenty of water, though a well 50 feet distant and 300 feet deep was not a success, both striking rock at the same depth.
Thomas Farrell	NW. ¼ NE. ¼ sec. 34.	108		55			
Church	Bryant	128		70		Limestone	
	SW. ¼ SW. ¼ sec. 1.	200		68		do	Yellow clay, 30; blue clay, 38; limestone, 135.
	NE. ¼ SE. ¼ sec. 23.	156				Gravel	Yellow clay, 30; blue till, 116; gravel, 10.
	SE. ¼ NE. ¼ sec. 24.	180		125		Limestone	High ridge.
	SW. ¼ SE. ¼ sec. 26.	160				Gravel	Ridge. Yellow clay, 20; blue till, 135; gravel, 5.
	SW. ¼ SW. ¼ sec. 26.	225		125		Limestone	Drift, 125; limestone, 100.
——— Hicks	Sec. 7	108					Goose Lake channel. Alluvial clay and sand.
T. 83 N., R. 6 E. (PART OF ELK RIVER).							
George Egger	SE. ¼ SW. ¼ sec. 35.	212		212		Sand	
J. Sullivan	NW. ¼ sec. 31	399		142		Shale	Drift, 142; limestone, 100; shale, 157. 80 rods north on same place a well found limestone 180 feet thick 75 feet from surface.
F. Naeve	NW. ¼ NE. ¼ sec. 27.	97					Soapstone (Maquoketa shale) at 97 feet.
	Teeds Grove, sec. 10.	100		88			Alluvium and blue till to rock.
J. F. Diercks	Sec. 33	220		50			
C. Schroeder	Sec. 33	88		40			
T. 83 N., R. 7 E. (PART OF ELK RIVER).							
——— Shattock	W. ½ sec. 31	100				Sand	Terrace 60 feet above water level in Mississippi River. Stops in sand under blue mucky clay.
Frank Naeve	Andover, S. ½ sec. 22.	200		60		Shale	Surface deposits, 60; limestone, 30; shale, 110; water heads near surface.

Typical wells in Clinton County—Continued.

Owner.	Location.	Depth.	Diameter.	Depth to rock.	Depth to water-bed.	Water-bearing formation.	Remarks (logs given in feet).
T. 82 N., R. 6 E. (HAMPSHIRE; PART OF SPRING VALLEY).		*Feet.*	*Inches.*	*Feet.*	*Feet.*		
J. Lindmeyer	SE. ¼ sec. 14	118		45			
H. B. Paulson	NE. ¼ SE. ¼ sec. 18.	162		90			
Peter Ehlers	NW. ¼ NW. ¼ sec. 28.	100		90			
Peter Swartz	NE. ¼ NW. ¼ sec. 3.	150		63			
A. Clausmann	NW. ¼ SE. ¼ sec. 10.	48		20			
W. Wenzel	NE. ¼ sec. 14	175					High ground.
Claus Knutsen	SE. ¼ NE. ¼ sec. 18.	170		80		Limestone	High ground; all yellow clay to rock.
School district	SE. ¼ NW. ¼ sec. 21.	140					
G. Lueders	Sec. 16 or 17	180		100			
James Hand	N. ½ sec. 30	150		55			
George Lange	SW. ¼ SE. ¼ sec. 5.	192		140			
N. Everhard	Sec. 2	137					Heads 72 feet below curb.
	Sec. 8	240		140		Limestone	
B. Manning	Sec. 9	110		50			
G. F. Cook	Sec. 12	157		90			
T. 82 N., R. 7 E. (PART OF SPRING VALLEY).							
Eagle Point Park	Lyons	464		20			Loess, 20; Niagara dolomite, 140; Maquoketa shale, 200; Galena dolomite, 104; a weak well.
George An	W. ½ sec. 7	160		60			Weak well. Head, 70 feet below curb.
Marion Gates	Lyons	200		30			Bluff. Ends on shale.
Oakland Cemetery	do	276		60		Sand veins in shale.	Loess and drift, 60; limestone, 116; shale, 100.
George An	NW. ¼ NW. ¼ sec. 7.	(?)		76			Yellow clay, 76.
T. 82 N., R. 5 E. (CENTER).							
James McDevitt	Sec. 3	84				Sand	Goose Lake channel. All sand. Head, 1 foot below curb.
William Wiese	NE. ¼ NE. ¼ sec. 11.	82				Gravel	Hillside, about 25 feet above creek; flowed for several years from gravel under blue clay.
	NW. ¼ NW. ¼ sec. 14.	425		30			Valley. Drift, 30; limestone, 120; shale, 180; Galena dolomite 95.
Hans Wiese	SW. ¼ SW. ¼ sec. 9.	250		106		Limestone	Ends in Niagara dolomite.
A. Steudemann	SW. ¼ SE. ¼ sec. 15.	132				Sand	Goose Lake channel. All sand.
Do	SW. ¼ sec. 14	175				do	Goose Lake channel.
William Buech	SE. ¼ NE. ¼ sec. 14.	230		130			Upland overlooking Goose Lake channel.
Robert Swartz	SE. ¼ SE. ¼ sec. 23.	148		60			
Center Grove Creamery.	SW. ¼ SW. ¼ sec. 2.	170		130			

Typical wells in Clinton County—Continued.

Owner.	Location.	Depth.	Diameter.	Depth to rock.	Depth to water-bed.	Water-bearing formation.	Remarks (logs given in feet).
T. 82 N., R. 5 E. (CENTER)—Contd.		*Feet.*	*Inches.*	*Feet.*	*Feet.*		
Town	Elvira	118				Sand	Alluvium, 5; yellow clay with sandy streaks, 50; sandy blue clay, 60; sand 3.
John Tierney	E. ½ NW. ¼ sec. 4	147		75			
T. 82 N., R. 4 E. (WASHINGTON; PART OF DE WITT).							
	NE. ¼ sec. 6	158		132			Yellow clay, 40; blue clay nearly to rock; a little sand on rock; blue quicksand 50 feet on rock.
	SW. ¼ NE. ¼ sec. 17.	87		51			Lowland.
M. Shannon	E. ½ sec. 23	118		75			High ground.
Peter Hanson	SE. ¼ sec. 12 or NW. ¼ sec. 13	70					
William Burka	Sec. 9	66		64			
E. Kelly	Sec. 10	175		125			Hard blue till, 105.
J. McDermott	Sec. 10	187		180			Hard blue till, 120.
T. Naughton	SW. ¼ NE. ¼ sec. 15.	194					Clay; no rock. High land.
	NW. ¼ NW. ¼ sec. 15.	225				Gravel	Yellow clay, 40; hard blue till, 80; quicksand, 70; coarse sand and gravel, 35. Surrounding wells struck rock at about 125.
T. 82 N., R. 3 E. (WELTON; PART OF DE WITT).							
M. Duffy	Sec. 1	160					Curb 770 feet above sea level; hence rock less than 610 feet above sea level.
E. Parker	Sec. 4	160		158			Loess and yellow till, 25; rather soft blue till with sand streaks 75; blue till compact, 58.
William Betts	Sec. 6	140		100		Limestone	
P. H. Ryan	NE. ¼ NE. ¼ sec. 11.	106		66		do	Yellow clay, 36; blue clay, 30; limestone, 40.
W. Rilly	NW. ¼ sec. 16	130		100		do	Yellow clay, 20; sand, 80; limestone, 30.
L. A. Loofboro	SE. ¼ SE. ¼ sec. 17.	180		80		do	Yellow clay, 30; blue clay, 50; limestone, 100.
—— Reedinger	Old Welton	227		227		Gravel	Yellow clay, 35; blue clay to gravel on rock.
T. 82 N., R. 2 E. (BERLIN).							
Mary Hassett	SW. ¼ sec. 2	132				do	High upland. Yellow clay, 30; blue clay, 98 gravel, 4.
A. Galloway	Sec. 3	326		324			High upland; curb 840 feet above sea level. Black soil, 3; yellow clay, 30; blue clay, 288; red clay, 3; limestone, 2.

Typical wells in Clinton County—Continued.

Owner.	Location.	Depth.	Diameter.	Depth to rock.	Depth to water-bed.	Water-bearing formation.	Remarks (logs given in feet).
T. 82 N., R. 2 E. (BERLIN)—Contd.		*Feet.*	*Inches.*	*Feet.*	*Feet.*		
Dougherty Estate..	Sec. 4	175		80		Limestone	High upland. Yellow clay, 30; blue clay, 50; limestone, 95;
Patrick Conners	S. ½ sec. 7	172		170		Sand	Sandy soil, 20; blue clay, 20; sand, 120; limestone, 2.
H. Schocker	SE. ¼ sec. 8	117		102		Limestone	
M. J. Pinter	SE. ¼ SE. ¼ sec. 12.	242		222		...do	Yellow clay, 32; blue clay, 190; limestone, 20.
P. Peterson	SE. ¼ sec. 13	210		205		...do	Yellow clay with sand, 50; blue clay, 30; quicksand, 15; blue clay, 110; limestone, 5.
William Rock	NE. ¼ sec. 23	130		85		...do	
P. Twogood	NE. ¼ sec. 26	100		99			
William Betts	SE. ¼ sec. 28	70		30		...do	Sandy soil, 30; limestone, 40.
Kohler Bros	Center of S. ½ sec. 36.	180				Gravel	Sandy yellow clay, 32; blue clay, 40; sand, 10; blue clay, 96; gravel, 2.
J. M. Wolfe	SE. ¼ sec. 36	85		40		Limestone	
T. 82 N., R. 1 E. (LIBERTY).							
J. Figly	Sec. 5	100		70		...do	Sand, 70; limestone, 30.
J. E. Wolfe	Sec. 14	140		110			Wapsipinicon bottoms. Sand, 110; limestone, 30.
T. Horstman	Sec. 27	175		155			Wapsipinicon bottoms. Yellow clay, 35; blue clay, 120; limestone, 20.
T. 81 N., R. 1 E. (SPRING ROCK).							
M. Pingel	SW. ¼ sec. 4	130				Sand	Soil, 1; sand, 120; hardpan, 9.
City of Wheatland..	Wheatland	171		87		Limestone	Iowan plain. Alluvium, 5; yellow clay, 43; blue clay, 39; limestone, 84.
K. Jergenson	NE. ¼ NE. ¼ sec. 25.	245		180		...do	Wapsipinicon bottoms. River sand, 60; blue clay, 80; black hard clay, 40; blue shale, 40; limestone, 9.
L. Homrighausen	SE. ¼ NE. ¼ sec. 28.	287		185		...do	Bluffs.
T. 81 N., R. 2 E. (OLIVE).							
C. Reming	Sec. 5	117		102		...do	Soil, 2; sand, 100; limestone, 15.
A. Tumpani	S. ½ SE. ¼ sec. 11.	55		48			Yellow clay, 48; limestone, 7.
O. F. Ludwigson	Sec. 20	230		228		Sand	Sand, 100; blue clay, 20; sand, 108; limestone, 2.
Bruce Walker	Calamus	137		120			Yellow clay, 20; blue clay, 100; limestone 17.
T. 81 N., R. 3 E. (ORANGE AND PART OF DEWITT).							
Town of Grand Mound.	Grand Mound	88		41		Limestone	Soil and gravel, 41; limestone, 47.
C. Munts	Sec. 19	60				Sand	

Typical wells in Clinton County—Continued.

Owner.	Location.	Depth.	Diameter.	Depth to rock.	Depth to water-bed.	Water-bearing formation.	Remarks (logs given in feet).
T. 81 N., R. 3 E. (ORANGE AND PART OF DE-WITT)—Cont'd.							
		Feet.	*Inches.*	*Feet.*	*Feet.*		
George Jordan......	Grand Mound...	144	4	15	125	Limestone	Heads, 80 feet below curb.
Chauncey Herrington.	1 mile northwest of De Witt.	130	....	130	....	....	High ridge.
T. 80 N., R. 6 E. (PARTS OF EDEN AND COMANCHE).							
E. B. Wilkes.......	Folletts.........	51	....	37	....	...do......	Sand, 37; limestone, 14.
Maple Grove School	2 miles west of Folletts.	97	....	....	....	Limestone at bottom.	
C. Van Epps.......	NW. ¼ sec. 3....	172	....	....	....	Gravel....	Sand, 40; blue clay 130; gravel, 2.
T. 81 N., R. 4 E. (PART OF DE WITT).							
Town of De Witt No. 1.	De Witt.........	524	10	40	....	Limestone	Yields 50 gallons a minute.
Chicago & North Western Ry.	.....do..........	267	....	....	....	...do......	Soil and sand, 40; limestone, 220; shale, 7.
H. E. Vickery......	SW. ¼ NE. ¼ sec. 36.	47	....	7	....	...do......	
Alex Works........	NE. ¼ SW. ¼ sec. 19.	26	....	....	....	Gravel....	

IOWA COUNTY.

By O. E. MEINZER and W. H. NORTON.

TOPOGRAPHY AND GEOLOGY.

The surface of Iowa County is well dissected and contains only isolated tracts of relatively level upland. The largest stream is Iowa River, which meanders through a broad flood plain.

The bedrock consists of indurated limestones, sandstones, and shales which belong to the Devonian and Carboniferous systems and dip gently southwest. (See Pl. XV, p. 670.) Though the main body of the Pennsylvanian series (upper Carboniferous) is found farther south and west, there is reason to believe that thin outliers of this series occur in this county, lying on an erosion surface of the older formations. The unconsolidated deposits, which rest on the bedrock, range in thickness from a mere veneer to more than 300 feet, this difference being due not only to the relief of the present surface but also to notable irregularities in the surface of the bedrock. There is evidence of the existence of two distinct drift sheets, the Kansan and the Nebraskan, separated by the Aftonian gravel.[1] Throughout most of the county the drift is concealed beneath loess, but in the principal valleys alluvial deposits are at the surface.

[1] Ann. Rept. Iowa Geol. Survey, vol. 9, 1899, pp. 523 et seq.; vol. 20, 1910, pp. 172 et seq.

UNDERGROUND WATER.

SOURCE.

Alluvial sand or gravel furnishes generous and permanent supplies of water wherever it occurs, but elsewhere most of the water comes from the drift or associated porous materials. Many of the older wells were dug or bored a short distance into the drift and these furnish only a scanty and precarious supply, but at present many drilled wells range in depth from 50 to more than 300 feet, ending in layers of sand and gravel interbedded with bowlder clay or lying immediately below the drift. Most of these latter wells are 2 inches in diameter and are finished with screens that become incrusted after a few years of service.

On account of the irregularities of the rock surface great differences are found in the occurrence and water-bearing capacity of the drift aquifers and in some localities the drill enters rock before it encounters a satisfactory source of water. The sandstones and some of the limestone strata will yield water but the shales and argillaceous or massive limestones are of little value as aquifers. Many successful rock wells of only moderate depth have been drilled, but in some places the indurated formations have been penetrated for several hundred feet without finding water. Where the drift is underlain by shale it is advisable to finish wells in the drift whenever possible, but in localities in which a good water-bearing sandstone or limestone lies within a few hundred feet of the surface it may be more satisfactory to case out the fine sand deposits that will give trouble by clogging the screens and to end the well in rock.

The water from the alluvium and upper part of the drift is only moderately hard; that from the deeper beds of sand differs greatly in mineralization, some being harder than that of the shallow water and some too hard and corrosive for either domestic or boiler use. The water from the rock formations is generally rich in dissolved solids.

At Marengo three or four flowing wells end at depths of several hundred feet in what is supposed to be Devonian limestone. Farther up the valley of Iowa River and also in the valleys of Honey Creek and Bear Creek many flowing wells obtain water in the Aftonian gravel and a few are supplied from rock strata. These flows belong to the famous Belle Plaine artesian basin (pp. 356–358).

CITY AND VILLAGE SUPPLIES.

Amana.—At Amana (population, 621), which is located in the wide valley of Iowa River, there is a 1,640-foot artesian well and also a well about 475 feet deep which passes through shale and ends in what is supposed to be Niagara dolomite.

The deeper well is 6 inches in diameter. The curb is 730 feet above sea level. The original head was 30 feet above the curb and the head in 1908, 20 feet above the curb. The original flow was 200 gallons a minute; in 1896 the flow was 100 gallons and in 1908 it was 50 gallons. The temperature of the water is 68° F. This well is located in the SW.¼ NW.¼ sec. 36, T. 81 N., R. 9 W. From the start in 1881 to the finish in 1883, it was drilled wholly by the labor and skill of the Amana Society. Originally it was cased to a depth of 400 feet with 6-inch pipe which withstood the corrosive action of the water about four years, when a 4-inch pipe of equal length was inserted and made tight at the bottom with secure packing.

Water began to flow at a depth of about 400 feet, 330 feet above sea level, about the horizon of the Independence shale member of the Wapsipinicon limestone. Like the flow from this horizon at Davenport, the yield was very small, not over 8 gallons a minute. A slight increase, raising the discharge to 16 gallons a minute, said to be from the Maquoketa shale, was the only addition met with until the St. Peter, 80 feet thick, was reached at a depth of 1,020 feet, when the discharge rose to 30 gallons. At about 1,200 feet (440 feet below sea level), in the Jordan sandstone, a rapid increase began and the full flow was reached at 1,640 feet. The water is used only for scouring in the woolen mill of the society.

Record of strata in Amana well.

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene deposits	50	50
Shale (Carboniferous and Devonian)	300	350
Limestone (Niagara)	200	550
Shale (Maquoketa)	220	770
Limestone (Galena and Platteville)	250	1,020
Sandstone (St. Peter)	80	1,100
Limestone (Prairie du Chien)	540	1,640

In the shallower well at Amana the water at first rose 7 feet above the valley surface but now stands 6 or 8 feet below the surface. It has been pumped at the rate of 29 gallons a minute.

Water diverted from the river and led through a canal to this settlement for use in power plants is used in the factory boilers and also supplies the small gravity system of waterworks. As it is softer than the underground water, it is generally employed for washing, but water from shallow wells is used for drinking and for culinary purposes.

East Amana.—At East Amana a 475-foot well is supposed to end in Niagara dolomite. It is located on somewhat higher ground than the wells at Amana and hence does not overflow. A similar well was drilled at West Amana. At South Amana the waterworks are supplied from a drilled well 600 feet deep, and at Middle Amana from a shallow dug well; at High Amana a spring is largely relied upon.

Homestead.—At Homestead the society has a well 2,224 feet deep which is located on higher ground and hence does not overflow, although it yields well when pumped. (See Pl. XV, p. 670.) It supplies a small gravity system of waterworks similar to the one at Amana.

This well, which was drilled by J. P. Miller & Co., of Chicago, is 10 inches in diameter to 340 feet, 7⅝ inches to 750 feet, 6 inches to 1,560 feet, 5 inches to 2,023 feet, 4 inches to 2,224 feet. The curb is 868 feet above sea level. The water originally stood 117 feet below curb, and the present head is 87 feet below curb. Water was found at 600 feet in the Niagara, rising to 150 feet below the curb, and at 1,700 feet in the Jordan, rising to 117 feet below curb. Date of completion, 1895. Casing was carried from the top to 340 feet, from 335 to 525 feet, and from 750 to 1,000 feet. No packing was used. The present yield of this well is 80 gallons a minute.

The strata penetrated are indicated by the following log and record:

Driller's log (geologic correlation added) of Amana Society well at Homestead (Pl. XV, p. 670).

	Thickness.	Depth.
Pleistocene, Carboniferous, and Devonian (505 feet thick; top, 868 feet above sea level):	*Feet.*	*Feet.*
Clay	300	300
Shale	205	505
Silurian (Niagara dolomite, 245 feet thick; top, 363 feet above sea level):		
Limestone	245	750
Ordovician:		
Maquoketa shale (250 feet thick; 118 feet above sea level)—		
Shale	250	1,000
Galena and Platteville limestone (300 feet thick; top, 132 feet below sea level)—		
Limestone	300	1,300
St. Peter sandstone (100 feet thick; top, 432 feet below sea level)—		
Sandstone	100	1,400
Prairie du Chien group (370 feet thick; top, 532 feet below sea level)—		
Sandy limestone	370	1,770
Cambrian:		
Jordan sandstone (100 feet thick; top, 902 feet below sea level)—		
Sandstone	100	1,870
St. Lawrence formation (230 feet thick; top, 1,002 feet below sea level)—		
Limestone	230	2,100
Dresbach sandstone and earlier Cambrian strata (124 feet penetrated; top, 1,232 feet below sea level)—		
Sandstone (penetrated)	124	2,224

Record of strata in well at Homestead.

	Depth in feet.
Shale, greenish yellow; many siliceous pebbles	275
Shale, yellow; numerous small brick-red ocher nodules; ferruginous, arenaceous; practically noncalcareous	285
Shale, light greenish gray, fissile, slightly calcareous; some red ocherous nodules and a few fragments of limestone, chert, quartz, and dark shales	475
Limestone and shale, light blue-gray; chips of light-gray compact limestone of earthy luster and highly argillaceous; in highly calcareous concreted powder	500
Dolomite, blue-gray, vesicular; in small chips	600
Dolomite; in white powder	750
Shale, greenish	805
Sand and gravel, superficial and recent	970
Limestone, drab; in thin flakes; earthy, fossiliferous	1,010
Shale	1,030
Shale, calcareous	1,250
Sandstone, fine, white	1,345
Sandstone, calciferous; chiefly quartz sand with considerable dolomite and chert	1,475
Sandstone, cream-yellow; coarser than at 1,345 feet; grains mostly rounded	1,800
Sandstone; very fine, white angular quartz sand; considerable dolomite and chert	1,825
Sandstone; in white powder of microscopic quartz	1,850
Dolomite, gray	2,025
Sandstone, red, highly calciferous; argillaceous and calcareous "from 2,100 to 2,200"	2,200

The wells at Homestead and Amana are less than 4 miles apart, but their records are greatly inconsistent. The summit of the Maquoketa in one is at 180 feet above sea level and in the other at 118 feet above sea level; the summit of the first sandstone in one is 290 feet below sea level and in the other is 432 feet below sea level. The record of the Homestead well, inexact as it may be, is used in the geologic section from Davenport to Des Moines.

Marengo.—The public supply of Marengo (population, 1,786) is derived from a well located in the valley and sunk through sand and clay into a bed of gravel lying at a depth of 35 feet. The well is 18 feet in diameter and is cased with brick. Water stands 2 to 12 feet below the surface, according to the season, and it is reported that when this level is lowered 6 feet by pumping water flows into the well at the rate of 350 gallons per minute. The analysis (p. 158) indicates that the water is only moderately hard and is relatively good for boiler use. Before the present well was dug, a system of driven sand points was used but was not satisfactory because of the clogging of the strainers.

The water is lifted into a tank elevated upon a tower and is thence distributed by gravity through a system of mains. It is used by about half of the people and by the Chicago, Rock Island & Pacific Railway, approximately 65,000 gallons being consumed in an average day.

Forecasts for artesian water at Marengo have special interest because of the difficulty usually experienced in getting good water from the shale of the Kinderhook (Mississippian), which forms the country rock in the vicinity.

After penetrating this shale the drill will enter the Devonian rocks, which also may be expected to contain considerable shale. Below these lie the Silurian dolomite (Niagara), which probably contains some water under a high head but not sufficient to reach the curb. The Silurian here may include the Salina (?) formation, which contains some gypsum or anhydrite, either disseminated or in layers or lenses, and the water from this formation may be rather highly sulphated. The dry Maquoketa shale should be next reached at a depth of about 638 feet (about 100 feet above sea level) and may be 250 feet thick. The next formations in descending order, the Galena limestone, Decorah shale, and Platteville limestone, will yield some water, which may contain sulphureted hydrogen. The St. Peter sandstone lies about 450 feet below sea level (about 1,200 feet from the surface). Drilling should not be stopped at the St. Peter, however, but should be carried a few hundred feet deeper, through the Prairie du Chien group—creviced dolomites with sandy layers—and through the water-bearing Jordan sandstone.

The water from the Jordan may be expected to flow with a pressure of about 10 pounds. The well should not be sunk deeper than 1,800 feet except under the advice of a competent geologist who has examined a full set of drillings from the well and to whom all the facts as to the water found have been submitted.

The quality of the water will depend in part on how effectively the upper waters—those of the Kinderhook and possibly the Silurian—have been cased out. Analyses should be made of all flows so that deleterious waters may be shut off and good waters with high heads admitted. With due precautions a fair drinking water should be obtained.

Victor.—Victor (population, 640), situated on the banks of Big Creek, has a system of waterworks that is supplied from an open shallow well.

Williamsburg.—The waterworks at Williamsburg (population, 1,060) are supplied from two wells at separate pumping stations—one in the valley of Old Man Creek and the other recently drilled on somewhat higher ground. The old well is 8 inches in diameter and 110 feet deep, and ends with a 20-foot screen in a bed of sand below blue clay, the water rising to about 45 feet from the surface. The new well is also 8 inches in diameter and ends with a long screen in what is apparently the same bed of sand. Starting from higher ground, it goes to a total depth of 145 feet with the water remaining at about 85 feet below the surface. With the cylinder at a depth of 128 feet, the well is reported to have been tested at 200 gallons a minute and is usually pumped at about 100 gallons. The water, as shown by analysis (p. 158), is only moderately mineralized. The water is stored in two compression chambers on relatively high ground and the pressure is supplied in part by gravity and in part by compressed air. The mains have a total length of about 2 miles and there are 24 fire hydrants and approximately 175 points at which the water is used. A large portion of the inhabitants are supplied and an average of 20,000 gallons are consumed daily.

The railway supply is obtained from a well which is similar to the two village wells and which has been tested at 250 gallons a minute.

JACKSON COUNTY.

By W. H. Norton.

TOPOGRAPHY.

The larger part of the upland of Jackson County has been carved by running water to high complex ridges whose rounded crests and gently sloping flanks descend to deep and in many places rock-walled valleys. The topography is that of the driftless area. The earlier invasions of the glacial ice probably covered nearly the entire county, the northeast corner alone being excepted; but the thinner deposit of the earlier ice sheets only slightly modified the preexisting relief, and the thicker ones were afterwards sculptured to much the same form. The thorough dissection of the area is due not only to the length of time in which it has been exposed to weather and running water, but also to its differences in elevation. In the northeastern part of the county the surface stands nearly 1,200 feet above sea level, and at Sabula, in the southeast corner, is only 603 feet above the sea.

The lower and more level lands include a small area in Butler Township referred to the Iowan drift, one of the same general character extending from Monmouth to Maquoketa and thence into Clinton County, together with the forested or grassy flood plains of the Mississippi and the wide valley floors developed in the weak Maquoketa shale by the broad ancient temporary channel of the Mississippi from Green Island to Spragueville and thence south to the county line.

GEOLOGY.

The drift commonly exposed to view is the Kansan, a stony clay, reddish where weathered but blue-gray originally and where unaffected by weathering. Over all the uplands of the area, except in a small tract in Butler Township allotted to the Iowan drift, is spread the loess, a yellow dust or silt reaching a maximum thickness of 25 or 30 feet.

The formations immediately underlying the drift in Jackson County comprise the Niagara dolomite, the Maquoketa shale, and the Galena dolomite. (See Pl. IX, p. 354; Pl. X, p. 374.)

The Niagara is a hard dolomite, which, except on some small areas underlain by the Maquoketa, forms the bedrock on which the surface materials are spread over all the uplands of the county.

The Maquoketa comprises a blue plastic shale, 150 feet thick, reached by the drill in different portions of the county and at once recognized by its clayey nature and by the fact that it immediately underlies the limestone which forms the country rock of the uplands and is the first shale to be reached by the drill. The Maquoketa forms the bedrock of the valleys of the creeks tributary to the Mississippi and of an area of several square miles about Preston.

The Galena, a hard dolomitic limestone, cut by the drill into sharp glistening yellow sand, is exposed at Bellevue near water level in the Mississippi (its southernmost outcrop) and forms conspicuous bluffs in the northeast townships of the county.

UNDERGROUND WATER.

SOURCE.

The available water beds of Jackson County are chiefly in the indurated rocks. Drift deposits, such as those at the base of the loess, and the gravels interbedded with stony clay or overlying rock, have generally been left dry, or at least inadequate for stock wells, by the gradual lowering of the ground water. In localities where 30 years ago water for domestic purposes could be obtained by wells 100 feet deep it is now necessary to drill to 150 and 175 feet.

The sands of the wide flood plain of the Mississippi between Bellevue and Sabula, the smaller flood-plain areas along the Maquoketa, and an area a mile wide which extends from Green Island to Spragueville, are saturated nearly to the surface and yield water to driven wells. The ancient terraces of alluvium along Mississippi River also afford water at moderate depths.

Over the larger part of the county wells are compelled to enter rock to find permanent ground water adequate for farm or village supply. The chief water horizon is the Niagara. This dolomite, in changing from its original form of a nonmagnesian limestone, became vesicular and porous, so that water seeps slowly through it, especially in certain layers. Moreover, percolating water has dissolved out passageways in the soluble rock, thus securing an active circulation. Furthermore, the Niagara is underlain by an impervious shale bed, the Maquoketa, which by arresting the descent of ground water tends to keep the lower portions of the limestone saturated. For this reason water is often found some distance above the summit of the shale. It occurs in porous granular beds cut by the drill to sharp shining fragments the size of sand, thus giving the false impression that the drill is working in sandstone. The layers of limestone interbedded with thin layers of chert or flint which occur near the base of the Niagara are generally water bearing. Abundant supplies may be obtained when the drill happens to strike a crevice or other opened passageway of ground water.

DISTRIBUTION.

Two areas in which water occurs in the drift are of special interest inasmuch as they mark river channels long since abandoned by the streams which formed them.

Goose Lake channel, carved and in part filled by the diverted Mississippi, crosses the southwestern part of Van Buren Township, passing thence into Clinton County. A well in the SW. ¼ sec. 32 of Van Buren Township, probably representative of much of the area, has the following log:

Log of well in Van Buren Township.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil, black	10	10
Clay, blue, hard and gritty; old forest bed at 30 feet	30	40
Quicksand	40	80
Gravel	10	90

A well in Preston, on the same lowland, shows the following sequence:

Log of well at Preston.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil, dark	10	10
Soft yellow "stuff"	15	25
Clay, blue, gritty; 5-foot streak of yellow "stuff"	90	115
Gravel	10	125

On the other hand, a well sunk by the town of Preston to a depth of 140 feet on the same ancient channel is reported to have been entirely in sand and gravel. A well at the stockyards at Preston ends in sand and gravel at 128 feet.

A second ancient channel forms a plain 1 to 2 miles wide, utilized by the tracks of the Chicago & North Western Railway from Monmouth to Maquoketa, and extending southward from the latter city. To the west it ends abruptly a short distance from Monmouth, where Bear Creek descends to it through a rock-walled gorge. An investigation of the wells of the vicinity has not disclosed any westward extension of the buried channel into Jones County. At Monmouth, on the south side of the town, wells reach rock within about 70 feet of the surface (670 feet above sea level) and find their supply in the upper 8 or 10 feet of porous and water-logged limestone, the head being sufficient to bring the water within 10 feet of the surface. But on the north side of town few wells exceed 50 feet in depth and they reach rock from 2 to 25 feet from the surface.

On the plain between Monmouth and Baldwin some wells about 60 feet deep end in gravel, and the rock floor is found at 40 feet from the surface. At Baldwin the rock floor is about 650 feet above sea level, wells near the Chicago & North Western Railway station entering it at 90 feet. In the NW. ¼ sec. 25, Monmouth Township, a well is reported as 225 feet deep, reaching rock at 200 feet, but one-fourth mile farther west rock outcrops 75 feet higher than the well curb. In sec. 29, South Fork Township, a well 240 feet deep ends in gravel, the drill having passed through blue clay and quicksand; the rock floor here lies below 520 feet above sea level. On the section south of that just mentioned the preglacial valley is partly covered with heavy drift cut into hills rising to more than 100 feet above the plain. Here wells go more than 200 feet—one goes to 240 feet—without entering rock, the rock floor of the ancient valley being here below 580 feet above sea. Water is obtained in gravels overlain by quicksand 40 feet thick, the whole being buried beneath 200 feet of till. In secs. 33 and 35 wells on this plain 90 and 120 feet in depth end in gravel, the rock floor here not rising above 610 feet above sea. In the southeastern part of the township the rock beneath the plain lies much nearer the surface; wells are known to reach it at 20 and 40 feet, finding water in the underlying limestone within 80 feet of the surface.

At Maquoketa, on the eastern border of this plain, the depth to water and the elevation of the rock surface are both variable. Rock outcrops near the station of the Chicago & North Western Railway and comes within 6 feet of the surface at the station of the Chicago, Milwaukee & St. Paul Railway. Six rods west of the last-named station, however, the drill finds rock more than 80 feet below the plain, and southwest of the station does not reach it for nearly 100 feet. In the southwestern part of the town there are wells 140 feet deep which fail to reach rock, whose surface must here lie below 600 feet above sea. The succession of deposits here is as follows:

Section at Maquoketa.

	Feet.
Clay, yellow, at surface	20
Clay, soft, blue, gritless	25
Quicksand, blue	100

The quicksand, which is found in many wells in town, is water bearing, but as it is too fine to afford footing for the casing the wells are continued to gravel or to rock and the sand cased out. How sharp are the descents to this narrow buried valley may be seen from the fact that rock is found at 40 feet on the next street west from the one on which wells go 140 feet without finding rock. On the hill east of the high school a well 84 feet deep penetrated blue clay nearly to the bottom of the well without entering rock, but within one block rock was found 50 feet below the surface and water in the Niagara dolomite 120 feet below.

The depth of wells in the Niagara varies greatly. Wells located in ancient rock-cut valleys obviously need to go a shorter distance to reach the base of the Niagara than wells on the summits or sides of hills. The height of the hills is in many places accentuated by deposits of drift and loess, and the depth of wells therefore depends in part on the thickness of these surface clays. With the dip of the strata to the southwest the Niagara thickens and may reach 250 feet or more in Monmouth Township. It thins to the north and east, and in Tete de Mort Township overlooks the valleys in steep cliffs 40 to 60 feet in height. An upfold of the strata which extends from Sabula northwest for 20 miles, together with subsequent denudation, has thinned the Niagara and brought the Maquoketa shale nearer to the surface over a considerable area in the southeastern part of the county, thus reducing the depth of ordinary wells. In southern Van Buren and Fairfield townships the Niagara has been widely removed by erosion and the Maquoketa forms the country rock. Fortunately the deep valleys excavated in the weak shales in preglacial time have been deeply filled with drift in which water is usually found so that it is not necessary for wells to enter the dry shales. In general, wells supplied from the Niagara horizons range in depth from less than 100 feet to 230 or 260 feet.

The Maquoketa almost everywhere consists of dry shales, and where water is not found above it the driller must choose between abandoning the drill hole for one in another location or continuing the drilling with the definite expectation of having to pass through the entire body of shale before finding water at a greater or less depth in the Galena dolomite. Inasmuch as the limestones of the middle Maquoketa found in counties lying farther north are absent in Jackson County, there need be no expectation of finding water before reaching the base of the Maquoketa.

As examples of the depths needed to get water if it is not found above the Maquoketa shale three wells situated not far west of the Niagara escarpment near Sabula may be cited. One of these (sec. 24, Union Township) gives the following section:

Section of well in Union Township.

Formation.	Thickness.	Depth.
	Feet.	*Feet.*
Drift	40	40
Niagara dolomite	154	194
Maquoketa shale	120	314
Galena dolomite	30	344

Another well, on the farm of L. P. Hunderad, in sec. 35, Iowa Township, is reported as 450 feet in depth; and a third well, in sec. 34, same township, is said to reach a depth of more than 500 feet, the Maquoketa shale being entered at 150 feet.

In the valleys of Tete de Mort, Spruce, and Mill creeks, excavated in the Maquoketa shale, wells find water in the Galena dolomite within moderate distances from the surface.

SPRINGS.

Large springs are numerous along the bluffs bordering the Mississippi and the sides of the valleys of its tributaries at the summit of the Maquoketa shale. Transitional upper impure limestones of the Maquoketa, 20 to 30 feet thick, and the massive Niagara dolomite serve as a reservoir whose floor is the impervious shale beneath. As examples may be mentioned the springs of George Egan (SE. ¼ SE. ¼ sec. 15, T. 86 N., R. 4 E.), of Nicholas Leg (SW. ¼ SW. ¼ sec. 16), of Peter Schreiner and of John Wagner (NW. ¼ NW. ¼ sec. 29), all on Little Mill Creek west of Bellevue. Some of these springs flow a rippling stream 2 feet wide and 3 or 4 inches deep of crystalline clear water. They emerge from talus slopes at the base of the bluffs, about 30 feet below the massive ledges of Niagara dolomite or from near the base of the yellowish, thin, layered beds which form the transition between the Niagara and the Maquoketa. The August temperature of these springs is 50° F. As the valley floor rises above the base of the Niagara up valley the series of springs comes to an end, the last one noted being that of Peter Wagner (NW. ¼ NE. ¼ sec. 29, T. 86 N., R. 4 E.). The same description applies to the large springs on Mill Creek up Paradise Valley, the largest being on the farm of L. R. Potter (NW. ¼ SW. ¼ sec. 10) and that of Anton Earnst (SW. ¼ SW. ¼ sec. 6).

The springs issuing along the upper reaches of Tete de Mort Creek in secs. 4, 9, and 16, T. 87 N., R. 3 E., have given name to the civil township of Prairie Spring. They emerge low down along the bluffs somewhat above the summit of the Maquoketa shale.

In eastern Jackson Township in all the valleys which transect the summit of the Maquoketa shale, springs almost universally take the place of wells. Each farm has its spring house for dairy purposes, and the supply is usually ample for all uses of home and farm.

CITY AND VILLAGE SUPPLIES.

Bellevue.—At Bellevue the base of the Maquoketa shale is 617 feet above sea level, and a deep well will pass through about 350 feet of Galena dolomite, Decorah shale, and Platteville limestone before reaching the St. Peter sandstone. Water from the dolomite and limestone will probably flow, but in insufficient quantity. The St. Peter should afford water in moderate quantity, but it is recommended that the drill should probe also the lower-lying creviced and sandy dolomites and sandstones, all water bearing, to a depth of 850 to 950 feet from the surface. This will give a flow of the purest water beyond all present needs of the town under a pressure at first adequate for fire protection. The well should be situated some rods back from the river front so as to avoid the old channel of the river filled deeply with alluvial sands and gravel and so as to encounter within a few feet the Galena dolomite. As the town is situated on a sand-covered rock bench, the well should be so located and so carefully cased as to reduce the danger of surface contamination to a minimum.

Green Island.—At Green Island (population, 128) water is obtained from drilled wells, 30 to 75 feet deep, entering rock at 30 feet, and from small springs.

The Chicago, Milwaukee & St. Paul Railway Co. has a well 823 feet deep, 8 to $4\frac{3}{4}$ inches in diameter, cased with 8-inch pipe to 140 feet, and with 6-inch pipe put down in 1906 (four years after the well was completed) to 180 feet from the curb and packed with rubber. The curb is 601 feet above sea level, and the head is 64.5 feet above the curb. Water was obtained from 60 feet and from 504 to 564 feet. The strata penetrated are indicated by the following table:

Record of strata of railway well at Green Island (Pl. X, p. 374).

[Based on drillers' log.]

	Thickness.	Depth.
Ordovician:		
Maquoketa shale (140 feet thick; top, 601 feet above sea level)—	*Feet.*	*Feet.*
Clay, blue, and shale	140	140
Galena dolomite to Platteville limestone (335 feet thick; top, 461 feet above sea level)—		
Limerock	310	450
Rock, gray	25	475
St. Peter sandstone (106 feet thick; top, 126 feet above sea level)—		
Sandrock	25	500
Shale	4	504
Sandrock	77	581
Prairie du Chien group (242 feet penetrated; top, 20 feet above sea level)—		
Rock, gray	25	606
Shale	2	608
Sandrock	28	636
Shale	5	641
Rock, gritty, hard	20	661
Shale, blue	5	666
Rock, gray	45	711
Shale	5	716
Sandrock	25	741
Rock, flinty	20	761
Shale	4	765
Sand and gravel	11	776
Shale	5	781
Limestone, shaly	42	823

La Motte.—The waterworks at La Motte (population, 288), used chiefly for fire protection, comprise a well, a standpipe, mains extending for five blocks, and five fire hydrants. Drilled wells, in depth from 75 to 100 feet, with some as deep as 190 feet, entering rock at about 40 feet, furnish the domestic supply.

Maquoketa.—Maquoketa (population, 3,570) takes its water from a well and from Maquoketa River. The water is pumped to a standpipe and is distributed under a domestic pressure of 70 pounds and a fire pressure of 125 pounds. There are 13 miles of mains and 102 fire hydrants. Drilled wells 100 to 160 feet deep are largely used for domestic supply.

The possibility of obtaining water from deep wells at Maquoketa is indicated by the record of a prospect hole for oil put down by the Texas Drilling Co. in 1907 to a depth of 1,716 feet in the SW. ¼ sec. 11, T. 82 N., R. 3 E. (See Pls. IX, X.) The mouth of the hole is about 760 feet above sea level; 10-inch casing was carried to a depth of 277 feet, and 8¼-inch casing to 1,103 feet. Water was struck in the Niagara dolomite at a depth of 155 to 215 feet, heading 85 feet below curb; at 215 feet, in the base of the Niagara; at 486 to 695 feet, in the Galena dolomite; at 1,110 to 1,190 feet, in the Jordan sandstone; at 1,338 to 1,596 feet and at 1,695 and 1,716, in the Dresbach and underlying sandstones. At 1,716 the water overflowed while the drill was in the well.

Record of strata in prospect hole at Maquoketa (Pl. IX, p. 354; Pl. X, p. 374).

	Thickness.	Depth.
	Feet.	*Feet.*
Residual and recent (6 feet thick):		
Soil	1½	1½
Clay hard yellow	4½	6
Silurian:		
Niagara dolomite (209 feet thick; top, 754 feet above sea level)—		
Dolomite	209	215
Ordovician:		
Maquoketa shale (225 feet thick; top, 545 feet above sea level)—		
"Sand and shale in seam, second water"	¼	215¼
Shale light blue; and limestone blue-gray hard, close textured; slight effervescence	63¾	279
Shale blue	151	430
Shale chocolate brown, fissile; rather hard; petroliferous, burning with strong flame	10	440
Galena dolomite (255 feet thick; top, 320 feet above sea level)—		
Dolomite, porous, subcrystalline, gray; in log called "hard white shale"	46	486
Dolomite, light buff, crystalline; in log, "mixed lime and shale hard"	79	565
Dolomite, light buff, cherty; in angular sand	130	695
Decorah shale (15 feet thick; top, 65 feet above sea level)—		
Shale, bright green, fissile, fossiliferous; with dark-gray, fossiliferous, nonmagnesian pyritiferous limestone; log—"slate and shale"	15	710
Platteville limestone (46 feet thick; top, 50 feet above sea level)—		
Limestone, gray, earthy, compact, nonmagnesian	5	715
Limestone, brown, nonmagnesian, hard; in flaky chips	7	722
Limestone, light gray, soft, earthy	28	750
Shale, blue, plastic, with some chips of brown limestone; in log "slate soft, blue" (Glenwood shale of Iowa State Survey)	6	756
St. Peter sandstone (59 feet thick; top, 4 feet above sea level)—		
Sandstone, clean, white; grains well rounded, moderately coarse, many having diameter of 1 millimeter or more	59	815
Beds between St. Peter sandstone and Oneota dolomite (241 feet thick; top, 55 feet below sea level)—		
Sandstone, fine, brick-red; considerable red argillaceous or ferric admixture; when washed in hot water, drillings remain pink owing to films of ferric oxide on grains of quartz sand; grains rounded, many broken; said by driller to contain seams of red shale; in log "red sandstone"	241	1,056

Record of strata in prospect hole at Maquoketa—Continued.

	Thickness.	Depth.
Ordovician—Continued.		
Oneota dolomite (54 feet thick; top, 296 feet below sea level)—		
Dolomite, light yellow-gray; with much dark-red and dark-brown hard fine-grained shale, some light-green shale, a fine yellow quartz sand, a fragment of red fine-grained sandstone set with pieces of green shale; all except dolomite probably foreign, at 1,056	*Feet.* 54	*Feet.* 1,110
"Shale, soft gray;" of log; sample supposed to represent this stratum consists of sand grains of St. Peter facies, but with an occasional grain showing secondary enlargement; rather fine, with considerable foreign red and light-green shale and some chert and chips of dolomite		
Cambrian:		
Jordan sandstone (80 feet thick)—		
"Sandstone, soft water;" of log; sample said to represent this stratum consists for the most part of angular sand of light-gray dolomite with some arenaceous admixture; a sample at 1,125 feet is of sandstone, some grains showing secondary enlargements, along with some chert and dolomite	80	1,190
St. Lawrence formation (198 feet thick; top, 430 feet below sea level)—		
Dolomite, light yellow-gray	110	1,300
Dolomite, purple-brown	20	1,320
Dolomite, light-gray	68	1,388
Dresbach sandstone (208 feet thick; top, 628 feet below sea level)—		
Sandstone, soft, white; grains well rounded, fairly uniform in size, largest 1 millimeter in diameter	208	1,596
Undifferentiated Cambrian strata (120 feet penetrated; top, 836 feet below sea level)—		
Sandstone; in buff sand with the appearance of dolomite to unaided eye, but seen under the microscope to consist of microscopic grains of crystalline quartz with dolomitic cement, along with some fine rounded grains of quartz sand and some glauconite at	....	1,596
Sandstone as above, with some gray shale	54	1,650
Sandstone of same composition as above; white	45	1,695
Sandstone, fine grained, light buff; in minute detached grains and in angular chips as above	5	1,700
Sandstone, white, clean, fine; grains imperfectly rounded, most grains from 0.0075 to 0.01 inch in diameter; "quicksand" of log	16	1,716

At Maquoketa the drill will probably pass through the country rock (Niagara dolomite) and discover the Maquoketa shale 184 feet below the surface (about 500 feet above sea level). Some water will probably be found in the Niagara and also in the dolomite beds generally present in the Maquoketa in this part of Iowa. About 200 feet deeper the drill will enter the Galena dolomite, passing thence into the Decorah shale and the limestones and shales forming the Platteville limestone, and the yield should be augmented from these horizons. The St. Peter sandstone should be reached about 35 feet below sea level, or about 720 feet below the surface at the Chicago & North Western Railway station.

For industrial enterprises, hotels, liveries, etc., the yield from these beds should be ample, but for a city supply the wells should be sunk about 1,200 feet, or to 500 feet below sea level, so as to secure the full yield of the Prairie du Chien group and the Jordan sandstone, and may indeed profitably go to 800 or 850 feet below sea level to tap the Dresbach sandstone. The limit of 1,500 or 1,600 feet from the surface need not be exceeded, as at about this depth the drill should pass into close-grained dry sandstones or marls underlying the Dresbach.

A flowing well with a head of about 20 feet is indicated, but is not assured, and to secure the best results the yield should be increased by the use, sooner or later, of deep cylinder pumps or air compressors.

Miles.—At Miles (population, 334) water is obtained from drilled wells ranging in depth from 50 to 90 feet and entering rock at 12 feet.

Monmouth.—At Monmouth (population, 221) wells, dug and drilled, range in depth from 16 to 100 feet. These wells reach rock 25 feet below the surface. Water stands 10 to 20 feet below the curb.

Nashville.—At Nashville wells are 40 to 50 feet deep, and the water level is 20 to 30 feet below the curb.

Preston.—At Preston (population, 642) the water-supply system is owned by a private corporation. Water is obtained from a well 108 feet deep and 6 inches in diameter, entering rock at 100 feet, and yielding from a vein in rock 75 gallons a minute. The well is located on a hill 90 feet above the level of the business street, and the water heads 60 to 80 feet below the curb.

Water is distributed from a tank with a capacity of 70,000 gallons under a domestic pressure of 50 pounds. The fire pressure is 75 pounds. There are 1½ miles of mains, 10 fire hydrants, and 150 taps. The consumption is 30,000 gallons daily.

Sabula.—The water supply of Sabula (population, 918) is drawn from one of the finest artesian wells in the State. (See Pl. IX.) The water is pumped directly through 3 miles of mains under a domestic pressure of 28 pounds, and 50 pounds for fires. There are 28 fire hydrants and about 400 taps.

This well is 973 feet deep, 8 to 6 inches in diameter, and is cased to 173 feet (rubber packer). The curb is 582 feet above sea level. The original head was 74 feet above curb; in 1905 it was 41 feet above curb. The original flow was 720 gallons a minute. Water was obtained at 400 feet (St. Peter sandstone), at 525 feet, and at 700 feet (Prairie du Chien group); total discharge at this depth, 350 gallons a minute; the strongest vein was struck at 950 feet (Cambrian). Temperature, 59° F. Drilling was completed in 1895 by J. P. Miller & Co., of Chicago.

With the original pressure of 32 pounds, the well furnished fire protection, as well as a superabundant water supply. With the diminution of pressure to 18 pounds, about 1904, it was found necessary to install a 32-horsepower gasoline engine and triplex pump, which are used only in case of fire. In 1908 the pumping capacity was reported at 500 to 600 gallons a minute.

Record of strata in city well at Sabula (Pl. IX, p. 354).

	Thickness.	Depth.
	Feet.	*Feet.*
Quaternary (163 feet thick; top, 582 feet above sea level):		
Sand, alluvial; in ancient channel of Mississippi River	163	163
Ordovician:		
Galena dolomite to Platteville limestone (262 feet thick; top, 419 feet above sea level)—		
Dolomite, hard, rough, crystalline, buff and gray; some vesicular; 10 samples	212	375
Sandstone, argillo-calcareous; drillings consist of light green-gray powder, with fragments of dark-gray sandstone; calciferous; grains not so well rounded and uniform in size as is common with the St. Peter	25	400
Shale, green, fissile, arenaceous, slightly calcareous	25	425
St. Peter sandstone (25 feet thick; top, 157 feet above sea level)—		
Sandstone, grains moderately fine, rounded, and ground; a large proportion of drillings consists of angular chips of gray dolomite; much green shale, probably from the superior shale	25	450
Prairie du Chien group (325 feet thick; top, 132 feet above sea level)—		
Shakopee dolomite:		
Dolomite, medium dark gray; in angular fragments, clean except for a few pieces of green shale	15	465
Dolomite, highly arenaceous; drillings consist of rounded grains of quartz and minute angular fragments of dolomite, in some of the larger of which quartz sand is embedded	10	475
Dolomite, gray and light brown; drillings contain sand, probably from above; 2 samples	35	510
Dolomite, light brown, arenaceous	15	525
Dolomite, gray and buff; 3 samples	50	575
New Richmond sandstone:		
Sandstone, argillaceous and calciferous	25	600
Oneota dolomite:		
Chert; in fine white powder, calciferous; 2 samples	50	650
Dolomite, gray, cherty	90	740
Dolomite, white, highly arenaceous, and cherty	10	750
Dolomite, white, cherty, slightly arenaceous	25	775
Cambrian:		
Jordan sandstone and underlying Cambrian (198 feet penetrated; top, 193 feet below sea level)—		
Sandstone; white, calciferous, cherty; grains of sand, mostly fragmental, but many rounded; 3 samples	35	810
Unknown, cuttings washed away; reported by drillers to be no change	163	973

WELL DATA.

Information concerning typical wells in Jackson County is presented in the following table:

Typical wells in Jackson County.

Owner.	Location.	Depth.	Depth to rock.	Depth to water-bed.	Source of supply.	Head below curb.	Remarks (logs given in feet).
T. 84 N., R. 1 E. (MONMOUTH).							
		Feet.	*Feet.*	*Feet.*		*Feet.*	
T. Volker	NW. ¼ NE. ¼ sec. 20.	68	58			10	Red sand and gravel on rock.
J. H. Sokol	NW. ¼ NW. ¼ sec. 21.	48			Gravel		Bear Creek; ends in gravel.
	NW. ¼ NE. ¼ sec. 21.	120	40		Limestone		Loess, 20; yellow till, 20; Niagara dolomite, 80.
—— Brown	NW. ¼ sec. 2	202	65	200	...do	192	Clay to rock.
	Sec. 7	173	65		...do		High ground. Flint from 153 feet to bottom.
	NW. ¼ SE. ¼ sec. 19.	42			Sand		Low ground Black soil, 8; blue clay, 31; sand, 3.
John Wood	NE. ¼ NE. ¼ sec. 30.	151	63		Limestone		High ground.

Typical wells in Jackson County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Depth to water-bed.	Source of supply.	Head below curb.	Remarks (logs given in feet).
T. 84 N., R. 1 E. (MONMOUTH)—Con.							
		Feet.	*Feet.*	*Feet.*		*Feet.*	
....	SE. ¼ sec. 2	194	32	....	....	162	Bluff; water in porous rock.
....	NW. ¼ NW. ¼ sec. 32.	281	20	....	....	251	Upland.
—— Teeple	Sec. 34	128	60	....	....	....	
Amanda Littell	NW. ¼ sec. 25	228	....	200	Gravel	20	Valley.
Charles Long	Sec. 31	270	Slight.	....	Niagara dolomite.	....	Maquoketa shale at 240 feet.
Schoolhouse	Baldwin	126	60	....	...do	....	Hill.
....	Near railway station, Baldwin.	96	90	....	....	26	Bear Creek bottoms.
—— Wright	Nashville	53	....	....	Gravel	....	All sand and gravel.
....	Millrock	102	10	....	....	....	Rise above creek bottoms.
....	SW. ¼ sec. 23	73	50	....	....	....	Creek bottoms, 60 rods from creek.
Will Campbell	SW. ¼ NW. ¼ sec. 12.	71	50	....	....	41	Hollow; mostly yellow clay to rock.
W. T. Clapp	NE. ¼ NE. ¼ sec. 28.	96	90	....	....	....	Soil 10; black quicksand, 80.
—— Graywich	NE. ¼ SW. ¼ sec. 28.	60	3	....	....	....	Creek.
—— Walker	SW. ¼ SE. ¼ sec. 29.	240	....	....	Gravel	....	Bottom. Blue clay and quicksand; ends in gravel.
T. 85 N., R. 1 E. (BRANDON).							
William Miller	SE. ¼ SW. ¼ sec. 31.	69	61	....	....	....	Valley. Black soil, 10; fine white sand, 51.
T. 86 N., R. 1 E. (BUTLER).							
....	NE. ¼ NE. ¼ sec. 32.	244	53	....	Porous limestone.	211	Bluff. Gravelly red clay (till), 53; limestone, 191.
D. Duggan	Sec. 26	217	22	....	....	....	Loess, 2; till, 10; gravel 10 to rock.
T. 84 N., R. 2 E. (SOUTH FORK).							
H. B. Griffen	SE. ¼ SW. ¼ sec. 30.	124	40	120	Niagara dolomite.	78	High hill.
W. G. Marster	S. ½ NW. ¼ sec. 13.	135	....	....	....	....	East side of deep ravine; rock at surface.
D. Stevens	NE. ¼ NE. ¼ sec. 31.	76	6	....	....	....	Ridge.
—— Heming	Maquoketa, west side.	135	50	....	....	....	Sand and sandy clay, 50 feet; limestone, 85 feet.
....	SW. ¼ SE. ¼ sec. 32.	240	....	....	Gravel	....	Drift, mostly blue till, 200; quicksand, 40; ends in gravel.
....	SW. ¼ SW. ¼ sec. 32.	206	....	....	...do	....	Ends in gravel.
Richard Elwood	SE. ¼ NE. ¼ sec. 33.	120	....	....	...do	....	Ends in gravel.
W. P. Dunlap	SE. ¼ SE. ¼ sec. 35.	90	....	....	...do	....	Blue till, 82; gravel, 7; blue till, 1.
—— Chapman	SE. ¼ SE. ¼ sec. 35.	85	40	....	....	....	Level land.
....	NE. ¼ SE. ¼ sec. 36.	82	37	....	....	....	
....	NW. ¼ NW. ¼ sec. 36.	36	20	....	....	....	
—— Wilson	Sec. 11	138	80	....	....	....	

Typical wells in Jackson County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Depth to water-bed.	Source of supply.	Head below curb.	Remarks (logs given in feet).
T. 84 N., R. 5 E. (VAN BUREN).		*Feet.*	*Feet.*	*Feet.*		*Feet.*	
—— Knack	SW. ¼ NW. ¼ sec. 25.	100	10		On shale		
Peter Kuhl	NE. ¼ NE. ¼ sec. 12.	190	40				Drift, 40; Niagara dolomite 85; Niagara dolomite, gray cherty, 60; Maquoketa shale, 5.
—— Van Buren	Center of sec. 15.	75	(a)				
—— Prussia	S. ½ NW. ¼ sec. 14.	225	30			125	Drift, 30 feet; Niagara dolomite, 195 feet.
H. Gosh	SW. ¼ SW. ¼ sec. 4.	175	20		Limestone		Maquoketa shale not struck.
—— Klemm	NE. ¼ SW. ¼ sec. 35.	175	40				Maquoketa shale at 170 feet.
—— Roe	NE. ¼ SE. ¼ sec. 16.	170	40		On shale		Maquoketa shale at 170 feet.
	SW. ¼ SE. ¼ sec. 15.	125	40			(b)	Stony blue clay, 40; Niagara dolomite, 85.
	NW. ¼ SW. ¼ sec. 16.	202	40		Limestone		Yellow clay, 20; blue clay, 20; limestone, 162.
E. A. Clausen	Sec. 2	230	36				Drift, 36; Niagara dolomite to shale at bottom, 194.
T. 85 N., R. 5 E. (PART OF WASHINGTON).							
Henry Schultz	NE. ¼ SW. ¼ sec. 25.	225			Gravel		Mostly gritty blue clay; ends in gravel.
	SE. ¼ SW. ¼ sec. 32.	90			...do	60	Goose Lake channel. Black soil, 10; hard, gritty blue clay, 30; quicksand, 40; gravel, 10. Old forest bed at 30.
	Green Island	200			...do		Bottoms. Soft blue clay, 50; dirty yellow clay, 20; gritty blue clay, passing into gravel, 130.
T. 84 N., R. 6 E. (IOWA).							
	NE. ¼ NE. ¼ sec. 34.	500–600			Galena dolomite.		High ridge; 150 feet to Maquoketa shale.
	NE. ¼ SW. ¼ sec. 32.	125	30		Limestone		
	SW. ¼ SW. ¼ sec. 19.	190	20		...do		
	NE. ¼ SW. ¼ sec. 24.	344	40	320	Galena limestone.		About 820 feet above sea level. Drift, 40; Niagara dolomite, 154; Maquoketa shale, 120; Galena dolomite, 30.
—— Crawford	SE. ¼ SE. ¼ sec. 23.	673	40				Yellow clay, 20; blue clay, 20; limestone, 110; shale, 222; Galena dolomite, 301.
T. 84 N., R. 4 E. (FAIRFIELD).							
	NE. ¼ NE. ¼ sec. 26.	80			Gravel		On rise from creek. Yellow clay, 25; hardpan, 50; gravel, 5.

[a] Near ground. [b] On rise from bottoms.

Typical wells in Jackson County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Depth to water-bed.	Source of supply.	Head below curb.	Remarks (logs given in feet).
T. 85 N., R. 2 E. (FARMERS CREEK).							
		Feet.	*Feet.*	*Feet.*		*Feet.*	
J. W. Sagers	SW. ¼ sec. 20	236	60	200		146	
Mrs. Rose Stoddard.	Sec. 21	90		40		30	High ground. All light blue clay. Adjacent wells are 180 to 263 feet deep, with only 25 to 30 feet of clay on rock.
Emory Dutton	Sec. 20	136	12	114	Limestone	14	
Walter Dutton	Sec. 30	240	90	150	...do	150	
Walter Hutt	Sec. 21	180	26	150	...do	150	
John S. Burrows	Sec. 20	190	36	168	...do	68	
George Willison	Sec. 18	186	28	150	...do	150	
Robert Wood	Sec. 35	217	40			102	
Schoolhouse	Sec. 34	223	100				Much quicksand.
P. W. Tracy	W. ½ sec. 35	200	75				
T. 86 N., R. 4 E. (PART OF BELLEVUE).							
H. Steich	Sec. 1	106	96		Limestone		A large amount of sand and gravel beneath loess.
—— Golden	West of city limits of Bellevue.	100	50		Limestone, Galena.		Terrace in Mill Creek valley.
T. 87 N., R. 4 E. (TETE DES MORTS).							
H. Soppe	Sec. 36	54			Gravel		Loess-capped terrace 90 feet above Mississippi.

JOHNSON COUNTY.

By A. O. THOMAS.

TOPOGRAPHY.

The surface of Johnson County is chiefly of the prairie type. Along the principal streams are belts of rather heavy native timber, much of which is being rapidly cut away.

Because of the location of the Territorial capital at Iowa City, Johnson County was one of the earliest west of those bordering Mississippi River to be settled. Its pioneers found an abundant supply of water in the main streams and their tributaries and in shallow open wells, but as population increased more reliable sources of supply, free from contamination and from possible exhaustion during times of droughts, had to be sought. Now drilled wells pumped by windmills or gasoline engines are a part of the equipment of each up-to-date farm.

Far more than half of the county is covered by Kansan drift, which is extensively overlain by loess, although in some areas along Old Mans Creek the loess is so thin that the preloessial topography may still be recognized. Except for the broad alluvial flood plain of Iowa River, which intersects it in a north and south direction, the southern half of the county is characteristically Kansan. The ridges and divides are much dissected, as a rule narrow, and in many places loess covered.

Several lobes of the Iowan drift sheet cross the northern part of the county. These lobes are characterized by bowlder-strewn fields and rich black loam which covers in a general way the entire surface of the drift. The freshness of the light-colored bowlders, the incomplete drainage, and the comparatively level surface, free from loess, present a marked contrast to the rougher and much-eroded Kansan drift. One lobe of Iowan drift crosses the eastern part of the northern boundary of the county and trends southeastwardly to Solon. Its level plains are well developed just north of that town. A second and larger lobe comes down to and a little beyond the village of North Liberty, covers Monroe and parts of Jefferson, Oxford, Madison, and Penn townships. It is crossed in an east-west direction by Iowa River whose broad flood plain blends into the drift plain on the south. The limits of these lobes are not yet definitely determined along their entire length. Their terminal moraines, though high and prominent in many places, are in others very indefinite, due to some extent to post-Iowan erosion.

A broad alluvial plain has been developed along Iowa River from the point where it enters the county to sec. 22, Madison Township where it flows into a narrow, rock-walled, tortuous channel from which it emerges near Iowa City after winding about for more than 20 miles. Here it again enters a broad valley with extensive flood plains, which continue until it has passed out of the county. A flood plain about 2 miles wide and 6 to 8 miles long extends along Cedar River in Cedar Township.

The larger tributaries of Iowa River, like Old Mans, Clear, and Rapid creeks, have developed alluvial flood plains of some extent, especially in that part of their valleys nearest the Iowa. That of Old Mans Creek is the most extensive, being 18 to 20 miles long and from half a mile to a mile or more in width.

Study of the course of Iowa River through the county shows that a preglacial channel must have existed between the east end of its northern flood plain and the north end of its southern flood plain, for the present course between these two points is neither the most direct nor the most easily constructed.[1] Well records are, however, too meager to afford data from which to project the valley of this ancient stream. It is certain that the buried channel affects the water supply of the area under which it lies, and it is to be hoped that future borings will clearly establish its approximate limits.

[1] Calvin, Samuel, Ann. Rept. Iowa Geol. Survey, vol. 7, 1897, p. 48.

GEOLOGY.

Indurated rocks are exposed only in the northern and northeastern parts of Johnson County. The rocks dip to the southwest (Pl. XV, p. 670), a fact of special interest to the well driller, for he must drill through a greater thickness of rock in the southwestern part of the county than in the northeastern part when seeking one of the deep-seated aquifers like the St. Peter sandstone. The character and kind of rocks which underlie the drift in the southern part of the county are indicated by such rock exposures as those along English River in the northern part of Washington County.

Silurian rocks (Niagara dolomite) are typically exposed along Cedar River in the northeastern part of the county. Southwest from this Silurian outcrop the lower beds of the Middle Devonian appear at Solon and elsewhere.

Rocks of Carboniferous age are exposed in only a few small outliers belonging to the Des Moines group (Pennsylvanian). The largest of these outliers is a body of coarse-grained sandstone in the southern part of Monroe Township just north of Iowa River and extending westward into Iowa County. Another is located immediately north of Iowa City and occupies an old deep pre-Carboniferous valley whose course runs at a wide angle to that of the present Iowa River valley and whose bottom is 60 feet or more below the bottom of the latter.

The drift of the southern part of the county is probably underlain by the Kinderhook group (Mississippian) of the Carboniferous. No record of well borings encountering these rocks has been obtained, but they doubtless have been reached by drillers in southern Washington and Sharon townships. Interglacial sands and gravels known as the Aftonian gravel and the Buchanan gravel are widely distributed, the former beneath the Kansan drift and the latter above the Kansan, and form aquifers of considerable importance in the county as a whole.

UNDERGROUND WATER.

SOURCE.

The exceedingly rough preglacial topography of Johnson County precludes expectation of finding extensive well-defined water-bearing formations in the drift deposits, which range in thickness in different parts of the county from an exceedingly attenuated layer to a deposit measuring 300 feet. Nevertheless, the most constant aquifer of the drift is the sand and gravel (Aftonian) underlying the stiff blue clay beds of the Kansan drift. Most of the deeper wells of the county derive their supply from this stratum, though well drillers frequently report failure to obtain water in it and are obliged to try elsewhere or to go deeper. Locally, however, the sand and gravel bed is absent and the drill passes directly from the Kansan clay to the hard rock. In the southern and southwestern townships of the county, in parts of Madison and Jefferson townships, and elsewhere in the areas covered by the Iowan drift sheet, these sands and gravels (Aftonian and Buchanan) yield a fairly abundant supply of good water to wells ranging in depths from 50 to 250 feet. In areas in which the drift is thin and the country rock lies close to the surface, most of the wells penetrate rock to some distance and obtain water either in a rock crevice or in a gritty layer which does not seem to lie at any regular horizon. The expense of sinking wells in these areas is usually greater than in the areas of deep drift and the possibility of failure is greater. The wells along Iowa River west and north of Iowa City are mainly of this type. Another area of this sort is in the vicinity of Solon, where the country rock comes almost to the surface; the town well of Solon, for example, strikes rock at a depth of 7 feet.

In the alluvial flood plains of the principal streams, an abundant supply of water is obtained cheaply by shallow dug wells curbed with cheap lumber, or by "sand points" driven into the earth to a depth of 15 to 25 feet and attached to hand pumps. "Drive wells" are abundant along Iowa River in Liberty and Lucas townships and in the valley of Clear Creek in Clear Creek Township.

In the northeast part of Lucas Township the wells average 100 feet and obtain water in the gravel above the rock.

Hundreds of shallow wells on the farms of every community, which are being slowly supplanted by deeper drilled wells, draw principally from the ground water below ground-water level, though some of them are filled by the surface run-off, for which they act as catch basins.

CITY AND VILLAGE SUPPLIES.

Coralville.—The water supply of Coralville (population, 151) is taken from shallow wells 15 to 30 feet deep.

Hills.—The water supply of Hills (population, 195) is all from shallow wells. Many of them are "driven wells" and these obviously furnish a purer supply than that of the shallow open wells.

Iowa City.—In Iowa City (population, 10,091) water for the city mains is pumped from the river to a large standpipe on an eminence in the north part of the city. River water is unfit for drinking unless it is boiled. When the city was visited the water company was installing a filter plant said to be capable of filtering all the water needed.

The homes on the west side of the river obtain satisfactory water from wells sunk into the limestone. Some of the wells are open but most of them are drilled. Many shallow wells, 20 to 50 feet deep, are still in use.

An artesian forecast[1] is of interest in view of the probability that sooner or later one or more deep wells will be drilled for artesian water for the city or for the State University.

The bedrock here is the Cedar Valley limestone (Middle Devonian). After passing through this formation the drill will enter the Wapsipinicon limestone (also Middle Devonian), which is characterized by brecciated beds, shaly and cherty layers, fine-grained and thin-bedded limestones, and magnesian limestones, which overlie the hard Silurian dolomites (Niagara). In both the Devonian and the Silurian formations water will probably be found in crevices and porous layers. If the head of these waters is higher than that of the main flows to be reached farther down, they may be allowed to enter the drill hole and thus augment that of the deeper flows; but if their head is less they should be cased out to prevent the escape of the deeper water through their channels. The drill will pass from Silurian rocks into a dry Ordovician shale, the Maquoketa, probably more than 200 feet in thickness, which should be cased to prevent caving. The Galena and Platteville limestones, which lie beneath the Maquoketa, contain large stores of water in irregular channels, crevices, or porous beds, but no assurance can be given that the drill will strike one of the waterways. The head of any inflows from these limestones should be tested and their waters analyzed for comparison with those of the main water horizons underneath.

After passing through the basal shale of the Platteville, which will need casing, the drill will enter the St. Peter sandstone at 1,000 to 1,050 feet below the surface (350 to 400 feet below sea level). A good yield is assured although exact estimates can not be made, as the sandstone varies in thickness and also to some extent in size of grains and porosity. It is not at all probable that the water obtained thus far will be sufficient to meet any large demands. The well should be drilled 500 or 600 feet deeper, or to 1,650 feet below the surface, in order to tap the large stores of water carried by the dolomites and interbedded sandstone of the Prairie du Chien group, and especially by the subjacent Jordan sandstone (Cambrian). The drill should stop at the heavy glauconiferous shales and marls of the St. Lawrence formation, the next terrane in descending order.

A flow may be confidently expected and although estimates of head are notoriously uncertain, it may be said that the head may reach 50 feet above the river.

A single well will yield a supply sufficient for such university use as a gymnasium, but for a city supply more wells should be sunk and the installation of an air compressor to increase the yield will be probably found advantageous, as at Waterloo, although the natural

[1] By W. H. Norton.

pressure of a well at Iowa City may be expected to considerably exceed that of one at Waterloo.

In choosing a location for city or university wells, the possibility of contamination from ground water through leaky or defective casings should be considered, and upvalley sites, other things being equal, should be given preference. Too much care can not be taken to exclude absolutely all soil and subsoil waters.

Lone Tree.—The town of Lone Tree (population, 782) has one of the best public water-supply systems in the county. A drilled well, 130 feet deep, penetrates, beneath deep drift, a gravel bed (possibly Aftonian) from which an abundant supply of pure water is obtained. A gasoline engine furnishes the power for pumping.

North Liberty.—The village of North Liberty (population, 200) has no public water supply. The shallow wells are 12 to 30 feet deep, the rise of water in them depending on the season. The village greatly needs a drilled well, especially because it is located on nearly level, poorly drained land, and the water in its shallow wells is within a few feet of the surface for the greater part of the year.

Oakdale Sanitarium.—Oakdale Sanitarium is an institution maintained by the State for the treatment of incipient cases of consumption. It is located in sec. 25, Clear Creek Township. As a large well-stocked farm is part of the general equipment a considerable supply of water is needed for domestic and other purposes. In the summer of 1909, a 3-inch well was sunk to 360 feet, at which depth water was obtained in a layer of "gritty shale," which underlies about 250 feet of limestone. The water rises in this well within 100 feet of the surface and is of excellent quality.

An artesian forecast made by W. H. Norton, in 1906, when the question of good water was a factor in the location of the sanitarium, predicted that the St. Peter sandstone would be reached at a depth of 300 to 400 feet below sea level and that this formation, with other water-bearing beds higher up, would furnish a supply sufficient for the institution, reckoned at 30,000 gallons a day. To obtain a larger supply it was recommended that the well be sunk into the Jordan sandstone, here probably about 700 feet below sea level.

Oxford.—At Oxford (population, 614) the water-supply system is owned by the town. Water is pumped from a shallow well not 50 feet deep and is distributed from a standpipe. Many shallow wells 20 to 40 feet deep, are in use over the town.

Shueyville.—The town of Shueyville (population, 100) has no public supply, the people depending mainly on shallow wells. Judging from experience on near-by farms, a well about 150 feet deep would develop an adequate supply.

Solon.—The public at Solon (population, 450) is abundantly supplied with water from a 6-inch well, which penetrates the limestone for 140 feet. The glacial mantle above the limestone is only 7 feet thick. The water is of good quality.

Swisher.—The water supply of Swisher (population, 40) is obtained from shallow wells 15 to 20 feet deep.

Tiffin.—The water supply of Tiffin (population, 176) is from shallow wells averaging about 30 feet in depth.

WELL DATA.

The following table gives data of typical wells in Johnson County:

Typical wells of Johnson County.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Remarks (logs given in feet).
T. 81 N., R. 7 W. (JEFFERSON; PART OF MADISON).	*Sec.*	*Feet.*	*Feet.*		
F. Novotny	13	74	18	Rock	Yellow sandy clay, 18 feet; very hard rock.
Anna Becicka	13	77	77	Gravel	Hill. Yellow clay, 20; the rest blue clay; gravel bed thin.
J. Louvar	14	210	70	Rock	Yellow clay, 20; blue clay, 50.
M. Herdlicka	27	156	24	Soft rock	High ridge above river; rock hard and bedded except the last 7 or 8 feet.
William Roberts	28	70		Gravel	Gravel bed thin.
T. 81 N., R. 6 W. (BIG GROVE; PART OF PENN).					
James A. Ulch	25	282	60	Soft rock	First water at 130, but flow not good.
J. Pesarek	4	158	72	Rock	A log struck at 60; loam, yellow clay, blue clay; thin layer of sand on rock.
T. 81 N., R. 5 W. (CEDAR).					
John A. Henick	17	235	No rock.	Sand	Yellow sandy clay; blue to 145; yellow sandy clay to 200; sand. Well 35 feet in this sand.
W. Verba	6	160	132	Rock	Reddish clay, 20; blue clay, yellow sandy clay, and red clay; 2 of black soil at 120; brownish clay and yellow clay to rock.
T. 80 N., R. 7 W. (PARTS OF MADISON, CLEAR CREEK, AND PENN).					
George Hoover	10	262	142	Rock	Loam; blue clay; no sand above rock.
H. Lininger	10	90		Sand	Same as last, but sand bed thick.
M. M. Snavely	7	115		do	Yellow clay; blue clay; water in sand.
J. C. Bowman	15	312	120	Rock	No sand at bottom of mantle rock; compare Hoover's well.
J. D. Colony	19	144		Gravel	Yellow clay; blue clay; gravel bed thin but coarse grained.
J. J. Craig	27	213	100	Rock	High ridge; no water in drift; the supply comes from a crevice in the rock.
Edw. Craig	27	65		Sand	Usual drift, underlain by sand.
Walter Cox	36	50		do	Drive well; many of this type in neighborhood.
Charles E. Colony	24	100		do	Water just above rock.
T. 80 N., R. 6 W. (PARTS OF PENN AND NEWPORT).					
Martha Bowman	19	288	98	Rock	High knoll; no water in drift; rock hard; water band "gritty."
Samuel Green	18	300	140	do	Very similar to Bowman well.
Do	18	140		Sand	Water at bottom of drift in thin sand.
Jos. Hemphill	31	126		Gravel	
James Hotka	23	108		Sand	Yellow clay; blue clay; gravel.
George Grizel	35	220			
T. 80 N., R. 5 W. (GRAHAM; PART OF NEWPORT).					
J. J. Dvorsky	18	62	57	Rock	Yellow clay; blue clay; no gravel; water in "crevice" in rock.
James J. Krall	18	217	90		Water in shaly rock, beneath very hard rock; unsatisfactory water bed at 100.

Typical wells of Johnson County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Remarks (logs given in feet).
T. 80 N., R. 5 W. (GRAHAM; PART OF NEWPORT)—Continued.	*Sec.*	*Feet.*	*Feet.*		
M. F. Dvorsky	19	110		Gravel	Yellow clay; blue clay; gravel.
G. C. Rossler	6	140			
T. 79 N., R. 7 W. (UNION; PART OF CLEAR CREEK).					
County poor farm	13	172	168	Rock	Yellow clay, about 60; blue clay, over 100; little or no gravel.
Do	13	174	166	...do	
Mrs. H. Schnarre	12	170		Sand	Similar to the poor-farm well.
Evan Williams	11	318	172	Sandy rock	Drift very similar to the preceding, but no gravel; three trials to find water at top of rock failed; water bed is shaly brownish-red sandstone or gritty limestone.
R. Williams	11	140		Sand	Sand bed thin; the well became dry in a few months.
Do	11	282	174	Rock	Yellow and blue clays; thin bed of sand; rock well bedded; the drill dropped into a crevice at the bottom and well yields an abundance of water.
John Hradek	10	340	100	Shale	Similar to Evan Williams well, but with shale below the gritty limestone.
Geo. Wicks	10	126		Sand	Yellow and blue clays.
J. R. Breese	17	90		...do	This well is located in a hollow.
Chas. Rohret	20	130		...do	Yellow clay, about 60; blue, 120; the water seems to run in a "vein" in the sand.
John Lloyd	24	100		...do	Yellow and blue clays.
E. T. Davis	22	100		...do	Yellow clay, about 20; blue clay, over 70.
Anna Zingula	24	170	170	Gravel	Yellow and blue clays; water on top of rock.
H. E. Edwards	19	179		...do	On top of rock.
Julius Tudor	25	96		...do	On lower ground than the last-named well.
H. Roeland	30	....	240		No water; driller gave it up.
S. E. Pate	31	400	260	Shale	Yellow clay, 30 to 40, blue clay, 260; sand; tough clay to the rock, which is quite hard down to the limy shale.
Lumley Tudor	36	90		Sand	
Mrs. H. Rowland	30	106		...do	Water bed loose sand, into which the drill sank for some distance by own weight.
D. W. Jones	30	205		...do	Yellow and blue clays.
T. 79 N., R. 6 W. (LUCAS AND PART OF UNION).					
Black estate	9	135	2	Shaly rock	Rock hard and well bedded.
Wm. Cannon	16	148	40	Rock	Yellow clay, 40; a little gravel; "bird's-eye" limestone, 40; blue limestone, over 60; water in a crevice.
Wm. A. Fry	7	122		Sand	
Mark H. Clear	7	200	200	On rock	Yellow clay, 40; blue clay, over 150; no gravel.
Edw. Rohret	16	64	64	Gravel	Yellow clay, 20; blue clay, 35; coarse gravel to rock.
O. Byington	9	190	40	Shale (?)	Residual material, mostly loess with some gravel below; water in "honey-combed" shale.
J. Cropley	17	126	126	On rock	Yellow and blue clays; no gravel; water bed on the rather friable rock.
A. R. Payne	16	116	116	Gravel	Clays as in the last, but the gravel is 10 to 15 feet thick.
Mrs. W. Black	16	200	50	Rock	Compare with Byington well.
Edw. Rohret	8	140		Gravel	Yellow clay, 30; blue clay, about 100; fine sand; coarser sand.
Mack Stevens	18	150	150	Sand	Yellow clay; blue clay; gravel.
J. K. Hemphill	6	108	108	Gravel	Yellow clay; blue clay; water on top of rock in gravel.
Mary A. Lindsey	16	140		Sand	
J. R. Breese	17	116		...do	
H. Garnett	16	124		...do	On top of rock.
Geo. Lewis	20	139	139	...do	All on same ridge, not over three-fourths of a mile apart.
T. H. Morford	20	120	120	...do	
W. J. Davis	20	120	120	...do	
Owen Davis	20	108	108	...do	
R. P. Jones	20	120	120	...do	

Typical wells of Johnson County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Remarks (logs given in feet).
T. 79 N., R. 6 W. (LUCAS AND PART OF UNION)—Continued.	*Sec.*	*Feet.*	*Feet.*		
Byron Dalton	20	40±		Sand (?)	"Drive well" along a creek.
Rich. P. Jones	29	207		Sand	Yellow clay, 20 to 30; blue clay, over 150; thick sand.
Elias J. Hughes	33	140		Gravel	
S. C. Jones	32	296	246	Rock	No water in gravel above rock; water bed rather shaly.
Robt. E. Jones	32	306	256	...do	Similar to last.
Jas. McCollester	22	40			Dug well; near river.
Chas. A. Vogt	26	30±		Sand	"Drive well."
Alfred Ohl	23	200	50	Soft shale	Not enough water on top of rock.
Lovell Swisher	13	186	100	Rock	Yellow clay; blue clay; thin gravel.
Nellie Swisher	13	62	62	Sand	Plenty of water.
Jno. C. Shrader	12	64			Low part of the farm.
Do	12	140	60	Rock	Hill.
Main's factory	East Iowa City.	62	57	...do	4-inch we l; abundant water; yellow clay, 20; blue clay, 37.
W F. Main	...do	162	60	...do	Water in a shaly rock.
Elmer Buck	19	162		Sand	
D. H. Hastings	30	200		...do	On top of rock.
Sarah Hastings	25	220		...do	Do.
T. 79 N., R. 5 W. (SCOTT).					
Frank Lord	20	220	200	Rock	
E. Westcott	18	180	175	...do	Water in friable rock.
W. P. Ten Eyck	16	400		...do	
R. Hunter	16	196	190	On rock	Water in top layer of rock.
Edw. Greer	34	260	240	Soft rock	No sand above rock.
Benj. Price	21	260	216	Rock	Soil and yellow clay, 36; blue clay, 180; no sand; limestone, 16; yellowish clay, 8; hard rock, 20, to water.
Geo. H. Bothel	34	232	232	Sand	Yellow and blue clays; the water in sand.
Jos. Krellek	35	104		...do	"Quicksand," below blue clay.
Chicago, Rock Island & Pacific Ry.	4	116	116	Gravel	4-inch well; plenty of water.
J. T. Strubble	7	224	100	Rock	Yellow and blue clays.
Lemuel Hunter	6	220	200	...do	
T. 78 N., R. 8 W. (WASHINGTON).					
J. P. Wagner	15	135		Sand	Yellow clay and loam, 45; blue clay, 90.
Jno. Fry	10	140		...do	Very similar to the last.
C. Swartzendruber	16	140		...do	Do.
T. 78 N., R. 7 W. (SHARON).					
Jno. Hughes	2	120		Sand	Hill. Yellow clay, 20 to 30; blue clay, about 90.
P. Zahner, sr	2	84		...do	Foot of Hughes Hill. Soil and yellow clay, 15; blue clay, about 60.
T. D. Davis	1	100		...do	
R. R. Hughes	1	127		...do	Below blue clay.
W. J. Davis	12	125		...do	Yellow and blue clays, then sand.
T. 78 N., R. 6 W. (LIBERTY; PARTS OF PLEASANT VALLEY).					
John Knebel	32	120		Sand	Yellow clay and soil, 30; blue clay, 85; sand, fine grained. Mr. Knebel reports that there are no wells down to rock in the township and that the general depth is about the same as his own. Along Old Mans Creek and on Iowa River bottom drive wells are about 20 feet deep.
T. 77 N., R. 5 W. (FREMONT).					
Town well, Lone Tree	10	130		Sand	Soil and yellow clay, about 30; blue clay, about 95; sand, about 5 to 8, with pieces of wood and bark at top. The driller penetrated a bluish tough clay below the sand to some distance, but withdrew the drill and made the sand the water bed.

JONES COUNTY.

By W. H. Norton.

TOPOGRAPHY.

Alternating belts of upland and lowland, of loess-covered Kansan ridges and Iowan drift plains, give to the surface of Jones County a peculiar "fluted" topography. The trend of these singular belts and of the rivers which cross them is northwest-southeast and the streams flow with seeming indifference either through wide post-mature valleys adjoining the plains or, leaving the lower lands cleave the ridges lengthwise with deep gorges.

Thus, on the right bank of the Maquoketa a bold ridge, loess-covered and fringed with lenticular loess-capped hills of drift, called paha, extends as far southeast as Monticello and its trend is continued by a lower ridge of similar character near Scotch Grove. These ridges overlook to the southwest a belt of prairie 4 or 5 miles wide, diversified in places with low, long swells of drift trending northward. Southwest of this prairie plain of Iowan drift, on which are located the towns of Onslow, Center Junction, and Langworthy, rises another upland. Northwest of Langworthy it is narrow, and its pahoid, forest-covered crests rise 100 feet and more above the level of the adjacent lowlands; from Amber southeast to the county line it is more massive, attaining a height of 140 feet above the neighboring valleys. A narrow belt of lowland parts this ridge from a massive upland cut by Wapsipinicon River to a depth of 220 feet, beyond which to the southwest lie other narrow belts of upland separated from one another by long enchained pahoid hills.

GEOLOGY.

The geologic structure of Jones County is of the simplest. The drift sheets of the county are the Iowan, the deeply buried Nebraskan, and the Kansan. The two last named are for the most part hard blue stony clays called "hardpan" by many of the drillers. The Kansan, however, may be reddened and loosened in texture by long weathering to a depth of from 10 to 20 feet from the surface. The Iowan lies on the surface of the lowlands—a brown sandy and gravelly drift with bowlders or a pale-yellow stony clay. On the hills and ridges the yellow dust or silt deposit known as loess has accumulated to a depth in places of 40 feet, although thin or entirely absent on the adjacent prairies. Throughout, the rock lying beneath the drift is the Niagara dolomite (Pl. IX), except probably over a few square miles in the extreme southwestern part, where the heavy drift may conceal Devonian limestones.

UNDERGROUND WATER.

SOURCE.

The diversified surface, in which well-dissected uplands where ground water stands far below the crests alternate with low young prairie plains only slightly scored by drainage channels where ground water stands high, makes it exceedingly difficult to give any averages as to the depth to water supplies, even in areas so small as townships.

The most important water-bearing formation is the Niagara dolomite. The water occurs in porous beds and in waterways opened by solution along joints and bedding planes, but not in any definite stratum whose depth at any point can be predicted. Water is found also in drift sands and gravels, both in those contained within the drift sheets and in those which separate them.

PROVINCES.

Northeast of Maquoketa River.—In Highland, Washington, and the northeastern part of Monticello townships the Niagara dolomite lies everywhere at no great distance below the surface and outcrops in numerous ledges on the hillsides and in discontinuous high rock walls along the deeper valleys. North and South forks of Maquoketa River below Monticello flow through narrow winding valleys destitute of flood plains. In these valleys wells find rock a few feet from the surface, but must penetrate it deeply to obtain sufficient water.

On the uplands the deep and intricate dissection of most of the area allows ground water to sink low. Few wells find it in less than 100 feet, and many are compelled to go more than 200 feet. In a few places the Niagara is found dry nearly to its base, and wells supplied from the water accumulating immediately above the impervious Maquoketa shale must be drilled a little way into the Maquoketa for reservoir. For example, the well of T. Cooper (sec. 20, T. 86 N., R. 2 W.) found clay to 20 feet, Niagara dolomite to 385 feet, and was carried 16 feet into the Maquoketa shale—a total of 401 feet.

Even on the high drift prairie of the northwest part of this area wells do not find enough water in the drift, which here ranges from 10 to 65 feet in thickness. Where the drift is comparatively thick for this area, reaching about 50 feet, water may be found within the limestone 15 or 20 feet below the rock surface. Where the drift is thin, and locally where it has some thickness, wells range in depth from 150 to 250 feet. Few wells of this province are less than 140 feet deep. Thus, the well of R. M. Hicks (sec. 2, T. 86 N., R. 2 W.) is 180 feet deep, rock being struck at 5 feet, and the well of J. F. Moore (sec. 5, T. 86 N., R. 2 W.) goes through 40 feet of drift and penetrates 240 feet into the Niagara dolomite to obtain sufficient water.

Between Maquoketa and Wapsipinicon rivers.—The larger part of the belt of country 12 to 14 miles wide, extending from northwest to southeast across the county between Maquoketa and Wapsipinicon rivers, is a prairie of Iowan drift, but it is traversed longitudinally and is bounded on the east side by massive ridges of Kansan drift capped with loess.

To the northeast, along a zone bordering the Maquoketa, the Niagara dolomite stands high and is covered with a thin mantle of drift. In the northern part of Castle Grove Township, as at Argand, it outcrops as high as 920 feet above sea level. In southwestern Monticello Township the loess and drift of the ridges may exceed 40 or 50 feet in thickness, but the rock outcrops about their bases or is found at slight depth below the surface. Southeast of Monticello the limestone also stands high, outcropping well up to the summits of the hills overlooking the Maquoketa, its height above sea level at Scotch Grove being about 900 feet. Here water is not found in the drift nor on the rock. Wells must be sunk a considerable distance in the Niagara dolomite to find sufficient supply. Locally plenty of water is obtained within 50 feet of the surface, as at the Scotch Grove creamery well, but most wells are 100 feet or more in depth. Even on the wide river valley northwest of Monticello, where rock comes within 15 to 20 feet of the surface, wells are about 100 feet deep, and on the adjacent hills some of them exceed 200 feet. On the high bluffs overlooking the Maquoketa, southeast of Monticello, it may be necessary to go 200 and even 300 feet to find water in the limestone.

An exceptional feature of the belt of country bordering the Maquoketa on the southwest is a buried river channel disclosed by wells in the lower valley of Kitty Creek and on the Maquoketa flood plain above Monticello. Thus, in sec. 27, Monticello Township, a well on the Kitty Creek bottoms found rock 70 feet from the surface, 720 feet above sea level. The city well at Monticello on the same bottoms enters rock at 135 feet, 665 feet above the sea, and a well in sec. 16 of the same township on the Maquoketa flood plain is reported as 119 feet deep, with 20 feet of alluvium at top, below which the well penetrated only sand. The rock floor at the last well must be less than 680 feet above sea level. The buried river channel thus disclosed was cut about 125 feet below the present channel of the Maquoketa. That the ancient valley does not coincide with the broad valley of the river above Monticello is seen in the numerous wells on both sides of the river which enter rock at 10 to 20 feet below the surface.

From the upland along the right bank of the Maquoketa, where the Niagara dolomite reaches an elevation of about 900 feet above sea level and where the drift is relatively thin, the rock everywhere descends to the southwest to a wide rock-cut valley now deeply filled with drift, on whose farther side the rock again ascends and again approaches the surface along a belt of country stretching along the left bank of the Wapsipinicon. The distance to which wells must be drilled to reach rock varies not only with the depth of this ancient valley and the positions of its numerous branch valleys with their divides of rock buried beneath drift, but also with the height to which the drift has been heaped over the area—whether it has been smoothed to the broad, flat plain which stretches from Castle Grove to Langworthy and Onslow or has been piled in the massive ridges which overlook this prairie from the south. The greatest depth to rock naturally occurs where the ridges directly overlie the central trough of the buried valley. In Castle Grove Township (sec. 8) the drift is in one place 190 feet thick, the rock floor being 810 feet above sea level. In sec. 33 the drift is more than 200 feet thick, the rock floor not being reached at 800 feet above sea level. On the ridges from northwest of Amber to Onslow a number of wells are reported which approach and exceed 300 feet in depth, and a few successful wells are reported as less than 200 feet deep. On the bluffs near the Wapsipinicon, where rock stands high, few wells exceed 150 feet and a number of successful ridge wells from 80 to 120 feet deep are on record.

South of Newport the Wapsipinicon is bordered by flood plains 1½ miles wide, and here driven wells are entirely adequate.

South of Wapsipinicon River.—On the high ridges southwest of the Wapsipinicon the depth of the wells reported ranges from 50 to 150 feet. On the prairie occupying the extreme southwestern part of the county about Morley and Martelle wells find water in the drift, and in few places exceed 130 feet, so far as reported. South of Fairview a number of successful wells are but 40 or 50 feet in depth.

SPRINGS.

Springs supplied by underground courses dissolved in the Niagara dolomite emerge in the deep gorges of the Maquoketa and the North Maquoketa. That of J. Kibury, in the NW. ¼ NW. ¼ sec. 30, T. 86 N., R. 2 W., feeds a small creek discharging into Maquoketa River.

To a somewhat less extent springs are found along the course of the Wapsipinicon where it leads through narrows cut in the Niagara dolomite.

CITY AND VILLAGE SUPPLIES.

Anamosa.—The public supply of Anamosa (population, 2,983) is derived from a city well drilled by J. P. Miller & Co., of Chicago, in 1898. The well is situated a few yards from the bank of Wapsipinicon River, is 1,754½ feet deep and 10 to 6 inches in diameter. It is packed with lead and rubber and carries 100 feet of casing. The head of the water is 30 feet below curb. The water comes from depths of 600, 950, and 1,200 feet. The original and present pumping capacity is 300 gallons a minute. Temperature, 52° F. Water is pumped to a reservoir and the pressures, gravity and direct, are 60 and 120 pounds, respectively. There are 3 miles of mains and 13 hydrants.

The only cuttings preserved from this well come from the St. Lawrence formation and underlying Cambrian strata. The following table presents the record:

Record of strata of city well at Anamosa.

	Depth in feet.
Dolomite, gray, arenaceous; as seen by grains embedded in dolomite chips	1,335 and 1,345
Dolomite, light yellow gray	1,370
Marl, light pink; powder contains large residue of minute angular quartzose particles; cement dolomitic glauconiferous	1,375
Marl, bright pink, as above	1,385
Marl, blue, dolomitic, quartzose, glauconiferous	1,435
Shale, white, calcareous, siliceous, in powder	1,440
Sandstone, green gray, grains minute, rounded, slightly calcareous, argillaceous, glauconiferous	1,525
Sandstone, white, rounded grains; largest, 0.6 mm. in diameter	1,530
Sandstone, gray, fine	1,660
Sandstone, white, very fine	1,670
Sandstone, buff, of finest grain, glauconiferous	1,690
Sandstone, pink, of finest grain, in loosely coherent chips	1,720
Shale, green	1,735
Shale, bright green, calcareous, glauconiferous, highly siliceous; with minute quartz particles	1,750

The water-supply problems of Anamosa seem to have been successfully solved by the excellent and abundant supply of water from the city well. Domestic supplies are still drawn, however, from many house wells, which on the hills are not uncommonly 100 to 160 feet in depth. The drift, which is 40 feet deep, is dry, and water must be sought in limestone.

In the remote contingency that the present supply from the deep well may be overdrawn by increasing population, tests might well be made of the amount of ground water available on the low ground west of the town near the mouth of Buffalo Creek, where the convergence of drainage lines points to some considerable store. Several wells of small diameter sunk about 320 feet to the horizon of the Maquoketa shale would probably yield a large supply.

The State penitentiary well has a depth of 2,007 feet and a diameter of 10 inches (cased) to 96 feet, 8 inches (uncased) to 290 feet, 6 inches (cased) to 987 feet, 5 inches to 2,007 feet. The curb is 816 feet above sea level. The original head was 760 feet above sea level; the present head is 768 feet. The original and present pumping capacity is more than 300 gallons a minute, and the amount pumped daily in summer is 135,000 gallons. When pumped at rate of 200 gallons a minute water is lowered 19 feet in half an hour. The water comes from 860 feet and from between 1,070 and 1,215 feet. The well was completed in 1896 by J. P. Miller & Co., of Chicago, at a cost of $11,000. Temperature, 53.5° F.

The well yields excellent drinking water. Since its completion no cases of typhoid fever have occurred in the penitentiary, although, from 1875 to 1891, 64 were reported by the prison physician. The water forms much scale in boilers but is not otherwise deleterious.

Record of strata of penitentiary well (*Pl. IX, p. 354*).

	Thickness.	Depth.
Pleistocene (78 feet thick; top, 816 feet above sea level):	*Feet.*	*Feet.*
Clay, yellow	30	30
Clay and sand	46	76
Quicksand	2	78
Silurian:		
Niagara dolomite (282 feet thick; top, 738 feet above sea level)—		
Dolomite, light bluish gray, crystalline, vesicular; 5 samples; at 145 feet, dark brown gray and more compact	137	215
Dolomite, as above, cherty	20	235
Dolomite, light gray, crystalline; 2 samples	30	265
Dolomite, cream colored and buff, cherty; 4 samples	60	325
Dolomite, gray, in flaky chips, argillaceous, luster earthy, with some chert; 2 samples	30	355
Dolomite, blue gray, highly argillaceous	5	360
Ordovician:		
Maquoketa shale (175 feet thick; top, 456 feet above sea level):		
Shale, green gray, slightly calcareous; 4 samples	130	490
Dolomite, brown, somewhat bituminous; blackens in closed tube	10	500
Shale, in molded masses; 2 samples	35	535
Galena dolomite and Platteville limestone (325 feet thick; top, 281 feet above sea level)—		
Dolomite, buff and gray, hard, rough, crystalline; 10 samples, at 675 feet, cherty	205	740
Limestone, magnesian, blue gray, granular, crystalline; 2 samples	30	770
Shale, blue and dark brown, bituminous	30	800
Limestone, magnesian, or dolomite, buff gray, fine grained, crystalline; samples at 800 and 820 feet; in the latter sample are found fragments of magnesian limestone which may extend from that depth to 852 feet	52	852
Shale, no sample	8	860
St. Peter sandstone (55 feet thick; top, 44 feet below sea level)—		
Sandstone; clean, white quartz sand; grains well rounded, moderately fine	55	915
Prairie du Chien group (335 feet thick; top, 99 feet below sea level)—		
Shale, green, noncalcareous, finely laminated, containing some rounded grains of quartz	40	955
Dolomite, light yellow gray	15	970
Shale; in large fragments, noncalcareous, green, finely laminated	20	990
Dolomite, gray and white; 5 samples	260	1,250
Cambrian:		
Jordan sandstone (95 feet thick; top, 434 feet below sea level)—		
Sandstone, light blue gray, calciferous	55	1,305
Sandstone, clean, white; grains rounded	20	1,325
Sandstone, white, calciferous	20	1,345
St. Lawrence formation (235 feet thick; top, 529 feet below sea level)—		
Dolomite, yellow gray, rough	35	1,380
Dolomite, cream yellow; rounded grains of quartz in drillings; 2 samples	35	1,415
Dolomite, ranging from white to brown	70	1,485
Sandstone, red, argillaceous and calcareous, of microscopic grain, with green grains like glauconite	5	1,490
Shale, light green gray, slightly calcareous	50	1,540
Dolomite; fragments mottled pink and gray	40	1,580
Dresbach sandstone (180 feet thick; top, 764 feet below sea level)—		
Sandstone, cream yellow, buff and white, fine grained; 4 samples; softest sandstone in well by driller's log	180	1,760
Undifferentiated Cambrian strata (247 feet penetrated; top, 944 feet below sea level)—		
Shale, green, fissile	10	1,770
Sandstone, buff, very fine, glauconiferous; 3 samples	45	1,815
Sandstone, brick-red, very fine grained, argillo-calcareous, glauconiferous	40	1,855
Sandstone, as above, but less calciferous	20	1,875
Sandstone, gray and buff, fine; argillo-calcareous at 1,890; 3 samples	20	1,895
Sandstone, coarser; with green shale	5	1,900
Sandstone, gray; moderately fine grains, angular, hard	50	1,950
Sandstone, white, rounded; unbroken grains, soft	45	1,995
Sandstone, light pink, sample of rounded grain, mostly unbroken, hard, 2½ hours to drill 5 feet; sample not a quartzite	12	2,007

Center Junction.—The domestic supply of Center Junction (population, 199) is drawn from deep wells, which range from 116 to 140 feet in depth and find water in the Niagara dolomite 6 or 8 feet below the rock surface. Here, as at Onslow, a sand mixed with small gravel and reaching a thickness of 50 or 60 feet occurs beneath glacial stony clays, but, on account of difficulties in screening, wells are drilled through it into rock and are cased to a few feet below the rock surface.

Langworthy.—At Langworthy (population, 100) shallow wells in sand and gravel are about 15 feet deep; drilled wells range from 50 to 200 feet. Langworthy is on low ground on the Iowan drift plain and ground water stands near the surface, heading 2 to 10 feet below the curb in most wells, and in one or two overflowing.

Monticello.—The city supply of Monticello (population, 2,043) was originally from an artesian well drilled in 1875, which had a depth of 1,198 feet and a diameter of 8 to 5 inches. The curb was 820 feet above sea level and the head 40 feet below the curb. The tested capacity, original, was 200 gallons a minute; about 1898, with pump cylinder set 45 feet below the curb, it was 25 gallons a minute; and with air compressor working 200 feet below the curb it was 125 gallons a minute. The well was abandoned in 1900. The strata penetrated are shown in the following table:

Record of strata in Monticello city well.

	Depth in feet.
Pleistocene 85 feet thick; top, 820 feet above sea level:	
Drift	60
Silurian:	
Niagara dolomite 180 feet thick; top, 735 feet above sea level—	
Dolomite, light buff	85
Dolomite, lighter in color than above, porous, subcrystalline; some chert	100
Dolomite, gray; with chert	200
Dolomite, buff, hard, porous	235
Ordovician:	
Maquoketa shale (195 feet thick; top, 555 feet above sea level)—	
Shale, greenish, calcareous at 263 and 380 feet	380
Shale, dark brown, strongly bituminous, pyritiferous, slightly calcareous	420
Shale, light greenish gray, magnesian	460
Galena dolomite and Plattesville limestone (315 feet thick; top, 360 feet above sea level)—	
No sample	460–550
Dolomite, gray and buff; much shale powder and foreign coarse quartz sand	550
Dolomite and limestone, soft, white	615
Limestone, blue gray nonmagnesian; in flaky chips; fossiliferous, rather soft	645

	Depth in feet.
Ordovician—Continued.	
St. Peter sandstone (25 feet thick; top, 45 feet above sea level)—	
Sandstone, white, grains rounded, fine	775
Prairie du Chien group (340 feet thick; top, 20 feet above sea level)—	
Dolomite, cream colored; some quartz sand, probably from above	800
Dolomite; as above, but darker	820
Dolomite, light gray	920
Dolomite, light yellow	975
Sandstone, calciferous, or dolomite, highly arenaceous	1,025
Dolomite, hard, siliceous, reddish buff	1,025
Sandstone, argillaceous; drillings largely coarse quartz sand, imperfectly rounded	1,040
Dolomite, gray	1,085
Cambrian:	
Jordan sandstone (58 feet penetrated; top, 320 feet below sea level)	1,140–1,198

In 1893 the supply was found insufficient for the needs of the town and a well 120 feet deep was drilled a short distance away and connected with the pumps. In 1895, 250 gallons (?) per minute could be pumped from the dual supply without lowering the water. A few years later the diminishing yield was increased by the use of an air lift which discharged from the deep well 125 gallons per minute from a depth of 200 feet, but this increase proved to be but temporary. The loss of capacity was thought to be largely due to defective casing, but on attempting to recase the well it was found that the bore hole was "crooked" and a 4-inch pipe could not be driven below 400 feet. As the Maquoketa shale lies at about this depth it is possible that the so-called crookedness was due to creep of the thick body of shale constricting the bore and diminishing its capacity. It is reported that no casing had been placed in the well below 105 feet.

In 1902 the municipality abandoned both wells, which were situated near the Chicago, Milwaukee & St. Paul Railway station, and found an abundant supply in a well sunk in the outskirts of town on the flood plain of Kitty Creek near its junction with the Maquoketa. This well, supplying 250 gallons per minute, is 8 inches in diameter and 219 feet deep. The water heads but 15 feet below the curb. The driller's log is as follows:

Log of well at Monticello.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	4	4
Sand, water bearing	16	20
Clay, blue, hard	105	125
Gravel of white flint with some water	10	135
Limestone (Niagara), water bearing	84	219

The water is distributed from a reservoir under gravity pressure of 65 pounds. For fire protection, direct pressure of 80 pounds is available. The system comprises 4½ miles of mains, 37 fire hydrants, and 536 taps.

The depth of the well, the heavy impervious blue clay, and the casing which extends to rock, give assurance that with due care in keeping the casings intact, thus excluding all water in surface sands, the well will remain entirely safe as a city supply, notwithstanding the low ground on which it is situated and the increasing settlement of the area above it.

The yield from the Niagara is exceptionally large at other points in town; the capacity of the well of the Chicago, Milwaukee & St. Paul Railway, for example, which is sunk 40 feet in the Niagara, is 100 gallons a minute; but the supply near Kitty Creek is especially large because of the broad deep sag in the rock surface which underlies the valley. In this sag the limestone is no doubt saturated with water supplied from the higher rock on either side, and perhaps from a considerable distance to the north and the south.

Olin.—Water at Olin (population, 659) is found in sands of the ancient flood plain of Wapsipinicon River on which the village is built, and in the underlying Niagara dolomite, which is reached at different depths, in places somewhat more than 100 feet. Water rises within 10 or 15 feet of the surface.

The town is supplied from an 8-inch well 272 feet deep. Water was found in sand at 25 feet, and also in the Niagara, which was entered at 117 feet. Casing shuts out water above that of the limestone. Water stands at 13 feet from the surface, and the capacity of the well is 100 gallons a minute. On pumping at this rate water lowers 9 feet. There is a pneumatic storage tank. The pressure is from 45 to 80 pounds. There are 6,400 feet of mains and 16 hydrants.

Onslow.—Onslow (population, 207) is supplied by deep drilled wells, some of which are sunk in the deposits filling an ancient buried valley (p. 430).

House wells find abundant water in the Niagara just beneath the drift. Rock is found at different depths from the surface, as the Iowan plain on which the town is built here overlies the sloping side of a buried valley. At the south end of the village rock is found at 80 feet; 700 feet north the rock floor has descended to 137 feet and 300 feet north to 206 feet. In some of these wells as much as 70 feet of sand is found beneath heavy glacial stony clays.

Oxford Junction and Oxford Mills.—The level plain adjacent to Wapsipinicon River about Oxford Junction (population, 822), and Oxford Mills (population, 233) is underlain by the Niagara dolomite, which comes to the surface within the limits of the former town, but is cut with deep ancient channels of the river. Thus in Oxford Mills rock occurs within 4 feet of the surface at the schoolhouse, and a block away a house well enters rock at 11 feet.

Stone.—The village of Stone (population, 700), situated on the bluffs of Wapsipinicon River, depends on drilled wells for house supply. On the highest elevations wells are 265 feet in depth and water stands 190 feet from the surface.

Wyoming.—The waterworks of Wyoming (population, 733) comprise a well 78 feet deep, a storage basin, and 2 miles of mains. Water is distributed by gravity and by direct pressure of 55 pounds. There are 15 hydrants. The well is located in the valley of Beaver Creek and is sunk 41 feet into the Niagara dolomite. An 8-inch casing is driven 3 feet into the rock, but is not packed. The material penetrated above the rock is river sand, deriving its water by percolation from the surface.

It may be necessary in the future to prevent the ingress of water liable to contamination by recasing the well to considerably greater depth and by very thorough packing. Water stands within 9 feet of the curb, and is not lowered by pumping 100 gallons a minute.

Many house wells are used throughout the town. On the flat land in the northern part rock is found at about the same depth from the surface as at the city well. On the hills bordering the valley, house wells enter rock after passing through 70 feet of glacial clays and obtain water in the Niagara at depths of 90 and 100 feet below the surface.

WELL DATA.

Information concerning typical wells in Jones County is presented in the following table:

Typical wells in Jones County.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Remarks (logs given in feet).
T. 86 N., R. 4 W. (Castle Grove).					
		Feet.	*Feet.*		
P. Kehoe	NW. ¼ NW. ¼ sec. 5	125	40	Limestone	Blue clay to rock.
T. Cashman	NW. ¼ sec. 8	200	190		Do.
A. W. Cramer	SW. ¼ NW. ¼ sec. 14	150	40	Limestone	
Geo. Henderson	Sec. 19	80	70		Ridge.
Wm. Henderson	N. ½ NW. ¼ sec. 20	100	0	Gravel	
D. W. Cunningham	NE. ¼ SW. ¼ sec. 21	126	124		
J. Lukken	SW. ¼ SE. ¼ sec. 25	125	115		Fairly level ground.
J. M. King	SE. ¼ SW. ¼ sec. 29	150	74	Limestone	
N. Deischer	NW. ¼ NW. ¼ sec. 29	90	75	do	
C. Pheil	NW. ¼ NW. ¼ sec. 32	125	50		All blue clay.
M. Brown	SW. ¼ SW. ¼ sec. 33	220	218		
N. Nichols	NW. ¼ NW. ¼ sec. 33	200		Sand	Blue clay to sand.
A. B. Harms	NW. ¼ SW. ¼ sec. 34	175	160		Mostly blue clay; one 10-foot stratum of sand.

Typical wells in Jones County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Remarks (logs given in feet).
T. 86 N., R. 3 W. (MONTICELLO).		*Feet.*	*Feet.*		
R. A. Ryerson	SE. ¼ NE. ¼ sec. 1	95	10	Limestone	
R. M. Hicks	NW. ¼ NE. ¼ sec. 2	180	5	do	
J. McNutt	NW. ¼ NW. ¼ sec. 2	85	65		
H. Sandhouse	W. ½ SW. ¼ sec. 5	85	15	Limestone	River bottom.
P. Meyer	NE. ¼ NE. ¼ sec. 6	105	20	do	Do.
J. Joussi	NE. ¼ SW. ¼ sec. 6	220	40	do	Hilly ground back from river.
J. Mangold	SW. ¼ NW. ¼ sec. 8	85	15	do	River bottom.
Wm. Rolston	SW. ¼ NW. ¼ sec. 14	55	40		
C. A. Schatz	NE. ¼ NE. ¼ sec. 15	150	10	Limestone	Across road from Rolston well.
J. Voorhees	SE. ¼ NE. ¼ sec. 17	100	20	do	
Mrs. Ferring	SW. ¼ SW. ¼ sec. 16	119		Sand	Dirt, 20; sand, 99. River bottoms.
James Skelly	SW. ¼ SE. ¼ sec. 22	100	10	Limestone	
G. H. George	SE. ¼ SE. ¼ sec. 27	100	70	do	Creek bottoms.
P. Byerly	NW. ¼ NE. ¼ sec. 29	150	50	do	Rock; yellow clay, 50.
T. 86 N., R. 2 W. (RICHLAND).					
J. F. Moore	SW. ¼ SE. ¼ sec. 5	280	40	Limestone	
Diamond Creamery	NW. ¼ NE. ¼ sec. 19	60	12	do	80 gallons per minute.
	SE. ¼ SW. ¼ sec. 17	100	20	do	
Wm. Farragher	N. ½ SW. ¼ sec. 19	150	40	do	
T. Casper	SE. ¼ SE. ¼ sec. 20	401	20		Clay, 20; limestone, 365; shale, 16.
M. Allen	E. ½ SW. ¼ sec. 20	219	2		Started in a spring.
John Shover	SE. ¼ SE. ¼ sec. 30	100	25		Sand, 25.
T. 85 N., R. 4 W. (CASS).					
E. Head	SW. ¼ SW. ¼ sec. 1	220	200		
Mrs. Mayberry	SW. ¼ SE. ¼ sec. 1	185	170		Hill.
A. B. Harms	SW. ¼ SW. ¼ sec. 2	177	157		Do.
Norman Clark	SW. ¼ NE. ¼ sec. 2	280	260		
Colton	SE. ¼ SE. ¼ sec. 3	200	190		Do.
Geo. Watt	NW. ¼ SW. ¼ sec. 3	185	155		
H. C. Thompson	SE. ¼ sec. 5	97	60		
P. Osborne	NW. ¼ NW. ¼ sec. 10	160	140		
L. H. Darrow	NW. ¼ NE. ¼ sec. 11	180	180		
John Gerdes	SW. ¼ NW. ¼ sec. 13	136	104		
A. C. Stickle	SE. ¼ NE. ¼ sec. 15	185	161		Much blue clay in locality.
J. J. Richards	SW. ¼ NW. ¼ sec. 20	54	17		
George Ketcham	SE. ¼ NE. ¼ sec. 22	144	93		
R. Stout	NE. ¼ sec. 24	127			
P. Berryman	N. ½ SW. ¼ sec. 25	200	167		Rather low ground.
L. Hartman	SE. ¼ SE. ¼ sec. 28	203	107		
T. Deming	SE. ¼ NW. ¼ sec. 36	200	197		
T. Foley	NW. ¼ NE. ¼ sec. 36	257	240		Nearly 100 feet of quicksand on rock.
T. 85 N., R. 3 W. (WAYNE).					
R. Batchellor	SE. ¼ NE. ¼ sec. 7	130			Heads 11 feet above curb. Blue clay, 100; sand, 30.
Langworthy Creamery	Langworthy	120	100		Flowing well; blue clay and sand in alternate strata, 100; rock with water, 20.
H. Himebaugh	SE. ¼ SW. ¼ sec. 10	100		Sand	Yellow clay, 20; sand, 80.
A. B. Jacobs	SE. ¼ SE. ¼ sec. 12		20		
S. Woster	SE. ¼ SW. ¼ sec. 18	180	170		Sand and blue clay to rock.
T. H. Dunn	NE. ¼ SW. ¼ sec. 19	240	230		
H. M. Dirks	NW. ¼ SW. ¼ sec. 20	320	300		From 120 to 190 feet sand; a well on same section, 306 feet to rock, has 100 feet of sand.
Noah Bigly	NW. ¼ SW. ¼ sec. 21	250	245		
William Helgens	SW. ¼ NW. ¼ sec. 22	100	80		Blue clay, 50; sand, 30; rock, 20.
A. G. Zimmerman	SW. ¼ SW. ¼ sec. 22	190		Sand	Blue clay, 100; sand, 90.

Typical wells in Jones County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Remarks (logs given in feet).
T. 85 N., R. 3 W. (WAYNE)—Contd.		*Feet.*	*Feet.*		
J. H. Hoyen	SE. ¼ SE. ¼ sec. 23	170	160		
A. Balster	NE. ¼ SE. ¼ sec. 24	185	184		Blue clay with sand streaks 6 and 8 feet thick, 144; gravel; hard clay, 40; rock, 1.
H. S. Hartman	NE. ¼ SW. ¼ sec. 26	245	200	Limestone	Yellow clay, 20; blue clay, 180; limestone and shale in alternate layers about 5 feet thick, 35; limestone with water, 10.
J. Cunningham	SE. ¼ SE. ¼ sec. 27	300	299	Gravel	Blue clay; sand and gravel; gravel 30 feet thick on rock.
Aug. Toenges	SW. ¼ NE. ¼ sec. 28	200	175		Drill dropped 12 inches in rock cavity.
William Rilken	NE. ¼ SW. ¼ sec. 29	420	415		Ridge. Yellow clay, 50; remainder sand and blue clay to rock.
J. Dorsey	SE. ¼ NW. ¼ sec. 29	330	300		
William Stout	SW. ¼ NW. ¼ sec. 30	300	280		
A. B. Hungerford	NW. ¼ SE. ¼ sec. 30	328	320		Yellow clay, 30; blue clay, 160; quicksand with water, 130; limestone, 8.
—— Bigler	SW. ¼ SE. ¼ sec. 31	250	225		
G. E. Strawman	SW. ¼ sec. 32	320	320		High ground.
J. Schron	SE. ¼ NE. ¼ sec. 33	245	225		Yellow clay, 50; blue clay and streaks of sand, 175.
Amker Creamery	Amker	225		Gravel	Yellow clay, 15; sand, 65; hard blue clay; gravel.
T. 85 N., R. 2 W. (SCOTCH GROVE).					
P. E. Preibilbis	SE. ¼ NW. ¼ sec. 11	50	18	White flint	River bottoms.
A. O. Preibilbis	NE. ¼ NW. ¼ sec. 11(?)	170	9	Limestone	Bluff.
David Sutherland	NW. ¼ NW. ¼ sec. 14	315	34		Do.
	NE. ¼ NE. ¼ sec. 23	280	16		Do.
	NW. ¼ NE. ¼ sec. 25	213	210		Heads 11 feet below curb.
A. G. Haukea	SW. ¼ SW. ¼ sec. 27	120	120		Blue clay to rock. Level ground.
J. Sutherland	SE. ¼ SW. ¼ sec. 28	240	235		Much sand.
P. Kahns	SE. ¼ NW. ¼ sec. 29	110	100		Blue clay to rock.
R. Williamson	SE. ¼ NE. ¼ sec. 31	250	240		Sand and blue clay; sand quicksand above growing coarser toward bottom.
R. Livingston	NW. ¼ NW. ¼ sec. 33	280	260		"Surface," 15; "hardpan," 135; sand, 98; clay, 12; rock, 20.
Wm. McIntyre	SW. ¼ NE. ¼ sec. 33	160	148		
Wm. Leech	NW. ¼ NE. ¼ sec. 34	100	45		
S. Walworth	SW. ¼ NE. ¼ sec. 36	111	100		Low ground near creek; heads 4 feet above curb. Blue clay, 40; sand and gravel, 45; clay, 15; rock, 11.
G. Overly	2 miles east of Center Junction.	398	391		
Elmer Overly	2 miles east of Center Junction.	311	311		Surface soil, hardpan, sand, old wood, 4; clay rock. In same locality wells of Mrs. Van Slyke, 325 feet deep. 317 feet to rock and Wm. Alexander, 348 feet deep, 300 feet to rock.
Scotch Grove Creamery	Scotch Grove	44	10	Soft limestone.	
R. Gunn	SW. ¼ SW. ¼ sec. 19	130	123		
W. H. Chatterton	SE. ¼ SW. ¼ sec. 20	226	221		100 feet "hardpan"; 121 feet sand to rock.

Typical wells in Jones County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Remarks (logs given in feet).
T. 85 N., R. 2 W. (Scotch Grove)—Continued.		*Feet.*	*Feet.*		
—— Neelans	SE. ¼ SE. ¼ sec. 20	156	150		
T. MacManus	NE. ¼ NE. ¼ sec. 21	205	2		5-foot crevice full of water with strong current.
R. Haynor	NE. ¼ SW. ¼ sec. 23	282	20		
Carstens	NW. ¼ sec. 28	156	150		
—— Oar	SW. ¼ NE. ¼ sec. 29	130	20		
J. Russell	SW. ¼ NE. ¼ sec. 31	85	15		
Mrs. MacMasters	SW. ¼ NW. ¼ sec. 32	115	2		
T. 84 N., R. 4 W. (Fairview).					
L. J. Adair	SW. ¼ NE. ¼ sec. 1	165	139		
Wm. Bromley	SE. ¼ NE. ¼ sec. 2	124	123		Mostly sand to rock.
James Shonflin	NW. ¼ NE. ¼ sec. 3	131	80		
Robt. Lister	NW. ¼ NE. ¼ sec. 5	215	86		High ridge, nearly all yellow clay to rock.
M. Wagener	SW. ¼ sec. 9	175	116		Nearly all yellow clay to rock.
A. Alspaugh	SW. ¼ SW. ¼ sec. 15	175	91		
Edward Grimm	NW. ¼ NE. ¼ sec. 16	190	100		
J. Joslin	SW. ¼ NW. ¼ sec. 22	142	70		
J. Meeks	SW. ¼ NW. ¼ sec. 24	134	52		
—— Ercanbrack	SE. ¼ sec. 25	202	109		
Allen Stone	NE. ¼ SE. ¼ sec. 25	188	142		
T. Helberg	NE. ¼ NE. ¼ sec. 27	152	128	Limestone	60 to 90 feet clean clay "river sand."
J. Dumont	SW. ¼ SW. ¼ sec. 29	96	40		
J. Underwood	SW. ¼ NE. ¼ sec. 33	70	51		
Daniel Joslyn	NE. ¼ SE. ¼ sec. 35	100	86		
S. E. Bills	SW. ¼ SE. ¼ sec. 36				
T. 84 N., R. 3 W. (Jackson).					
Frank McNeely	SE. ¼ SE. ¼ sec. 1	300	289		Heads 127 feet below curb. 100 feet quicksand on rock.
P. Cheshire	SW. ¼ SW. ¼ sec. 3	290	200		
W. Johnson	NE. ¼ NW. ¼ sec. 4	260	130		
Melvin Strawman	NW. ¼ NE. ¼ sec. 5	270	262		Yellow clay, 30; stony clay, 110; sand, 100; cemented sand and gravel, 22; rock, 8.
H. Mowery	NW. ¼ SW. ¼ sec. 6	170	144		Blue clay; quicksand, 30; cemented gravel, 4; rock.
J. L. Brown	NE. ¼ NE. ¼ sec. 11	143		Gravel	
Frank Barly, sr.	Sec. 12	213	205		Top of ridge. Heads 198 feet below curb.
John McNeely	NE. ¼ NE. ¼ sec. 12	238	229		All blue clay to rock.
Creamery	Sec. 13	160	153		Heads 115 feet below curb.
I. Hay	NE. ¼ NE. ¼ sec. 17	85	31		
Ben Johnston	NE. ¼ SE. ¼ sec. 19	112	85		
T. 84 N., R. 2 W. (Madison).					
J. F. Brown	NE. ¼ SW. ¼ sec. 6	245	240		Ridge. Heads 125 feet below curb.
Carlston Kettleson	SW. ¼ sec. 7	322		Sand and gravel.	Sand at 200 feet; much sand on ridge.
John McDonald	NW. ¼ NW. ¼ sec. 8	214	210		
M. O. Felton	SW. ¼ sec. 11	324	320		Much sand.
F. Baily	Center sec. 13	190		Gravel	Heads 177 feet below curb.
J. V. Smith	NE. ¼ NE. ¼ sec. 13	135	132		"Surface," 15; hard blue clay, 25; sand and gravel, 10; hardpan, 50; sand, 30; clay, 2; rock, 3.
G. H. Simpson	NW. ¼ NW. ¼ sec. 14	120	30		
B. C. Bromwell	NE. ¼ NW. ¼ sec. 17	235	230		
	SE. ¼ SE. ¼ sec. 20	317	310		"Surface," 10; yellow clay and "hardpan"; clear sand and gravel 225. Not 50 feet above Bear Creek.

Typical wells in Jones County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Remarks (logs given in feet).
T. 84 N., R. 2 W. (MADISON)—Continued.					
		Feet.	*Feet.*		
J. S. Bromwell	NE. ¼ NE. ¼ sec. 22	240	230		
J. L. Finch	NE. ¼ SE. ¼ sec. 23	211	205		
J. Thompson	SW. ¼ NE. ¼ sec. 25	165	160		
—— Niles	NW. ¼ NW. ¼ sec. 27	63	20		Sand and gravel to rock. Creek bottoms.
E. Anderson	NE. ¼ NW. ¼ sec. 29	280	275		
T. 84 N., R. 1 W. (WYOMING).					
J. Corbit	SE. ¼ NE. ¼ sec. 5		80		Mostly blue hardpan.
Israel Edwards	Sec. 11	120	30		
J. F. Allen	SW. ¼ SW. ¼ sec. 13	116	65		
J. Edward	E. ½ sec. 23	162	70		
Peter Kegly	Sec. 24	88	15		Hill.
J. W. Kegly	Sec. 24	170	50		
T. 83 N., R. 4 W. (GREENFIELD).					
Geo. Lamb	NW. ¼ SE. ¼ sec. 1	214	202		All clay to rock.
F. B. Hakes	SE. ¼ NW. ¼ sec. 3	98	68		Nearly all sand. Ravine.
J. Ellison	SE. ¼ NW. ¼ sec. 4	62	32		
J. H. Armstrong	NW. ¼ NE. ¼ sec. 5	86	53		Low ground.
Wm. Breeds	NW. ¼ NW. ¼ sec. 6	86	80		Yellow clay, 20; blue clay to rock.
A. D. MacCanahy	NE. ¼ NW. ¼ sec. 10	100	99		
Peter Duncan	NE. ¼ SW. ¼ sec. 12	132	132		
T. 83 N., R. 3 W. (ROME).					
Jane Gauser	NW. ¼ SE. ¼ sec. 6	216	195		
R. J. Boots	NE. ¼ NE. ¼ sec. 7	131	95		Water heard running in vein.
H. P. Farnham	SW. ¼ NW. ¼ sec. 8	159	158		
S. Strong	SE. ¼ NW. ¼ sec. 10	210	80		Soil, 4; yellow clay, 71; no blue clay.
B. A. Jeffries	SE. ¼ SW. ¼ sec. 13	60	12		
	SW. ¼ SW. ¼ sec. 14	76	50		First rock hard gray flint underlain with soft porous limestone. Plenty of water.
—— Thrapp	NW. ¼ SW. ¼ sec. 17	61	32		
W. R. Vernon	SW. ¼ NW. ¼ sec. 25	179	70		Heads 59 feet below curb.
J. Rummel	SW. ¼ SW. ¼ sec. 36	78	36		Heads 48 feet below curb.
T. 83 N., R. 2 W. (HALL).					
Murray Bros	SE. ¼ SW. ¼ sec. 1	200	70		
B. Sherman	NW. ¼ NW. ¼ sec. 7	45	20		
—— Baumgartner	SW. ¼ SW. ¼ sec. 13	160	70		
P. W. Mitchell	SE. ¼ SE. ¼ sec. 16	163	100		
W. & L. Glick	SW. ¼ SW. ¼ sec. 20	72	26		Heads 30 feet below curb.
	NW. ¼ SW. ¼ sec. 22	42	23		
B. Meyers	SW. ¼ NE. ¼ sec. 24	160	70		
G. A. Phillips	NW. ¼ NW. ¼ sec. 27	150	145		

LINN COUNTY.

By W. H. NORTON.

TOPOGRAPHY.

The salient topographic features of Linn County are two long belts of dissected upland, consisting of loess and Kansan drift, coincident in the main with the courses of Cedar and Wapsipinicon rivers and hence traversing the county diagonally from northwest to southeast. These ridges rise 60 to 100 feet above the bordering drift plains and as much as 200 feet above the streams which cleave them. In places they close in on the rivers from either side and leave but narrow rock-bound gorges for the pathways of the streams, and for long stretches they draw back, leaving space for alluvial plains 1 to 2 miles wide. Here and there the upland disappears on one or both sides of the rivers and the Iowan drift plain comes down to the immediate valley of the stream.

The remainder of the county is occupied by the plain of Iowan drift. To the north of the Kansan upland bordering the Wapsipinicon lies a drift prairie, the only village upon it within the limits of the county being fitly named Prairieburg. To the south of the upland of Cedar River is an area of Iowan drift prairie fluted with numerous loess-capped elliptical hills, called paha, which rise in places as much as 120 feet above the adjacent streamways and whose major axes bear northwest and southeast. The surface is here further diversified by the wide and ancient channel now held by Prairie Creek. Fairfax and Ely are the villages of this area.

Between the two river ridges lies a broad plain of Iowan drift, on which are built Walker, Center Point, Marion, Springville, Mount Vernon, Lisbon, and several villages. The valleys of a number of southward-flowing creeks trench the prairie to a depth of from 40 to 60 feet. Paha are generally absent from the area except about its margins. Southeast of Springville, however, the plain is divided by a belt of hilly country with pahoid crests, leaving on either side an undulating prairie 3 or 4 miles wide.

GEOLOGY.

The uplands of the county are mantled, in some places to a depth of 40 feet, with loess, a yellow silt distinguished by the driller from the yellow stony clays beneath by its freedom from pebbles and by its darker and duller tint. The Iowan drift, which covers the prairies with its brownish pebbly sands and light yellow till, is too thin to be of importance in this inquiry. The Kansan drift sheet underlies the entire county. To it belong most of the blue and yellow stony clays which the driller finds everywhere. In places the Nebraskan drift is indicated by a dark till, separated from the overlying Kansan by old soils (Aftonian).

In the eastern part of the county the drift rests on the Niagara dolomite—a coarsely granular, crystalline, buff or blue-gray dolomite—which presents two phases. The first, the so-called "lime rock," seen at Viola and at the palisades near Mount Vernon, occurs in massive lenses 80 feet thick, almost destitute of structure planes, and also in highly tilted layers which afford easy descent for ground waters. The second phase, a buff, granular, finely laminated stone, is used extensively as a building stone; the strata are approximately horizontal and the joints and numerous bedding planes and porous layers offer ready passageways for the water.

In the central and western parts of the county (Pl. XI) the drift rests on strata of Devonian age, of which two formations have been distinguished. The upper, a yellowish limestone, in places highly fossiliferous, is known as the Cedar Valley limestone. The lower is an assemblage of strata, chiefly limestones, called the Wapsipinicon limestone, which includes a number of members to which names have been given by the Iowa State Survey from places of outcrop in this or adjoining counties. At the base of the Wapsipinicon is a soft, granular magnesian limestone (Coggon beds of Iowa Survey) somewhat resembling the Niagara, on which it rests. Next in ascending order is a variable brown or drab limestone, in places flinty (Otis beds of Iowa Survey), succeeded by a series of shales and shaly limestones, normally blue but locally black with carbonaceous content, and even containing thin discontinuous seams of coal, to which the Iowa State Survey has given the name Kenwood beds but which are considered as the equivalent of the Independence shale member of Buchanan County.

In the latter beds much flint is contained in concretionary masses. Upon them lies a heavy bed of broken or brecciated limestone made up of angular fragments (the Upper Davenport and Lower Davenport beds of the Iowa Survey), which may even embrace some of the underlying beds and in places include some of the lower beds of the overlying Cedar Valley limestone. In small areas in the county the bedrock is a sandstone or coaly shale belonging to the Pennsylvanian series.

The limestones of the Devonian are exceptionally soluble because of their slight magnesian content, and contain many water passages and some crevices where the drill drops slightly and in which running water is found. As the "Kenwood beds" (Independence shale member) are more or less clayey, they serve to arrest the descent of ground water and to impound it within the overlying limestones as in a reservoir. In Otter Creek, Washington, Spring Grove, and Fayette townships drillers report beds of "soapstone" which are referable to the Independence member.

UNDERGROUND WATER.

SOURCE AND DISTRIBUTION.

On the broad flood plain of Cedar River open and driven wells 15 to 30 feet deep obtain an abundant supply of water in river-laid sands and gravels.

About the margin of the Iowan drift the loess graduates downward by interstratification into yellow sands, which furnish small supplies for house and farm wells in the areas bordering paha hills and the Kansan upland, and in some of the towns of the county bring ground water into the cellars of houses located on the flanks of loess-capped hills. The lower portion of the loess, which is in many places gray or ashen in color, may become so saturated with water as to form a quicksand in railway cuts and other excavations, and may afford a scanty and inconstant supply for shallow wells. The loess and its basal sands are poor aquifers. The loess is thick upon the summits of the uplands and of the paha hills; but these uplands are deeply dissected and water readily drains out, leaving little stored for the supply of wells; and where the land is low and comparatively level, the loess is either so thin as to be negligible, or is wholly wanting. Wells sunk in loess should, if possible, be located where the subsurface seepage follows along channels cut in the Kansan drift, as, for example, near the foot of a large ravine or where several ravines converge.

Beds of sand and gravel occur in the drift clays and may separate the upper weathered zone of yellow stony clay from the blue unweathered till beneath. The sands immediately beneath the yellow tills may yield small supplies of water, but as a rule wells are compelled to seek deeper aquifers, which may occur in sands and gravels (Aftonian) lying beneath the Kansan drift sheet, in lenses of sand in either of the older drifts, or in gravels lying on bedrock. The gravels above bedrock are in some places found oxidized and even cemented to a hardpan through the seepage of water, while the overlying till retains its normal bluish color.

On the Iowan drift plain ground water stands high wherever porous beds capable of storing and transmitting water are found near the surface, but even here impervious thick beds of stony clay may force the owners of wells to drill deep to find water in adequate amounts in interglacial and preglacial sands or in the rock. On the uplands of loess and Kansan drift in the immediate vicinity of the rivers and creeks the ground-water surface approaches the level of its outlets at the water level of the streams, and wells are necessarily deep.

In general, all these Pleistocene beds have been decreasing in value as water bearers, owing both to the progressive lowering of ground water since the settlement of the country and to the continued increase in the drafts upon them.

Old soils and accumulations of wood which affect the quality of well water are reported from some wells, but are relatively so few that they do not seem referable to any special horizon. Thus, in secs. 10 and 11 of Washington Township dug wells encounter at about 60 feet from the bottom deposits of wood, like driftwood, with some logs said to show marks of beaver cutting. The forest bed here occurs beneath blue clay which extends upward to within a few feet of the surface, yellow till being absent.

The Niagara dolomite is one of the chief aquifers of the county. The towns of Mount Vernon and Lisbon draw from it their town supply, and farm wells tap it over all the eastern townships of the county. The formation measures more than 300 feet in thickness and rests upon the thick and impervious Maquoketa shale which effectually prevents any leakage of ground water downward. In the central and western parts of the county the westward dip of the Niagara carries it beneath overlying Devonian strata along a sinuous line extending south from Coggon to near Bertram, and the formation carries with it the ground water received on its broad area of outcrop. The lower argillaceous beds of the Devonian here to a large extent prevent upward leakage from the artesian pressure to which the water of the Niagara is subjected. Wells sunk into the Niagara in the central and western townships of the county have fair prospects of obtaining a bountiful supply of water, although in this, as in all other limestone formations, it is never certain that the drill will strike one of the water channels of the rock.

BURIED CHANNELS.

Some exceptionally deep wells in drift indicate ancient channels excavated in rock in interglacial or preglacial time and later filled with deposits of ground moraine or outwash sands. Thus a belt of "deep country" where a number of wells in drift exceed 275 and 300 feet in depth extends north from Prairieburg to the Delaware County line, embracing secs. 2, 10, 11, 15, 22, and 28 of Bowlder Township. This channel is probably a continuation of that of western Jones County. In several places farm wells have disclosed such buried channels which can not be traced across the country with the little data at hand. Thus 3 miles west of Mount Vernon (SE. ¼ SE. ¼ sec. 12, T. 82 N., R. 6 W.) the following well section is reported. It will be noticed that the depth at which rock was reached is 110 feet below low water in the Cedar River and nearly 100 feet below its rock-cut bed.

Section of well 3 miles west of Mount Vernon (Pl. XI, p. 382).

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, yellow	14	14
Clay, hard, blue, pebbly	48	62
Soil, dark, and wood	6	68
Clay, blue, stony	66	134
Sand and gravel	8	142
Clay, blue, stony	63	205
River sand to rock	6	211

In the northern part of the county (NW. ¼ sec. 17, T. 86 N., R. 6 W.) another buried channel shows the following section:

Section of well in northern part of Linn County.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and clay, yellow, pebbly	19	19
Sand, yellow	4	23
Clay, blue; changeable from hard to soft every few feet	190	213
Sand, fine, white	13	226
Sand, coarser, with wood	12	238
Gravel, coarse	3	241

In towns, house wells are so closely spaced that even narrow gorges cut in rock can be discovered and traced. At Lisbon, where the rock outcrops or is found within 6 to 24 feet of the surface, a gorge half a mile long, 115 feet deep, and about 18 rods wide extends through the town. The drift, which completely fills this ancient channel, leaving no surface indication of it, consists of yellow and blue clays with some beds of gravel. At Central City an old channel of Wapsipinicon River is disclosed by wells on the east side of the village. It is separated from the present channel by a rocky elevation that comes within a very few feet of the surface of the low plain on which the village stands. The channel, which is filled with yellow sand, is 96 feet deep, or 60 feet below water in the river.

In Cedar Rapids, on the west side of the river, a buried channel 60 feet deep extends parallel to the river and separated from the present rock-cut bed of the stream by limestone rising nearly to the level of the low, broad flood plain on which this portion of the city is built.

SPRINGS.

No marked spring horizons are found in Linn County, for in it there are no outcropping planes of contact of limestones with underlying thick and persistent shales. The most important springs are those which form the main supply of the town of Marion. (See p. 449.) Other springs rise from the Devonian along its outcrops on the valley sides of Cedar River north of Cedar Rapids, and still others along the Wapsipinicon from Central City to Troy Mills, but few, if any, are strong enough to yield a stream of any size.

Springs from the Niagara are found in many localities over the outcrop of that formation. Thus the springs in Spring Hollow, at the summer resort of the Palisades of Cedar River, rise from the base of cliffs of the Niagara. A large spring from the same formation is that of Granger, on Wapsipinicon River, 2 miles northwest of Central City. The large spring which supplies Lisbon may in part draw its waters from the Niagara.

Small springs and seepages occur in large numbers where the valleys transect the porous sands and gravels of the drift.

CITY AND VILLAGE SUPPLIES.

Cedar Rapids.—The public supply of Cedar Rapids (population 32,811) is drawn from Cedar River and from three artesian wells located 100 to 200 feet apart at the apices of a triangle. (See Pl. XI.) The total capacity of the works is 10,000,000 gallons daily and the consumption is 2,500,000 gallons. The domestic pressure is 60 pounds and the fire pressure 130 pounds. There are 53 miles of mains, 4,200 taps, and 310 fire hydrants. The wells are described as follows:

The waterworks well No. 1 has a depth of 2,225 feet and a diameter of 5 inches. The curb is 733 feet above sea level. The original head was 28 feet above the curb and the original discharge 250 gallons a minute; the present head is 2 feet above the curb and the present discharge 150 gallons a minute. First water was from 85 feet and first flow from 1,050 feet; water was also found at 1,300 to 1,450 feet and at 2,000 feet. The well was completed in 1888 at a cost of $6,065 by J. P. Miller & Co., of Chicago. Corroded casing was drawn in 1893. In 1894 the well was reamed to 8 inches to a depth of 1,450 feet and plugged there to shut off a lower salty and corrosive water; no increase in flow resulted.

The following record of strata is based on only 25 samples, and its accuracy is, therefore, open to question:

Record of strata of waterworks well No. 1, at Cedar Rapids (Pl. XI, p. 382).

	Thickness.	Depth.
	Feet.	*Feet.*
Alluvium	10	10
Limestone, light buff, rather soft, magnesian, and gray, very hard, nonmagnesian, compact; somewhat fragmental in structure	40	50
Limestone, gray, sparry, subcrystalline	85	135
Limestone, moderately hard, light buff, magnesian	40	175
Dolomite, pink, minutely vesicular, subcrystalline	65	240
Dolomite, bright buff, porous	60	300
Dolomite, hard, light gray, porous	30	330
Dolomite, light yellow; coarser grained than that above	20	350
Dolomite, hard, light gray, subcrystalline; some white chert	25	375
Dolomite, yellowish; like above but softer	45	420
Shale, fine, bluish green, calcareous, magnesian	200	620
Limestone, magnesian and nonmagnesian	295	915
Shale	5	920
Sandstone, slightly bluish or greenish gray; grains of quartz rounded; considerable calcareous powder; some gray shale	65	985
Shale, dark colored	1	986
Sandstone; clean, white grains, rounded and somewhat uniform in size	50	1,036
Dolomite, light gray, rather hard, arenaceous, fine textured; much finely laminated green shale	114	1,150
Dolomite, gray; with chert, white, and quartzose sand	270	1,420
Sandstone; fine, white, rounded grains with much finely comminuted quartz and many small angular fragments of white dolomite	88	1,508
Sandstone, fine, yellowish, water bearing	42	1,550
Sandstone, with slight admixture of calcareous powder	140	1,690
Shale, tough and hard; small amount of very fine siliceous particles and some dolomite	100	1,790
Sandstone; light, reddish grains largely angular; some with crystalline facets	160	1,950
Sandstone, cream colored, very fine grained	200	2,150
Quartzite, reddish brown; grains angular; rock drilled with great difficulty	75	2,225

The waterworks well No. 2 has a depth of 1,450 feet and a diameter of 5 inches; cased to 85 feet. The curb is 733 feet above sea level. The original head was 28 feet above the curb; present head, 2 feet above the curb. The original discharge was 250 gallons a minute; present discharge, 150 gallons a minute. Water comes from depths of 485 feet, 1,050 feet, and 1,300 to 1,450 feet. Temperature, 62° F. The well was completed in 1888, at a cost of $3,205, by J. P. Miller & Co., of Chicago.

Waterworks well No. 3 is of the same dimensions as well No. 2. It is not now used.

The Young Men's Christian Association well has a depth of 1,462 feet and a diameter of 5 inches. The curb is 733 feet above sea level and the original head is 2½ feet above the curb. It was at first cased to a depth of 1,372 feet, but as a large part of the flow was thus shut off the casing was drawn and the well left cased to 85 feet. The well was completed in 1894 by A. K. Wallen, of Ottawa, Ill.

The following record of strata is based on a large number of drillings taken at frequent intervals. Unfortunately, samples were not saved for the first 90 feet, within which space the drill must have passed through the lowest beds of the Devonian system.

Record of strata of Young Men's Christian Association well at Cedar Rapids.

	Thickness.	Depth.
Devonian (95 feet thick; top, 733 feet above sea level)—	*Feet.*	*Feet.*
No samples	90	90
Nonmagnesian limestone, dark, slate-colored; in chips; argillaceous, hard, compact, subconchoidal fracture; pyritiferous; showing junction surfaces with green clay; smaller chips of light buff magnesian limestone; not porous; earthy luster; green clay	5	95
Silurian:		
Niagara dolomite (349 feet thick; top, 638 feet above sea level)—		
Magnesian limestone, or dolomite, light buff; slightly vesicular, earthy luster; samples at 95, 105, 115 feet	25	120
Dolomites, buff, pinkish, and gray; mostly vesicular, subcrystalline and subtranslucent; 17 samples	324	444
Ordovician:		
Maquoketa shale (276 feet thick; top, 289 feet above sea level)—		
Dolomite, hard, gray, argillaceous; with argillaceous powder	6	450
Shale, bluish; intercalated limestones at 525, 565, and 595 feet; 7 samples.	270	720
Galena dolomite and Platteville limestone (305 feet thick; top, 13 feet above sea level)—		
Dolomites, rough, hard; 6 samples	65	785
Limestones, magnesian, some cherty; 8 samples	135	920
Limestones; briskly effervescent, earthy; in flaky chips; bluish gray	15	935
Shale and limestone, brown, petroliferous	15	950
Shale, blue	40	990
Limestone, bluish gray; in flaky chips; briskly effervescent; samples at 990 and 1,000 feet	35	1,025
St. Peter sandstone (20 feet thick; top, 292 feet below sea level)—		
Sandstone; of clean, white quartz sand; grains rounded and ground	20	1,045
Prairie du Chien group (355 feet thick; top, 312 feet below sea level)—		
Shakopee dolomite (125 feet thick)—		
Dolomite, gray, cherty; samples at 1,045, 1,080, 1,100, and 1,115 feet	85	1,130
Dolomite, arenaceous; in fine buff dolomitic powder with some quartzose grains	40	1,170
New Richmond sandstone (55 feet thick)—		
Sandstone; in fine, light yellow quartz sand of angular grains; some dolomite; 3 samples	55	1,225
Oneota dolomite—		
Dolomite, gray; 12 samples; at 1,240 and 1,380 feet arenaceous	....	1,400
Cambrian:		
Jordan sandstone (62 feet penetrated; top, 667 feet below sea level)—		
Sandstone; clean white quartz sand similar to the St. Peter, but coarser; 4 samples; at 1,435 feet slightly calciferous	....	1,462

This section indicates that the lower strata of water-works well No. 1 may be correlated as follows:

St. Lawrence formation, 1,462 (?) to 1,790 feet; earlier Cambrian, 1,790 to 2,150 feet; Algonkian (?) quartzite, 2,150 to 2,225 feet.

A number of moderately deep wells, such as those of the gas company, the starch works, and the Montrose Hotel, draw an excellent supply of water from the Niagara. The well at Montrose Hotel is 8 inches in diameter and 235 feet deep. Water heads 11 feet below the curb and can be lowered but 7 feet by pumping. The well is cased to rock about 30 feet below the level of the street. An older well, 95 feet deep, yielded a wholly insufficient supply.

Central City.—At Central City (population, 558) the St. Peter sandstone will be found at about 75 feet above sea level or 912 feet below the surface. Possibly this sandstone, together with the water of such veins as might be struck in the Niagara and Galena, would furnish a supply ample for the town at present. Otherwise the well should be sunk about 400 feet deeper, or to a total depth of about 1,300 feet.

Coggon.—Water is supplied to Coggon (population, 471) by a well and pumped to an elevated tank affording a gravity pressure of 43 pounds. There are 3,000 feet of mains and nine hydrants.

Lisbon.—At Lisbon (population, 848) a spring whose water issues from Niagara dolomite, near the head of a ravine in the northwestern part of town, is pumped to a standpipe. The domestic pressure is 45 pounds and the fire pressure 100 pounds. There are 16 hydrants and 1½ miles of mains.

Marion.—Water for Marion (population, 4,400) is obtained from four large springs, supplemented for fire protection by water from Indian Creek. Four springs—the Bowman, Lower Bowman, Davis, and Riley—are inclosed in stone reservoirs with roofed superstructures and screened openings. They flow 3,000,000 gallons a day from near the base of the Wapsipinicon limestone. The pressure is direct, the domestic being 60 pounds and the fire pressure from 80 to 120 pounds. There are 15 miles of mains, 73 hydrants, and 1,000 taps. The supply from the springs far exceeds the maximum daily consumption.

The record of the Cedar Rapids deep wells indicate approximately the prospects for such wells at Marion. Allowing for the difference in elevation and the dip of the strata, a well about 1,500 feet deep would obtain water which would not flow, but which should rise nearly to the surface.

Mount Vernon.—The water supply of Mount Vernon (population, 1,532) is drawn from a well 328 feet deep, ending near the base of the Niagara dolomite. (See Pl. XI.) The yield is augmented from surface gravels whose waters are admitted to the well, so that pumping draws the water down in adjacent shallow wells.

The well entered rock at 10 feet and the principal supply is said to have been found at 160 feet. Water rises within 6 feet of the curb. The water is distributed under direct pressure and from a standpipe; the pressure varies, according to location, from 45 to 80 pounds. There are 2¾ miles of mains, 42 hydrants, and 275 taps. The consumption is estimated at 25,000 gallons daily.

A statement of the artesian conditions at Mount Vernon was prepared by W. H. Norton several years ago, when the city waterworks were built, but was not acted on, as the supply obtained by the city well was considered sufficient. The advisability of a deep well has been again raised, however, as a supply for Cornell College and especially for the swimming pool of the new gymnasium.

At Mount Vernon (elevation, 843 feet) the drill will find below the country rock (Niagara) 250 feet or more of a dry shale—the Maquoketa. This shale rests on a series of dolomites and limestones with some shales, aggregating 300 feet or more in thickness and known as Galena dolomite, Decorah shale, and Platteville limestone. The St. Peter sandstone will be struck somewhere between 100 and 250 feet below sea level, the exact position being doubtful because of the strong upwarp of the strata whose axis probably lies east of the town. (Pl. XI). It is probable that the effect of the uplift extends as far west as Mount Vernon, and the St. Peter is expected to occur nearer the first-mentioned than the last-mentioned depth.

The water from the St. Peter and such as may be found in the superior limestones may be found adequate for the college needs. The water will be of good quality and should rise within 50 to 100 feet of the level of the surface at the railway station.

A deep well for city supply should be drilled to a depth of 400 or 500 feet below the St. Peter sandstone to obtain the much greater yields of the water-bearing strata underlying that terrane. To tap the Prairie du Chien and the Jordan aquifers, a well need not exceed 1,600 feet in depth, and a depth of 1,400 feet would probably suffice if the St. Peter lies as high as there is some reason to suppose. The well should be so located as to avoid all ground-water drainage lines passing through the town through surface sands and gravels, and should be so cased as absolutely to exclude such waters.

Springville.—The water supply of Springville (population, 588) is drawn from a well of which no report has been obtained. The gravity pressure from standpipe is 62 pounds and the direct fire pressure is 120 pounds. There are nine hydrants and 1 mile of mains.

Walker.—Artesian wells at Walker (population, 517) should find the St. Peter sandstone about 965 feet below the surface or 75 feet below sea level. From 540 to 310 feet above sea level (350 to 580 feet below the surface) the drill would pass through dry shales (Maquoketa) which should be cased. Water would probably be found in small quantities in the Devonian and Silurian limestones, which overlie these shales, and in the Galena and Platteville limestones which underlie them. Probably sufficient water could be found in the St. Peter for the present needs of the town, but if not, the well should be carried to about 1,400 feet below the surface to tap the large stores of the Prairie du Chien group and the Jordan sandstone.

The water will not flow at the surface, as the head in the St. Peter sandstone can hardly be higher than 100 feet below the surface. The upper limestone waters will probably rise higher.

Minor supplies.—Details of water supplies of minor towns and villages are given in the following table:

Village supplies in Linn County.

Town.	Nature of supply.	Depth.	Depth to water-bed.	Head below curb.
		Feet.	*Feet.*	*Feet.*
Alburnett	Drilled wells	55-100		
Bertram	Drilled and driven wells	23-124		12- 75
Center Point	Drilled wells	15-175	15-130	30- 50
Ely	Open, drilled, and driven wells	17- 48	20	10+
Fairfax	No report			
Norway	Drilled wells	150-400		
Paralta	Wells and cisterns	25- 50	100	10- 95
Prairieburg	Drilled wells	13-140		3-100
Palo	Driven wells	18- 24	20	
Viola	Drilled wells and cisterns	30- 85		20

WELL DATA.

The following table gives data, largely gathered by the late Dr. M. J. Iorns, of the Department of Agriculture, of typical wells in Linn County:

Wells in Linn County.

Owner.	Location.	Depth.	Depth to rock.	Depth to water supply.	Source of supply.	Head above or below curb.	Remarks (logs given in feet).
T. 86 N., R. 5 W. (BOWLDER).		*Feet.*	*Feet.*	*Feet.*		*Feet.*	
T. Cushman	SE. ¼ SE. ¼ sec. 1.	160	160	155	Sand on rock.		
L. Gehringer	SW. ¼ sec. 2		270				
A. McDonald	SE. ¼ sec. 4	160	160				
L. McEvoy	SE. ¼ NW. ¼ sec. 4.	160	159		Limestone	−60	All yellow and blue clay; no sand.
E. C. Bebb	SE. ¼ SE. ¼ sec. 8	45	20				
D. Carr	NE. ¼ NE. ¼ sec. 9.	170	150		Limestone		All clay; 10 feet of red sticky clay (geest) on rock.
D. Hennessy	SE. ¼ SE. ¼ sec. 10.	160	160				

Wells in Linn County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Depth to water supply.	Source of supply.	Head above or below curb.	Remarks (logs given in feet).
T. 86 N., R. 5 W. (BOWLDER)—Con.		*Feet.*	*Feet.*	*Feet.*		*Feet.*	
S. McAleer	SW. ¼ SW. ¼ sec. 12.	160		125	Sandstone		
D. Hennessy Creamery.	NW. ¼ sec. 11		308				
W. McAleer	NE. ¼ NE. ¼ sec. 13.	130	130				
C. LeClaire	NW. ¼ sec. 14	160	160				
J. Franklin	SW. ¼ sec. 14	160	160				
W. G. Zimmerman	SE. ¼ NW. ¼ sec. 15.	160	160				
P. Pillard	NW. ¼ SE. ¼ sec. 15.	160	160				
W. McEvoy	NW. ¼ NE. ¼ sec. 17.	60	40		Limestone	− 40	Trace of red geest on rock.
J. W. Braselton	SE. ¼ SW. ¼ sec. 17.	95	95		Sand	− 15	Quicksand 35 feet deep to rock.
C. Jensen	NE. ¼ NE. ¼ sec. 19.		140				
Kimball estate	SE. ¼ NW. ¼ sec. 20.		130				
J. Whitney	SW. ¼ NE. ¼ sec. 20.		70				
P. McMurtin	NW. ¼ NE. ¼ sec. 20.		145				
E. Berlingham	SW. ¼ SW. ¼ sec. 21.		100		Gravel		All gravel to rock.
J. Sibil	SE. ¼ SE. ¼ sec. 22.		180				
G. Cowan	NW. ¼ sec. 23	303		276	Sand	−103	3-foot sand bed, at depth of 25 feet; considerable water from 276 to 303. Sand and gravel with water.
P. H. Ryan	SE. ¼ NE. ¼ sec. 23.	180	180		On rock		
M. A. Leonard	SE. ¼ SE. ¼ sec. 23.	313	313				
O. Rundall	SW. ¼ SW. ¼ sec. 23.	240	240				From 220 to 230. "soluble" blue clay.
J. I. Henderson	NW. ¼ NW. ¼ sec. 24.		125				
J. I. Henderson	SW. ¼ sec. 24	150	150		On rock		
T. Shaffer	NE. ¼ NE. ¼ sec. 25.	80	80		On rock		
J. H. Holub	NE. ¼ SE. ¼ sec. 25.	35			Sand		Dug well.
J. Plower	SW. ¼ SW. ¼ sec. 25.	195	185	195	Limestone		
W. Johanek	NE. ¼ NE. ¼ sec. 26.		190				
A. Kula	NW. ¼ NW. ¼ sec. 26.	165			Sand and gravel.		Yellow and blue clays, 150; sand gravel, 15.
F. J. Kula	SW. ¼ NE. ¼ sec. 27.		128				
F. Valanta	SW. ¼ NW. ¼ sec. 27.	50	50		On rock		
J. Kula	SW. ¼ SW. ¼ sec. 27.	50	20		Limestone		
Prairieburg	NW. ¼ NW. ¼ sec. 28.	120	120		On limestone.		All blue clay.
J. Walker	SE. ¼ sec. 28	50	50		On rock		
W. Hill	NE. ¼ SW. ¼ sec. 29.						
J. Whitney	NW. ¼ sec. 24						
F. L. Williams	NW. ¼ NW. ¼ sec. 30.		100				
A. Burnside	SW. ¼ NE. ¼ sec. 30.	120	120				Yellow and blue clays to rock.
G. Borsky	SW. ¼ SE. ¼ sec. 30.	120	120				

Wells in Linn County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Depth to water supply.	Source of supply.	Head above or below curb.	Remarks (logs given in feet).
T. 86 N., R. 5 W. (BOWLDER)—Con.							
		Feet.	*Feet.*	*Feet.*		*Feet.*	
A. E. Butler	NW. ¼ SW. ¼ sec. 34.	188	88	188	Limestone		Loess, 45; blue clay, 15; sand, 10; blue clay, 18; limestone, 100.
M. C. Walker	SW. ¼ NW. ¼ sec. 34.	92	40		Limestone		All gravel above rock.
A. Lawrence	SE. ¼ NE. ¼ sec. 35.		198			− 14	
W. Johanek	SE. ¼ SE. ¼ sec. 35.		213				
J. B. Holub	NE. ¼ NE. ¼ sec. 36.		149				Yellow clay, 30; solid blue clay, 119.
M. Holub	SE. ¼ SE. ¼ sec. 36.		185				
F. Stack	SW. ¼ sec. 36		185				
T. 86 N., R. 6 W. (JACKSON).							
Lawton estate	NW. ¼ NW. ¼ sec. 1.	180	40	180	Limestone	− 40	
W. H. Sherman	NW. ¼ NW. ¼ sec. 2.	180	40				
T. L. Main	NE. ¼ NW. ¼ sec. 3.	160	8				
J. H. Ashby	NW. ¼ NE. ¼ sec. 3.	125	25			− 25	
L. H. Webb	NW. ¼ NE. ¼ sec. 5.	52			Gravel	− 10	
S. N. Joslyn	SW. ¼ SE. ¼ sec. 5.		270				
F. M. Phillips	NW. ¼ NW. ¼ sec. 5.	180	180		On rock		Yellow clay, 15; blue clay to rock.
D. L. Castle	SW. ¼ sec. 6	140	40	140			
C. Ellis	NE. ¼ SE. ¼ sec. 6.	100	100		Limestone		
L. Dix	SW. ¼ SE. ¼ sec. 6.	242	242				
S. M. Dennis	NW. ¼ NW. ¼ sec. 7.	75	50	75	Spongy limestone.	− 50	
C. Boone	NW. ¼ sec. 7	100	40	100			
R. W. Trumble	SE. ¼ NW. ¼ sec. 8.			200+			
H. P. Hanna	NW. ¼ NW. ¼ sec. 9.		190				
H. Henderson	SE. ¼ NE. ¼ sec. 9.	186			On rock	−126	Yellow clay, 20; sand and gravel, 20; blue clay to limestone rock.
G. Joslyn	NE. ¼ SW. ¼ sec. 9.	232	230	180	Sand	− 50	Yellow clay, 20; blue clay, 160; clear sand, 50; limestone, 2.
W. McTavish	SW. ¼ SW. ¼ sec. 9.	240	240				Yellow and blue clay with layers of quicksand.
H. Henderson	SE. ¼ sec. 10		171		Sand		Yellow and blue clay, 166 feet; sand, 5 feet.
W. J. Woods	SW. ¼ SE. ¼ sec. 10.	122	116		Rock	−116	All yellow and blue clay.
C. Medary	SE. ¼ SE. ¼ sec. 14.						
A. S. Green	SW. ¼ sec. 14		195				
C. B. Chesmore	NW. ¼ NE. ¼ sec. 15.	180	180		On rock		
O. Woods	NE. ¼ sec. 15	202	202			−102	Sandbeds.
W. Woods	NW. ¼ SE. ¼ sec. sec. 15.						
C. Forest	NE. ¼ SE. ¼ sec. 16.	140	130				Blue clay to rock.
T. Long	SE. ¼ SE. ¼ sec. 17.	142	140		"Shell-rock."	− 60	Blue clay to rock.

Wells in Linn County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Depth to water supply.	Source of supply.	Head above or below curb.	Remarks (logs given in feet).
T. 86 N., R. 6 W. (JACKSON)—Con.							
		Feet.	*Feet.*	*Feet.*		*Feet.*	
C. J. Avis	NW. ¼ NE. ¼ sec. 18.	185	35	185			
C. Waterhouse	NE. ¼ NE. ¼ sec. 20.	80					
P. I. Henderson	SE. ¼ NE. ¼ sec. 21.	35					At 32 feet old soil, 8 more layers 3 feet thick.
J. Cutlers	SW. ¼ SE. ¼ sec. 23.		124				
C. B. Chesmore	NW. ¼ NW. ¼ sec. 23.		195				
J. Slife	SW. ¼ NE. ¼ sec. 25.		145				Yellow clay with streaks of gravel; blue clay to rock.
S. N. Krutzer	NW. ¼ SE. ¼ sec. 26.	126	126		On rock		
H. R. Shakespear	SW. ¼ NW. ¼ sec. 26.		60				
R. Moles	SW. ¼ SW. ¼ sec. 29.						
B. T. Hall	SW. ¼ SE. ¼ sec. 30.	70	40	70			
J. D. Moles	NW. ¼ sec. 32	140	120	140	Limestone		
B. W. Long	SW. ¼ SW. ¼ sec. 32.		70				At cemetery.
B. W. Long	SW. ¼ SW. ¼ sec. 32.	140					Yellow clay, 25; blue clay with sandy layers, 75 yellow sand changing to gravel, 6.
J. Blodgett	SW. ¼ SW. ¼ sec. 35.	70	70				
D. J. Powell	NW. ¼ SW. ¼ sec. 33.		190				Rock bluffs to rock on rivers.
J. R. Stone	NE. ¼ NE. ¼ sec. 36.	100	80	100	Limestone		
O. Gilchrist	NE. ¼ SE. ¼ sec. 29.	47	9				Yellow clay, limestone, blue sandstone, and shale, 45; a little coal.
T. 86 N., R. 7 W. (SPRING GROVE).							
J. Peyton	SE. ¼ SE. ¼ sec. 3.	200	20			−25	
James McKnight	SE. ¼ NE. ¼ sec. 8.	180					Rock from near surface.
G. C. Gardner	NW. ¼ NE. ¼ sec. 13.	185	35				
S. B. Mills	NW. ¼ SE. ¼ sec. 23.	40			Gravel		
E. C. Cook	SW. ¼ NE. ¼ sec. 20.	252	62				Yellow clay, blue clay to rock, small vein.
W. D. Bucklon	NE. ¼ NE. ¼ sec. 22.	140	20				Dark shale (Independence) at bottom.
F. A. Wilson	SE. ¼ SE. ¼ sec. 22.	109	20				
W. Forest	NE. ¼ NE. ¼ sec. 25.	140	120	138			Yellow clay, 20; blue clay with bowlders, 100; very hard blue limestone, 18; yellow limestone 2.
E. D. Powers	NW. ¼ SW. ¼ sec. 25.		245				
S. R. Mills	SE. ¼ NE. ¼ sec. 26.		70				
J. F. Robinson	NE. ¼ SE. ¼ sec. 26.	140	65				
F. W. Bleakley	NE. ¼ NE. ¼ sec. 27.						

Wells in Linn County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Depth to water supply.	Source of supply.	Head above or below curb.	Remarks (logs given in feet).
T. 86 N., R. 7 W. (SPRING GROVE)—Continued.		*Feet.*	*Feet.*	*Feet.*		*Feet.*	
C. Robinson	SE. ¼ SE. ¼ sec. 32.	54	54		On rock	−20	Yellow clay, 16; blue clay, 38, to rock.
A. G. McBurney	NE. ¼ sec. 34	150	75	150		−60	Rock, very porous.
Sisler estate	NE. ¼ sec. 36	105	80				Yellow clay, 20; blue clay, 60; black shale, 25.
A. Simon	SE. ¼ sec. 19						
P. W. Mix	SE. ¼ NE. ¼ sec. 22.	140	20				At 140 feet thin layer of dark shale (Independence).
T. 86 N., R. 8 W. (GRANT).							
J. Wachal	NE. ¼ NW. sec. 21.	33	30		On rock	−18	Dug well. Loam, 5; yellow clay, stony, 5; blue clay, 20; rock, 3.
M. Darrow	NE. ¼ SE. ¼ sec. 21.	62	18	62			
W. H. Newland	NE. ¼ SW. ¼ sec. 28.	80	35			−40	
J. Heverly	SE. ¼ SW. ¼ sec. 31.						
M. Hazeltine	NE. ¼ sec. 32	137	40	137	"Sandstone."	−17	Yellow clay, 15; solid blue clay, 25.
C. Cox	NW. ¼ NE. ¼ sec. 34.	130			Gravel		Yellow clay; blue clay; sand, blue clay at 130 feet; gravel.
C. H. Nietert	NW. ¼ SE. ¼ sec. 25.	117	30				Yellow and blue clay to rock.
M. L. Kerly	NW. ¼ sec. 21	203	130		"Sandstone."	−20	Drift, 130; limestone, 40; blue "marble," 16; "sandstone," 17.
M. A. Hamlin	SE. ¼ SW. ¼ sec. 33.	100	52	100	"Sandstone."	−40	Yellow clay; blue clay with layers of sand; "sandstone," water-bearing, at 100 feet.
T. 85 N., R. 5 W. (BUFFALO; PART OF MAINE).							
J. Plower	NW. ¼ NE. ¼ sec. 1.	128	128				
F. Fousek	NW. ¼ NW. ¼ sec. 1.	240	240				Yellow clay, 25; blue clay to rock.
J. Bouchtela	SW. ¼ NE. ¼ sec. 1.	140	140		On rock		Northern blue clay.
M. Holub	NE. ¼ SW. ¼ sec. 1.	120	120		do		Northern blue clay, some sand and gravel.
W. Lawrence	NE. ¼ NE. ¼ sec. 2.		229				
W. Johanek (2 wells).	SW. ¼ NW. ¼ sec. 2.	213 / 108	213 / 0		On rock / Gravel		All gravel.
J. Peet	NE. ¼ SW. ¼ sec. 3.		30				
J. McNamera	NE. ¼ SE. ¼ sec. 3.	108			Gravel		Do.
Story estate	NW. ¼ SW. ¼ sec. 3.	80	80				All gravel and sand.
H. Story	SE. ¼ NE. ¼ sec. 4.	80	80			− 6	
J. Peet	SE. ¼ SE. ¼ sec. 3.	125	125		Gravel		All gravel to rock.
Matsell Bros	NE. ¼ SW. ¼ sec. 8.		150				
T. Neilly	NE. ¼ SE. ¼ sec. 11.	140	140				Mostly blue clay.

Wells in Linn County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Depth to water supply.	Source of supply.	Head above or below curb.	Remarks (logs given in feet.)
T. 85 N., R. 5 W. (BUFFALO; PART OF MAINE)—Con.		*Feet.*	*Feet.*	*Feet.*		*Feet.*	
W. Jackson	SE. ¼ SE. ¼ sec. 13.	30	30		Gravel		Creek bottom; all gravel.
M. Green	SE. ¼ SW. ¼ sec. 13.	80	50		Limestone		Mostly yellow clay.
J. Anderson	SE. ¼ NE. ¼ sec. 14.	100	100		Gravel		Mostly sand and gravel.
W. Ross	SE. ¼ SW. ¼ sec. 15.	140	140				Yellow clay, 30; blue clay to rock.
G. Minehart	SE. ¼ SE. ¼ sec. 15.		156				Ridge. Yellow clay, 30; blue clay to rock.
J. M. Parsons	NW. ¼ sec. 17		130				
J. G. Denny	NW. ¼ NW. ¼ sec. 19.	105	30				
J. C. Kennedy	NW. ¼ sec. 20	60	20	60	Showing water in crevice.		
F. Richards	SE. ¼ NW. ¼ sec. 23.		160		On rock		Ridge. Yellow clay, 30; blue clay to rock.
D. C. Peet	NE. ¼ NE. ¼ sec. 25.	180	80	180	Shelly limestone.		
J. Birk	SE. ¼ SE. ¼ sec. 25.		100				
S. L. Bowdish	NE. ¼ SW. ¼ sec. 29.		185				Mostly blue clay.
R. Bennett	SW. ¼ NW. ¼ sec. 29.		162				
W. Hartsell	NW. ¼ NW. ¼ sec. 29.		120				
S. F. Bowdish	NW. ¼ NW. ¼ sec. 32.		292				Yellow clay, 30; sand with some water at 40; blue clay with streaks from 60 and to rock.
T. Wilkinson	NW. ¼ NW. ¼ sec. 31.	297	289			−89	Yellow clay, 35; blue clay, 100; white sand, 20; blue clay, 134; shell rock, 8.
A. Shanklin	NW. ¼ NE. ¼ sec. 33.	120	120				First 40 feet dug; blue clay from 40 feet to bottom.
T 85 N., R. 6 W. (PART OF MAINE).							
H. Smith	SE. ¼ NE. ¼ sec. 2.	100	1	75		−30	Pockets of very sticky, waxy, yellow clay.
I. Floss	SE. ¼ SE. ¼ sec. 4.	+240	240				
A. M. Jayne	SE. ¼ NE. ¼ sec. 4.		160				
Harms Bros	NW. ¼ NE. ¼ sec. 4.		93				
L. B. Stark	NE. ¼ SE. ¼ sec. 4.		100				
G. Nightingale	SW. ¼ sec. 5	185	172				Yellow and blue clay to rock.
C. J. Church	NE. ¼ SE. ¼ sec. 6.	135	135		On rock	−95	Do. clay to rock.
J. H. Summers	NE. ¼ SW. ¼ sec. 6.	185					
G. M. Rogers	NE. ¼ NE. ¼ sec. 7.	240	232			−70	Yellow clay, 30; blue clay, 170; shell rock and gravel 32; rock, 8.
Creamery	NE. ¼ NE. ¼ sec. 7.		245			−70	No sand; nearly all blue clay.
Martha Taylor	SE. ¼ NE. ¼ sec. 7.	233	233				Yellow clay 30; blue clay, 200; sand, 3.

Wells in Linn County—Continued.

Owner.	Lacation.	Depth.	Depth to rock.	Depth to water supply.	Source of supply.	Head above or below curb.	Remarks (logs given in feet).
T. 85 N., R. 6 W. (PART OF MAINE)—Continued.							
		Feet.	*Feet.*	*Feet.*		*Feet.*	
W. Butters	SE. ¼ SE. ¼ sec. 7	230	190				
M. A. Benton	NE. ¼ SW. ¼ sec. 8.		180				Blue clay from 25 to 160; yellow clay, 25, overlying rock.
Fair Ground	NW. ¼ NE. ¼ sec. 10.	146					
Goldsberry & Haskell.	NW. ¼ SW. ¼ sec. 10.		75				
J. Benest	SE. ¼ NW. ¼ sec. 13.		30				
C. Jordan	SE. ¼ SE. ¼ sec. 14.		112				
E. Finsen	NW. ¼ SW. ¼ sec. 15.	80			Sand and gravel.		All sand and gravel.
L. J. Reed	NE. ¼ SE. ¼ sec. 15.	90	50	90			
J. McLead	SE. ¼ NW. ¼ sec. 15.	100	100		Sand and gravel.		Do.
L. Smith	NW. ¼ NW. ¼ sec. 15.		30				
A. T. Crosby	NW. ¼ SE. ¼ sec. 16.		100				
C. Nightingale	SW. ¼ SW. ¼ sec. 17.		118				Yellow clay, 30; blue clay, 75; yellow clay, 13.
E. Brewer	NE. ¼ NE. ¼ sec. 19.	100	100				
S. C. Scott	NE. ¼ NW. ¼ sec. 21.		137				Yellow clay, 30; bowldery blue clay to rock.
M. Stickney	SE. ¼ SE. ¼ sec. 21.	160	150				Yellow clay, 40; blue clay, 80; yellow clay, very stony, 30; yellow rotten limestone, 10.
Susan Rowley	NE. ¼ NW. ¼ sec. 22.		70				
F. Stickney	SE. ¼ SW. ¼ sec. 22.	160	150				Mostly sandy blue clay.
A. M. Noah	SW. ¼ NW. ¼ sec. 23.	230					Quicksand; no water.
J. A. Wagor	NW. ¼ SE. ¼ sec. 24.		200				
G. L. Jordan	SW. ¼ NW. ¼ sec. 25.		229		Sand		Yellow clay, 70; blue clay to sand on rock.
A. M. Kennedy	NE. ¼ SE. ¼ sec. 25.	270	270		On rock		Yellow clay, 30; blue clay, 90; sticky blue clay, 5; blue clay to thin sand layer on rock.
A. Maag	NE. ¼ SE. ¼ sec. 26.	225					Driftwood on rock.
N. Jordan	NE. ¼ NE. ¼ sec. 26		170				Yellow clay, 20; blue clay, 15; sand and gravel, 15; blue clay, 50; quicksand, 20.
D. Hedges	NE. ¼ NW. ¼ sec. 26.	146					Very sandy clay.
L. C. Clarup	NW. ¼ SW. ¼ sec. 27.	203			Gravel	−63	Drift, 73; gravel, 15; blue clay, 79; sand and gravel, 36.
I. Miller	SE. ¼ sec. 28		100				Thin sand streak between yellow and blue clay.
F. K. Balderson	NE. ¼ SW. ¼ sec. 29.		70				Yellow and blue clay to rock.
E. J. Craft	NE. ¼ NE. ¼ sec. 33.		109				Thin sand layer with a little water between yellow and blue clay.

Wells in Linn County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Depth to water supply.	Source of supply.	Head above or below curve.	Remarks (logs given in feet).
T. 85 N., R. 6 W. (PART OF MAINE)—Continued.		*Feet.*	*Feet.*	*Feet.*		*Feet.*	
G. W. Anderson	NW. ¼ NW. ¼ sec. 36.	135			Gravel		Sand and gravel from 100 feet down.
W. McTanst	NE. ¼ NW. ¼ sec. 36.		165				Sand and gravel throughout; rotten wood at 150 feet.
T. 85 N., R. 7 W. (OTTER CREEK).							
B. Norris	SE. ¼ SE. ¼ sec. 1.		150				Solid blue clay, 90; soft blue clay; solid blue clay to rock.
E. Stragsburg	SE. ¼ sec. 2		110				
C. Lyman	SE. ¼ NE. ¼ sec. 5.	75	64				
P. Bowman	SE. ¼ NE. ¼ sec. 12.	160	100				
G. Dolderer	SW. ¼ SW. ¼ sec. 14.	82	71		"Sandstone."	−66	Sandy yellow clay, 20; blue clay, 40; sand giving off strong currents of gas, 5; gray clay, 5; yellow "sandstone" to 82.
E. E. Fleming	SW. ¼ NW. ¼ sec. 24.		128				
E. M. Lanning	NW. ¼ SW. ¼ sec. 28.	75					
J. B. Fishel	NW. ¼ NE. ¼ sec. 32.	80			"Sandstone."		
J. Maier	NW. ¼ NE. ¼ sec. 33.	92	3	92	...do	−22	Soil, 3; limestone, 71; soapstone (Independence), 15; "sandstone," 3.
M. Karch	Sec. 34	70	68		In upper layers of rock.	−58	Yellow clay, free from stones, 18; tough blue clay, 50.
T. 85 N., R. 8 W. (WASHINGTON; PART OF FAYETTE).							
J. R. Elliott	NE. ¼ sec. 1	24				− 4	Much wood at 20 feet.
H. H. Martin	SW. ¼ SW. ¼ sec. 2.	248	131				Yellow pebbly clay, 20; blue clay with bowlders, 111. At 220 shell rock and mud seams; poor supply of water.
W. H. Stewart	NE. ¼ SW. ¼ sec. 4.	95	95		On rock	−26	Yellow clay, 30; blue clay, 65.
J. Roger	NE. ¼ NW. ¼ sec. 5.	76				−26	Clay and sand, 35; black muck, 3; sand and gravel.
Cemetery	Center Point	160				−60	Limestone; streaks of shale, thickest being 10 feet.
D. W. Esget	NE. ¼ SE. ¼ sec. 10.	110	110				Yellow stony clay, 20; blue clay, 90; soft limestone.
M. Wilson	SW. ¼ SW. ¼ sec. 14.	130	130		Gravel and rock.	−60	
H. D. Newland	SW. ¼ sec. 17	60			Sand and gravel.		
J. Pifer	SW. ¼ NE. ¼ sec. 15.	133			Vein in clay.		Blue clay, 133; strong water vein; blue clay.
P. McGuff	SW. ¼ NW. ¼ sec 13.	80	60	80	Limestone		
Thompson S. Yakle	SE. ¼ NE. ¼ sec. 21.	120	120		On rock		Yellow clay, 20; blue clay, 90; hardpan of cemented pebbles, 10.

Wells in Linn County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Depth to water supply.	Source of supply.	Head above or below curve.	Remarks (logs given in feet).
T. 85 N., R. 8 W. (WASHINGTON; PART OF FAYETTE)—Con.		*Feet.*	*Feet.*	*Feet.*		*Feet.*	
F. P. Kratzer	NW. ¼ sec. 21	128					Soapstone, 3 or 4 feet thick at 120 feet.
M. B. Thomas	SE. ¼ sec. 22		78				
J. Ashlock	SW. ¼ sec. 26	74	14	74	Limestone		Gravel to rock.
T. Newman	SW. ¼ NW. ¼ sec. 27.	45			Gravel		Yellow clay without pebbles, 15; light blue clay to gravel, 30.
M. Schmickle	NE. ¼ sec 24	34	18				Drift, 18; limestone and shale, 8; dirty coal, 6 to 8.
F. Mobey	NE. ¼ sec. 4	75	40				
E. T. Pickerel	SE. ¼ SE. ¼ sec. 31.	178	40				Some shale near bottom.
T. 84 N., R. 8 W. (PARTS OF FAYETTE AND MONROE).							
S. McClintock	SW. ¼ SW. ¼ sec 4.	225			Sand		Yellow clay, 15; solid blue clay, 180; sand, 30.
A. Elsen	NE. ¼ SE. ¼ sec 5.	238	180				No sand.
	NE. ¼ SE. ¼ sec. 5.	213	190				Mostly clay and rock.
J. C. Adair	SE. ¼ SW. ¼ sec. 5.	100	75				
S. B. Mather	NE. ¼ SE. ¼ sec. 6.	200	130				
F. Shurtliff	NE. ¼ sec. 7	164	80				Yellow clay, 10; blue clay to rock; rock sandstone; no limestone.
J. Railsbock	SE. ¼ sec. 7	53	45				Peat and black clays, 20; quicksand to rock, on an old lake bed.
L. D. Lewis	NE. ¼ sec. 5	262	140	160			Yellow clay, 40; blue clay, 100; rock.
A. McManus	SE. ¼ NE. ¼ sec. 8.	138	138				Almost entirely sand to rock.
W. H. Rahde	SE. ¼ sec. 8	53	30				A little quicksand on rock.
J. H. Ray	SW. ¼ NE. ¼ sec. 9.	97	70				
L. F. Wright	NE. ¼ sec. 19	80	20		Limestone	−40	On high elevation.
C. Beatty	Sec. 29.	32	32				
C. Rake	NW. ¼ SW. ¼ 9.. sec. 2	174	50	174	Crevice in Independence shale member.	−10±	Soil, 10; sand, 23; thin bed of yellow clay; blue clay, 30; limestone, 20; shale, 15; rock; coal layer; hard pyritiferous stone; sulphur-bearing rock at 165; water sulphurous.
P. E. Wilse	NE. ¼ SW. ¼ sec. 33.	135	40				
C. Rabe	SE. ¼ SW. ¼ sec. 30.	47	30		In crevice in rock.		A little yellow clay mixed with soil; blue clay to rock; on coal or shale.
Robert J. Hoff	SW. ¼ SE. ¼ sec. 12.	140	25	140		− 4	On hillside, tapped with pipe and flowing.
D. Roy	SW. ¼ NE. ¼ sec. 12.	48	40		"Sandstone."		Yellow clay without pebbles, 16; sand, 4; blue clay, 20; "sandstone," 8.

Wells in Linn County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Depth to water supply.	Source of supply.	Head above or below curb.	Remarks (logs given in feet).
T. 82 N., R. 7 W. (COLLEGE).		*Feet.*	*Feet.*	*Feet.*		*Feet.*	
M. Buresh	SE. ¼ NE. ¼ sec. 23.	116			Sand		Reddish clay; blue clay, 55; black soil, 2; layer of light gray soil; sand to bottom.
J. Buresh	SE. ¼ NE. ¼ sec. 35.	40			do		All sand.
T. 82 N., R. 6 W. (PUTNAM; PART OF BERTRAM).							
J. Cack	SW. ¼ NW. ¼ sec. 14.	100	60				
F. Havlicek	SE. ¼ SE. ¼ sec. 16.	170	75				
F. Bohak	NW. ¼ SE. ¼ sec. 22.	196	30		Limestone		Rock bedded at this point.
J. Bartosh	SW. ¼ NE. ¼ sec. 26.	182	100				
J. Rousar	NE. ¼ NE. ¼ sec. 31.	50			Sand		Yellow clay, 15; sand, 35.
M. Pisarek	SE. ¼ NE. ¼ sec. 32.	125	123				
T. 84 N., R. 6 W. (PART OF MARION).							
D. J. Simpson	NE. ¼ NW. ¼ sec. 3.		160				
E. R. Mason	NE. ¼ NW. ¼ sec. 4.	170			Sand and gravel.	+ 4	Dark sand, 100; clean sand growing coarser to bottom, 70.
T. 84 N., R. 7 W. (PARTS OF MARION AND MONROE).							
J. Pahms	SW. ¼ NW. ¼ sec. 1.	50	40	50	"Sandstone."	− 20	Yellow clay, 15; blue clay, 20; sand and "rock" layers to rock.
F. Walser	SE. ¼ SE. ¼ sec. 15.	59	18				
T. C. Marton	SW. ¼ SW. ¼ sec. 23.	168	40	160±	"Sandstone."	−108	Yellow clay, 40; hard gray fossiliferous flinty limestone, 80; soapstone (Independence) to near bottom; "sandstone."
W. Howe	SE. ¼ NE. ¼ sec. 24.	62	(?)				Sand, 2; very porous rock and abundant water with little head.
J. Stockey	SE. ¼ NE. ¼ sec. 27.	117	17		Fissure in limestone.	− 60	Loess, 15; blue clay; red rock, 10 feet thick at 50; limestone, 40; very hard limestone, 17; limestone full of seams and crevices.
M. J. Certain	NW. ¼ SW. ¼ sec. 26.	120	17				
R. Stinson	NW. ¼ NW. ¼ sec. 35.	87	15		Limestone		Yellow and white limestone from 15 to 87.
G. Leidigh	SE. ¼ SW. ¼ sec. 9.	165	20		"Sandstone."		
R. Hagerman	NW. ¼ NE. ¼ sec. 14.	+200	170		Shelly rock.		Yellow clay, 6; blue clay to rock.
D. Miller	SW. ¼ SW. ¼ sec. 16.	67	15		In crevice.	− 20	
C. A. Coleman	NW. ¼ SW. ¼ sec. 33.	48	20		Crevice in rock.		Sand, 20, to rock.

Wells in Linn County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Depth to water supply.	Source of supply.	Head above or below curb.	Remarks (logs given in feet).
T. 84 N., R. 7 W. (PARTS OF MARION AND MONROE)—Continued.		*Feet.*	*Feet.*	*Feet.*		*Feet.*	
W. McCreary	SE. ¼ sec. 4	60	20	60	"Sandstone."		Sand, 20; limestone, 30; "sandstone," 10.
E. Quass	Sec. 31	168	140		Crevice in rock.		
A. Senger	NW. ¼ SW. ¼ sec. 28.	106	20	106	...do		Blue, gray, and white limestone.
T. 83 N., R. 5 W. (LINN).							
J. Drips	NW. ¼ NW. ¼ sec. 2.	113	35				
F. Martin	SW. ¼ SW. ¼ sec. 2.	100	30				
S. Johnson	NW. ¼ SW. ¼ sec. 14.	100			Gravel		Log in gravel bed at 100 underneath blue clay.
J. Napier	NE. ¼ NE. ¼ sec. 19.	75	50		Limestone	− 50	Yellow and blue clay to rock.
J. Beechley	SE. ¼ SE. ¼ sec. 26.	80			Gravel		
W. Walm	SW. ¼ NE. ¼ sec. 31.	50					Mostly blue clay to 40; log and black soil in gravel bed at 40.
J. Bovey	NW. ¼ NE. ¼ sec. 36.	200	55				
F. W. Frederick	SW. ¼ SW. ¼ sec. 36.	80	30			*a* ±120	Sand 3 feet thick on rock.
R. Smith	NW. ¼ sec. 36	65			Sand		Ridge; yellow clay, 15; yellow sand, 49; black sand, coarse, with much wood, 1.
T 82 N., R. 8 W. (FAIRFAX).							
M. Kilberger	NW. ¼ NE. ¼ sec. 34.	106	100		Limestone	− 76	Yellow clay, 20; blue clay, 80; blue, hard limestone, 6.
F. Bys	SE. ¼ SW. ¼ sec. 27.	130	125	130	....do	− 90	Yellow clay, 20; blue clay, 105; limestone, 5; no gravel beds.
C. Farrell	NW. ¼ NW. ¼ sec. 6.	30			Sand		Driven well.
E. J. Farrell	SE. ¼ NW. ¼ sec. 6.	70			Gravel		All sand and gravel.
H. Mordorst	NW. ¼ SW. ¼ sec. 5.	117	100				Yellow clay; blue clay; quicksand, 10 feet thick, 50; blue clay; thin yellow clay on rock; rock, 17; below it bed of sand full of water.
T. M. Hunter	NE. ¼ SE. ¼ sec. 6.	117	100				
A. Delancy	NE. ¼ SW. ¼ sec. 16.	180	180				
E. P. Taylor	SW. ¼ NE. ¼ sec. 21.	32				+	
C. C. Dye	NW. ¼ SE. ¼ sec. 20.	91	91	91	Sand on rock.		Stony yellow clay, 15; blue clay full of bowlders to thin sand layer on rock.
	NW. ¼ SE. ¼ sec. 30.	91	25		"Sandstone."		

a Approximate.

Wells in Linn County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Depth to water supply.	Source of supply.	Head above or below curb.	Remarks (logs given in feet).
T. 83 N., R. 8 W. (CLINTON).							
L. Lafter	NW. ¼ SE. ¼ sec. 2.	*Feet.* 180	*Feet.* 60	*Feet.*	Limestone	*Feet.* – 25	Near Cedar River. Sand, 2; blue clay with some bowlders, 58.
P. Lang	NE. ¼ SW. ¼ sec. 4.	238	238	....	....	....	
A. Sisam	NW. ¼ NW. ¼ sec. 9.	213	213	....	....	....	30 feet of quicksand; quicksand rare in vicinity.
G. H. Phelps	SE. ¼ NW. ¼ sec. 9.	277	277	....	Sand	–100	Mostly blue clay with layers of sand; sandy from 192 to 242; blue clay, 33; sand with water, 2.
E. L. Lang	SW. ¼ NE. ¼ sec. 15.	248	40	....	....	....	Clay full of bowlders.
J. E. Rawson	SE. ¼ SE. ¼ sec. 15.	73	1	....	....	....	
J. Young	NW. ¼ sec. 9	102	....	....	Gravel	....	Drift clays; gravel, 2 feet at bottom resting on clay; clay above gravel very full of bowlders.
T. 83 N., R. 6 W. (BERTRAM; PART OF MARION).							
W. C. Litts	SW. ¼ SE. ¼ sec. 1.	175	172	....	....	....	
S. Harmon	NW. ¼ SE. ¼ sec. 2.	206	....	....	Gravel	–100	Streaks of sand and gravel at 13 and 165; bed of gravel at 206.
J. R. White	NE. ¼ SE. ¼ sec. 2.	150	100	....	....	....	
J. Hunter	NE. ¼ NE. ¼ sec. 3.	125	90	....	Limestone	....	Mostly blue clay to rock, no gravel.
F. M. Elrod	NW. ¼ NW. ¼ sec. 4.	42	42	....	....	....	All quicksand and gravel.
A. P. Knapp	SE. ¼ SE. ¼ sec. 3.	61	61	....	....	....	
V. Zoback	SE. ¼ sec. 10	45	8	....	....	....	
S. H. Berry	SE. ¼ NW. ¼ sec. 11.	142	....	....	....	– 26	Blue clay throughout.
R. Berry	SW. ¼ NW. ¼ sec. 11.	106	33	....	....	....	Mostly sand, gravel, and small bowlders.
J. Moore	SE. ¼ NE. ¼ sec. 11.	168	168	....	....	....	
J. Bowsh	SE. ¼ SE. ¼ sec. 12.	210	(?)	....	....	....	
F. Bidderman	SW. ¼ SW. ¼ sec. 12.	110	20	....	....	....	
J. W. Smythe	SE. ¼ SW. ¼ sec. 12.	100	40	....	Limestone	....	Sand and gravel to rock.
G. Smythe	NE. ¼ NE. ¼ sec. 12.	203	203	....	....	....	Mostly blue clay.
R. Calhoun	NW. ¼ SE. ¼ sec. 24.	52	27	....	Limestone	....	Thin vein of shale (Independence?) in limestone.
J. R. Grove	SW. ¼ SE. ¼ sec. 21.	134	134	....	....	....	
S. Stambaugh	SE. ¼ NW. ¼ sec. 21.	48	40	44	Limestone	....	Blue clay to rock.
J. Paul	NE. ¼ NW. ¼ sec. 22.	204	....	....	Gravel	–104	Few feet yellow clay; blue clay to gravel at bottom.
B. F. Parker	NW. ¼ SE. ¼ sec. 22.	85	....	....	....do	– 65	

Wells in Linn County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Depth to water supply.	Source of supply.	Head above or below curb.	Remarks. (logs given in feet).
T. 83 N., R. 6 W. (BERTRAM; PART OF MARION)—Con.		*Feet.*	*Feet.*	*Feet.*		*Feet.*	
J. Berry	SE. ¼ NW. ¼ sec. 23.	49	19			— 30	Drift, 19; hard stone, 5; shale, 20; hard stone, 5.
F. M. Ham	Sec. 24	124	90			— 64	Blue clay from soil to rock.
J. S. Caraway	NW. ¼ SE. ¼ sec. 25.	45	7				
M. Brown	SW. ¼ NE. ¼ sec. 27.	86	75	86	Limestone		Dry gravel at 40 feet.
G. Berry	NW. ¼ NW. ¼ sec. 27.	137	130				Blue clay, 16 to 137
R. Berry	NW. ¼ NW. ¼ sec. 28.	129	129				
W. L. Weller	NE. ¼ NW. ¼ sec. 30.	98	45		In crevices		Sand and yellow clay to rock.
T. 82 N., R. 5 W. (FRANKLIN)							
Lester R. Cook	SW. ¼ NW. ¼ sec. 6.	135	135	100	Sand		Water at 35; "river" sand below; yellow and a little blue clay.
D. M. West	SE. ¼ SE. ¼ sec 7.	60	40		Limestone	— 30	
Dr. Kate Mason	Sec. 16	145	80		do	—100	All blue clay except a little yellow clay at surface.
Elmer Neal	NE. ¼ NW. ¼ sec. 17.	170	170		Sand		Water on rock in a little sand.
Charles Platner	NE. ¼ NE. ¼ sec. 17.	150	80		Limestone	— 70	
Ely West	NE. ¼ SE. ¼ sec. 20.	196	177		do	— 46	Yellow clay, 25; sand, 15; blue clay to rock.
James Milhallen	SE. ¼ sec. 18	181	181		do		Yellow clay, 30; blue clay to rock.

MUSCATINE COUNTY.

By W. H. NORTON.

TOPOGRAPHY.

The larger topographic features of Muscatine County are two uplands and two river plains. Of the plains the more extensive is that of Cedar River, a flat fluviatile or lacustrine floor, aggraded largely in Pleistocene time to its present level, extending across the county from northeast to southwest with a width of 6 or 7 miles. The towns of Wilton, Moscow, and Nichols are situated upon it. This strip of lowland separates the small triangular upland of Kansan drift which occupies the northwest corner of the county from an extensive upland of Illinoian drift which covers the eastern and larger portion of the area.

The second lowland is that of the Mississippi flood plain. Up valley from Muscatine the river approaches the Iowa bluffs, leaving to this county an inconsiderable flood plain hardly more than one-fourth mile wide. South of Muscatine the valley widens. The great river turns sharply southward from its westward course, leaving the crescent of its ancient river-cut bluffs far to the west and separated from the channel by alluvial plains 5 to 6 miles wide. Both lowlands are poorly drained and in both ground water stands near the surface. The uplands, while well dissected near their margins, preserve in their central portions flat initial surfaces but slightly etched with erosion channels.

GEOLOGY.

Over most of the county bedrock is deeply buried by deposits laid down by successive ice sheets and their outflowing drainage. The two lowest of these deposits, the Nebraskan and the Kansan drift sheets, are both dark-bluish stony clays, hardly to be distinguished in wells except when parted by the deposits of the Aftonian interglacial stage. The Aftonian deposits consist of peaty beds and old soils and of beds of sand and gravel, which occur still more extensively in some townships.

The Kansan drift where weathered is oxidized and reddened, and can then scarcely be distinguished by the driller from the yellow stony clay of the overlying Illinoian drift, the uppermost of the drift sheets of the area. The Illinoian and Kansan drifts are not uncommonly separated by ancient soil or peat beds or by seams of sand and gravel. The upper surface of the Illinoian is in many places leached and bleached by long weathering and the reducing action of ancient soils, and is separated from the overlying loess by peaty soils or thin layers of yellow sand.

Outside of small areas negligible in connection with ground-water supplies, the rocks of Muscatine County belong to two geologic systems. (See Pl. XV, p. 670.) The lower, the Devonian, consists in part of hard gray limestones of numerous types, some fine grained and brittle, made up of angular fragments (Lower Davenport beds of Iowa State survey), some gray and tough (Upper Davenport beds of Iowa State survey), some of shelly limestone, more or less clayey (Cedar Valley limestone); and in small part of green-gray or dark-drab shale (Sweetland Creek shale). The upper and later series belongs to the Carboniferous system (the Pennsylvanian series or coal measures), and is variable both horizontally and vertically, consisting of abruptly changing beds of limestone, sandstone, pebblestone, shale, and coal. It is found only in the southern townships of the eastern half of the county (except in scattered patches) and is evidently an outlier cut off by the trench of the Mississippi from the northern margin of the Illinoian coal field.

UNDERGROUND WATER.

SOURCE AND DISTRIBUTION.

Because of the large areas underlain by river deposits the waters in the alluvial sands and gravels are of exceptional importance in Muscatine County. Muscatine Island and extensive portions of the Mississippi bottoms bounded on the west by Muscatine Slough are supplied by driven wells from 20 to 30 feet in depth. The supply is copious, easily raised to the surface by steam pumps for irrigation, and the water is so slightly mineralized that it is not injurious to crops. The area is thus rendered independent of rainfall in dry seasons, and this fact, together with the warmth of its light soil, has made Muscatine Island and Fruitland Township one of the garden areas of the State and of the upper Mississippi Valley.

The wide plain adjacent to Cedar River draws its ground-water supply from driven and dug wells 20 to 40 feet deep, the water bed being a sand underlying the surface loess. Wells deeper than 30 or 40 feet reach horizons where the water is apt to be pretty highly mineralized with iron salts. On some low tracts temporary flowing wells have been obtained by boring through the impervious cover of hardpan. A few deep borings show that the rock floor of the plain lies more than 250 feet below the surface, but the records are not definite enough to show the character of the materials with which this ancient and wide valley has been so deeply filled. From the records of a single well in sec. 26, Pike Township, it may be inferred that beneath the water-bearing sand, which here extends to 30 feet from the surface, is a clay 10 feet thick, beneath which occurs a water-bearing gravel. It is not known whether this gravel is a sheet deposit formed along a delta front encroaching on a lake, or was deposited by a stream the width of the present plain, or was laid down in long narrow strips in the channels of an aggrading stream perhaps no larger than the Cedar of to-day. At and near Wilton drillers report 90 feet of sand succeeded by 100 feet of blue clay underlain by 10 feet of sand and gravel, the rock floor here not exceeding 470 feet above sea level.

On the eastern upland of the county water occurs in sands covered with a cap of loess, forming certain low long ridges directed generally at right angles to the western margin of the upland. Wells on such ridges may obtain adequate supplies at very moderate depths though wells on the lower ground adjacent would need to go down more than 100 feet before finding water.

On both the eastern and the western upland the Aftonian gravel is the chief aquifer. In Lake Township these sands and gravels are tapped at about 100 feet below the surface. A general section in the southwestern part of this township is as follows:

Section of Pleistocene deposits in Lake Township.

	Thickness.	Depth.
	Feet.	*Feet.*
Loess and sand	20	20
Clay, blue (Illinoian and Kansan)	100	120
Water sand (Aftonian)	10	130
Clay, blue (Nebraskan)	120	250

The Aftonian is particularly valuable because of the great depth at which bedrock and rock aquifers lie over much of the eastern upland. Here the great bedrock trough which underlies the Cedar River lowland extends for 4 or 5 miles east of the river and the deepest wells go down 250 and even 400 feet without striking rock. Fortunately water is usually found in the Aftonian or, much less commonly, in glacial sands interbedded with or underlying stony clays of the Nebraskan.

The Devonian and Silurian (Niagara) limestones are important aquifers in the northeastern townships and on the western upland, on which latter bedrock is not reported at less than 200 feet below the surface. Most wells find water in glacial gravels, but a few have been drilled into the country rock. In one well a white limestone is reported to extend from 220 to 350 feet, below which lies 17 feet of brown porous rock, which may be assigned to the Niagara.

In the four eastern townships drift seldom exceeds 100 feet and numerous wells draw water from the country rock. Where the bedrock is Devonian limestone, water is usually found at a moderate depth from the surface, the deepest wells being those in which the drift is underlain by heavy Carboniferous shales. In Sweetland Township two wells found the coal measures to be 97 and 120 feet thick, and after piercing these were compelled to go 100 and 185 feet into the subjacent limestones before obtaining adequate supplies.

SPRINGS.

The important springs of the county rise from the Aftonian gravel and the Devonian limestone.

The outcrop of the Aftonian gives rise to numerous and often copious springs. These are well marked near the base of the bluffs bordering Mississippi River south and west of Muscatine in Fruitland and Seventysix townships. Below the bluffs east of Cedar River, in Moscow Township, many springs flow from the drift. Several of these, with a July temperature of 55° F., lie south and west of Muscatine, on farmsteads located along the road under the foot of the bluffs, and their excellent water is therefore available for house and dairy and all farm purposes. Almost every farm is thus supplied. In some places, where the spring issues from 20 feet or less above the base of the bluffs, sufficient power is developed to run a milk and cream separator. The spring of Edwin Wills is estimated to have 1½ horsepower. Its temperature at outflow is 51° F. Two large springs emerge near Atalissa—one on the farm of David McClure and one on that of Mrs. C. E. Kephart. The latter was leased for several years by the Chicago, Rock Island & Pacific Railway for the supply of its locomotives before the artesian well was drilled at West Liberty.

CITY AND VILLAGE SUPPLIES.

Muscatine.—The city of Muscatine (population, 16,178) has had a public supply since 1875, the plant being long owned by the Muscatine Waterworks Co. For about 20 years the raw water of Mississippi River was used, being pumped through a conduit extending 700 feet out into the river. This extremely unsatisfactory supply has recently been completely changed, new works begun in 1904 having been completed and put in use in 1906. The pumping station and wells are situated on the flood plain of the Mississippi, at the south line of the corporation area, three-quarters of a mile from the settled portions of the town. The new supply is drawn from a gang of 13 driven 6-inch wells about 50 feet deep and 150 feet apart, located on a line parallel with the bank of Mississippi River and 500 feet distant from it. These wells are pumped through a 20-inch horizontal suction pipe connecting with vertical pipes, extending in each well practically to the bottom. The capacity of the wells is 2,000,000 gallons a day, twice the amount of the present consumption. The pumps are installed in a building 48 feet square, built of reenforced concrete. The cost of the new installation was $100,000, including $40,000 spent for the extension of mains in the southern parts of the city. The water is pumped to a reservoir with a capacity of 2,000,000 gallons, situated on West Hill, the bottom of the reservoir being 185 feet above low-water level in the Mississippi. Domestic gravity pressure ranges in different parts of the town from 20 to 90 pounds. Fire direct pressure is from 100 to 150 pounds. There are 16 miles of mains, 185 hydrants, and 1,500 taps.

This very satisfactory supply was chosen at the recommendation of Mr. W. Kiersted, of Kansas City, after an exceptionally thorough investigation of local conditions. Some of the results as given in Mr. Kiersted's report to the council, November, 1903, are of such general interest and wide application that they may be given here in some detail.

The two sources under consideration were (1) Mississippi River, with proper equipment for settling and filtration, and (2) the ground water in gravels underlying Muscatine Island. The preference naturally lay with the latter, provided that the supply should be found of suitable quality and quantity. The physical conditions of this large area of flood plain pointed to an abundant and excellent supply. The land is nearly level and lies but slightly above the maximum high-water line of the river. The soil is sandy, light, and porous. These conditions make the run-off of storm water slight and dispose of a very large percentage of the rainfall by absorption and underflow as ground water. The permanent ground-water surface, determined by the level of low water in the river, lies within 15 or 20 feet of the surface of the ground. Moreover, since the surface of the island lies somewhat above the ground-water level, the porous soil permits rapid alternate circulation of air and water and hence affords an efficient natural filtration.

These indications were fully confirmed by a series of tests. Nine wells about 65 feet deep were sunk upon the island along a line 3,000 feet in length at right angles to the river and beginning 300 feet from the river bank. The following succession of deposits was found, the thickness of the strata given being that found in the well nearest the river:

Section near Muscatine.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil, sandy, black	3	3
Clay, red, tough, hard; not uniformly distributed or continuous on island	5	8
Sand, red, and fine gravel	10	18
Gravel, coarse	10	28
Sand, coarse, and gravel	15	43
Sand, gravelly	6	49
Sand and coarse gravel	2	51
Blue clay; when dry nearly white; without sand	5	56
Shaly clay or soapstone, hard, laminated, light pink	3	59
Sandstone	6	65

The geologic conditions were thus found to be extremely favorable for a large yield of ground water. A bed of porous sand and gravel 50 feet in depth, resting on an impervious floor and water-logged to a depth of 30 feet, was found to underlie the area.

The question still remained as to the permeability of the gravels and whether they could deliver a supply adequate to emergencies as well as to the ordinary demands of city consumption. To aid in solving this problem a series of observations extending from September 6 to October 26, 1903, were made on the static level of the water in the test wells and in the river, in order to obtain data as to the ground-water slope and the effect of fluctuations of the water level in the river on the ground-water surface of Muscatine Island.

Up to September 13 the river fluctuations of level were small and the ground-water surface was comparatively stable for a distance of 3,300 feet west of the river. The pronounced slope of the ground-water surface toward the river (0.8 foot in 1,000 feet) demonstrated the underflow of the absorbed rainfall toward the Mississippi. Between September 13 and 21 the river rose a little more than 2 feet, causing a rise of 2.1 feet in well No. 1, 300 feet distant from the river, and a rise in the other wells, decreasing in amount with increasing distance from the river, until at well No. 9 the increase was but 0.3 foot. The slope of the ground-water surface toward the river was still well defined. Obviously the rise of the river dammed the underflow in its riverward movement. From these data it was computed that the water in the saturated gravels to a depth of about 43.5 feet flowed toward the river at a rate of at least $2\frac{1}{2}$ feet a day.

About September 23 the river rose a little more than 4 feet. The slope of the ground-water surface was now reversed, and with continued high water so remained until October 9. The average slope inland of the ground-water surface was 0.84 foot in 1,000 feet, and from this was computed an average movement of river water inland of 2.3 feet a day. Using the velocity per day and the inclination of the ground-water surface, the average factor of porosity of the medium was obtained by Dupuit's formula. This factor was found to be 5,000 a foot, indicating a very porous subsoil formation compared with similar experiments and observations made elsewhere. Continuous pumping tests were made of well No. 1 for 125.5 hours, and simultaneous observations of the water level in the other test wells, in order to procure information as to the porosity and continuity of the gravel deposits. The delivery of the pump was computed at 1,500,000 gallons a day. During the test the water in the river rose over 3 feet, and notwithstanding the large amount of water pumped from the ground, the water of all the wells showed a corresponding rise. The zone affected by the pumping extended 700 feet.

The data secured by these tests settled most satisfactorily the questions as to the capacity of the supply and there only remained the question of the purity of the water. The geologic conditions pointed to a rapid and effective natural filtration of surface water, with a consequent destruction of pathogenic bacteria. A series of tests of the water of the test wells with sanitary and bacteriological analyses fully confirmed this inference. Although the chemical analyses showed a high per cent of fully decomposed organic compounds, and of chlorine and nitrates, in all the samples, owing to the fact that much fertilizer is used on the cultivated fields of the area, the percentage of undecomposed or partly decomposed organic compounds—ammonia, albuminoid ammonia, and the nitrates—was small, showing an effective purification of the surface waters by the natural filtration of the sandy soil. The bacterial analyses confirmed the chemical, showing but few bacteria and these of harmless varieties.

The question was also considered of the effect which the depression of the ground-water surface by a continuous draft in the area of supply would have upon the underflow of the contaminated ground water of South Muscatine. It was found that even in years of minimum rainfall the natural movement of the ground water of South Muscatine to the river could not be so diverted down valley as to reach the intake area of the city wells.

The recent installation of the shallow wells described makes artesian forecasts unnecessary so far as the municipality is concerned. But in a city as large as Muscatine and with extending industries, it may be taken for granted that sooner or later information as to artesian possibilities will be useful to manufacturers and other large consumers who for various reasons may have under advisement an individual water supply.

At Muscatine (elevation, 552 feet) the drill will penetrate first the Devonian and Silurian (Niagara) limestones, reaching the Maquoketa shale (Ordovician) at about 500 feet and may find small flows in either limestone terrane. These flows will be under low head and should be cased out so as to prevent the lateral escape of the deeper waters through their channels. The Maquoketa strata, which are weak and caving, should be cased. Good flows under moderate pressure should occur in the Galena and Platteville limestones which immediately underlie the Maquoketa, from about 725 to 1,025 feet from the surface, and it is possible that the yield will be sufficient for some industrial plants. To carry these waters a bore of 4 or at most of 5 inches will be ample. For larger drafts the St. Peter sandstone and the loose-textured sandstones and creviced and vesicular limestones which underlie it must be utilized, and in these an inexhaustible supply of water of fine quality should be found. To tap them the well should be sunk to 1,500 or 1,600 feet. To tap the underlying Cambrian beds drilling should continue about 400 feet deeper still, but it is not apprehended that this will be needed. The pressure should considerably exceed 20 pounds.

West Liberty.—The town of West Liberty (population, 1,666) has drawn its water supply from artesian wells since 1888. (See Pl. XV, p. 670.) Water is pumped directly through the mains, and also to an elevated tank holding 60,000 gallons, giving a domestic pressure of 40 pounds and a fire pressure of 100 pounds. There are 7 miles of mains, 27 fire hydrants, and 472 taps. The consumption is 45,000 gallons daily, and the water is said to be used by 90 per cent of the population.

The extension of the waterworks in 1899, involving the sinking of a new artesian well, was financed in an ingenious way, worthy of record. Owing to the change in the State assessment laws which went into effect in 1897, the valuation of property in the town was reduced many thousands of dollars. The municipal indebtedness, which had been increased by the building of the waterworks and an electric lighting system, was thus brought to near the legal limit and another bond issue for the extension of the waterworks was thus out of the question. In this emergency thirty public-spirited citizens advanced the money for the extension and were paid out of the revenues of the waterworks. The city council entered into contract for an artesian well to be drilled upon the city's lot, the well to remain the property of the driller and contractor until the annual rentals received by him equaled the cost of the well, when its ownership was to be transferred to the city. The annual rental was fixed at $600 and 6 per cent interest on the cost of the well. When the well was tested and accepted, the driller's lease was purchased by the thirty citizens. The total cost of the well, $3,600, was raised by six promissory notes, drawing 6 per cent interest and due in six years, each note being signed by five persons drawn by lot from among the thirty. All payments, rentals and interest were indorsed pro rata on each note, thus keeping them equal in amount until their final liquidation. With the extension of the water system the revenues increased, all payments were promptly met, and at the end of six years the notes had all been paid and, under the terms of the lease, the well passed into the full ownership of the municipality.

City well No. 1 has a depth of 1,768 feet and a diameter of 6 to $4\frac{3}{16}$ inches; casing to 128 feet. The curb is 696 feet above sea level. The head was originally 9 feet above curb; in 1896, at curb or below. The original discharge was 120 gallons a minute. Temperature, 65° F. Date of completion, 1888. Driller, A. K. Wallen.

During the drilling the water stood at 40 feet below the curb for more than 1,000 feet. At 1,040 feet, the horizon of the St. Peter, it rose 20 feet. Rising a little higher each day, it overflowed when the drill reached a depth of 1,354 feet and the flow increased as the drill went still deeper. A tube sunk to 1,100 feet and packed at base decreased the flow and was taken out. In 1900 the head had fallen to 12 feet below the surface and the pumping capacity to 75 gallons a minute.

Record of strata in well No. 1, at West Liberty (Pl. XV, p. 670).

	Depth of sample in feet.
Silurian:	
Niagara dolomite—	
Dolomite, light bluish gray	400
Ordovician:	
St. Peter sandstone—	
Sandstone, very fine white particles, angular	1,000
Sandstone, coarser, larger grains rounded, "from 1,040 to 1,080"	1,050

	Depth of sample in feet.
Ordovician—Continued.	
Prairie du Chien group—	
Shakopee dolomite—	
Sandstone, moderately coarse, white; unusually sharp to the touch; under microscope many grains are seen to be faceted with secondary crystalline enlargements	1,160
Dolomite, gray; considerable arenaceous admixture in drillings	1,250
"Flint;" 12 inches thick; no sample	1,260
Dolomite, white; considerable admixture of finest particles of quartz	1,290
New Richmond sandstone—	
Dolomite, highly arenaceous	1,310
Oneota dolomite—	
Dolomite, white, porous	1,380
Sandstone, larger grains rounded; mostly angular particles with some dolomite	1,400
Sandstone; matrix calciferous	1,450
Cambrian:	
Jordan sandstone—	
Sandstone, in fine powder of particles of quartz and a little dolomite	1,500
Sandstone, saccharoidal, rather coarse, white grains usually rounded, some faceted	1,600
St. Lawrence formation—	
Dolomite, hard, pinkish	1,765

City well No. 2 has a depth of 1,594 feet and a diameter of 12 inches to 202 feet, 8 inches to 1,016 feet, and 6 inches to bottom; casing 96 feet to rock. The curb is 671 feet above sea level; the head was not tested. The original discharge was 225 gallons a minute. Temperature, 66° F. The well was completed in 1900 by W. H. Gray & Bro., of Chicago.

Water stood 20 feet below the curb until the St. Peter sandstone was reached at 1,015 feet, with a thickness of 40 feet, when it overflowed with a discharge of 20 gallons a minute. At 1,411 feet a pumping test developed a capacity of 240 gallons a minute, with the cylinder at 100 feet below curb, and 300 gallons with the cylinder at 135 feet, the natural flow being estimated at 75 gallons. At 1,435 feet the flow had increased to 100 gallons a minute. No perceptible increase occurred during the next 100 feet, but at 1,583 feet, in sandstone, a sudden increase was noted. At 1,584 feet a crevice was encountered and the flow suddenly rose to 225 gallons a minute at the base of the sandstone. Since 1902 or 1903 a gradual decrease in the head and flow of the well has been observed, the water now barely overflowing. Under continued pumping, the suction pipe extending to 26 feet below the curb, the water is lowered to 20 feet below the surface.

The only record extant is that of three water-bearing sandstones; the first, from 1,015 to 1,055 feet (344 to 384 feet below sea level), the St. Peter; the second, from 1,300 to 1,435 feet (628 to 764 feet below sea level); the third, from 1,535 to 1,584 feet (864 to 913 feet below sea level), occupying the horizon of the Jordan.

The Iowa Condensed Milk Co. well has a depth of 1,721 feet and a diameter of 12 inches to 150 feet, 7 inches to 1,000 feet, and 6 inches to bottom; cased to 120 feet; bedrock at 90 feet. The curb is 669 feet above sea level and the head, above curb. The tested capacity is 300 gallons at 1,600 feet. The first flow was at about 1,000 or 1,025 feet and increased to the bottom. The well was completed in 1904 by Gray Bros., of Chicago.

Wilton.—At Wilton (population 1,157) the public water supply is pumped from a deep well to a tank whose capacity is 50,000 gallons. Domestic pressure from the full tank is 54 pounds and the direct pressure for fires is 110 pounds. The daily consumption ranges between 15,000 and 25,000 gallons daily. There are 2 miles of mains, 23 fire hydrants, and 180 taps.

The well (Pl. XV, p. 670) has a depth of 1,360 feet and a diameter of 8 to 6 inches; casing to 900 feet. The curb is 683 feet above sea level. The original head, as reported, was 18 inches above the curb; the present head is 20 feet below. The original discharge was 300 gallons a minute; the present pumping capacity is 120 gallons a minute. The first flow was at 900 feet. Date of completion, 1891. The well was reamed to an unreported depth in 1900 without effect on supply.

Driller's log of city well at Wilton (Pl. XV, p. 670).

	Thickness.	Depth.
	Feet.	*Feet.*
Drift	220	220
Limestone (Niagara)	280	500
Shale (Maquoketa)	180	680
Limestone (Galena and Platteville)	300	980
Sandstone (St. Peter)	120	1,100

Minor supplies.—Water supplies at minor villages are set forth in the following table:

Village wells in Muscatine County.

Town.	Nature of supply.	Depth.	Depth to water-bed.	Head below curb.		Depth to rock.
				Shallow wells.	Deep wells.	
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Atalissa	Bored and drilled wells	30–180				
Conesville	Driven wells	10–20		10		
Cranston	do	120–125	120		100	
Fairport	Wells and river	12–217	12	9	30	25
Fruitland	Driven wells	12–30		8		
Moscow	do	20–50	32	20		
Stockton	Drilled and dug wells	40–180				
Sweetland	Wells	16–300		10	60	
Nichols	Driven wells	16–20				

WELL DATA.

The following table gives data of typical wells in Muscatine County.

Wells of Muscatine County.

Owner.	Location.	Depth.	Diameter.	Depth to rock.	Depth to water supply.	Source of supply.	Remarks (logs given in feet).
T. 78 N., R. 4 W. (PART OF WAPSINONOC).		*Feet.*	*Inches.*	*Feet.*	*Feet.*		
Joseph Mountain	6 miles southwest of West Liberty.	206		206		Sand	Yellow clay underlain by dry sand 60; blue clay, 42; gray sand with a little water, 6; blue clay to rock. Well weak, closed. Another 30 feet away found plenty of water in yellow sand 8 feet thick at 95, under blue clay.
T. W. Stoops	Sec. 8	220		220			Loess, 6; yellow clay, 20; sand, 2; blue clay, 160; sand, 28; cream colored rock at 220.
R. Wagner	Sec. 15	175					Mostly drift.
John Gibson	Sec. 18	284		284			
Pliny Nichols	Sec. 20	367					White limestone from 220 to 350; below this a porous brownish rock.
Frank Hunter	Sec. 23	120				Sand	
Christian Wolf	Sec. 28	260				do	Unknown, 40; blue clay, 60; sand, 6; yellow clay, 25; blue clay with muck, wood, and sand, 107; sand, 8.
F. Kirchner	Sec. 32	398		200			Rock; hard and white above; reddish and porous below.
T. 78 N., R. 3 W. (GOSHEN; PART OF WAPSINONOC).							
Louis Watson	Sec. 7	138		95		Limestone	Loess, 15; blue clay 50; yellow bowlder clay, 30; soft brown limestone, 43.
Frank Barnes	Sec. 1	156		50		Devonian limestone.	Drift, 50; coal measures, 100; limestone, 6.
W. A. Howell	Sec. 5	58				Sand	Yellow clay, 15; blue clay, 35; sand, 8.
John Venatta	Sec. 8	245		100		Limestone	Drift, 100; limestone, 145.
George Venatta	Sec. 9	220		95			Yellow stony clay, 20; blue clay, 60; brown stony clay, 15; blue limestone, 80; soft brown material, 8; hard limestone, 29; soft limestone, 8.
Isaac Dickenson	do	78		64		Carboniferous sandstone.	Yellow clay, 15; blue clay, 25; sand, 4; hardpan, 20; soft yellow sandstone, 14.

Wells of Muscatine County—Continued.

Owner.	Location.	Depth.	Diameter.	Depth to rock.	Depth to water supply.	Source of supply.	Remarks (logs given in feet).
T. 78 N., R. 3 W. (GOSHEN; PART OF WAPSINONOC)—Contd.		*Feet.*	*Inches.*	*Feet.*	*Feet.*		
——— Overman	Atalissa	136		86			Yellow clay and sand, 42; blue clay, 44; blue limestone (Devonian), 44; brown porous limestone, 6.
Mrs. Morris	3 miles east and 2 miles north of West Liberty.	226		94			Yellow clay, 40; dry sand, 2; blue clay, 50; sand with water, 2; blue limestone, 110; shale, 8; white porous rock with water, 14.
	Near north line sec. 2.			90			
	Sec. 26	200		198			
T. 78 N., R. 1 W. (WILTON; PART OF SWEETLAND).							
E. Reimers	Sec. 2	312				Sand	Yellow clay, sand, and gravel, 60; blue dirt, 80; quicksand, 60; blue clay, 90; coarse sand, 22.
William Boot	Sec. 9	200				Sand and gravel.	Sand, 90; blue clay, 100; sand and gravel, 10.
Hans Kai	Sec. 10	101		90			
W. Felthorn	Sec. 13	100				Sand	Yellow and blue dirt, 14; brown sand, 7; blue clay, 68; sand, 10.
C. W. Collins	Sec. 14	113				Gravel	Yellow clay, 8; blue clay, 32; black "hardpan" (till?), 68; gravel, 5.
——— Smith	Sec. 15	135		100			Sand, 10; blue clay, 20; sand, 30; blue clay, 40; rock, 35.
M. A. Roy	Sec. 27	135		134			Yellow clay and sand, 20; blue clay, 108; sand, 6; rock, 1.
S. Wintermirte	Sec. 36	67				Sand	Clay, 48; gravel, 4; blue and yellow pebbly clay, 10; ashen clay, 5; sand.
T. 78 N., R. 1 E. (FULTON).							
J. H. Broders	Sec. 3	106		78			Yellow and blue clay, 70; sand, 8; limestone, 28.
B. Alton	Sec. 7	105		98			
H. Stoltenburg	Sec. 12	105		70			Drift, 70; soft white limestone, 35.
	Sec. 23	75		70±			
	Sec. 31	121		116			Drift, 116; rock, 5.
C. Wolfe	Sec. 33	144		115			Yellow clay, 30; blue clay, 40; quicksand, 7; blue dirt (probably in part shale) 38; rock, 29.

Wells of Muscatine County—Continued.

Owner.	Location.	Depth.	Diameter.	Depth to rock.	Depth to water supply.	Source of supply.	Remarks. (logs given in feet).
T. 77 N., R. 1 E. (MONTPELIER).							
		Feet.	*Inches.*	*Feet.*	*Feet.*		
C. Howard	Sec. 9	101		20			Drift, 20; sandrock 80; limestone, 1.
T. 77 N., R. 1 W. (SWEETLAND).							
Frank Nettlebush	Sec. 27	322		40		Limestone	Drift, 40; soft sandstone, 40; soapstone, 57; limestone, 185.
Daniel Roberts	Sec. 18	80				Sand	Yellow clay, 3; sand and clay, 77.
J. Newman	Sec. 4	60				do	Yellow clay, 5; blue pebbly clay, 25; forest bed, 10; ashen clay changing to sand, 20.
P. Brosart	Sec. 26	200		130			Drift, 130; sandstone and shale, 65; limestone, 5.
J. Monsen	Sec. 20	304		90		Limestone	Drift, 90; coal measures, 120; limestone, 94.
T. 77 N., R. 2 W. (BLOOMINGTON; PART OF LAKE).							
J. Greiner	Sec. 3	200					
G. Parks	Sec. 5	115				Sand	Loess and blue clay, 105; sand, 10.
County farm	Sec. 33	208		180			Clay, 100; sand, 20; clay, 60; limestone, 28.
T. 77 N., R. 3 W. (PARTS OF LAKE AND PIKE).							
F. P. Wood	Sec. 27	265				Sand	
C. Humphries	Sec. 13	100				do	
I. Sager	Sec. 25	150				do	
T. 77 N., R. 2 W. (PART OF PIKE).							
	Nichols	250				Gravel	No rock; all clay, sand, and gravel; well tubed 250 feet.
G. N. Aylesworth	Sec. 26	59				do	Sand, 30; clay, 10; gravel, 19.
T. 76 N., R. 4 W. (ORONA AND CEDAR).							
William Verink	Sec. 14	80				Sand	Loess, 15; yellow sand, 40; blue clay without pebbles, 10; white sand with gas, 15.
J. Fanning	Sec. 15	130+					
A. Cone	Sec. 24	200+					Soft till, 130; hard blue till, 60.
C. Carpenter	Sec. 33	125				Sand	Loess and yellow sand, blue clay, sand below.
T. 76 N., R. 3 W. (SEVENTY-SIX; PART OF FRUITLAND).							
J. Venatta	Sec. 2	150				do	
	Sec. 10	115					Bluff. Loess, 12; old soil, 3; mainly blue till, 100.

Wells of Muscatine County—Continued.

Owner.	Location.	Depth.	Diameter.	Depth to rock.	Depth to water supply.	Source of supply.	Remarks (logs given in feet).
T. 76 N., R. 3 W. (SEVENTY-SIX; PART OF FRUITLAND)—Contd.		*Feet.*	*Inches.*	*Feet.*	*Feet.*		
A. Migim	Sec. 10	170					Ridge. Loess, 12; yellow till, 38; gravelly sand, 25; blue till, 25; yellow cemented gravel, 10; hard blue till, 60.
Daniel McCabe	Sec. 11	80				Gravel	Sand, blue clay, and gravel. Base of bluff.
Patrick O'Brien	Sec. 17	175				Sand	
H. J. Jeffries	Sec. 22	94					Yellow clay above; red sand, 60; white sand and gravel.
T. 76 N., R. 2 W. (PART OF FRUITLAND).							
C. S. Miller		110					
Dershey Creamery	Sec. 4	44					
I. W. Kincaid	Sec. 5	160		160			Base of bluff.

POWESHIEK COUNTY.

By HOWARD E. SIMPSON and W. H. NORTON.

TOPOGRAPHY.

Poweshiek County is situated slightly southeast of the central portion of Iowa. As it has scarcely a stream large enough to bear the name of river, save perhaps the North Skunk, which crosses the southwest corner, its drift plain is a broad rolling prairie of decided upland type. The county is, however, divisible into two distinct topographic areas, coincident in a general way with the surface areas occupied by two drift sheets, the Iowan and the Kansan.

Iowan drift covers about 75 square miles in the northwestern part of the county, its eastern edge being not far east of Sheridan and Westfield. Here the plain is gently undulating, broken only by a few swells and by slight sags, in which grassy sloughs may be found The stream channels are neither numerous nor well defined, and, in fact, this area bears all the characteristics of topographic youth; it remains very much as it was molded by the overriding ice.

The much larger portion of the county to the south and east belongs to the Kansan drift area and presents evidences of early maturity. The stream valleys are comparatively deep and broad, and the uplands, though still broad, are almost completely drained through a multitude of small V-shaped valleys.

The drainage is southeastward through characteristic prairie creeks tributary to Iowa, English, and Skunk rivers. The largest streams, especially the North Skunk, have well-developed flood plains. Only in the northwest corner is the imperfection of drainage shown by small sloughs and ponds, remnants of old and larger glacial lakes occupying depressions in the drift. Even these are almost extinct, for man is aiding nature in the work of drainage, both by open ditches and by tile.

GEOLOGY.

The country rock of Poweshiek County (Pls. VIII, XV) belongs to the Carboniferous system, the Osage group and "St. Louis limestone" of the Mississippian series and the Des Moines group of the Pennsylvanian series being represented. The Mississippian rocks consist of limestones and some shales, so similar as not to be distinguished in ordinary well borings. They form the country rock over about three-fourths of the county, lying north and east of a line passing near Newburg, Grinnell, Jacobs, Montezuma, and Tilton. The Des Moines group (Pennsylvanian) consists chiefly of shales, together with some sandstones and limestones, and is the productive coal division. It unconformably overlies the Mississippian west and south of the line mentioned above, except where North Skunk River has cut through and the alluvium rests directly upon the "St. Louis limestone."

The older Kansan drift rests upon the country rock and is overlain in the northeast corner by the younger Iowan drift and elsewhere by a thin veneer of loess. In places there seem to be traces of a drift older than the Kansan, but these have not yet been well made out.

UNDERGROUND WATER.

SOURCE.

In Poweshiek County water is obtained from the alluvium (including some outwash gravel), the drift, the Des Moines group, the Mississippian limestones, and deeper strata. Only the drift and the Mississippian limestones are of importance.

The alluvium in the stream valleys is comparatively unimportant, owing not only to its small areas, but to its slight depth. However, in the valleys of North Skunk River and of a few of the larger creeks sufficient gravel, probably of Buchanan age, underlies the silt in such a way as to permit a strong underflow, which is utilized in shallow driven and open wells, chiefly in pasture wells for stock.

The water beds of the drift are several but are not generally differentiated. In the loess-Kansan area shallow wells obtain a meager, variable, and insufficient supply in the sandy phase at the base of the loess. In the Iowan area a gravel corresponding to the Buchanan gravel is not uncommon between the Iowan and the Kansan drifts, but is not easily distinguished on the uplands and is variable and uncertain as a source of supply. In the valleys it is more important, but it can not there be distinguished from the alluvial sands and has therefore been classed with them.

The persistence and abundance of their waters make the extensive gravel deposits, which lie deep below the surface of the Kansan drift, the most valuable of all the Pleistocene sources. In many places these gravels are double, one bed occurring well up within the drift and another at the base. The former is probably of Aftonian age and the latter is probably residual rock material or rubble from the surface of the bedrock. Whatever their origin, they form excellent waterways and reservoirs. In Poweshiek County these gravels are all deeply buried, lying at depths of 50 to 200 or even 400 feet.

Small veins and seeps are found at intervals throughout the drift, and from these by far the greater number of the wells in Poweshiek County draw a somewhat variable supply of good, wholesome water. Only when larger supplies for town or stock-farm use are desired is it necessary to resort to rock wells.

The Des Moines group consists chiefly of shales, too impervious and too strongly impregnated with mineral matter to be of value as a water bearer. A few local sandstone beds furnish good water, but these are not common in the thin margin of the formation found in Poweshiek County.

The Mississippian limestones have sufficient sandy and porous layers to form a good water bed, which is persistent throughout Poweshiek County. Though deeply buried by drift, this bed may well be sought where a moderately large and constant supply is desired. Though hard, it is generally free from obnoxious minerals and is an almost ideal water for stock. Wells of 180 to 200 feet are most common, but some of 400 and 500 feet are reported.

Deeper sources are reached by the city wells at Grinnell (p. 481) and by a well on the "Farwell ranch," near Montezuma; this last is reported to be about 2,500 feet in depth, but no record of it is obtainable.

BELLE PLAINE BASIN.

About 4 square miles of the extreme northeast corner of Poweshiek County is included within the Belle Plaine artesian basin (see pp. 356–358). Within this area wells ranging from 200 to 250 feet in depth yield a strong flow. In other near-by wells the water rises close to the curb but does not flow.

SPRINGS.

A number of strong springs are found in Poweshiek County, especially in the southern and eastern parts. The spring near Montezuma (p. 484) and one on the farm of W. H. Taylor, south of the town, are among the more important.

CITY AND VILLAGE SUPPLIES.

Brooklyn.—The public supply of Brooklyn (population, 1,233) is from a 208-foot well, the water bed being a sand and gravel layer, probably Aftonian, overlying blue clay near the bottom of the well. A higher water bed was found at 80 feet, but the flow was insufficient. This is the fourth well put down to this water bed, the others being abandoned chiefly on account of difficulty with sand. The present well was sunk in 1903, is used without a screen, and no trouble is experienced.

The water is pumped by a gasoline engine into an elevated tank; capacity 16,920 gallons. The gravity pressure is 76 pounds in the business district, and in case of fire may be raised to 220 pounds by direct pressure. A large reservoir, having a capacity of 1,000 barrels, is used to supplement the tank and hold the reserve; 2½ miles of mains supply 22 hydrants and 180 taps. Only about 500 or 600 barrels are used daily.

An excellent water supply is that of John F. Scott, on Jackson Street, whose well probably reaches at 230 feet the same gravel bed that supplies the city well. The water is pumped by windmill to an elevated tank and supplies some of the neighboring houses. The Chicago, Rock Island & Pacific Railway uses the water of a small creek in preference to a shallow well.

In the vicinity of Brooklyn drift wells are ordinarily dug to about 40 feet, though they range from 15 to 65, and some on the higher lands reach 90 feet. An abundance of good water is ordinarily obtained at this depth in gravel probably of Aftonian age. For larger supplies the gravels and sands at the base of the drift, in places at depths of 200 to 230 feet, are sought. The great depth of the drift and the abundance of water in its lower gravel beds is such that rock is rarely reached. The depth of the limestone is variously reported from 150 feet to the very unusual depth of 400 feet. Water from limestone is hard but very constant in supply.

The elevation at Brooklyn is 848 feet above sea level. The drill will probably leave the Kinderhook about 500 feet above sea level, will find the Silurian limestones from 275 above to 75 feet below sea level, the Maquoketa shale to 300 feet below, and the Galena and Platteville limestones to 600 feet below sea level, at which depth the water bed of the St. Peter sandstone should be discovered. Drilling should be carried at least 300 feet deeper, or to 900 feet below sea level (1,750 feet from the surface), in order to secure the flows from the creviced limestones and the sandstones underlying the St. Peter. Water will probably be found in the Galena and surely in an adequate amount in the St. Peter and adjacent terranes. The Silurian is probably here somewhat gypseous, and absolutely water-tight casing should be carried down to the Galena and securely bedded there with the best of packing.

Deep River.—The village of Deep River (population, 467) owns a waterworks system in which a deep well is pumped by gasoline, compressed air being used to force the water from the storage tank through a mile of mains to 11 fire hydrants and several private taps under a normal pressure of 25 pounds, which is increased in case of fire to 65 pounds.

Most wells are in drift and are 30 to 40 feet in depth. Heavy beds of sand are reached at about 135 to 175 feet, and of limestone between 200 and 250 feet. All ground water is hard, but the limestone water is harder than the drift water.

Grinnell.—The public water supply of Grinnell (population, 5,036) is obtained from deep wells (Pls. VIII, XV) by an air lift and is emptied into a covered reservoir (capacity, 188,000 gallons) at a rate of 7,500 gallons per hour. From this reservoir the water is forced into the main standpipe by a direct-pressure pump having a capacity of 1,000 gallons a minute. A pressure of 50 pounds is ordinarily maintained, but this may be increased to 125 pounds in case of fire after cutting off the standpipe. A battery of two boilers of 50 horsepower each furnishes the steam for the station plant. From the standpipe 5½ miles of mains distribute the water to 55 fire hydrants and many private taps.

A second supply suitable for boiler purposes is obtained from Crescent Lake, formed by impounding the waters of a small branch of Sugar Creek. From this it is pumped into an elevated tank, located at the city station, which has a capacity of 40,000 gallons. Two miles of mains distribute about 40,000 gallons daily, under 25 pounds pressure, to the city waterworks and the electric light plant, and to practically all the manufacturing plants of the town using steam power. It makes a very satisfactory boiler supply. The amount available is limited only by the capacity of the pump, approximately 10,000 gallons an hour.

City well No. 1 has a depth of 2,003 feet and a diameter of 10 inches to 208 feet, 6 inches to 408 feet, 5 inches to 1,185 feet, and 4 inches to 2,003 feet; 10-inch casing is used to 208 feet, 5-inch from 408 to 958 feet, and 4-inch from 1,145 to 1,185 feet. The curb is 1,028 feet above sea level and the head 230 feet below the curb. The tested capacity is 105 gallons a minute. Strongly mineral water, almost yellow in color, rises from a depth of 212 feet to 90 feet below the curb; water also occurs at 1,530 feet, at 1,700 feet, and lower. The well was completed in 1893 by J. P. Miller & Co., of Chicago.

Record of strata in city well No. 1 at Grinnell.

	Thickness.	Depth.
Quaternary:	*Feet.*	*Feet.*
Soil, loess, and drift	212	212
Carboniferous (Mississippian):		
"St. Louis limestone" and Osage group—		
Limestone, rather soft, buff; in chips mixed with sand and small pebbles of northern drift	8	220
Shale, dark gray, fissile; fragments of impure chert; in light-drab argillo-calcareous powder	20	240
Limestone, cherty, arenaceous, argillaceous; after washing is seen to contain many minute crystals of selenite	30	270
Limestone, gray; as fine sand in argillo-calcareous powder	45	315
Limestone, cherty, and shale; as chips in argillo-calcareous powder	50	365
Shale and limestone; soft, fissile, dark drab; in powder; with a few minute fragments of limestone and considerable chert	35	400
Kinderhook group—		
Shale, blue, calcareous; in powder, concreted into readily friable masses containing microscopic particles of quartz	15	415
Shale, hard, green-gray; with compact, light yellow, calcareous, siliceous; angular grains of transparent quartz; the largest 0.09 millimeter in diameter.	20	435
Shale, fine grained, calcareous, greenish	5	440
Shale, brownish drab	10	450
Shale, light blue-gray, somewhat calcareous; 2 samples	100	550
Shale, brownish drab	20	570
Devonian:		
Limestone, fine grained	....	570
Shale, light blue-gray, seleniferous, calcareous; a few particles of limestone	30	600
Shale, light drab and bluish, somewhat calcareous; a little finely divided quartzose residue after washing; 5 samples	200	800
Silurian:		
Limestone, light yellow-gray, granular, subcrystalline; brisk effervescence; much shale	10	810
Shale and limestone; in light blue-gray argillaceous powder containing a few fragments of limestone	15	825
Shale, light blue and green gray; somewhat calcareous; 7 samples, last at 900	115	940
Limestone, magnesian, medium dark gray, earthy, argillaceous	9	949
Limestone, magnesian or dolomite; considerable hard, finely arenaceous, greenish shale	20	969
Shale, light gray, argillo-calcareous	21	990
Limestone, highly cherty	22	1,012
Limestone, white, soft	53	1,065
Limestone, highly cherty; 2 samples	65	1,130
Limestone, cherty	45	1,175
Dolomite or magnesian limestone, light buff; in fine sand	25	1,200
Ordovician:		
Maquoketa shale—		
Shale, light drab, calcareous	60	1,260
Shale, light brown, pyritiferous; 2 samples, last at 1,280	60	1,320
Magnesian limestone or dolomite, buff; residue cherty and microscopically arenaceous	60	1,380
Shale, brown	20	1,400
Galena dolomite—		
Magnesian limestone or dolomite, ferruginous; in dark buff powder; residuary quartzose particles 0.018 to 0.18 millimeter in diameter; 4 samples	75	1,475
No samples	135	1,610
Limestone, magnesian, cherty, light yellow; in powder	20	1,630
Limestone, light gray, fossiliferous; in flaky chips	10	1,640
Decorah shale—		
Shale, green, noncalcareous, "fossiliferous"	15	1,655
Platteville limestone—		
Limestone, magnesian; in buff powder	45	1,700
St. Peter sandstone—		
Sandstone, calciferous; quartzose particles from 0.018 to 0.18 millimeter in diameter; particles of white dolomite mingled with the quartz in the drilling.	6	1,706
Sandstone, white; grains rounded and smooth; usual size about 0.55 millimeter, largest 0.92 millimeter in diameter	34	1,740
Sandstone, light reddish buff; fine grains, mostly broken; many stained with film of ferric oxide; largest 0.28 millimeter in diameter	....	1,740
Prairie du Chien group—		
Shakopee dolomite and New Richmond sandstone—		
No samples	262	2,002
Sandstone, highly calciferous, or limestone, arenaceous; sand grains angular, some rounded; largest 1 millimeter in diameter, matrix of dolomite, white, at	....	2,003

Record of strain in city well No. 2 at Grinnell (Pl. VIII, p. 352; Pl. XV, p. 670).

	Thickness.	Depth.
Pleistocene (209 feet thick; top, 1,028 feet above sea level):	*Feet.*	*Feet.*
No sample	41	41
Till, greenish yellow	49	90
Till, blue	85	175
Till, blue; darker than above	5	180
Till, blue; lighter	29	209
Carboniferous (Mississippian):		
"St. Louis limestone" and Osage group (191 feet thick; top, 819 feet above sea level)—		
Limestone, buff, dense, hard; brisk effervescence; in small cuttings and concreted powder	5	214
Sandstone, highly calcareous; grains of clear quartz, coarse, diverse in size, imperfectly rounded	26	240
No record	6	246
Limestone, light blue-gray; dull luster; slow effervescence; some cuttings of sandstone, dark blue, fine grained	2	248
No record	8	256
Limestone, blue, highly cherty, argillaceous, pyritiferous; effervescence slow; also shale	12	268
Limestone, light gray, fossiliferous, encrinital; brisk effervescence	32	300
Chert; in large chips; some limestone	25	325
Limestone, blue-gray and whitish; cherty and with microscopic angular particles of quartz; brisk effervescence	25	350
Limestone, light gray, cherty, arenaceous; rapid effervescence	25	375
Shale, light blue-gray; in powder; chert, blue; and limestone, gray	25	400
Kinderhook group (167 feet thick; top, 628 feet above sea level)—		
Shale, blue gray; in friable concreted powder; largely composed of microscopic angular particles of quartz	15	415
Shale, green-gray; in hard concreted masses, quartzose	5	420
No record	5	425
Shale, blue-gray and olive-gray, calcareous; in tough concreted masses; 7 samples	142	567
Devonian (216 feet thick; top, 461 feet above sea level):		
Limestone, gray; rapid effervescence; crystalline; some chips pyritiferous; much shale from above	25	592
Shale, light blue, calcareous; in tough concreted masses	8	600
Limestone, blue-gray; rapid effervescence; also shale, blue	33	633
Shale; in tough, blue, concreted masses; 2 samples	67	700
Limestone, drab, hard; rapid effervescence; and shale, blue, in concreted masses	23	723
Limestone, light yellow-gray, argillaceous, or shale, highly calcareous; in concreted powder	27	750
Limestone, light yellow-gray, lithographic; brisk effervescence	26	776
Shale, blue, somewhat calcareous	7	783
Silurian (414 feet thick; top, 245 feet above sea level):		
Limestone, brown, crystalline; rapid effervescence; in angular sand; also gypsum, in white cuttings	77	860
Limestone, light gray, hard, compact, subcrystalline	10	870
No record	5	875
Limestone, light yellow-gray and dark drab; moderately rapid effervescence; much white gypsum	14	889
Shale, calcareous, light blue; chert, white; and light-gray limestone of slow effervescence	26	915
Dolomite, light gray, crystalline; slow effervescence	35	950
Dolomite, light brown, macrocrystalline; in large chips; a little white gypsum	40	990
Dolomite, light gray, crystalline; in small chips	10	1,000
Gypsum, white, with shale, hard, dark green, calcareous, and highly arenaceous; fairly large rounded grains and minute angular particles	25	1,025
Gypsum and shale; in whitish concreted powder	5	1,030
Chert, white, gray, yellow, and black; with limestone, light gray, of rapid effervescence	10	1,040
Limestone, light yellow-gray, macrocrystalline; rapid effervescence; chert, white; and hard, green, arenaceous shale; cuttings chiefly chert	40	1,080
Limestone, light gray, earthy; rapid effervescence; much white chert	30	1,110
Limestone, whitish and light yellow; rapid effervescence; shale, reddish and green; calcareous in molded masses; flint, brown and gray	10	1,120
Limestone, whitish, pink, and yellow, with much gray flint; shale, dark green and a little dark reddish; all concreted in greenish argillaceous powder	30	1,150
Limestone, whitish and yellow; rapid effervescence; much chert	20	1,170
Limestone, magnesian or dolomite, crystalline, light yellow	27	1,197
Ordovician:		
Maquoketa shale (211 feet thick; top, 169 feet below sea level)—		
Shale, green, slightly calcareous	23	1,220
Shale, green and brown	3	1,223
No samples	40	1,263
Shale, dark brown, bituminous, burning freely, and rather hard, blue shale, pyritiferous	2	1,265
Shale, brown; in calcareous concreted masses	19	1,284
Shale, blue, in concreted powder, and limestone, dolomitic, in crystalline sand; some dark-brown siliceous cuttings	6	1,290
Shale, blue	50	1,340
Shale, light brown, calcareous; 3 samples	35	1,375
Shale, drab	33	1,408

Record of strata in city well No. 2 at Grinnell.

	Thickness.	Depth.
Ordovician—Continued.		
Galena dolomite to Platteville limestone (291 feet thick; top, 380 feet below sea level)—	*Feet.*	*Feet.*
Dolomite, light buff and brown, crystalline, porous; in chips	42	1,450
Dolomite; as above; cherty; in sand	25	1,475
Dolomite; as above; with greenish, argillaceous and microscopically arenaceous powder; 3 samples	75	1,550
Limestone, gray; brisk effervescence; in sand	10	1,560
Dolomite, buff and brown; in crystalline sand; 2 samples	65	1,625
Limestone, dark drab and light gray; rapid effervescence	25	1,650
Shale, green, hard, laminated, slightly calcareous	4	1,654
Limestone, yellow-gray, crystalline; rapid effervescence; some rounded grains of quartz sand	37	1,691
Shale, green, laminated, hard; practically noncalcareous	8	1,699
St. Peter sandstone (32 feet thick; top, 671 feet below sea level)—		
Sandstone, white; grains rounded; largest 0.8 millimeters in diameter	32	1,731
Prairie du Chien group—		
Shakopee dolomite (169 feet thick; top, 703 feet below sea level) :		
Dolomite, dark brown and gray, hard; much quartz sand in drillings; dolomite cuttings very sparingly arenaceous	39	1,770
Dolomite, buff, arenaceous; with grains seen to be embedded; in sand and large chips of vesicular dolomite	34	1,804
Sandstone and dolomite; in buff sand; quartz sand in excess	9	1,813
Dolomite; in buff sand, cherty, oolitic, arenaceous, as inferred from quartz sand in drillings	27	1,840
Dolomite, gray, vesicular, crystalline; in large chips	20	1,860
Sandstone, white; largest grains 1 millimeter in diameter, showing some secondary enlargements; with chips of finer-grained sandstone, with calcareous cement	6	1,866
Dolomite, gray; in large chips	34	1,900
New Richmond sandstone (79 feet thick; top, 872 feet below sea level):		
Sandstone and dolomite; in buff, fine sand; quartz sand in excess; grains of quartz sand and cuttings of dolomite of about same size	33	1,933
Sandstone, white, rather coarse; grains with secondary enlargements; some chips showing calcareous cement	17	1,950
Sandstone, buff; finer than above; in chips showing calcareous matrix	29	1,979
Oneota dolomite (8 feet penetrated; top, 951 feet below sea level):		
Dolomite, white; in chips	4	1,983
Dolomite, cherty, bright buff; in sand	4	1,987
Dolomite, buff; in sand.		

Malcom.—The town of Malcom (population, 377) is provided with a water supply from two wells. An elevated tank furnishes 65 pounds pressure for a mile of mains, supplying nine hydrants and a few private consumers.

Montezuma.—The public supply of Montezuma (population 1,172) is from a 300-foot well. The water is pumped by gasoline engines into a 20 by 24 foot tank, elevated on a 100-foot steel tower. Distribution is entirely by gravity, through 2 miles of mains to 17 fire hydrants and 35 taps. Only about 200 barrels are used per day in summer. A pressure of about 45 pounds is maintained throughout the town. The water is hard and deposits a red precipitate on the pipes, showing that, though some of it may be drawn from the limestone, a large part of it comes from the overlying Pleistocene gravels, which in many places carry much iron.

Two miles northeast of Montezuma is a spring which is said to flow in a 2-inch stream from a sand bed into a 12 by 12 foot brick reservoir, from which arrangement is made for pumping by a gasoline engine. This spring is being considered as a source of public supply.

In the vicinity of Montezuma plenty of water may usually be found in drift sand at depths of 50 to 60 feet or perhaps 80 feet on the uplands. Fine sand has caused some difficulty in pumping and on that account a few wells have been abandoned or extended to limestone at depths of 200 to 300 feet. The limestone water is hard and stands about 100 feet below the surface; the supply, however, is certain and very constant.

Montezuma is 948 feet above sea level, but an accurate estimate of the depths of the different water beds is difficult because of a hypothetical east-west sag bounded on the south by the up warp of the lower Paleozoic formations of southeastern Iowa. If the dip of the strata from Belle Plaine to Pella is uniform the St. Peter should be found at Montezuma about 640 feet below sea level, a depth nearly coincident with that given on a section from Grinnell to Sigourney. But the sag may carry the St. Peter down to 675 or 700 feet below sea level or at most 1,650 feet below the surface. A deep well should be drilled at least 300 or 400 feet below the St. Peter into the subjacent limestones and sandstones, where an abundant supply of water will probably be obtained. The well should be sunk to a depth of 1,950 to 2,050 feet.

The upper waters from the Mississippian and probably also any water found in the Silurian will be heavily mineralized and should be shut out. The quality of the lower and main waters is a matter of prime importance which regrettably can not be definitely predicted. In general, it is believed that these waters are of a fair quality, but there are some indications to the contrary for this locality. The experience of Sigourney, where casing carried to the Galena, as reported, still left an unpotable water, is distinctly discouraging, although the probabilities are that at the latter place either the casing leaked or the Galena water was heavily mineralized. On this last supposition a water-tight casing bedded a short distance above the shales of the lower Platteville should have remedied the difficulty. At Pella the upper waters were found unpotable, but when cased out, the lower or Ordovician waters were insufficient in quantity. The Pella well, however, reaches only to the St. Peter; had it been sunk a few hundred feet deeper fair waters of good yield would have probably been secured. The experience of the second city well at Grinnell, which succeeded in casing out the injurious sulphated waters of the first well and still had an abundant supply, would probably be duplicated at Montezuma with due care in the construction of the well. The water will probably head at about 175 feet from the surface.

WELL DATA.

The following table gives data of typical wells in Poweshiek County:

Typical wells of Poweshiek County.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head below curb.	Remarks (logs given in feet).
T. 78 N., R. 14 W. (PART OF JACKSON).						
		Feet.	*Feet.*		*Feet.*	
W. H. Taylor	SW. ¼ sec. 34	217	177	Limestone	90	Yield, 10 gallons per minute; pumped by gas and wind engines. "Iron and sulphur" taste. First water bed at 180.
City of Montezuma		300±	200±	do	65	Pumped by 10-horsepower gas engine. Hard. Iron taste. Used but little.
T. 80 N., R. 16 W. (GRINNELL).						
J. W. Fowler	Grinnell	434	200	Limestone and shale.	130	Pure. Water beds at 216 and 300. Pumps 9 gallons a minute without lowering.
M. A. Sears	do	183	(a)	Fine sand	83	Plenty of soft water.
T. 80 N., R. 14 W. (BEAR CREEK).						
Talbot and Thompson.	Sec. 12	605	325	Red sandstone.	125	Pumps 12 gallons a minute. Black soil, 3; red clay, 75; blue clay, 246; sand (dry), 1; blue and gray shale, 225; white clay, 7; limestone, 46; red sandstone, 2.
City of Brooklyn		208		Sand and gravel.		
John F. Scott	Brooklyn	233		do	100	Abundant soft water. Soil and yellow clay, 30; blue clay, 200; fine sand and gravel, 3.
James Calderwood	SE. ¼ sec. 2	575	400±	Limestone	50	Very constant. Red clay, 50; blue clay, 350; limestone, 175.
Luther Triplet	SE. ¼ sec. 4	201	(a)	Gravel	65	
Jos. F. Coulter	S. ½ sec. 15	170	169	Limestone(?)	50	Fine well; probably from gravel.
S. E. Brush	do	172	170	Limestone	60	Probably from gravel.
J. N. Newkirk	NE. ¼ sec. 16	578	325	do	75	Strong well. Soil and yellow clay, 60; blue clay, 262; gravel and sand (dry), 3; shale (?) slaty color, 247; limestone, hard, gray, 6. Hard and strongly mineral. Pumped by gasoline engine to tanks of farm; also of neighbor.
T. 81 N., R. 14 W. (MADISON).						
John W. Jones	W. ½ sec. 20	400	(a)	Sand	65	
T. 78 N., R. 13 W. (DEEP RIVER).						
W. L. Buxton	NE. ¼ sec. 5			Limestone	75	Can not pump down.
John Doonan	1½ miles north of Deep River.	194	180	do	94	First water at 165 feet in sand and clay; yield 8 gallons a minute. Hard.
T. 79 N., R. 14 W. (SCOTT).						
R. F. Hutchinson	SE. ¼ sec. 28	202	152	do	100	First water bed at 50. Sand and gravel. Hard. Drift, 152; slate, 16; coal and fire clay, 2; shale; limestone, water bearing.

a No rock.

Typical wells of Poweshiek County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Source supply	Head below curb.	Remarks (logs given in feet).
T. 79 N., R. 14 W. (SCOTT)—Contd.						
John Hutchinson ..	SW. ¼ sec. 27....	181	171	Limestone.	68	Strong well. Drift, 168; sand, partly cemented, 3; limestone, 9; limestone, very hard, 1. White and milky after storm; hard.
Wm. T. Hutchinson.	NE. ¼ sec. 34....	184	181	.....do......	....	Black water at first, bad odor; later cleared.
John R. Johnson...	NE. ¼ sec. 35....	412	131	.....do......	100	Red clay, 75; blue clay, 50; sand (scant water), 6; limestone, hard gray, 281. Pumped 8 gallons per minute at test without lowering.
Do.............	NE. ¼ sec. 22....	118	(a)	Gravel.....	35	Strong well.
Maggie R. Johnson.	NW. ¼ sec. 6....	324	....	Sandstone .	40	Very strong well.
T. 79 N., R. 13 W. (LINCOLN).						
J. A. Dougherty....	SE. ¼ sec. 3......	180	(a)	Gravel.....	100	Never pumps lower.

a No rock.

SCOTT COUNTY.

By W. H. NORTON.

TOPOGRAPHY.

Scott County is an area of faint relief. The larger part is an upland of well-nigh level Illinoian drift, sharply dissected along its margins, but elsewhere drained by shallow though broad waterways. The extreme northwestern part is occupied by a maturely dissected area of Kansan drift. Along the right bank of the Wapsipinicon Valley in Butler and Princeton townships rises a narrow and high ridge composed largely of loess and sand. The recently cut channel of the Mississippi from Princeton south gives room for a narrow alluvial lowland south of Valley City and one somewhat wider below Davenport. That part of the wide flood plain of Wapsipinicon River which lies south of the channel, an area of about 35 squares miles, falls to Scott County. Across the western part of the county stretches a broad marshy sag once occupied as a temporary channel by the Mississippi and now held by an insignificant stream called Mud Creek.

GEOLOGY.

Buff and bluish dolomitic limestone quarried at Le Claire and belonging to the Niagara underlies the northern part of the county; higher and younger limestones of Devonian age, of which the Davenport quarries furnish examples, underlie the drift in Davenport and Blue Grass townships; and shales and sandstones belonging to the Pennsylvanian series occupy the extreme southern part of the county. (See Pl. XV, p. 670.)

UNDERGROUND WATER.

PROVINCES.

Wapsipinicon flood plain.—Wapsipinicon River, which forms the northern boundary of the county, flows over a flood plain whose

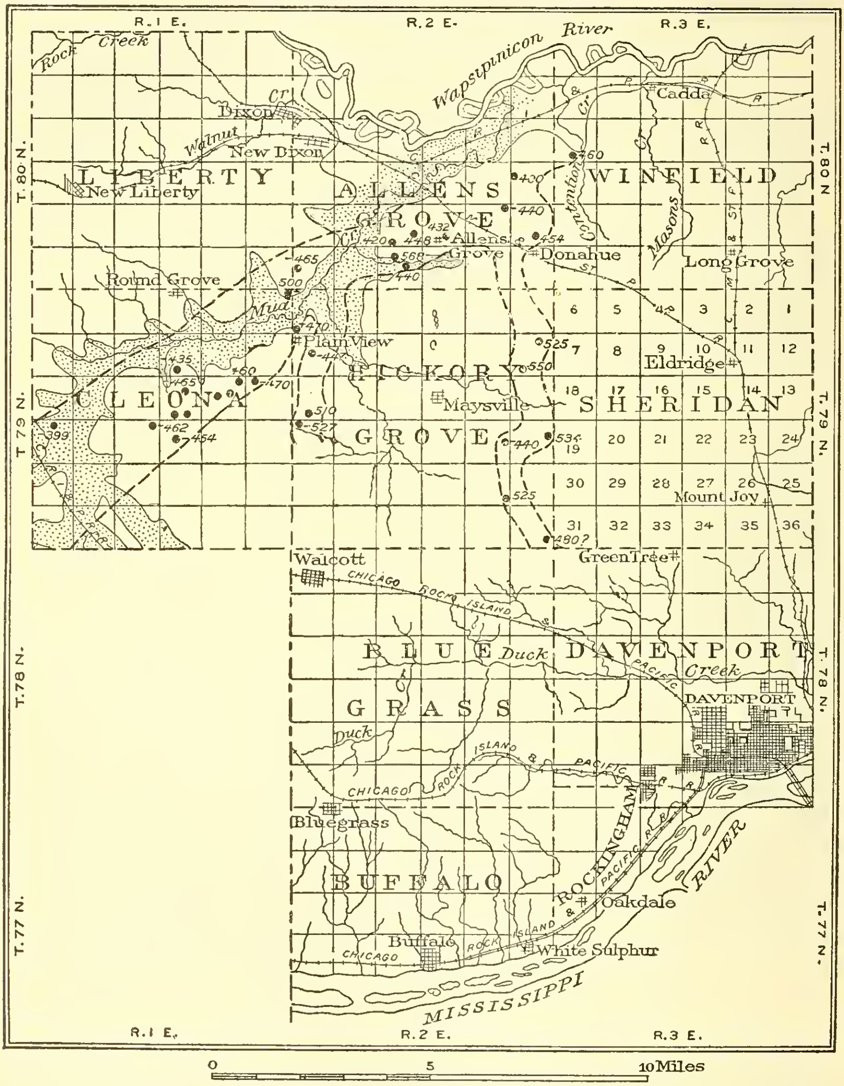


Figure 5.—Map of western Scott County, showing the ancient channel now occupied by Mud Creek (shown by shading) and the buried Cleona channel (bounded by broken lines). Figures at deep wells (●) indicate the elevation of the rock surface above sea level. Figures prefixed by minus sign (—) indicate depths of wells that did not reach rock.

width on the right bank of the stream ranges from half a mile near Dixon to 3 miles at McCausland. On this plain alluvial sands and gravels supply abundant water to shallow dug and driven wells.

Mud Creek channel.—The little stream of Mud Creek drains the northern portion of an ancient channel held by several geologists to have been cut in glacial time by the diverted waters of Mississippi River. The channel floor is about a mile wide, increasing in width at the mouths of the valleys of tributary creeks. Ground water stands high. Much of the area is ill drained and ponds and marshes occur, especially at the col which crosses the flat valley floor at the head of Mud Creek, separating it from the headwaters of another creek, Elkhorn, whose course is in the opposite direction. Along this channel ground water is easily reached by shallow wells.

Cleona buried channel.—In the western part of the county a distinct ground-water province exists in the ancient and deeply buried river valley called Cleona channel, from a township through which it passes. The depth and width, which considerably exceed that of the present Mississippi Channel contiguous to the county, lead to the inference that it was cut in rock by a stream of large size. Apparently the rock-cut valley is wide floored and bounded by steep bluffs now buried deep from sight. In the village of Plainview wells a few rods apart show sharp descents of the rock surface of about 150 feet, and in Cleona Township the rock surface declines more than 260 feet within a mile.

The Cleona channel joins the valley of the Wapsipinicon north of Allen Grove and Donahue, and probably continues down that valley to join the deep preglacial channel of the Mississippi north of Princeton. From Allen Grove southwest to Plainview it coincides in part with the broad flat-floored valley of Mud Creek, but from Plainview to Durant it lies mostly on the east side of Mud Creek Valley.

In sec. 19, Cleona Township, northeast of Durant, the channel has a depth of more than 300 feet below the surface of the ground. The rock floor is not reached here at an elevation of 399 feet above sea level. This elevation is but 20 feet above extreme low water in the Mississippi at St. Louis, and the fall thence to the Gulf of Mexico is but 3 inches to the mile. The rock floor here is more than 160 feet lower than the present bed of the Mississippi at Le Claire.

In this province water occurs in river or glacial-outwash sands with which the channel has been heavily aggraded, and which have been deeply buried beneath stony clays deposited by ancient ice sheets. The formations to be met with by the driller vary considerably, as the following well logs show:

Log of well of H. Goettsch, NW. ¼ sec. 9, Cleona Township.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, yellow and blue, Kansan	102	102
Clay, black, ill-smelling, Aftonian	45	147
Clay, blue, hard, Nebraskan	50	197
Quicksand, mostly fine	134	331

Log of well of Henry Roh, NE. ¼ sec. 26, Allen Grove Township.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, yellow and blue	100	100
Quicksand	25	125
Clay, blue, stony, underlain by 70 feet of river sand resting on blue till	150	275
Gravel	25	300

Log of well of J. Rathjen, SW. ¼ sec. 12, Cleona Township.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, yellow	35	35
Clay, blue	205	240
Sand	2	242

Log of well of Lena Mumm, NE. ¼ sec. 21, Cleona Township.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, yellow	12	12
Clay, blue	236	248
Sand and gravel	30	278

These and other wells show that in places beds of sand covered with stony clays occur at a depth from the surface of about 100 feet. These sands are apt to be too fine to be available for wells with the methods now in use in well construction. At depths of 200 to 275 feet a body of sand is encountered, which probably rests on bedrock, although, as it has not been drilled through, this is not altogether certain. The thickness of this bed may reach 130 feet. Because of the fineness of grain over much of this depth, it may be expected to give much trouble to the driller, but there are coarser layers and gravel beds in which a good supply can be obtained.

Niagara province.—The Niagara province embraces the two northern tiers of townships, where most of the wells are compelled to pass through the drift and find water either in the Niagara dolomite within a short distance from its surface or in overlying gravels.

In Liberty Township rock outcrops in the northern sections, as about Big Rock and Dixon, but the southern half is covered with 50 to 140 feet of drift. The depth to water varies widely in wells but a short distance apart; throughout the township water is found in rock within 50 to 150 feet of the surface.

In Hickory Grove Township, except along the buried channels of Cleona River and of another preglacial stream which passes through the eastern tier of sections, rock occurs within 30 and 50 feet between

Plainview and Maysville and within 80 and 150 feet elsewhere, water being commonly found within a few feet below the rock surface.

In Winfield, Butler, and Princeton townships, outside of the Wapsipinicon Valley, water is found but a short distance below the rock surface, which lies within 60 to 170 feet of the surface of the ground on the upland back of the bluffs of Mississippi River, at whose base rock outcrops. Northwestern Winfield Township, however, lies in Cleona channel, and a series of wells from 190 to 225 feet deep to rock in secs. 15, 26, and 35 indicate a buried channel somewhat less deep and wide than the Cleona, with an approximately south-north course.

In Sheridan and Lincoln townships and the western parts of Le Claire and Pleasant Valley townships rock is generally found at 60 and 70 to 150 feet, some wells reaching it, however, at 170 feet or even more. In the eastern sections of Le Claire and Pleasant Valley townships rock occurs at or near the surface, and wells passing through 30 to 60 feet of drift find water within 75 to 150 feet of the surface of the ground.

Devonian province.—In Davenport Township rock is generally entered at 80 to 170 feet, and water is found 10 to 50 feet below rock surface. Along the Mississippi rock outcrops in the side of the bluffs, but is covered with heavy drift and loess. A buried deep channel is suggested by wells in sec. 12 which strike rock at 212 to 230 feet, and by a well in Davenport, on Gains Street, said to be 200 feet to rock. These wells are aligned with the channel traced near Leroy Grove, in Winfield Township, but there are no well reports from the eastern sections of Sheridan Township, through which the channel connecting the two "deep countries" would run.

In Blue Grass Township, Devonian limestones lie 40 to 50 feet below the surface about Walcott, and from 80 to 100 feet below elsewhere. In secs. 1 and 12, however, two wells, one 230 feet to rock, and the other 275 feet deep, ending in sand, probably mark the southward extension of the buried channel which stretches across the eastern tier of sections of Hickory Grove Township. No data are at hand to trace the channel south of sec. 12.

Carboniferous province.—The Carboniferous province includes the larger part of Buffalo Township and parts of Rockingham, together with outliers in Le Claire and Sheridan townships. Here beneath the drift the drill strikes the shales and sandstones of the Pennsylvanian series or coal measures. As the water contained in these beds is meager in quantity and is, as a rule, highly mineralized, wells are generally drilled to the underlying limestones, where water of excellent quality is found in ample amounts and with a head which lifts it high in the well.

Outside of Buffalo Township the outliers of the Pennsylvanian are small in area, but as they occupy very ancient channels cut in Niagara dolomite may reach 200 feet in depth. The following are typical wells in the Pennsylvanian province:

Log of well in Buffalo Township, SE. ¼ SE. ¼ sec. 16.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, yellow	20	20
Soapstone	25	45
Slate	2½	47½
Coal	½	48
Fire clay	2	50
Shale	20	70
Coal	2½	72½
Fire clay	1	73½
Limestone (Devonian)	66½	140

Log of well of Le Claire Brick & Tile Co., Island City.

	Thickness.	Depth.
	Feet.	*Feet.*
Shale, dark	90	90
Sandstone, white	6	96
Shale, blue	70	166
Sandstone	9	175
Shale, blue	25	200
Limestone (Niagara) with water vein beneath the shale; water heads 4 feet from surface.	26	226

The White Sulphur Springs well is located in the NW. ¼ sec. 24, Buffalo Township. Its depth is 800 feet. It has a flow of strongly sulphureted water. The well was completed prior to 1870.

CITY AND VILLAGE SUPPLIES.

Bettendorf.—At Bettendorf (population, 909) the well of the Bettendorf Improvement Co. has a depth of 1,650 feet and a diameter of 12 inches at top and 9 inches at bottom; casing, 80 feet of 12 inch at top. The principal water bed is from 500 to 650 feet; flow, about 1,000 gallons a minute. Temperature, 65° F. Driller, John D. Shaw, of Davenport.

The Bettendorf Metal Wheel Co. well No. 1 has a depth of 400 feet and a diameter of 8 inches; cased to rock, 20 feet. The curb is 585 feet above sea level and the head 15 feet below the curb. Tested capacity, about 30 gallons a minute; water somewhat sulphureted.

The Bettendorf Metal Wheel Co. well No. 2 has a depth of 1,539 feet and a diameter of 10 inches to 60 feet, 8 inches to bottom; cased to 60 feet. The curb is 585 feet above sea level; head not reported. The flow is 200 gallons a minute. The well was completed in 1909 at a cost of $2,300 by J. D. Shaw, of Sioux City.

Davenport.—Davenport (population 39,797) is supplied with water drawn from Mississippi River and filtered. It is distributed by gravity pressure, 65 pounds, and direct pressure, 125 pounds. There are 72 miles of mains and 650 hydrants. The works are owned by the Davenport Water Co.

The 30-inch cast-iron intake pipe opens 1,000 feet off shore, the joints being all thoroughly calked with lead. The water flows from the intake pipe into a forebay, which is screened to prevent fish or floating débris from entering, and thence into the well, from which the suction is taken. Well and forebay are cleaned from 20 to 40 times a year. The water is then pumped into a settling basin with a capacity of 5,000,000 gallons, where it remains for 24 hours. This basin is cleaned once a year, the sediment collected during this time amounting to about 3 feet at the end of the basin at which the water is delivered, and 1 foot at the end where it is taken out.

From the settling basin the water flows through a flume over a weir into the coagulating basin with a capacity of 300,000 gallons, at whose entrance it is met by the coagulant solution. From 2 to 5 grains of sulphate of alumina to the gallon is used, the amount depending on the condition of the raw water. The alkalinity is tested daily. The filter alum is dissolved in tanks into which air is blown under pressure through pipes at bottom. The solution flows by gravity to a lead-lined centrifugal pump, by which it is lifted to an upper tank, which overflows into the bottom tanks, from which it is fed by gravity into the water in the coagulating basin. This method is believed to keep the solution at uniform strength and insure a uniform head. The water in the coagulating basin is given three hours for the completion of the process, and is then pumped under pressure through the filters into the main distribution. Each of the 10 horizontal filter shells is 32 feet long and 7½ feet in diameter. Each shell is divided into two compartments, in each of which are 5 feet of sand. The filter shells are capable of sustaining a pressure of 200 pounds to the square inch.

The bacterial efficiency is reported to range from 96 to 99.06, the percentage increasing with the number of bacteria in the raw water.

An upper and lower distributing service is employed. The lower service is supplied from the river station, which is designated station No. 1, and serves, under direct pressure, the business section of the town and that along the flood plain of the river. At station No. 2 the filtered water is pumped into a reservoir and the mains are so arranged that the pumps can be brought into commission at time of fire on the lower service to aid the pumps of station No. 1. When fire occurs on the upper service the pumps of station No. 2 supply direct pressure.

The Davenport waterworks supply the Iowa Soldiers' Orphans' Home, whose daily consumption is about 15,000 gallons, at a cost of 10 cents for 1,000 gallons. The supply had previously been drawn from a well on the grounds of the institution, but the capacity proved insufficient.

The sequence of formations at Davenport has been fully treated by Udden[1] and by the writer,[2] and the correlations specified in the papers cited have been confirmed, on the whole, by the records of wells drilled since their publication.[3] (See Pls. XII, XV.)

The surface rock at Davenport is the Wapsipinicon limestone of the Devonian system, the type outcrops of the Upper and Lower Davenport limestones of the Iowa State Survey being within the city limits near the water level of Mississippi River. The Devonian includes shales (as shown by the Kimball House samples, and by the record of "caving material" of the Malt & Grain Co. well No. 2) which may be assigned to the Independence shale member of the Wapsipinicon. The base of the Devonian may be placed at 475 feet above sea level.

The samples from the Kimball House well, confirmed by other well records, define the lower limit of the Niagara and summit of the Maquoketa at about 130 feet above and the base of the Maquoketa at about 100 feet below sea level.

The Galena dolomite extends at least to 250 and perhaps to 300 feet below sea level. The undolomitized limestones and accompanying shales of the Platteville limestone meet the St. Peter sandstone at about 448 feet below sea level, according to Udden. The records as to the summit of the St. Peter are singularly conflicting, however, varying from 376 to 511 feet below sea level. The base of the St. Peter sandstone is also variously reported, and Udden's estimate of 524 feet below sea level may be accepted as an approximation to its average place.

The Prairie du Chien group, on which the St. Peter rests, consists in its upper beds of shales and interbedded dolomites which reach a thickness of more than 100 feet. In several wells red marl is reported from this horizon.

The Jordan sandstone, which succeeds the Prairie du Chien at about 800 feet below sea level, is at least 150 feet thick and is continued downward into sandy limestones and limy sandstones of the St. Lawrence formation, from which its parting is ill defined in the driller's logs. The shale from 1,268 to 1,308 feet below sea level may be taken as the basal portion of the St. Lawrence, the latter depth marking the summit of the Dresbach sandstone. The deepest wells

[1] Water resources of Illinois: Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, pp. 829-849.
[2] Artesian wells of Iowa: Rept. Iowa Geol. Survey, vol. 6, 1897, pp. 272-280.
[3] Many of the data as to the newer wells were collected by Udden.

show that the Dresbach is underlain by heavy shales, succeeded below by another sandstone.

The first water obtained at Davenport comes from the Devonian at 440 to 480 feet above sea level. It may represent the natural springs which rise from the Independence shale member of the Wapsipinicon limestone along its outcrops. The water is insignificant in quantity, but is noteworthy because of its corrosive qualities, which eat the casing from the outside, where the drill hole passes through water channels.

A second flow is obtained in the Galena dolomite at depths of 108 to 242 feet below sea level. This is the so-called "upper water" and is noticeably impregnated with sulphureted hydrogen. Aeration and relief from pressure insure a rapid and complete escape of the gas. The water is frequently separated from lower flows. The yield has been generous, amounting in the Witts well to 300 gallons a minute.

A third flow comes from the St. Peter sandstone, which has so far furnished the larger part of the discharge of the Davenport basin and is the main water bed supplying wells from 1,050 to 1,200 feet in depth.

The analogy of other localities, where observations as to discharge seem to have been more carefully made, suggests that the Prairie du Chien group, especially its middle and lower portions, will also contribute largely to the flow of wells.

The Jordan sandstone at 745 to 945 feet below sea level may be depended on to yield generously with a head at present more than 20 feet higher than that of the St. Peter.

The St. Lawrence may be expected to yield little, if any, water, but the underlying Cambrian strata contain a well-filled reservoir 1,300 to 1,500 feet below sea level.

As is commonly the case when numerous artesian wells are drilled in a small area, the Davenport artesian field has shown from the beginning a progressive loss of pressure, lowering of static level, and diminution of discharge. This has been specially marked in wells 1,200 feet and less in depth, in which the main supply comes from the St. Peter. The initial head of these wells seems to have reached 651 feet above sea level, as shown by the woolen mills well drilled in 1890. In 1891 an initial head of 612 feet was reported, in 1892 initial heads of 606 and 631 feet, in 1893 of 610 feet, and in 1905 the initial head (at the Malt & Grain Co. well) of the St. Peter was less than 592 feet above sea level; all these heads are those of new wells and are therefore affected by no causes other than overdraft.

The head of the Jordan and lower waters remains higher than that of the St. Peter. Thus the head of the Park well, drilled in 1888, was initially 682 feet above sea level and in 1895 had declined to 670 feet. It should be noted, however, that this well is situated on high ground and is nonflowing. The initial head of the Malt & Grain Co.'s well for the Jordan, drilled in 1905, was 612 feet and that of the well of the Bettendorf Metal Wheel Co., drilled in 1909, is 606 feet above sea level.

In recent years the static level has been lowered by the use of compressed air in pumping a number of the wells, and though the discharge of the wells pumped has been increased to even more than the initial flows the head of other wells has been so reduced that they no longer flow. Thus the initial flow of the four wells of the Corn Products Refining Co. is reported at 1,413 gallons a minute. In 1908 the natural flow had declined to 842 gallons, but with compressed air a discharge is obtained of 1,635 gallons a minute. The well at the woolen mills yields at present but 25 gallons a minute under its natural pressure, but with compressed air gives 225 gallons. The two wells of the Independent Malting Co., which yielded in 1905 but 350 gallons, now pump 800 gallons. The well of the Crystal Ice Co., which flowed 250 gallons, pumps 240 gallons a minute.

The flow from the deeper aquifers still remains fair in new wells. Thus the new well of the Malt & Grain Co. flows 150 gallons, that of the Davenport Malting Co. and that of the Bettendorf Metal Wheel Co. each 200 gallons a minute.

As the static level of the St. Peter waters is now below the surface and the supply overtaxed, it is advised that new wells be sunk to the Jordan sandstone and to the sandstones underlying the St. Lawrence formation from 1,550 to 2,100 feet from the surface, although wells of 1,000 and 1,200 feet in depth will still yield largely under the pump.

The glucose factory has four wells. Well No. 1 has a depth of 1,500 feet and a diameter of 5 inches. The curb is 562 feet above sea level, and the head in 1896 was 58 feet above curb. The flow in 1896 was 230 gallons a minute; in 1908 it was 60 gallons a minute; tested capacity, under compressed air, in 1908, 160 gallons a minute. The temperature of the water is 61° F. Date of completion, 1876.

Well No. 2 has a depth of 2,101 feet and a diameter of 6 inches. The curb is 562 feet above sea level. The head in 1896 was 81 feet above curb; in 1905 it was 24 feet above curb. The original flow was 380 gallons a minute; the present flow is 228 gallons a minute; tested capacity, under compressed air, 380 gallons a minute. Temperature, 64° F. The well was completed in 1889 by J. P. Miller & Co., of Chicago.

Well No. 3 has a depth of 2,105 feet and a diameter of 6 inches. The curb is 562 feet above sea level. The original flow was 400 gallons a minute; present flow, 264 gallons a minute; tested capacity, under compressed air, 530 gallons a minute. Temperature, 64° F. The well was completed in 1892 by J. P. Miller & Co., of Chicago.

Well No. 4 has a depth of 2,107 feet and a diameter of 8 inches. The curb is 562 feet above sea level. The original flow was 400 gallons a minute; present flow, 290 gallons a minute; tested capacity, under compressed air, 565 gallons a minute. The temperature of the water is 64° F. The well was completed in 1892 by J. P. Miller & Co., of Chicago.

Repairs have been made only on well No. 4, new casing to 650 feet having been inserted in 1906, slightly increasing the flow. In 1905 these four wells discharged into the basin from which the water is pumped. The wells are situated not more than 240 feet apart, but no interference has been noticed.

Driller's log of glucose factory wells.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface material	52	52
Limestone, bluish, at		410
Shale, at		635
Limestone, at		970
Shale	30	1,000
Sandstone (St. Peter)	42	1,042
Limestone, sandy	530	1,572
No record	258	1,830
Shale	40	1,870
Limestone, sandy	20	1,890
Sandy rock	160	2,050
Shale	50	2,100

The Park well has a depth of 1,797 feet. The curb is 704 feet above sea level. The original head was 22 feet below curb; head in 1896, 34 feet below curb. The tested capacity is 125 gallons a minute. The well was completed in 1888 by J. P. Miller & Co., of Chicago.

Record of strata in Park well at Davenport.[a]

	Thickness.	Depth.
	Feet.	*Feet.*
"Loess;" no sample	40	40
"Bowlder clay;" no sample	60	100
Shale; dark; no sample	30	130
Limestone; pure, hard, gray, compact, fine textured, nonmagnesian	220	350
Dolomite; hard, highly vesicular, light pinkish-buff, with casts of crinoid stems and casts of apex of *Platystoma niagarense* Hall	30	380
Dolomite; subcrystalline, cream-colored, highly vesicular, with obscure cast of bryozoans	20	400
Dolomite; hard, bluish gray, subcrystalline	90	490
Shale; lead colored, argillaceous, very slightly calcareomagnesian, fossiliferous; blackens in closed tube before the blowpipe; turns white	30	520
Dolomite; white, arenaceous	80	600
Dolomite; hard, gray, subcrystalline	50	650
Dolomite; hard, rough, brownish, white; some fine gray shale	75	725
Dolomite; lighter in color, with obscure casts of fossils referred to Zygospira	50	775
Dolomite; light brownish	125	900
Dolomite; as above, with white chert	50	950
Dolomite; magnesian limestone, white	75	1,025
Limestone; light bluish gray, nonmagnesian, argillaceous; in thin, flaky chips	50	1,075
Shale; green, pyritiferous	10	1,085
Sandstone; grains rather coarse, rounded, white and pinkish	75	1,160
Shale; indurated, slightly arenaceous, fine grained, gray, green, and purplish	30	1,190
Dolomite; light gray, arenaceous	60	1,250
Dolomite; light buff, arenaceous	50	1,300
Dolomite; buff, arenaceous	100	1,400
No record	25	1,425
"Sandstone"	10	1,435
"Limestone"	100	1,535
Dolomite; in minute fragments, with large admixture of siliceous sand		1,797

[a] From drillings preserved by A. S. Tiffany, Davenport, Iowa.

The Kimball House well has a depth of 1,560 feet and a diameter of 8 inches to 710 feet and 4 inches to bottom. The curb is 579 feet above sea level. The original head (of lower water) was 58 feet above curb; in 1896, 20 feet above curb; in 1908, below curb a flow of sulphur water, 120 gallons a minute from a depth of about 700 feet, was cased out. The well was completed in 1890 (?) by A. K. Wallen. Between 1896 and 1905 the casing became corroded and the upper and lower waters mingled.

Record of strata in Kimball House well.[a]

	Thickness.	Depth.
	Feet.	*Feet.*
"Modified drift"	13	13
Limestone, magnesian, compact, fine textured, hard, light, and dark gray	67	80
Limestone, softer, lighter colored; similar in composition and texture to that above	48	128
Dolomite, hard, pure, subcrystalline, vesicular, light greenish gray; casts and molds of fossils	47	175
Dolomite; as above, but darker	130	305
Dolomite; as at 128 to 175 feet	120	425
Dolomite, light bluish gray; with white chert	23	448
Shale, black, pyritiferous, noncarbonaceous	27	475
Shale, blue	90	565
Limestone, blue, argillaceous, fossiliferous	125	690
Dolomite, hard, rough, subcrystalline, medium dark buff	40	730
Sand, fine, buff, largely dolomitic, with rounded grains of quartz; also many grains of pyrite in minute, agglomerated crystals; water bearing	45	775
"Limestone, soft, yellow, magnesian;" no sample	75	850
"Limestone, hard, buff, nonmagnesian;" no sample	50	900
"Limestone, argillaceous, ferruginous;" no sample	90	990

[a] From samples supplied by A. S. Tiffany.

The woolen mills well has a depth of 1,053 feet and a diameter of 3½ inches. The curb is 564 feet above sea level. The original head was 87 feet above the curb; head in 1905, at curb. The water at 85 or 120 feet, at 700 feet, and near bottom, was corrosive, cutting the casing from the outside. The original flow is unknown; flow in 1908, 25 gallons a minute; tested capacity in 1908, 225 gallons a minute. The well was completed in 1890 by A. K. Wallen. New casing was inserted in 1895, in 1901, and in 1906, to 200 and to 280 feet below the curb and each time a higher pressure was obtained.

The Witts Bottling Works well has a depth of 780 feet and a diameter of 6 and 3 inches. The curb is 575 feet above sea level. The original head was 82 feet above curb; head in 1896, 59 feet above the curb. The original and present flow is 300 gallons a minute, but is said to diminish when the well of Crystal Ice Co. is used. Date of completion, 1891. Drillers, J. P. Miller & Co., of Chicago.

The gasworks wells Nos. 1 and 2 have depths of 1,200 feet and a diameter of 5 to 4 inches; 5-inch casing nearly to bottom. The curb is 564 feet above sea level. The head of lower water, original, was 48 feet above the curb; head in 1896, 48 feet above the curb; head in 1905, 4 feet above the curb. Temperature, 65° F. The wells were completed in 1891 by A. K. Wallen.

The Schmidt building well has a depth of 1,200 feet and a diameter of 4 inches. The curb is 576 feet above sea level and the original head was about 30 feet above the curb. Head in 1905, less than the original. The original flow was about 45 gallons a minute. Date of completion, 1892; driller, A. K. Wallen.

The Malt & Grain Co. well No. 1 has a depth of 1,076 feet and a diameter of 5 inches. The curb is 592 feet above sea level. The original head was 39 feet above the curb; the head in 1896, 15 feet above the curb; in 1909, 14 feet below curb. The water comes from depths of 700 feet and 1,055 to 1,076 feet. Temperature, 62° F. The well was completed in 1892 by A. K. Wallen.

The Malt & Grain Co. well No. 2 has a depth of 1,653 feet and a diameter of 12 to 5 inches; cased from 100 to 120 feet, to shut out caving material, and from 1,100 to 1,135 feet. The curb is 592 feet above sea level and the flow 150 gallons a minute, the water rising 20 feet above the curb. The first flow was from Jordan sandstone at depths of 1,385 to 1,535 feet. Temperature, 64° F. The well was completed in 1905 by L. Wilson, of Chicago. During the drilling of the second well the flow of the first was permanently increased. The two wells are 100 feet apart.

Driller's log of Davenport Malt & Grain Co. well No. 2.

	Thickness.	Depth.
	Feet.	*Feet.*
Sand	35	35
Hardpan and gravel	31	66
Shale, sandy	15	81
Gravel	10	91
Loose limestone	1½	92½
Limestone	6½	99
Caving sand and gravel	3	102
Limestone, sandy	9	111
Shale	11	122
Limestone, white	161	283
Shale, sandy	15	298
Limestone, sandy	123	421
Limestone, brown	11	432
Shale, blue	74	506
Limestone	90	596
Limestone and blue shale	40	636
Shale, sandy	25	661
Shale, gray	100	761
Limestone	168	929
Limestone, flinty	2	931
Limestone, brown	65	996
Limestone, caving	7	1,003
Shale, blue and gray	22	1,025
Sandstone	62	1,087
Shale and caving rock	30	1,117
Limestone	39	1,156
Limestone and blue shale	6	1,162
Limestone and shale, caving	22	1,184
Limestone and shale	17	1,201
Marl, red, and limestone	49	1,250
Limestone, sandy	40	1,290
Sandstone	60	1,350
Limestone, gray	100	1,450
Limestone, brown	125	1,575
Limestone, sandy	78	1,653

The Crystal Ice Co. well has a depth of 1,067 feet and a diameter of 6 to 4 inches; cased to 1,067 feet. The curb is 590 feet above sea level and the original head 15 feet above the curb. The original flow was 250 gallons a minute; tested capacity in 1908, 240 gallons a minute. The first flow was at about 600 feet. Temperature, 60° F. The well was completed in 1893 by A. K. Wallen.

The Tri-City Packing & Provision Co. well has a depth of 1,100 feet and a diameter of 8 to 5 inches; cased to 800 feet. The curb is 564 feet above sea level. The original head was 46 feet above the curb; head in 1896, 46 feet above the curb; head in 1905, 7 feet above the curb. The original flow was 250 gallons a minute. The water comes from 800 and 1,100 feet. Date of completion, 1893. Driller, J. P. Miller & Co., of Chicago.

The Independent Malting Co. well No. 1 has a depth of 1,285 feet and a diameter of 4 inches. The curb is 573 feet above sea level (aneroid). The original head is unknown; the head in 1905 was 20 feet above the curb; in 1909, 9 feet above the curb. The flow in 1905 was 150 gallons a minute; tested capacity in 1909, 400 gallons a minute. Sulphureted water comes from a depth of a little more than 700 feet; other water from a sandstone near the bottom; waters separated. Date of completion, 1896.

The Independent Malting Co. well No. 2 has a depth of 1,285 feet and diameter of 6 inches. It is 175 feet distant from well No. 1. The head in 1905 was 12 feet above the curb and the flow 200 gallons a minute. The tested capacity in 1909 was 400 gallons a minute. Date of completion, 1904.

The well of the Martin Woods Co. has a depth of 415 feet and a diameter of 12 and 8 inches; casing, 12 inches for 48 feet, 8 inches for 98 feet; space between casings filled with concrete. The curb is 559 feet above sea level and the head is 1 foot above the curb. The pumping capacity is 33 gallons a minute; temperature, 53° F. The principal water bed is at 415 feet. Date of completion, 1910; driller, J. E. Shaw. On completing the well the head was found to be 4 feet below the curb, but in a few days the water had risen within a few inches of the surface. The use of a centrifugal pump has increased the natural flow.

The Davenport Malting Co. well has a depth of 1,998 feet (also reported as 1,880 feet) and a diameter of 8 inches. The curb is 560 feet above sea level (aneroid) and the head 45 feet above curb. The original flow was 200 gallons a minute; present flow, 150 gallons a minute. The first flow was of sulphureted water at 800 feet; second flow at 1,750 feet. Temperature, 62° F. The well was completed in 1900 by Wilson & Co., of Chicago.

The Independent Baking Co. well has a depth of 900 feet and a diameter of 10 inches. Water from depth of 100 feet rises within

20 feet of surface; the flow comes from a depth of 873 feet. Temperature, 56° F. Driller, J. D. Shaw.

To better define the place of the chief water beds there may be added the lower portions of the logs of two wells across Mississippi River from Davenport.

Log of lower part of Moline Paper Co.'s well at Moline, Ill.

[Curb, 564 feet above sea level.]

	Thickness.	Depth.
	Feet.	*Feet.*
Sandstone (St. Peter)	65	1,141
Marl, red, and limestone	16	1,457
Sandstone	101	1,578
Limestone	50	1,628

Log of lower part of Mitchell & Lynde Building well at Rock Island, Ill.

[Curb, 558 feet above sea level.]

	Thickness.	Depth.
	Feet.	*Feet.*
Sandstone (St. Peter)	145	1,104
Limestone	811	1,915
Sandstone, compact	30	1,945
Limestone	35	1,980
Sandstone	130	2,110
Limestone, shaly, and shale	75	2,185
Sandstone	97	2,282

Donahue.—At Donahue (population, 62) a small water-supply system is owned by two citizens. Water from wells is pumped to a tank with a capacity of 600 barrels. The number of taps is reported as 50. Drilled wells 100 to 300 feet deep find rock from 10 to 300 feet below the surface. Water from 150 feet has a head of 20 feet below the curb.

Eldridge.—The waterworks owned by the town of Eldridge (population, 217) consist of a well 180 feet deep, a tank, about a mile of mains, 16 fire hydrants, and 50 taps. The consumption is 800 gallons daily. The domestic and fire pressure is 45 pounds. Eldridge also uses cisterns and dug and drilled wells. The wells are from 103 to 201 feet deep, averaging 130 feet. They find rock at 100 feet. The water heads 90 feet below the curb.

Le Claire.—Le Claire (population, 690) draws its supplies from cisterns, drilled wells, and Mississippi River. The wells are from 30 to 150 feet deep with an average of 60 feet. They tap Niagara dolomite at about 60 feet, and are in rock from 20 feet down. There are some small springs in the neighborhood.

Le Claire is 580 feet above sea level. An artesian well was recommended in 1899 for it by W. H. Norton.[1] On account of the steeply

[1] Report on the geology of Scott County: Iowa Geol. Survey, vol. 9, 1899, p. 505.

inclined layers of the country rock, which apparently afford open waterways, the surface water may reach the common wells now in use in the town. A deep well will find the St. Peter 900 to 950 feet from the surface and this together with the supplies found in the Galena and Platteville should be adequate.

Walcott.—The waterworks in Walcott (population, 416) are owned by the town. They include a well 85 feet deep, from which water is pumped to a tank with a capacity of 2,000 barrels, affording a pressure of 42 pounds. There are a mile of mains, 16 fire hydrants, and 128 taps. House wells in the village range in depth from 20 to 42 feet. The shallower wells find water in gravel and the deeper in limestone, which is entered at 55 feet.

Minor supplies.—The following table gives data concerning the supplies of minor villages.

Village supplies in Scott County.

Town.	Nature of supply.	Depth.			Depth of water bed.	Source of supply.	Depth to rock.	Head above or below curb.		Springs.
		From—	To—	Common.				Shallow wells.	Deep wells.	
		Ft.	*Ft.*	*Feet.*	*Feet.*		*Ft.*	*Feet.*	*Feet.*	
Big Rock	Dug and drilled wells.	14	130	30	60	Limestone	8–14	−14		
Blue Grass	Drilled wells	35	90	50				−25	−50	None.
Buffalo	Open and drilled wells.	16	270	24		Limestone	4–10	−16		Medium
Dixon	Wells and cisterns	50	160	75				−30		
Long Grove	Drilled wells and cisterns.	135	180		135–170	Limestone	120	−40		
McCausland	Wells	16	60					−10		Small.
Noel	do			30				−25		Small.
New Liberty	do	80	165	90–125	100	Sand		−20 to −50	−10 to −40	None.

WELL DATA.

The following table gives data of typical wells in Scott County:

Typical wells in Scott County.

Owner.	Locality.	Depth.	Depth to rock.	Depth in rock.	Rock surface above sea level.	Remarks (logs given in feet).
T. 80 N., R. 1 E. (LIBERTY).						
		Feet.	*Feet.*	*Feet.*	*Feet.*	
L. Riefe	SE. ¼ SE. ¼ sec. 2		100			
Z. Parker	NE. ¼ NW. ¼ sec. 7	113	93			Yellow clay, 18; blue clay, 75.
J. Stoltenberg	SE. ¼ sec. 7	90	60	30		
J. L. Andre	NE. ¼ NE. ¼ sec. 8		150			Yellow clay, 35; yellow sand; blue and yellow clay to bottom.
—— Klahn	NW. ¼ sec. 8	118	60	58		

Typical wells in Scott County—Continued.

Owner.	Locality.	Depth.	Depth to rock.	Depth in rock.	Rock surface above sea level.	Remarks (logs given in feet).
T. 80 N., R. 1 E. (LIBERTY)—Con.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	
G. Parker	SE. ¼ SE. ¼ sec. 8	143	143			Yellow clay, 40; sand; remainder blue clay.
J. Hickson	NE. ¼ NW. ¼ sec. 10		112			
Dixon City Hotel	SE. ¼ SE. ¼ sec. 12	73	23	50	657	Nearly all fine blue silty quicksand.
J. Holt	SE. ¼ SE. ¼ sec. 13	108	60			Yellow clay, 25; black muck, 35.
J. Flinker	NW. ¼ sec. 15	135	60	75		
J. Killian	SW. ¼ sec. 16		60			
P. Mohr	NE. ¼ NW. ¼ sec. 17		60		740	
Do	SE. ¼ SE. ¼ sec. 18		81			
A. Paustian	NW. ¼ NE. ¼ sec. 9		18		782	
Town of New Liberty.	SW. ¼ sec. 20		90			
Do	SW. ¼ sec. 20		108		692	Yellow clay, 16; yellow sand, 3; blue clay, 89.
Do	SW. ¼ sec. 20		50			
A. Weise	NW. ¼ NE. ¼ sec. 20		100			Yellow clay, 16; quicksand, 10; blue clay, 74.
W. N. Lensch	SE. ¼ SW. ¼ sec. 20		90			Yellow clay, 20; sand, 3; blue clay, 67.
Do	SE. ¼ SW. ¼ sec. 20	90	60	30		Little blue clay.
H. Schmidt	SW. ¼ SE. ¼ sec. 22	115	50	65		Yellow clay, 25; red clay, 25; bowlders on rock.
M. Smallfield	SW. ¼ NW. ¼ sec. 24	165	105			
J. Flinker	SE. ¼ sec. 24		110			
H. Quistorf	SE. ¼ SW. ¼ sec. 25					Hard blue clay, from 12 to 40; stopped in sand.
H. Meinert	Sec. 26	48	36			
E. Moeller	SW. ¼ SW. ¼ sec. 32	72	60			Yellow clay, 20; sand, 2; blue clay, 38.
H. Arp	SW. ¼ SW. ¼ sec. 33	150				
T. Ketelson	NE. ¼ NW. ¼ sec. 35	150	128	22	672	
T. Killian	SE. ¼ SE. ¼ sec. 16	64	8			
J. Killian	Sec. 16	125	120			
J. Ketelson	SE. ¼ NE. ¼ sec. 26	74	70			Thick yellow clay throughout.
T. 79 N., R. 1 E. (CLEONA).						
D. Boll	NE. ¼ NE. ¼ sec. 1					
——— Wheeler	Sec. 2		110			Wood like decayed walnut, 65 to 75.
C. Ginn	NW. ¼ NE. ¼ sec. 4	72	42			
W. Rheims	SW. ¼ sec. 4	163	162			
Do	NW. ¼ NW. ¼ sec. 7		121			
J. Schroder	SW. ¼ SE. ¼ sec. 7	108	80			
H. Kroeger	SW. ¼ SW. ¼ sec. 9	113	45		595	All yellow clay.
H. Hein	SW. ¼ SE. ¼ sec. 10					
F. Kardel	NE. ¼ SW. ¼ sec. 11					
J. Rathjen	SW. ¼ SW. ¼ sec. 12					Yellow clay, 35; blue clay, 205; sand, 2.
H. Speth	NW. ¼ sec. 13					Yellow clay, 10; blue clay, 116; quicksand, 150; ends in gravel.
A. Franz	SE. ¼ NE. ¼ sec. 13		193			All slushy blue mud to rock, below a little yellow clay.
H. Hein	NW. ¼ SE. ¼ sec. 14					
G. Paustian	NE. ¼ NE. ¼ sec. 14					Yellow clay, 10; blue clay, 268; sand and gravel, 2.
Juergen Mumm	NE. ¼ SW. ¼ sec. 14					
M. Hoersch	SE. ¼ SW. ¼ sec. 15					
Johann Mumm	SW. ¼ sec. 15					Yellow clay, 15; blue clay, stony, 171; gravel, 2.
P. Paulson	NE. ¼ NW. ¼ sec. 16	122	58			
Do	NW. ¼ SW. ¼ sec. 16	137	111			
H. Goettsch	NW. ¼ NE. ¼ sec. 19	331				
Lena Mumm	NE. ¼ NE. ¼ sec. 21					Yellow clay, 12; blue clay, 236; sand and gravel, 30.
H. Mumm	NW. ¼ SE. ¼ sec. 22					
J. Theil	NE. ¼ NE. ¼ sec. 22					Yellow clay, 15; blue clay, 129; sand and gravel, 2.
H. Wessel	NW. ¼ SE. ¼ sec. 23					Yellow clay, 20; sand, 10; blue clay, 100; gravel, 3.

Typical wells in Scott County—Continued.

Owner.	Locality.	Depth.	Depth to rock.	Depth in rock.	Rock surface above sea level.	Remarks (logs given in feet).
T. 79 N., R. 1 E. (CLEONA—Contd).		*Feet.*	*Feet.*	*Feet.*	*Feet.*	
J. Reimer	SW. ¼ SW. ¼ sec. 30					
W. Rheims	SW. ¼ sec. 4	161	146			
J. Tesrow	NW. ¼ sec. 24					Yellow clay, 7; red sand, 7; sand, 21; gravel, 25.
Durant						Yellow clay, 25; sand, 5; blue clay, 109.
Near Durant on creek.						To rock, 100 to 150 feet.
T. 80 N., R. 2 E. (ALLENS GROVE).						
C. Rohwer	Sec. 13					Ends in 25 feet of sand.
D. Yale	NW. ¼ SW. ¼ sec. 29	111	99			Yellow clay, 20; blue clay, stony, 70; hard pan, 9.
E. Gallegher	NW. ¼ SE. ¼ sec. 20		155			
M. King	SE. ¼ NW. ¼ sec. 20	75				Yellow clay, 20; blue clay, 50; hardpan, dry, 5. No water.
E. Richardson	SE. ¼ SE. ¼ sec. 20	118	100			Blue clay, 70; sand, 30.
Do	NW. ¼ sec. 24					
O. H. Walton	Sec. 24					Yellow clay; blue sticky clay; quicksand; stopped in 50 feet of river sand.
Wm. Biythe	SE. ¼ NW. ¼ sec. 25		246			
H. Rohwer	NE. ¼ NE. ¼ sec. 26					Stopped in gravel.
Gilmore	SE. ¼ SE. ¼ sec. 27		228		472	
J. Hasenmiller	NW. ¼ SE. ¼ sec. 28					Stops in sand.
E. O'Neil	SE. ¼ NE. ¼ sec. 28	323	312		448	Yellow clay, 50; sand, 50; mostly blue clay; coarse gravel.
J. Carter	SW. ¼ SE. ¼ sec. 28					
H. Ketelson	NE. ¼ SE. ¼ sec. 30					
C. H. Brockmann	SW. ¼ NW. ¼ sec. 31					
H. Schultz	SW. ¼ SE. ¼ sec. 33		113			Yellow clay, 16; quicksand; blue stony clay to 50; sand and gravel, 2; blue clay, 61.
H. Stahft	NE. ¼ SW. ¼ sec. 33	250	240		440	Mostly quicksand; 100 feet of sand in one bed.
H. Latrode	NW. ¼ NE. ¼ sec. 33		212		508	
R. C. Curtis	SE. ¼ SE. ¼ sec. 34					Struck rock.
H. Weise	NE. ¼ sec. 35					
Town of Donahue	NE. ¼ sec. 36		100			
Do	NE. ¼ sec. 36	160	157	3		Yellow clay; blue clay; quicksand, 15.
Chas. Middlemass	NW. ¼ SW. ¼ sec. 24					Mostly fine sand.
T. 79 N., R. 2 E. (HICKORY GROVE).						
H. Klindt	SE. ¼ NW. ¼ sec. 2	81	71			
C. Rock	NE. ¼ SW. ¼ sec. 4	82	72			
F. Rock	SE. ¼ NW. ¼ sec. 4	150	144	6		
P. Burmeister	NW. ¼ NE. ¼ sec. 4	74	70			
M. Spelletich	SE. ¼ SE. ¼ sec. 5	77	69			
D. Wunder	SW. ¼ SE. ¼ sec. 5					
Joseph Vort	Sec. 6		215			
Plainview	NW. ¼ NW. ¼ sec. 7					
Do	NW. ¼ NW. ¼ sec. 7		232			
M. Spelletich	NW. ¼ SE. ¼ sec. 7					
Do	SE. ¼ NW. ¼ sec. 7		245			
Do	SE. ¼ SE. ¼ sec. 7		55		665	
J. Soutter	NE. ¼ SE. ¼ sec. 8	77	30	47		
P. Burmeister	NW. ¼ NW. ¼ sec. 9		70	75		
Do	SW. ¼ NE. ¼ sec. 9		80	85		
H. Arp	SE. ¼ SW. ¼ sec. 9		50	53		
J. Kerker	SE. ¼ SE. ¼ sec. 9		40	64		
P. Meyer	NW. ¼ SE. ¼ sec. 10		80	95		
C. Meyer	SW. ¼ SE. ¼ sec. 11	81	67			
B. Painter	NE. ¼ sec. 12		215		525	
Ira Burch	SW. ¼ SE. ¼ sec. 12	191	190		550	Yellow clay, 40; blue till, 150.
Hans Joens	SE. ¼ NW. ¼ sec. 13	157	155			Water on rock.
J. Steenbock	SW. ¼ SE. ¼ sec. 13	212	208		502	

Typical wells in Scott County—Continued.

Owner.	Locality.	Depth.	Depth to rock.	Depth in rock.	Rock surface above sea level.	Remarks (logs given in feet).
T. 79 N., R. 2 E. (HICKORY GROVE)—Continued.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Maysville	Sec. 15		78			
Do	Sec. 15	130	120			
W. Koberg	NE. ¼ SW. ¼ sec. 15		105			
A. Lage	NW. ¼ SW. ¼ sec. 16	91	85			All yellow clay.
H. Klindt	SW. ¼ SW. ¼ sec. 16	74				Ends in rock.
G. Golinghast	SE. ¼ sec. 17	78	50			
M. Spelletich	SW. ¼ SE. ¼ sec. 18		270		510	
J. Frauen	NW. ¼ NW. ¼ sec. 19				1	Ends in gravel.
J. Paustian	SE. ¼ NE. ¼ sec. 19					Yellow clay, 20; sand, 5; blue clay, 105; gravel, 7.
J. Hamann	NE. ¼ NW. ¼ sec. 20		110			
Th. Karbel	SE. ¼ NE. ¼ sec. 21					All blue till, except gravel at bottom.
M. Gries	SW. ¼ SW. ¼ sec. 22	170	165		555	Below 100 feet all quicksand and sticky clay.
J. Plambeck	NE. ¼ SE. ¼ sec. 23					Mostly blue clay.
W. Fry	NE. ¼ SE. ¼ sec. 24	208	206		534	Yellow clay, 17; blue clay, hard, 60; sand, 129.
Schoolhouse	SE. ¼ SE. ¼ sec. 26	250	215		525	Ends in gravel.
E. Sindt	NW. ¼ NE. ¼ sec. 27					Yellow clay, 15; blue clay, 15; quicksand; ends in gravel.
C. Haller	NE. ¼ SE. ¼ sec. 29					
P. Riessen	NW. ¼ NW. ¼ sec. 29					
C. Paustian	NE. ¼ NW. ¼ sec. 30	143	130			Yellow clay, 20; sand, 5; blue clay, 105.
Geo. Dietz	SW. ¼ SE. ¼ sec. 31					Yellow clay, 15; quicksand, 5; blue clay, 30; gravel, 5.
Schoolhouse	NW. ¼ NW. ¼ sec. 32					Ends in gravel.
A. H. Lamp	NW. ¼ NW. ¼ sec. 33					Yellow clay, 20; sand, 6; blue clay, 58; gravel, 2.
Maysville Creamery	NW. ¼ SE. ¼ sec. 15	90	90		650	Yellow clay, 16; quicksand, 10; greenish clay, 64.
Geo. Deitz	SW. ¼ SE. ¼ sec. 31					Yellow clay, 16; sand, 5; blue clay with bowlders; gravel.
J. Plambeck	SE. ¼ sec. 36	240	230		510	Quicksand, 60; rock.
J. Soutter	NE. ¼ sec. 8	90	80			Yellow clay, 40; blue clay to rock.
T. 78 N., R. 2 E. (BLUEGRASS).						
S. R. Miller	NW. ¼ sec. 1					
Do	SW. ¼ SW. ¼ sec. 1					Yellow clay, 35; blue, hard clay to bottom. Did not cave.
Do	SE. ¼ NE. ¼ sec. 1					Ends in gravel.
Do	NE. ¼ NW. ¼ sec. 2					Do.
Do	SE. ¼ SW. ¼ sec. 2					
W. Arp	SW. ¼ SW. ¼ sec. 3		100		660	
G. Muhl	SW. ¼ sec. 5	104	40	64		Soft white limestone.
H. F. Strohbeen	SW. ¼ SW. ¼ sec. 5	90	47	43		
Walcott	Sec. 6		50			Yellow clay, 14; sand, 5; blue pebbly clay, 31.
T. Giese	SW. ¼ NE. ¼ sec. 7		26			
J. Franz	NE. ¼ NW. ¼ sec. 8	89	86			
H. Goering	NW. ¼ sec. 10	101	91			
Do	SW. ¼ SW. ¼ sec. 10	118	90			
H. Meyer	NW. ¼ NE. ¼ sec. 12	256	235		504	
Eggert Puck	SE. ¼ NE. ¼ sec. 12	210	204		536	
A. Le Buhn	NE. ¼ NE. ¼ sec. 16					Yellow clay, 20; sand, 5; blue clay, 50; gravel, 5.
H. Wiese	NW. ¼ SW. ¼ sec. 19		78			
H. Schlichting	SE. ¼ NE. ¼ sec. 23	120	110			
Schoolhouse No. 3	NW. ¼ sec. 19	200	78	122		Yellow clay, 20; sand. 10; blue clay, 48; white limestone, 122.
T. 77 N., R. 2 E. (BUFFALO).						
E. James	SW. ¼ sec. 3	316	35			Limestone, 160.
L. Daurer	NW. ¼ NW. ¼ sec. 8	270	50			
C. Rowan	SW. ¼ sec. 10		60			
Barnwick	SE. ¼ SE. ¼ sec. 16	144	20			

Typical wells in Scott County—Continued.

Owner.	Locality.	Depth.	Depth to rock.	Depth in rock.	Rock surface above sea level.	Remarks (logs given in feet).
T. 77 N., R. 2 E. (BUFFALO)—Con.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	
F. Beh	NE. ¼ sec. 18	261	100			Limestone, 161.
J. Murray	NW. ¼ sec. 10	305	35			No coal; limestone, 160.
T. 80 N., R. 3 E. (WINFIELD).						
J. Ennis	SW. ¼ SW. ¼ sec. 11					All sand.
C. Gillian	SE. ¼ SE. ¼ sec. 7					Sand, 20; hard, blue, pebbly clay, 120; sand, 5; gravel, 5.
School No. 4	NW. ¼ sec. 14		125			
St. Ann's Church	SE. ¼ SW. ¼ sec. 14	100	64	36		Sand, 15; yellow clay, 10; blue clay; a little sand.
P. Jones	NW. ¼ NW. ¼ sec. 15		190		530	
School No. 3	NW. ¼ NW. ¼ sec. 16					Sand, 70; blue clay, 20; gravel, 4.
N. Schallmeier	SW. ¼ SE. ¼ sec. 18					
N. Denklau	SW. ¼ NW. ¼ sec. 19	173	153			
A. Brownlee	NW. ¼ SE. ¼ sec. 26		220		505	
J. Robertson	NE. ¼ NE. ¼ sec. 27	121	120			Yellow clay, 50; hard, blue, stony clay, 70; sand and gravel, thin.
J. Grill	SE. ¼ SE. ¼ sec. 30					
C. Preston	NE. ¼ SE. ¼ sec. 31		180			
J. Neil	SW. ¼ SW. ¼ sec. 35		225		555	
Hotel Long Grove	NW. ¼ sec. 35					Ends in gravel.
A. D. Brownlee	¼ mile north of Long Grove.	256	220			Yellow clay, 20; blue clay, 140; sand and gravel, 30; blue clay, 30.
P. E. Jones	Southwest of Noel		190			Blue clay, 100; much sand beneath it to rock.
T. 79 N., R. 3 E. (SHERIDAN).						
C. Clapp	SW. ¼ NE. ¼ sec. 2	128	122			
J. Lensch	SE. ¼ SE. ¼ sec. 2	118	114			
C. Meier	SW. ¼ SE. ¼ sec. 4	199	100			Yellow clay, 25; old soil, 10; blue clay, 65; coal, 2; shale, 97.
J. Paustian	NE. ¼ SW. ¼ sec. 5	237	200		560	Shale, 37.
J. T. Cooper	SW. ¼ SW. ¼ sec. 5	145	140			Yellow and blue clay; gravel on rock.
S. Burmeister	NW. ¼ SE. ¼ sec. 6		120			
E. Rohwer	NE. ¼ SW. ¼ sec. 6		140			
L. Husted	SE. ¼ SW. ¼ sec. 7		166			
Eldridge	SW. ¼ sec. 11	135	127			Yellow clay less than 20; mostly blue clay; ends in limestone.
Eldridge Creamery	NW. ¼ NE. ¼ sec. 14	201	180		600	
Chas. Erhsam	NW. ¼ NE. ¼ sec. 20		72		658	
J. L. Seaman	NW. ¼ SW. ¼ sec. 27		90			
H. Stoltenberg	NW. ¼ SE. ¼ sec. 28		100			
W. Hughes	NW. ¼ SE. ¼ sec. 33	180	170			
Claus Lamp	SW. ¼ SW. ¼ sec. 19	285	270		470	Mostly hard blue clay.
T. 78 N., R. 4 E. (PART OF DAVENPORT).						
Chas. Murray	SE. ¼ NE. ¼ sec. 1		105			
W. Untiedt	NE. ¼ SW. ¼ sec. 7					Ends in gravel.
School No. 2	NE. ¼ sec. 7					Yellow clay, 30; sand, 10; blue clay, 80; gravel, 2.
Capt. Stahr	NW. ¼ NW. ¼ sec. 7		160			
J. Carlin	SW. ¼ SE. ¼ sec. 10	140	115			
G. Conklin	SW. ¼ NW. ¼ sec. 11	106	90			
E. Daugherty	SW. ¼ sec. 12					
R. Clay	NE. ¼ SW. ¼ sec. 12					
M. Boyle	NW. ¼ SW. ¼ sec. 13	94	85			
J. Armel		245	202			
Dr. G. T. Maxwell		130	100			
Schuetzen Park		240	160			
J. Hever	SE. ¼ SE. ¼ sec. 21	200	155			
Thos. Sindt	NW. ¼ NW. ¼ sec. 7	167	160			

Typical wells in Scott County—Continued.

Owner.	Locality.	Depth.	Depth to rock.	Depth in rock.	Rock surface above sea llvel.	Remarks (logs given in feet).
T. 78 N., R. 3 E. (PARTS OF DAVENPORT AND PLEASANT VALLEY).		*Feet.*	*Feet.*	*Feet.*	*Feet.*	
I. Barr	SE. ¼ NW. ¼ sec. 4	150	100			
C. Van Evera	SW. ¼ sec. 4	115	90			
R. Schaefer	SW. ¼ SW. ¼ sec. 4	85	80			
J. Barnholdt	NW. ¼ sec. 5	98	88			
H. Wiese	NE. ¼ sec. 6	94	79			
I. Barr	NE. ¼ SW. ¼ sec. 7	157	142			
F. Thomas	NW. ¼ SW. ¼ sec. 9	163	150			
C. Carstens	SE. ¼ SW. ¼ sec. 17	138	120			
H. Woodford	NE. ¼ NW. ¼ sec. 18		176			
A. J. Partridge	NE. ¼ NE. ¼ sec. 18	106	90			
I. Barr	NW. ¼ sec. 18	90	70			
J. Barr	SE. ¼ NE. ¼ sec. 18	65	58			
Wm. C. Schaefer	NE. ¼ SW. ¼ sec. 19	93	80			
J. L. McCullough	SW. ¼ sec. 20	160	90			
E. S. Kellog	NW. ¼ SE ¼ sec. 18	105	90			
T. 80 N., R. 4 E. (BUTLER).						
—— Gambril	Sec. 7		525			
J. Henry	NE. ¼ SW. ¼ sec. 22		100			
Do	NE. ¼ SE. ¼ sec. 22		62			
J. McCausland	NE. ¼ sec. 23		67			
	Sec. 25	65				Sandstone at 65.
E. Mueller	NW. ¼ NW. ¼ sec. 35		60			
T. 79 N., R. 4 E. (LINCOLN AND PART OF LE CLAIRE).						
D. Arp	SW. ¼ NW. ¼ sec. 2	130	120			Ends in limestone.
C. Schneckloth	SE. ¼ SE. ¼ sec. 7		140			
I. Barr	NE. ¼ NE. ¼ sec. 7	121	101			
J. H. Barr	NE. ¼ SW. ¼ sec. 22		190		550	
Thos. Criswell	NW. ¼ SW. ¼ sec. 23		160			
M. Jones	SE. ¼ sec. 23	150	120			
M. Thompson	NE. ¼ NE. ¼ sec. 27	182	175			
H. Schroeder	SW. ¼ SW. ¼ sec. 33	75	55		665	
M. Barr	SW. ¼ SW. ¼ sec. 26	116	86			
Benj. Criswell	NW. ¼ sec. 23		190			
G. Leamer	NW. ¼ NE. ¼ sec. 25	381	210		530	Shale, 210–375; ends in limestone.
J. Stafford	SE. ¼ NW. ¼ sec. 36	246	150			
H. Stafford	NE. ¼ SW. ¼ sec. 36	121	100			
H. Whitson	SE. ¼ NE. ¼ sec. 25	15	120			
G. Hyde	SW. ¼ NW. ¼ sec. 36	100	80			Limerock, 20.
Porters Corners	NE. ¼ NE. ¼ sec. 25	305	175			Yellow clay, 30; quicksand; blue till; shale, 100; limestone, 30.
T. 80 N., R. 5 E. (PART OF PRINCETON).						
J. Carroll	NW. ¼ NE. ¼ sec. 30		60			
T. 79 N., R. 5 E. (PARTS OF PRINCETON AND LE CLAIRE).						
C. Fulmer	NW. ¼ NE. ¼ sec. 4		80			
C. Like	NE. ¼ SE. ¼ sec. 4		100			
O. Peaslee	SW. ¼ SW. ¼ sec. 9		169		551	
W. Florence	SW. ¼ SW. ¼ sec. 5	82	70		630	
J. Brown	SW. ¼ NE. ¼ sec. 17		100			
J. Wilson	SE. ¼ NW. ¼ sec. 21		100			
J. C. McGinnis	SE. ¼ NW. ¼ sec. 30	250	170			
W. H. McGinnis	SE. ¼ NE. ¼ sec. 30	150	120			
M. Miller	SW. ¼ NE. ¼ sec. 31		150			
M. Wilson	NE. ¼ sec. 32	150	60			
T. Taylor	NE. ¼ sec. 32	75	55			
H. Stone	SW. ¼ sec. 32		61			
J. Suiter	NW. ¼ SE. ¼ sec. 33		35			

Typical wells in Scott County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Depth in rock.	Rock surface above sea level.	Remarks (logs given in feet).
T. 78 N., R. 5 E. (parts of Le Claire and Pleasant Valley).		*Feet.*	*Feet.*	*Feet.*	*Feet.*	
J. McCaffry	NW. ¼ sec. 4		40			
A. Schurr	NW. ¼ sec. 4	78	50			Yellow clay, 25; blue clay to rock; shale.
T. 77 N., R. 3 E. (Rockingham).						
F. J. Shaeffer	NW. ¼ sec. 5	216	40			Shale, 40 to 206.
Walnut Hill School	NE. ¼ NW. ¼ sec. 5	225	40			Do.
J. A. Punt	NW. ¼ NE. ¼ sec. 5	186	30			Shale to 10 feet of bottom.
Fairview School	NE. ¼ SE. ¼ sec. 7	110				Shale and blue clay in alternate layers.

TAMA COUNTY.

By W. J. Miller.

TOPOGRAPHY.

Tama County may be roughly divided into northern and southern provinces of about equal size. In the northern half of the county the Iowan drift forms the surface and its characteristic topography is shown by a gently undulating surface. The hills are low and broad and the drainage is fairly good. Wolf Creek, which flows from west to east across this region, has cut out a broad, shallow valley, modifying the generally more level surface. The southern province, including most of southern Tama County, is loess covered and has a much more hilly and rugged topography. The hills are higher and the region is dissected by numerous small streams, giving a good drainage. Iowa River, the largest stream in the county, enters this province at the west and leaves it at the southeast; its valley is broad and deep.

GEOLOGY.

The drift formations are represented by the sub-Aftonian or Nebraskan, the Kansan, and the Iowan. The Kansan drift extends over the entire county and is everywhere covered by either Iowan or loess. In some localities the Kansan is known to be underlain by small areas of Nebraskan. The Iowan drift is spread over three-fourths of the county, everywhere concealing the Kansan, and is, in turn, partly covered by loess. From the northern half of the county, which is all covered by Iowan drift, one tongue of Iowan extends southward to Toledo, and another southward, on the east side of Salt Creek, to Irving. The southwest corner of the county is also covered by Iowan. The loess covers most of the southern portion of the county and a narrow strip of the northern portion along Wolf Creek. These drift formations, as shown by well sections, range in thickness from 200 to 400 feet.

Immediately below the drift and extending over all the county except the extreme northeast corner are Mississippian (lower Carboniferous) shales and limestones. (See Pl. XI, p. 382.) The northeast corner probably shows some Upper Devonian limestone.

Viewed broadly, the drift deposits may be said to be spread over the county in nearly horizontal beds with local thickening or thinning. The old rock formations show a slight inclination westward.

UNDERGROUND WATER.

SOURCE.

Water is found in sand and gravel beds in the drift and in limestones in the deeper formations. As a rule, an abundant supply is readily obtained, especially from the deeper drift and from rock wells. All the waters are generally of good quality, but always hard.

By far the most important aquifer in the drift is the sand or gravel at the bottom of the blue Kansan clay. This water-bearing stratum is absent in a few places only. Nearly everywhere it underlies a so-called hardpan, which is merely a tough compact clay which serves to confine the water in the porous sands and gravels. This aquifer is seldom struck at less than 200 feet or more than 400 feet below the ground surface. Water obtained from this source is very persistent and abundant.

Other aquifers occur as sandy layers higher up in the drift (blue clay), but these layers are local in their extent and water supplies from them are in many places small and not persistent. In many surface wells in the yellow clays or in the alluvium along the streams the supply fluctuates according to season.

A very important water bed in Tama County lies just below the drift in the limestones or shales. Sometimes a good supply is struck soon after entering the rock and at other times the drilling must proceed a hundred feet or more. Many of the recent farm wells are rock wells with a never-failing supply of good water.

PROVINCES.

All the southeast portion of the county may be looked upon as a separate underground-water province. It possesses two types of flowing wells—those which originate in the drift and those which originate in the underlying rock formations.

The region of flowing drift wells forms a part of the well-known Belle Plaine artesian basin, which extends into Benton, Iowa, and Poweshiek counties. In Tama County this basin extends northward to Elberon and Vining and westward to Chelsea. The flowing wells receive their supply from a bed of sand and gravel which underlies the impervious blue Kansan clay. The drift deposits, which were laid down in the trough cut by the preglacial Iowa River, slope downward toward the lowest part of the trough in the vicinity of Belle Plaine, developing sufficient head to cause flowing wells in the lower portion of the drift-filled basin.[1]

Closely associated with the flowing wells from the drift are others whose water is derived from rock formations below the drift. Wells of this kind occur within the drift basin of flowing wells and also as far north as Clutier and as far west as Long Point. The source of water is usually a limestone (Devonian), which underlies a thin bed of shale (Carboniferous), the shale acting as an impervious covering.

Aside from the region of flowing wells all of Tama County may be looked upon as a single underground-water province.

SPRINGS.

Springs in Tama County are of little importance, consisting almost invariably of small seepages from the drift materials, especially along the main waterways.

CITY AND VILLAGE SUPPLIES.

Tama.—The town of Tama (population, 2,290) is supplied with well water under a domestic pressure of 60 pounds and a fire pressure of 100 pounds. There are 4 miles of mains, 36 fire hydrants, and 160 taps. About 1,400 people consume 200,000 gallons daily. Ordinarily the water is good but hard.

A forecast of the local artesian conditions made by W. H. Norton is as follows: Tama is 820 feet above sea level. At about 550 feet above sea level the drill may be expected to enter the Devonian limestone, leaving behind shales of the Kinderhook and shales of the Upper Devonian not easily distinguished from them. The Devonian yields largely, as is seen in the city well at Toledo and in the first rock flow found at Belle Plaine. The waters of the drift and of the Kinderhook are exceedingly poor in this vicinity and should be carefully cased out before a test of the Devonian water is made. Both Devonian and Silurian waters should be of good quality, but it is possible that the former may have been contaminated by interior higher waters which have descended to their level, and that the gypseous beds of the Silurian extend this far to the east and add a large calcium sulphate content to the water. The Maquoketa shale (Ordovician) may be estimated to extend from sea level to 200 or 250 feet below

[1] Mosnat, H. R., Artesian wells of the Belle Plaine area: Rept. Iowa Geol. Survey, vol. 9, 1899, pp. 521-562.

it and will be found dry. Passing through the Galena and Platteville limestones the drill will come to the St. Peter sandstone at 475 to 550 feet below sea level. Below the St. Peter the drill will enter the Prairie du Chien group, the upper formation of which, the Shakopee dolomite, a creviced dolomite, should add materially to the supply. The other formations of this group (the New Richmond sandstone and the Oneota dolomite) are also large contributors of artesian water. At 400 to 500 feet below the summit of the St. Peter the main water bed, the Jordan sandstone, should be reached. Drilling contracts should provide for continuing, if necessary, to 1,100 or 1,200 feet below sea level or, in round numbers, to 2,000 feet below the surface. The water should head at about 800 feet above sea level.

The excellent water obtained at Grinnell in well No. 2 encourages the belief that at Tama also water of low mineralization may be secured from the Cambrian and Ordovician water beds, provided the heavily mineralized waters are completely excluded.

The well of Mrs. A. Huber, near Tama (NE. ¼ sec. 26, T. 83 N., R. 15 W.) has a depth of 816 feet and diameter of 2 inches. The curb is 880 feet above sea level and the head 20 feet below the curb. Water was found at 361 feet and at 450 feet, the latter heading at the curb. Lower veins have lower heads. Rock was reached at 108 feet. Date of completion, 1893.

Driller's estimate (generalized), Mrs. A. Huber's well.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil, black	2	2
Clay, yellow (loess)	18	20
Clay, blue (Kansan)	64	84
"Hardpan" (shale and limestone?)	170	254
Flint	1½	255½
Limestone	40	295½
Limestone, flint, shale, etc	......	....

This is the deepest well in Tama County. The water is strongly mineralized. Analysis has shown iron, soda, magnesia, sulphur, etc. The mineral content is said to be decreasing.

Toledo.—At Toledo (population 1,626) water is delivered under a pressure of 80 pounds through 4½ miles of mains to 36 fire hydrants and 230 taps, supplying 1,500 persons with 60,000 gallons daily. The water is of good quality but is hard.

The city well has a depth of 344½ feet and a diameter of 6 to 5 inches; cased throughout except in limestones. The head is 30 feet below the curb, the water coming from 343 feet. The capacity is 500 gallons a minute. The well was completed in 1905.

Driller's log of city well at Toledo.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay and sand	25	25
Quicksand and water	6	31
Clay	50	81
Quicksand	12	93
Clay	18	111
Limestone; water-bearing near top	32	143
Shale (Kinderhook)	160	303
Limestone	40	343
Shale	1½	344½

Toledo is 852 feet above sea level. It is so near Tama that its deep-well forecast may be considered to be identical with that of the latter place. (See pp. 510–511.)

The Tama County farm well, which is located 2½ miles north of Toledo, has a depth of 445 or 555 feet and a diameter of 6 to 3½ inches. Its head is 150 feet below curb. The water comes from 345 feet in Devonian limestone and from 245 feet in drift sands. It was drilled by McLurk Bros., of Traer, and was completed in 1896(?).

Log of county farm well near Toledo.

	Thickness.	Depth.
Pleistocene:	*Feet.*	*Feet.*
Clay, yellow, and sand	50	50
Clay, blue, and bowlders	150	200
Clay, hard, yellow and blue, and pebbles	40	240
Sand (water bearing)	5	245
Carboniferous (Mississippian):		
Kinderhook—		
Shale	100	345
Devonian:		
Limestone and water	100	445

Traer.—The Traer town well, 249 feet deep, 54 feet of which is in rock, yields 200 gallons a minute to a steam pump. The water, which is from limestone, heads 189 feet below the curb. It is distributed by gravity with a domestic pressure of 55 pounds and a fire pressure of 160 pounds, through 2 miles of mains to 20 fire hydrants and 150 taps to 800 persons, who consume 25,000 gallons daily. The water is good, but hard.

Driller's log of town of Traer well.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, yellow	5	5
Clay, blue; some water-bearing sand	190	195
Shale	35	230
Limestone (water bearing)	19	249

Though the high elevation of Traer (916 feet above sea level) precludes any hope of a flowing well, water should rise within easy pumping distance from the St. Peter sandstone and the subjacent Ordovician and Cambrian water beds, the static level of whose waters is probably somewhat higher than 850 feet above sea level, or less than 70 feet from the surface.

The St. Peter will be encountered at about 250 feet below sea level, or 1,170 feet from the surface. Small yields may also be expected in the Galena and Platteville limestones overlying the St. Peter. Wells should be sunk 500 or 550 feet below the summit of the St. Peter in order to tap the far larger reservoirs of the Prairie du Chien group and the Jordan sandstone, which underlie the St. Peter. A well about 1,700 or 1 750 feet deep is indicated.

WELL DATA.

The following table gives data of typical wells in Tama County:

Typical wells of Tama County.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head.	Remarks (logs given in feet).
		Feet.	*Feet.*			
Town of Toledo	Toledo	345	111	Limestone	−30	
Mrs. A. Huber	Tama	816	106	...do	−19	
John Hodecheck	2 miles north of Vining.	380	None.	Drift sand	−120	Hill. Yellow clay, 40; bluish clay, 35; sand (water bearing), 1; blue clay, 288; sand and water, 6.
Frank Krizek	Clutier	210	196	Limestone	+18	Strong flow. Dark soil, 10; sand and clay (water bearing), 30; blue clay, 156; limestone and water, 14. At well bottom drill dropped 19 inches and water gushed out.
John Earhart	7 miles north of Toledo.	366	365	Limestone(?)	−150	Black soil, 3; blue clay and pebbles, 120; sand and some water, 3; blue clay and pebbles, 239; rock (limestone) and water, 1.
Town of Traer	Traer	249	195	Limestone	−189	
Tama County farm	2½ miles north of Toledo.	445	245	...do	−150	
Fred Praher	Crystal	307	300	...do	−100	Hard water. Yellow and blue clays, 287; "hardpan" or hard clay, 10; shale and some water, 3; limestone and water, 7.
Pete Schmidt	2½ miles south of Traer.	644	300±	...do	−150	
O. Angel	3 miles east of Gladbrook.	310	306	...do	−120	Yellow and blue clay and "hardpan" or hard clay, 306; limestone, 4.

CHAPTER X.

SOUTHEAST DISTRICT.

INTRODUCTION.

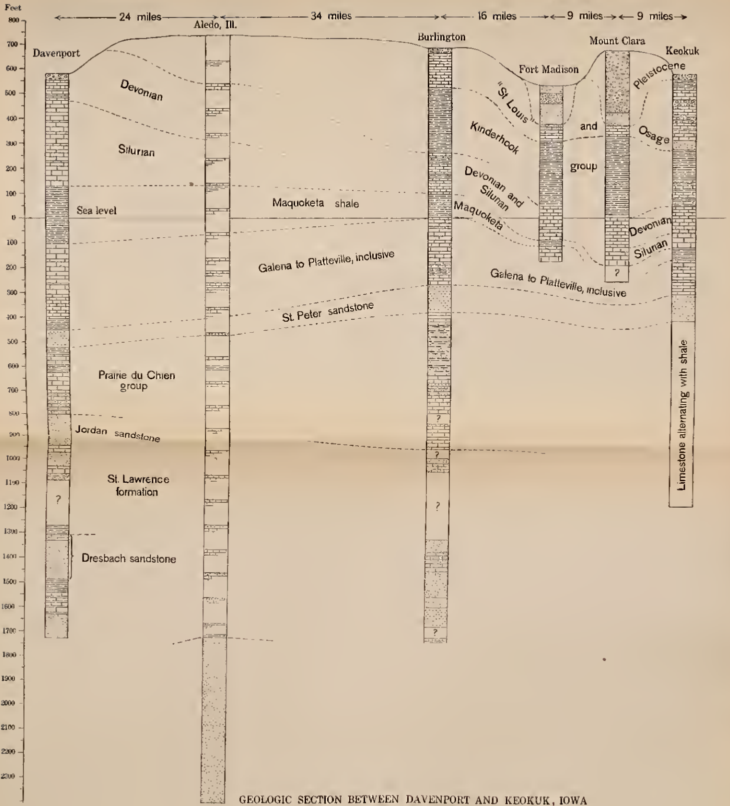
By W. H. Norton.

The southeast district embraces the 11 counties of Davis, Des Moines, Henry, Jefferson, Keokuk, Lee, Louisa, Mahaska, Van Buren, Wapello, and Washington.

If the deeper terranes continued through southeastern Iowa with the same thickness and the same degree and direction of inclination which they hold farther north, they would be carried too deep for profitable well drilling before they reached the Missouri State line. Fortunately a reversal of dip brings the St. Peter and its associated water beds higher in Lee and Des Moines counties than in Cedar and Muscatine counties of east-central Iowa. From Burlington, where the St. Peter reaches its highest recorded elevation in this area, it dips northward at a rate of more than 6 feet to the mile to the Muscatine County line. The dip to Davenport is 3 feet to the mile (Pl. XII). Between Burlington and Letts, the northward dip probably meets the southward in a sag. Northeast of Burlington the dip is to the north, at least as far as Aledo, Ill. Between Burlington and Mount Pleasant (Pl. XIII, p. 526) the dip is 5 feet to the mile, and to the west, to Centerville, it is 4.6 feet to the mile.

Where the Cambrian and Ordovician strata of southeastern Iowa are warped up to form a low dome the Silurian and Devonian strata are markedly thinner. For example, between Burlington and Keokuk (Pl. XII) the Devonian and Silurian strata barely exceed 150 feet in thickness; farther north, at Letts, they are more than 300 feet thick; still farther north, at Tipton, the Silurian alone is 325 feet thick; and to the west, at Pella, these formations include more than 400 feet of rocks. (See Pl. X, p. 374; Pl. XIV, p. 548.) The Maquoketa shares in the thinning. At Davenport it is 240 feet thick, at Pella 190 feet, at Burlington 100 feet, and at Fort Madison and Keokuk less than 50 feet. (See Pl. XII.) The Galena and Platteville limestones likewise form a wedge that tapers toward the southwest. At Davenport their combined thickness is 340 feet and at Keokuk only 140 feet.

The upwarp of the Cambrian and Lower Ordovician and the thinning of the higher terranes up to the Mississippian combine to bring



GEOLOGIC SECTION BETWEEN DAVENPORT AND KEOKUK, IOWA
By W. H. Norton

artesian water from the St. Peter and deeper aquifers within easy drilling distance of the surface. (See Pl. I, in pocket.) At Keokuk, for example, the St. Peter is reached only about 900 feet below the valley level. The Silurian and the Galena and Platteville limestones in the southeastern district also furnish exceptionally large quantities of water. At Burlington 6 deep wells obtain flows from the Silurian within about 500 feet of the surface, and the same formation, or possibly the Galena, is tapped by some of the deep wells at Keokuk. The wells at Fort Madison obtain their supplies largely from the Galena.

The dome of southeastern Iowa is only the northward extension of the upwarp of northeastern Missouri which brings the St. Peter sandstone to the surface about 50 miles south of Keokuk, in Ralls County, Mo. This upwarp appears somewhat narrower in Iowa than in Missouri. Thus, though the St. Peter sandstone lies 613 feet below sea level at Bloomfield it is found at Baring, Knox County, Mo., at 136 feet below sea level, a southward rise of about 13 feet to the mile.

For comparison with the sections of southeastern Iowa the record of the Baring well is appended. It will be noted that the Silurian is arenaceous, that the Maquoketa has pinched out, and that the Galena and Platteville limestones and the Decorah shale combined measure only 79 feet in thickness. Water occurs in the Silurian sandstone, the Galena dolomite, the St. Peter sandstone, and at several horizons in the Prairie du Chien group. Reports have not been received as to the water beds in the Cambrian.

Record of strata in the Atchison, Topeka & Santa Fe Railway well at Baring, Mo.

	Thickness.	Depth.
Pleistocene (100 feet thick; top, 808 feet above sea level):	*Feet.*	*Feet.*
Till, blue, predominantly clayey	100	100
Carboniferous (Mississippian):		
"St. Louis limestone" and Osage group (365 feet thick; top, 708 feet above sea level)—		
Chert, with white limestone and chalcedonic and crystalline silica; in sand	175	275
Shale, green gray, highly arenaceous; with minute irregular grains of crystalline quartz, calcareous	5	280
"Limestone, white;" no sample	65	345
Sandstone, very coarse; very imperfectly rounded grains of quartz and other minerals; water heading at 180 feet below curb	15	360
Chert; fine sand of particles of cryptocrystalline silica with some white limestone and some crystalline quartz; water at 375 feet	15	375
Marl, light yellow; rapid effervescence, large siliceous and argillaceous residue	35	410
Limestone, light drab, fine-grained	50	465
Kinderhook group (33 feet thick; top, 343 feet above sea level)—		
"Shale;" no sample	28	493
"Blue clay;" no sample	5	498
Devonian (217 feet thick; top, 310 feet above sea level):		
"Limestone;" no sample	12	510
Limestone, gray; rapid effervescence; earthy, fossiliferous, with joints of crinoid stems and fragments of shells of brachiopods; in flaky chips	205	715
Silurian (150 feet thick; top, 93 feet above sea level):		
Limestone and sandstone; limestone, light yellow gray, rapid effervescence; sandstone, fine-grained, larger grains of pure quartz and well rounded, a few with secondary enlargements; much cryptocrystalline silica in chips; water at 860 feet	145	860
"Sand, white;" no sample	5	865

Record of strata in the Atchison, Topeka & Santa Fe Railway well at Baring, Mo.—Contd.

	Thickness.	Depth.
Ordovician:		
Galena limestone (69 feet thick; top, 57 feet below sea level)—		
Dolomite or magnesian limestone, cherty; in brown crystalline sand; water at 900 feet	*Feet.* 69	*Feet.* 934
Decorah shale (4 feet thick; top, 126 feet below sea level)—		
"Shale;" no sample	4	938
Platteville limestone (6 feet thick; top, 130 feet below sea level)—		
Limestone, light gray; rapid effervescence; some chert; in small chips	6	944
St. Peter sandstone (46 feet thick; top, 136 feet below sea level)—		
Sandstone, light yellow, fine-grained; of pure quartz, grains moderately well rounded, some showing secondary enlargements; 4 samples; water at 956 feet	46	990
Prairie du Chien group (702 feet thick; top, 182 feet below sea level)—		
Dolomite, light yellow; in sparkling sand	10	1,000
"Slate, blue;" no sample	9	1,009
Sandstone, buff, very fine; grains imperfectly rounded	30	1,039
Sandstone, coarser, heavily rusted; water bearing	2	1,041
Dolomite, buff and light brown, cherty, highly arenaceous; 3 samples	67	1,108
Dolomite, light brown and gray, oolitic, cherty, somewhat arenaceous; 3 samples; water bearing at 1,140 feet	97	1,205
Dolomite, light buff, highly arenaceous	35	1,240
Dolomite, light buff, somewhat arenaceous	78	1,318
Dolomite, light buff, highly arenaceous and cherty	90	1,408
Dolomite, buff; some sand in drilliugs	86	1,494
Dolomite, light gray; water heading at 126 feet below curb	21	1,515
"Limestone" (dolomite); no sample; water at 1,535 feet	20	1,535
Dolomite, cherty, somewhat arenaceous; 2 samples	37	1,572
Marl, light buff, in concreted powder; and dolomite, in fine meal	4	1,576
Dolomite, light buff, cherty	14	1,590
Dolomite, light yellow	35	1,625
Dolomite, light brown	17	1,642
Dolomite, rusted grains; some chert and a few grains of quartz sand	4	1,646
Dolomite, buff; some chert, minute grains of quartz sand and a little glauconite; 2 samples	20	1,666
Dolomite, buff; cherty; 2 samples	26	1,692
Cambrian (150 feet penetrated; top, 884 feet below sea level):		
Sandstone, light yellow; in clean quartz sand; grains well rounded; larger grains reach from 0.6 to 1 millimeter	8	1,700
Sandstone, light yellow, coarser; 3 samples	60	1,760
Sandstone, light yellow; some green shale	14	1,774
Marl, light yellow gray, calcareo-argillaceous	8	1,782
Sandstone, whitish	11	1,793
Sandstone, buff; rounded grains with an admixture of marl; 2 samples	49	1,842

DAVIS COUNTY.

By O. E. Meinzer and W. H. Norton.

TOPOGRAPHY.

The upland surface of Davis County slopes gently toward the east and in general lies between 750 and 950 feet above sea level. It represents an original plain which still exists in extensive remnants as upland prairies, but which throughout most of the county is dissected by a complicated system of valleys and ravines that have produced a hill country with a relief of 100 feet and more. The hill topography is best developed near the principal streams, as in the vicinity of Soap Creek, and the prairie topography in the districts most remote from streams, as on the divide followed by the Chicago, Burlington & Quincy Railroad. The prairies are sufficiently continuous to have been for the most part preferred to the lvaleys for railway construction, and hence it has come about that nearly all of the villages are located on the upland.

GEOLOGY.

The valleys are excavated almost entirely in glacial drift, only the deepest extending to bedrock. This fact and the information obtained from well sections indicate that in most localities the drift beneath the uneroded uplands is between 100 and 200 feet deep. S. J. Andrews, a well borer at Pulaski, sharply distinguishes two deposits, both of which are probably glacial drift. The upper deposit he describes as a crumbling clay, ordinarily yellow, and in many places about 50 feet thick, containing pebbles and bowlders; the lower he describes as more tough and "oily," generally black but exceptionally yellow, containing only a few pebbles and bowlders, but numerous leaves, shells, and pieces of wood. This lower deposit is absent over a large part of the county, but in certain localities it reaches a maximum thickness of more than 100 feet. A large specimen of this deposit was examined and was found to consist of tough, dense dark carbonaceous clay containing fragments and specks of black carbonized wood, minute lime concretions, and a few tiny greenstone pebbles, and showing an indistinct foliated or nodular structure.

Below the lower of these two deposits in most localities lies a bed of white sand only a few feet thick, and this sand or, in its absence, one of the other deposits, generally rests upon a stratum which is locally known as "blackjack" or "blue daub," but which appears to be shale interbedded with limestone strata. The upper deposit is probably Kansan drift thinly covered with loess or loesslike clay, and the underlying dark deposit may belong to the Nebraskan sheet.

The following section is more or less typical in this county. The bowlder clay probably begins at the depth of 15 feet.

Section of group of wells about 4 miles west of Pulaski.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	1	1
Clay, yellow	7	8
Clay, blue, stiff; without grit	7	15
Clay, yellow, pebbly	40	55
Clay, black, containing oil, wood, leaves, shells, etc	57	112
Sand, white (good supply of water)	2	114
Shale, dark, "blackjack," entered.		

Throughout nearly the whole of Davis County the bedrock consists of shale, sandstone, limestone, and coal belonging to the Des Moines group of the Pennsylvanian series. Near Soap Creek, in the northern part of the county, and at many places in its northeastern part outcrops of this bedrock occur. It is also exposed in a few coal mines, and is apparently reached by wells drilled in all parts of the county.

UNDERGROUND WATER.

SOURCE.

Water is obtained from several strata, none of which are entirely satisfactory. The chief reliance is placed on shallow wells dug or bored into the loesslike clay and upper part of the glacial drift, the seepage from which is adequate for ordinary purposes in some localities where gravelly beds are found, but is quite inadequate and unreliable in others where the material is less porous. The water table in this upper layer conforms closely to the surface configuration, the water in shallow upland wells commonly standing high above the level of deep valleys only short distances away. Especially is this true in rainy seasons.

More dependable supplies are in some localities obtained from beds of sand farther down in the drift, such as the white sand that usually lies below the carbonaceous deposit described; but beds of sand are not found everywhere, and in some places where present are not water-bearing, because they have drained into adjacent deep valleys. Moreover, in wells of small diameter the sand causes trouble by rising with the water.

A number of wells drilled into the Pennsylvanian rocks to depths ranging from 300 to 400 feet find small or moderate supplies of mineralized water that rises to a level far below the surface of the uplands, but nearly or quite as high as the flood plains of the deepest valleys. A well of this kind may cost more than $500.

At still greater depths are formations which yield large quantities of water that is hard but not so strongly mineralized as the average water from the Pennsylvanian coal measures. On the uplands the water from these sources will remain far below the surface, but in the lowest valleys it will closely approach the surface or overflow. For farms and small municipalities the cost of drilling to the deep horizons is practically prohibitive.

Rain water is largely employed in this county for household use and for watering live stock. It is stored in cisterns and in reservoirs made by damming ravines. Many of these dams are seen in the hill country, where the drift is thin and is in great measure drained into the numerous valleys by which the upland is dissected.

CITY AND VILLAGE SUPPLIES.

Bloomfield.—The public supply for Bloomfield (population, 2,028) is derived from a well 1,817 feet deep, cased with 12-inch pipe to rock at 320 feet, below which 636 feet of 8-inch pipe extends down to 942 feet, and 519½ feet of 6-inch pipe to 1,445 feet. The curb is 845 feet above sea level and the water rises within 130 feet of the curb, or 715 feet above sea level. Its temperature is about 65° F. Water was found at depths of 300 feet, 1,425 feet, and 1,750 feet. The well was drilled in 1900 by J. P. Miller & Co., of Chicago, and cost $6,500.

The strata penetrated are indicated by the driller's log:

Driller's log of city well at Bloomfield.

	Thickness.	Depth.
	Feet.	*Feet.*
Drift	320	320
Lime; caves badly at 420 feet	100	420
Lime and shale	130	550
Hard lime; caves at 670 feet	120	670
Streaks of lime and shale; caves badly at 780 feet	272	942
Limerock; caves badly at 967 feet	203	1,145
Streaks of lime and shale	45	1,190
Sandrock	70	1,260
Limerock	102	1,362
Shale; caves badly at 1,420 feet	83	1,445
Sandrock	15	1,460
Limerock	190	1,650
Sandrock	167	1,817

Rock caved more or less all the way down to 1,650 feet.

Rocks belonging to the "St. Louis limestone" and the Osage group (Mississippian) seem to extend to a depth of about 670 feet, and the streaks of lime and shale which are reported from 670 to 942 feet probably represent the Kinderhook. The "sandrock" from 1,190 to 1,260 feet may be correlated with the Silurian; the shale from 1,362 to 1,445 feet may be assigned to the Decorah shale or to a shale in the Platteville limestone. The water-bearing sandstone from 1,445 to 1,460 feet (613 to 628 feet below sea level) is probably the St. Peter; all the rocks below this level probably belong to the Prairie du Chien group.

By means of an air lift with a pipe extending to a depth of 345 feet 250 gallons a minute are ordinarily discharged from the well into an underground reservoir, but in a test this yield has been increased to over 300 gallons a minute. From the reservoir the water is pumped into a tank elevated upon a tower and is thence distributed by gravity through a system of mains whose total length is about 2 miles. There are 28 fire hydrants and 63 taps in the city; somewhat less than one-fifth of the dwellings have service connections, and the average daily consumption of water is about 15,000 gallons. The water is used freely for drinking and other purposes but is very hard, as is shown by the analysis (p. 169), and for this reason is avoided for toilet, laundry, and boiler uses, rain water stored in cisterns or other reservoirs being used instead.

Before the deep well was drilled the public supply was obtained from a 4-inch well that ended at a depth of about 300 feet in a thick bed of sand, from which a generous supply of hard water was obtained. The well was not provided with a screen, and it filled with sand to such an extent that it was abandoned.

DES MOINES COUNTY.

By W. H. Norton.

TOPOGRAPHY.

The topography of Des Moines County is controlled for the most part by a few simple factors. The county is wholly in the area of the Illinoian drift, and by far its larger part is an upland molded to a nearly level surface by the Illinoian ice.

On the east the upland overlooks from a singularly straight and steep escarpment the broad bottom lands of the Mississippi. The interstream areas of the upland, chosen by the railways in preference to the valleys, present to the eye level or slightly undulating floors, with low swells and sags 10 to 20 feet in relief. The tabular divides are incised along their edges by steep, narrow, young ravines which lead down to the broader shallow valleys of the creeks. Their digitate lobes, still flat-surfaced, reach even to the escarpment overlooking the Mississippi, where the minor water courses break into cascades as they descend from hanging ravines. Ground water in an upland so young may very naturally stand high, except near the dissected edges.

The Mississippi, which forms the eastern boundary of the county, here passes diagonally across a broad alluvial floor, 5 miles in width, traversed by numerous inosculating bayous and overflowed by the river's annual floods. To the south this strip of flood plain narrows until, at Burlington, where the great river saps the bluffs of the escarpment, it is entirely lacking.

Skunk River, which bounds the county on the south, flows for most of its course through a narrow valley. Five miles above its mouth it develops a flood plain which opens broadly on that of the Mississippi, since here the river traverses a deep preglacial valley filled with easily eroded drift.

GEOLOGY.

The country rock of Des Moines County belongs wholly to the Mississippian series of the Carboniferous. (See Pl. XIII.) At the base of this series lies a group of shales and shaly limestones, the Kinderhook, measuring, as sounded in the deep well at Crapo Park in Burlington, about 300 feet in thickness. (See Pls. XII, XIII.) Only the upper portions of the Kinderhook are exposed within the county. The bulk of the group consists of soft blue "mud-rock" shale, well known and easily recognized by all well drillers. Toward the top, however, are clayey sandstones and impure limestones—transition beds to the overlying Osage group.

The Osage group comprises two formations, the Burlington limestone at the base, and the Keokuk limestone at the top. The lower part of the Burlington limestone is characterized by the singular whiteness of the cuttings obtained by the driller and by the fragments of crinoid stems and plates of which the limestone in places is largely composed. Because of its easy solubility this limestone has been extensively tunneled by subterranean waterways to which numerous sink holes give access. It occurs in two beds separated by about 20 feet of cherty and calcareous shale, and forms the country rock over about one-fourth of the entire county, underlying a broad upland belt along the Mississippi. Upon this basal white limestone lies a well-defined bed of chert or flint about 30 feet thick to which the Iowa State Survey has given the name Montrose cherts. The chert, which composes the upper division of the Burlington limestone, is overlain by the Keokuk limestone, a blue compact limestone containing much chert in flinty nodules and irregular bands, passing upward into geode-bearing shales, which furnish cuttings of milk-white chalcedonic silica and crystals of quartz.

The "St. Louis limestone" forms the summit of the Mississippian series over southeastern Iowa and forms the country rock in the southwest corner of Des Moines County. The beds include white marl, gray and brown limestones, and a hard, brittle, broken, and recemented limestone of fine grain in angular fragments whose interstices may be filled with greenish clay.

The Des Moines group of the Pennsylvanian series occupies only a few isolated areas in the southwestern part of the county. Its rocks consist of buff sandstones and may reach a thickness of 50 or 100 feet.

The surface deposit over the uplands of Des Moines County is the loess—a soft silt or dust, buff above, in many places gray at base, and free from sand, pebbles, and larger stones. Beneath the loess in many places lie as many as three distinct stony clays separated by different water-laid deposits. The uppermost is the Illinoian drift, a yellow or, where unweathered, a bluish, stony clay, generally bleached and leached superficially and supporting an ancient soil developed during the long interval which elapsed after its deposition and the accumulation upon it of the loess. Beneath the Illinoian drift lies the Kansan, a hard, stony clay, blue where not weathered. Lowest of all lies the sub-Aftonian, or Nebraskan, drift, a still darker stony clay. Ancient soils and buried peat bogs and beds of sand and gravel in many places separate the Kansan drift from both the Illinoian and the Nebraskan.

UNDERGROUND WATER.

SOURCE.

On the broad flood plain of the Mississippi, sheet water is found in river sands and gravels at depths of 16 to 20 feet Driven wells, consisting of 1¼-inch pipe with a sand point, are almost universally employed.

On the narrow flood plains of Skunk River and the other streams of the county the alluvium is of little importance except in villages. The village of Augusta, situated on the Skunk River bottoms, draws its house supplies from wells from 16 to 24 feet deep, sunk to rock through river deposits which find a sheet of ground water about 2 feet deep moving riverward in sand resting on the rock surface.

Some of the silts at the base of the loess supply water, especially for shallow open wells on the tabular divides in places where ground water stands near the surface owing to the flatness of the land or to local sags. The beds lying between the Illinoian drift and the Kansan include in places sands of some thickness. Unfortunately these beds also include old soils, muck, and buried wood, which in places injure seriously the quality of the water.

Water is also obtained from the sands and gravels which separate the Kansan from the underlying Nebraskan drift and also from the sand and gravels that in some places rest on the country rock.

Besides these fairly constant water beds of the drift, irregular and inconstant beds of sand and gravel may occur in any of the drift sheets, and, where of sufficient continuity and extent or sufficient connection with interglacial sands, may form local water beds adequate for small wells.

On the whole the drift, where thickest and where least dissected by stream ways, forms an adequate reservoir for ground water and the supply of common wells. But where bedrock comes near the surface and the drift sheets are thin, and where they have been intricately cut by streams leaving the steep-sided and narrow divides locally called "breaks," the drift is often found nearly dry and water must be sought in the rock beneath. The drift is specially thick along the terminal moraine of the Illinoian sheet which extends from north to south through Washington and Pleasant Grove townships. Here the ridge of the moraine rises 60 or 70 feet above the level of the adjacent upland plains and the drift has not been found less than 120 feet in thickness. On this ridge wells find water in drift sands and gravels. Other areas of specially thick drift occur where ancient rock-cut river valleys have been filled with glacial and interglacial deposits. Several deep wells in drift from Sperry to southeast of Latty point to a buried channel which apparently debouches into the Mississippi channel between Flint River and the north line of

Burlington Township. A deep drift well a mile south of Kossuth marks perhaps a northeast tributary of this channel although it may point to an independent valley leading to the Mississippi. Thus near Latty, along a north-south line a mile in length, are three deep wells, two of which are nearly 190 feet deep and strike no rock, and the third—the most northern—233 feet deep, finds the blue shale of the Kinderhook[1] at 231 feet. Drillers report "deep country" from south of Dodgeville, running northwest to between Pleasant Grove and Yarmouth. Other wells of exceptionally deep drift reported from Middletown, northwest of Danville, and east of New London, may mark another buried channel whose rock floor lies at about the level of the present bed of the Mississippi at Burlington. A few flowing wells from the drift are reported on low ground from Danville to south of Middletown.

The basal member of the rocks exposed in the county, the shale of the Kinderhook, is dry. Wells finding little or no water before reaching this shale have penetrated it to a depth near Augusta of 220 and 257 feet, and near the Mississippi north of Burlington to even as much as 300 feet without success. Unless the owner is prepared to go through this heavy shale and several hundred feet still deeper to tap the Galena waters, the drilling should be stopped on reaching the Kinderhook, and a well sunk in another place.

The limestones overlying the Kinderhook are water bearing, the chief aquifers lying in the lower part of the Burlington limestone. Ground water collects in this limestone in the crevices, joints and waterways formed by solution, its downward progress being stopped by the underlying floor of impervious shale. The upper cherty member of the Burlington ("Montrose cherts") is also water bearing. The "St. Louis limestone" probably carries water in the small area which it occupies in the southwestern townships, as may be inferred from the known water beds along its outcrop farther to the west.

At and near Burlington, except for the drift gravels found on the rock and minor veins, the first dependable water bed is the Silurian. It is apparently this bed which supplies wells about 500 feet in depth, affording to some of them a generous yield. The initial head seems to have been about 570 feet above sea level, but no exact statements can be made, for requests sent to the city officials for information as to the elevation of the different well curbs have not been answered. A sharp fall of static level was observed in several wells on the completion of the Clinton-Copeland well. The water bed is evidently overdrawn, and flows from it can no longer be expected, except from the lowest levels. To protect the wells at Burlington which now draw from it no further drafts should be made, and all wells drilled

[1] Fultz, F. M., Proc. Iowa Acad. Sci., vol. 3, 1896, p. 62.

in the city should not only seek a deeper supply but should also case off the Silurian water. In quality the Silurian water is hard and corrosive. As shown in the analyses (p. 169), calcium approaches 400 parts per million, sodium runs between 700 and 800 parts, and the sulphate ions somewhat exceed 2,338 parts in one of the wells. The total solids were about 4,000 parts per million in the wells analyzed.

The reference to the Silurian of the water bed of the 500-foot wells at Burlington is made with a good deal of hesitation, although no other reference seems possible, as the Crapo Park well record places the base of the Maquoketa shale (Ordovician) below the bottom of these wells. On the other hand the Crapo Park record is supported by but few sample drillings over the critical horizons. Some of the wells reach nearly to the supposed base of the Maquoketa. Local drillers speak of this water bed as the St. Peter sandrock, a term rather easily applied to the water-bearing Galena dolomite, a rock which crushes under the drill to a sparkling crystalline sand, but which it seems hardly probable would be applied to any Silurian rock that appears in the samples of any of the Burlington wells. The Galena forms one of the chief water beds at Fort Madison, and appears in full thickness at Mount Pleasant, where again the Silurian contains no water-bearing rock, if the record and the large amount of anhydrite present are reliable guides. It is hoped that the question whether the Silurian or the Galena supplies the water for the 500-foot wells at Burlington may soon be definitely settled by obtaining a complete set of samples of the drillings of a well reaching to the well-defined horizon of the St. Peter.

New wells should not fail to go as deep as the St. Peter, which here lies about 260 feet below sea level. The formation is exceptionally thick at Burlington and yields generously. The pressure is much higher than that of the Galena, the static level apparently reaching at present 630 or 640 feet. Because of the marked difference in pressure of the St. Peter and the Silurian waters, the Silurian should be cased off to prevent lateral escape of the deeper waters through its waterways. The quality of the St. Peter water is much better than that of the higher flows, containing less than one-half the solids in solution, the greatest differences being in the sodium and the sulphate ions, according to Hendrixson's analyses. As but three wells at present draw water from the St. Peter, no overdraft has yet occurred.

The water beds lying beneath the St. Peter are tapped by but one well, that of Crapo Park. The water from these beds has about the same static level as that of the St. Peter, but is distinctly superior in quality, the combined waters of all horizons in the park well containing only about half as much dissolved solids as that of the

St. Peter and the Galena combined and one-fourth that from the Galena alone. As the static level at Crapo Park is more than 100 feet higher than the lower grounds of the city, wells drilled in the manufacturing parts of the city situated near the level of the Mississippi will have high pressure and proportionately large discharge.

SPRINGS.

The chief spring horizon in Des Moines County is at the base of the Burlington limestone, whose massive beds are water logged, owing to their resting upon a floor of impervious shale. As the lower part of the Burlington limestone is easily soluble and is therefore traversed by numerous channels opened by solution, springs along the outcrops of its basal layers are exceptionally abundant and copious. They are found along the escarpment of the Mississippi and along the lower courses of Skunk and Flint rivers. In many ravines the springs emerge above a massive basal layer of the limestone and cascade over the cliff formed by the sapping of the limestone by the retreat of the weak shale beneath. These springs are utilized only for stock and dairy and household purposes.

CITY AND VILLAGE SUPPLIES.

Burlington.—The water supply of Burlington (population, 24,324) is taken from Mississippi River and passed through settling tanks and filters. The water is brought through a 24-inch cast-iron pipe from a point near the center of the main channel of the river and above any possible source of pollution, it is said, from city drainage. The coarser materials are allowed to settle in an extension of the well, 20 feet wide and 125 feet in length. This extension is cleaned with a centrifugal pump whenever the river lowers to within 4 or 5 feet above the low-water stage. From the well the water is pumped by low-service pumps to four steel settling tanks, 30 feet in height and 44, 35, 28, and 22 feet in diameter. The water enters the tanks through several thousand small holes in cast-iron pipes about 6 feet above the bottoms of the tanks, and passes out over weirs at the top. The tanks are cleaned once each month by opening the sewer valves and washing with a hose. Cleaning requires from two to three hours.

From the settling tanks the water flows by gravity to the filters. These are in six units, fully equipped, and have a combined capacity of 3,000,000 gallons in 24 hours. The amount pumped is about 1,800,000 gallons. Each unit is 8 feet wide by 26 feet long, and is of reenforced concrete. The filters are placed at a sufficient height above the clear well and above the controllers in the pipe gallery to obtain the benefit of the "down draft." Each filter bed has 9 inches of gravel from Mount Tom, Mass., and 30 inches of filter sand from Red

Wing, Minn. Water strainers are placed on the floors of the filters, and air strainers in the gravel. Water for washing the filters is supplied from the clear well by a Lawrence centrifugal pump connected to a Lawrence vertical engine to which is also belted the air compressor.

There are two coagulant tanks. Compressed air is employed for their agitation. A specified number of inches is fed per hour, the feed being changed in the event of any change in the demand for water, as for example a large fire or a broken main. Sulphate of alumina is used as coagulant, the solution for the day run being stronger than that for the night. Before preparing the solution the turbidity of the raw water and of the water in the settling tanks is measured with a turbidity rod. From the records is then found the strength of solution which has been found to give satisfactory results with an equal turbidity and pumpage. Three times a week the alkalinity of both raw and filtered water is determined, and the color of the water from each filter is determined with standard disks. The color normally desired is that of disk No. 6, but the color frequently gets as high as that of No. 12. When it rises to No. 18 the strength of the coagulant solution is increased. The average amount of coagulant used is between 3 and 4 grains to the gallon. When the turbidity rises to between 2,000 and 3,000, as much as 7 grains is used. Bacterial tests are made from time to time.

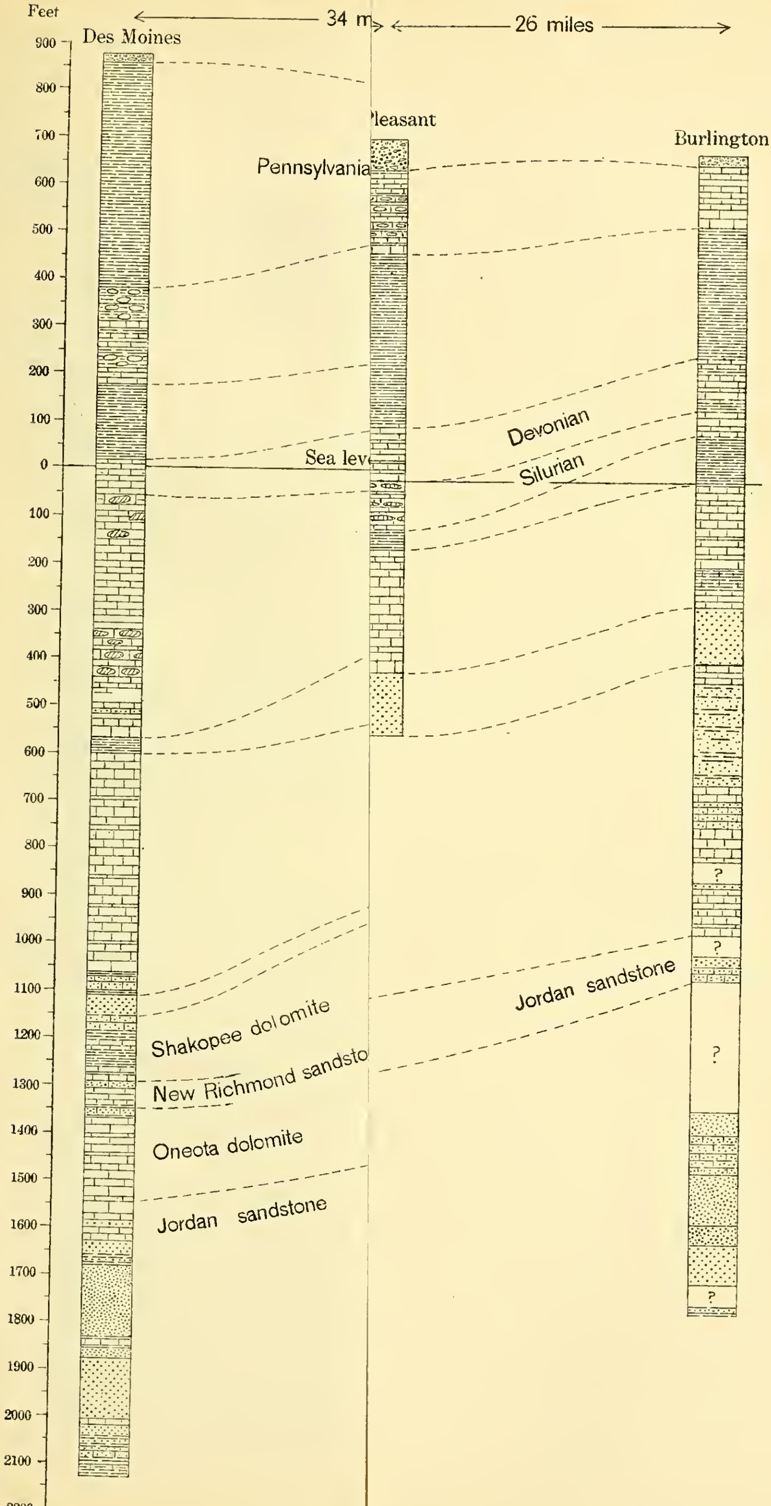
Once a week the filtered water is tested for alum with the logwood test, but none has ever been tested in the filtrate.

The coagulant is supplied by gravity to the suctions of the low-service pumps, which lift the raw water from the well to the settling tanks. The distribution is direct, with a domestic pressure of 100 pounds and a fire pressure of from 125 to 150 pounds. In 1907 there were 32 miles of mains, 339 fire hydrants, and 3,170 taps, and the mains were being extended about 2 miles each year.

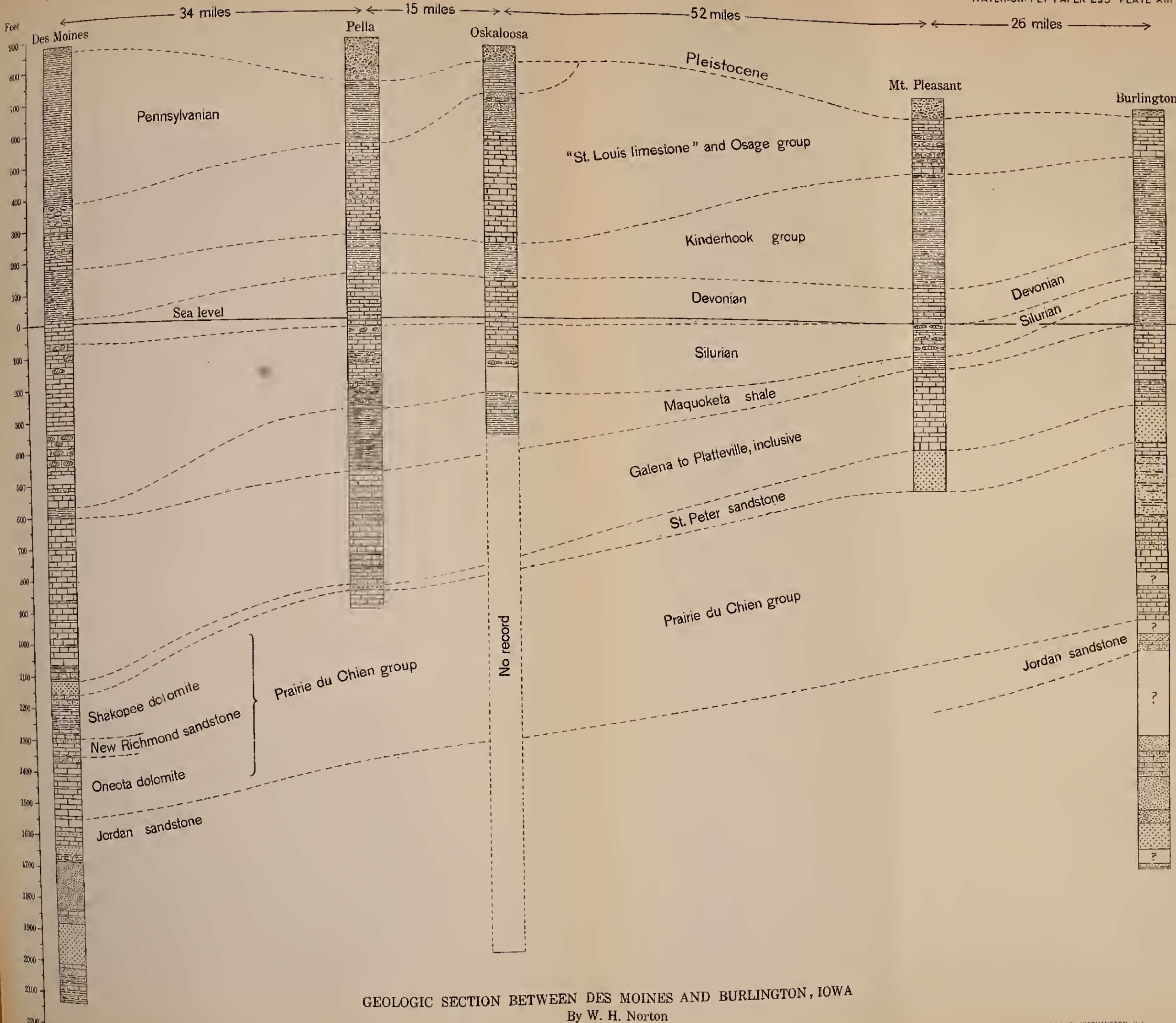
The city well at Crapo Park (Pls. XII, XIII) has a depth of 2,430 feet and a diameter of 6 inches from the surface to 1,700 feet and of 5 inches to bottom; cased to limestone at depth of 18 feet. The curb is 685 feet above sea level, and the head 38 feet below curb. The tested capacity is 250,000 gallons a day, the water coming principally from 950 feet below surface. The well was completed in 1898, at a cost of $5,095, by Tweedy Bros., of Keokuk. Later a casing was inserted between depths of 110 and 210 feet, as a result of which water rose to 30 feet below curb.

The following record is based on determinations by the writer of samples of drillings saved by F. M. Fultz, superintendent of the Burlington public schools. It agrees for the most part with the record given by Mr. Fultz.[1]

[1] Proc. Iowa Acad. Sci., vol. 6, 1899, pp. 70–74.



THE NORRIS PETERS CO., WASHINGTON, D. C.



GEOLOGIC SECTION BETWEEN DES MOINES AND BURLINGTON, IOWA
By W. H. Norton

THE NORRIS PETERS CO., WASHINGTON, D. C.

Record of strata in Crapo Park well at Burlington (Pl. XII, p. 514; Pl. XIII, p. 526).

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene:		
Loess and drift	18	18
Carboniferous:		
Mississippian (422 feet thick; top, 667 feet above sea level)—		
Limestone, buff; effervescence rather slow; some chert in small chips	23	41
Limestone, buff and white, granular; rapid effervescence	37	78
Limestone, light yellow; in fine meal; rapid effervescence; some chert	19	97
Limestone, buff; in fine meal and flour; rapid effervescence; some chert	13	110
Limestone, magnesian or dolomite, blue gray, crystalline	39	149
Shale, blue and drab (Kinderhook)	291	440
Devonian and Silurian (140 feet thick; top, 245 feet above sea level):		
Limestone; in light gray, highly argillaceous powder; rapid effervescence	140	580
Ordovician:		
Maquoketa shale (108 feet thick; top, 105 feet above sea level):		
Shale, light gray, highly calcareous; in powder	38	618
Shale, drab	70	688
Galena dolomite and Platteville limestone (257 feet thick; top, 3 feet below sea level)—		
Dolomite, light buff, crystalline-granular; with hard brown bituminous shale at 868 feet; 6 samples	207	895
Limestone, buff, finely granular; rapid effervescence	31	926
Dolomite, light yellow; in sand and powder	19	945
St. Peter sandstone (120 feet thick; top, 260 feet below sea level)—		
Sandstone, fine grained, white; some limestone; grains of considerable range in size, moderately well rounded	10	955
Sandstone, clean, white; somewhat coarser than above	45	1,000
Sandstone; as above; much hard, green shale like the basal shale of the Platteville limestone	40	1,040
Sandstone, clean, white; largest grains reach 0.7 millimeter in diameter	10	1,050
Sandstone; as above; largest grains slightly exceed 1 millimeter in diameter	15	1,065
Prairie du Chien group (565 feet thick; top, 380 feet below sea level)—		
Dolomite, light gray; some chert	35	1,100
Marl, white and pink, highly dolomitic; large residue of fine quartz sand and argillaceous material and flakes of chert; 3 samples	235	1,335
Dolomite; in fine, light yellow, crystalline meal	15	1,350
Sandstone and pink oolitic chert	10	1,360
Dolomite, arenaceous, or sandstone, calcareous, all in fine yellow sand	20	1,380
Dolomite, light yellow, highly arenaceous; angular grains of pure dolomite and rounded grains of quartz sand	20	1,400
Marl, white; residue minutely quartzose	10	1,410
Chert and dolomite	9	1,419
Dolomite, buff and light gray; in fine sand; cherty; 4 samples	56	1,475
Unknown; drillings washed away	44	1,519
Dolomite and chert	6	1,525
Chert and dolomite, gray	20	1,545
Dolomite, gray, cherty, and arenaceous	25	1,570
Dolomite, light brown, cherty	15	1,585
Dolomite, gray, cherty	45	1,630
Cambrian:		
Jordan sandstone, St. Lawrence formation, and underlying Cambrian strata (800 feet penetrated; top, 945 feet below sea level)—		
Unknown, drillings washed away	40	1,670
Sandstone, clean; grains well rounded; largest reaching 1 milimeter in diameter	20	1,690
Sandstone, calcareous, or dolomite, arenaceous, buff; dolomite in angular particles and rounded quartz grains	35	1,725
Unknown; drillings washed away	275	2,000
Sandstone, light gray; in fine angular meal; minute grains of quartz and of glauconite with dolomitic cement or matrix; 4 samples	95	2,095
Dolomite, gray; in fine chips, minutely quartzose, 3 samples	35	2,130
Sandstone; as from 2,000–2,095 feet; brownish, highly glauconiferous	95	2,225
Sandstone; fine grains of clear quartz, some pink, some with secondary enlargements	10	2,235
Sandstone, gray, glauconiferous, calciferous; grains varying in size, some being large and well rounded	35	2,270
Sandstone; as from 2,000 to 2,095 feet	5	2,275
Sandstone; in loose grains of clear quartz, largest, diameter of 1 millimeter	85	2,360
Unknown; drillings washed away	40	2,400
Sandstone, dark brown, glauconiferous; in rounded grains and minute siliceous particles; chips of drillings have rough surfaces (due to projecting granules) and not the smooth fractures of quartzite	5	2,400
Sandstone, yellow; in chips of minute grains of quartz and glauconite and some rounded quartz grains, embedded in dolomitic matrix or cement; chips crumble easily after digestion in acid; drillings contain considerable hard green shale		2,405
Sandstone, buff, calciferous, glauconiferous; much hard green shale	5	2,410
Sandstone, buff, calciferous, glauconiferous; much green and reddish shale	10	2,420
Shale, hard, dark green and reddish, fissile; and sandstone, calciferous and glauconiferous; in angular chips; grains minute and angular	10	2,430

The well of Iowa Soap Co. has a depth of 509 feet and a diameter of 6 inches; casing, 70 feet to rock. The curb is 540 feet above sea level. The original head was 33.5 feet above curb and the head in 1905, 4 feet above curb; the loss was due to the sinking of the Clinton-Copeland well. The flow in 1905 was 15 gallons a minute through 1¼-inch pipe. Temperature 56° F. The well was completed in 1904 by R. J. Johnson.

Record of strata in well of Iowa Soap Co. at Burlington.

	Thickness.	Depth.
Pleistocene (70 feet thick; top, 540 feet above sea level):	*Feet.*	*Feet.*
Till	15	15
Till, yellow; 4 samples	35	50
Gravel, coarse, up to 1½ inches diameter	10	60
Gravel, fine	10	70
Carboniferous (Mississippian):		
Kinderhook group (210 feet thick; top, 470 feet above sea level)—		
Shale, blue, plastic, calcareous; 2 samples	58	128
Shale, olive gray, fissile	7	135
Shale, light green gray	5	140
Shale, brown, hard, bituminous	15	155
Shale, blue and green gray; 4 samples	45	200
Shale, light brown, bituminous	10	210
Shale, olive bluish and green gray; 9 samples	70	280
Devonian and Silurian (160 feet thick; top, 260 feet above sea level):		
Limestone, gray, soft, argillaceous; effervescence slow; 2 samples	25	305
Shale, calcareous, hard, blue; in large flaky chips	10	315
Limestone, hard, gray, in sand; rapid effervescence	10	325
Limestone, light yellow; rapid effervescence; in fine sand and argillaceous powder	15	340
Limestone, yellow gray; fossiliferous, with fragments of brachiopods; soft; in flaky chips	10	350
Limestone, yellow; rapid effervescence; in fine meal; 2 samples	10	360
Limestone, strong blue; fossiliferous; hard, compact; earthy luster; siliceous but not arenaceous	10	370
Shale and limestone in light yellow gray concreted powder; effervescence rapid	10	380
Limestone, blue, dense, hard, in part of lithographic fineness of grain and conchoidal fracture; rapid effervescence; in chips	10	390
Limestone, compact, gray, in sand; rapid effervescence	5	395
No record	5	400
Limestone, blue gray, rough; slow effervescence; some chert	10	410
Limestone, light buff and white, compact, fine grained; rapid effervescence	10	420
Limestone, light yellow gray or white; rapid effervescence; residue quartzose with minute grains and flakes and prismatic crystals of quartz; in fine meal; 4 samples	20	440
Unknown; no samples	69	509

The well of George Boeck, at 2–8 North Fifth Street, has a depth of 450 feet and a diameter of 5 inches; casing, 74 feet. The head is 30 feet above bottom of cellar. The well flowed "a full 5-inch stream," with no decrease in 1905. Water was found in white limestone 150 feet below soapstone (Kinderhook). Temperature, 60° F. Effect on boilers, not good. The well was completed in 1904 at a cost of $650 by W. N. Jennings, of Burlington.

The well of the Clinton-Copeland Co., at 100 South Fourth Street, has a depth of 465 feet and a diameter of 5 inches throughout; casing, to 72 feet. The head originally was 28 feet above curb, and no change has been noticed. Water is said to have begun to overflow when well reached depth of 440 feet. The temperature, taken after flowing through 175 feet of hose, was 59° F. The well was completed in March, 1905, at a cost of $675 by J. R. Stanly, of Stronghurst, Ill.

The well of the Moehn Brewing Co. has a depth of 510 feet and a diameter of 5 inches. The original head was 30 feet above curb, but the well had ceased to flow in 1905, and the capacity under pump was small. Water was found in small quantity at 90 feet, but the main supply came from 500 to 510 feet. The well was completed in 1904 at a cost of about $1,000 by W. N. Jennings, of Burlington. The water is too heavily mineralized for use in boilers or for beer, but is used in cooling and for other purposes in the brewery.

The well of the Murray Iron Works has a depth of 831 feet and a diameter of 6 to 4 inches; casing, 120 feet from surface into blue shale. The head is 92 feet above curb. The original flow of 300 gallons a minute had not diminished in 1905. The first water was in a gravel just above rock at 75 feet, and the first flow at 450 feet; a strong flow came in at 500 feet and the drillings were washed away from 600 to 760 feet and from 800 to 831 feet. The rock from 800 to 832 feet is said to be like granular sugar. The temperature at tap after water has passed through 300 feet of pipe in foundry was 63.5° F. The water is too hard for use in boiler. The well was completed in 1903 at a cost of $1,038 by W. N. Jennings, of Burlington.

The well of the Sanitary Ice Co., near the intersection of Osborn Street and Central Avenue, has a depth of 852 feet and a diameter of 5 inches; casing, 95 feet from surface. The head was 51 feet above curb, and the flow 500 gallons a minute. Water at 80 feet was shut off; water at 430 feet rose nearly to the surface; the first flow was at 700 feet, and water from the 800-foot level rose 51 feet above curb. Temperature, 64½° F. The water corrodes boilers and is used for condensing. The well was completed in 1908 at a cost of $1,600 by Jennings & Sons, of Burlington.

The well of the Sanitary Milk Co. has a depth of 487 feet and a diameter of 6 inches. The original head was 15 feet above level of corner of Third and Court Streets, but the head in August, 1905, was 31 feet below same level; the head lowered on completion of Clinton-Copeland well. The well was completed in January, 1905, at a cost of $700 by W. N. Jennings, of Burlington.

The well of Smith & Dalton has a depth of 460 feet and a diameter of 5 inches. The original head was 30 feet above curb. The original flow was estimated at 40 gallons a minute, but had decreased in 1905. Temperature reported as 60° F. Date of completion, March, 1905. Drillers, Jennings & Son, of Burlington.

Mediapolis.—Mediapolis (population, 858) depends for its water on drilled and bored wells from 50 to 110 feet deep, all but 30 to 40 feet of which are in rock. The water heads 20 to 30 feet below the curb.

The well of D. Hutchcroft, 2 miles east of Mediapolis, has a depth of 600 feet and a diameter of 5⅝ inches to 360 feet and 5 inches to bottom; casing to 360 feet. Water found at depth of 40 feet, in drift, was not cased out. Pumping capacity, 8 gallons a minute. The well was completed in 1905 by J. F. Tweedy, of Keokuk.

Record of strata in Hutchcroft well near Mediapolis.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, yellow, sandy, calcareous, arenaceous	75	75
Shale, drab, or sandstone, argillaceous, in coucreted masses	60	135
Shale, olive-green, hard, noncalcareous	213	348
Limestone, blue-gray, argillaceous, minutely arenaceous	22	370
Limestone, light gray, nonmagnesian, argillaceous and slightly arenaceous	20	390
Limestone, light yellow-gray, granular, soft, fossiliferous, nonmagnesian	22	412
Limestone, light blue-gray, and white soft earthy; in thin flakes	18	430
Limestone, blue-gray and white; earthy; in fine chips	25	455
Limestone, light yellow-gray and drab, nonmagnesian; cherty	20	475
Limestone, light yellow-gray, nonmagnesian; in fine sand; drillings slightly arenaceous	25	500
Shale, dark blue; in chips; calcareous and cherty	100	600

The shale whose base is found at 348 feet is evidently the Kinderhook; below it, the drill, as at Burlington, passed through about 150 feet of limestones, which may represent the Devonian and Silurian. The shale from 500 to 600 feet may be taken as the equivalent of the shale (Maquoketa) at Burlington which immediately succeeds the limestones below the Kinderhook. The drill therefore seems to have passed through the water bed which supplies the less deep wells at Burlington and yet to have found very little water.

Mediapolis is 764 feet above sea level. If an adequate supply is not found in the Mississippian limestones, a well which adventures through the heavy dry shale of the Kinderhook, here at least 200 feet thick, will probably find water in the Devonian or Silurian. Should the supply still prove insufficient, the drill should proceed through the next considerable shale, the Maquoketa, and tap what water may be found in the Galena dolomite and Platteville limestone. The water bed of the St. Peter sandstone will be encountered at about 1,150 feet from the surface.

Minor supplies.—Minor village supplies are described in the following table:

Village supplies in Des Moines County.

Town.	Nature of supply.	Depth.	Depth to rock.	Depth to water bed.	Head below curb.
		Feet.	*Feet.*	*Feet.*	*Feet.*
Augusta	Wells	16–24		24	10
Danville	Bored and drilled wells	16–125		75	12
Roscoe	Drilled wells	60–100	40		

WELL DATA.

The following table gives data of typical wells in Des Moines County:

Wells in Des Moines County.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Remarks (logs given in feet).
T. 69 N., R. 3 W. (PART OF UNION).		*Feet.*	*Feet.*		
County Infirmary	Sec. 4	235	20		Rock (limestone) from 20 to 235, where soapstone, with water, was encountered. Main water at 190.
George Barnes	4 miles east and 1 mile north of Augusta.	22		Sand	Light-blue clay; sand on top of blue-black clay at bottom. Flows.
S. Cartwright	¾ mile northwest of above.	42		do	Flow from sand underlying light-blue clay.
Louis Pfeiff	NE. ¼ sec. 33	357	20		Soil, 20; limestone, 80; soapstone (Kinderhook), 257; little water. Midway between river bottoms and bluffs.
T. 69 N., R. 4 W. (AUGUSTA).					
Palmer Orton	Near Augusta	400			Drift; limestone; "soapstone" (shale) at 180; ends in soapstone at 400; not enough water for windmill.
L. Hilleary	SW. ¼ sec. 11	100	20	Limestone.	No shale. Water at 98.
Alfred Weg	NE. ¼ sec. 3	70		Sand and gravel.	
T. 70 N., R. 2 W. (PART OF BURLINGTON).					
—— Wykert	Sec. 19	418	164		Loam and sand, 164; limestone, 4; shale, 250. Head, 31 feet above curb.
William Penrod	2½ miles northwest of Burlington.	135		Gravel	Drift, 20; fine sand to gravel at bottom.
T. 70 N., R. 3 W. (FLINT RIVER).					
James Graham	NW. ¼ sec. 28	138		Gravel	No yellow or blue clay; all dirt and gravel; white soapstone at bottom.
John Sellers	NW. ¼ sec. 33	188		Sand	Yellow clay; white clay; blue clay to sand or rock at bottom.
Joseph Saters	SW. ¼ sec. 31	140		Gravel	Yellow clay, 40; blue clay to gravel at bottom.
Fair Ground	West Burlington	45	20	Limestone.	Water in crevice.
T. 70 N., R. 4 W. (DANVILLE).					
Thomas Grant	NE. ¼ sec. 8	305	300	Rock	Yellow clay; white clay; blue clay with sand at 150 feet; 300.
—— Hurlburt	1½ miles south of Danville.	135		Sand	Largely blue till.
Mrs. Allen	1½ miles west of Middleton.	227		Sand and gravel.	Yellow clay, 54; light-blue clay, 12; no record, 111; dark-blue clay, 48; sand and gravel on rock, 2.
—— Hunter	2 miles west of Danville.	165	66	Limestone.	Head, 20 feet below curb. Yellow clay, 42; light-blue clay, 12; sand with water, 2; dark-blue clay, 10; rock, 99. Water from upper sand heads at −5 feet.
T. 71 N., R. 2 W. (BENTON).					
	Latty	250			Sand and mud; sand, fine, dark. No water. Bones found at 188.
Fred Kaster	Sec. 33	304		Sand	Loam; sand; black mud; sand; wood and coal; old soil; mussel shells at 257; blue till, 20, overlying sand bed at bottom.

Wells in Des Moines County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Remarks (logs given in feet).
T. 71 N., R. 4 W. (PLEASANT GROVE).					
		Feet.	*Feet.*		
Anton Totemeir	Sec. 19	276			Yellow till (Illinoian), 30; blue till (Illinoian), 10; reddish brown till (Kansan), 12; blue till with thin beds of sand (Kansan and Nebraskan), 224.
John Shepherd	SW. ¼ sec. 34	50		Coarse gravel.	Well in valley; yields 2 to 3 gallons per minute; diameter, 4 inches. Head, 5 feet above curb.
T. 71 N., R. 3 W. (FRANKLIN).					
—— Brady	Near Sperry	400			No hard rock struck, but perhaps entered Kinderhook in lower part.
T. 72 N., R. 2 W. (PARTS OF YELLOW SPRING AND HURON).					
W. B. Dutchcroft	Sec. 31	462			Casing, 360 feet. Entered hard rock at 342; some shale may have been penetrated. Water at 40. Well weak; 1 gallon per minute.
	Sec. 4	159			Largely yellow till.
	Sec. 10	127	95		
	Sec. 20	120	118±		
	Sec. 27	147	40	Limestone.	Limestone from 40 to bottom where shale was struck.
	Mediapolis	56	42	...do	Diameter, 5 inches; yield, 5 gallons per minute; main water at 55; water at 23.
W. J. Cumings	Linton	360	90	...do	Other wells find black mucky soil under the loess.
T. 72 N., R. 4 W. (WASHINGTON).					
William Steiter	Yarmouth	110		Sand	Soil and loam, 4; yellow till (Illinoian), 20; gray till (Illinoian), 10; peat bed, twigs, and bones, 15; gray sandy clay with wood, 12; fine sand, 16; yellow sandy till (Kansan), 33.
F. Smith	1 mile south of Yarmouth.	180		...do	Yellow till becoming gray below (Illinoian), 36; sand with thin bed of blue clay and of cemented gravel, 73; black muck with wood, 6; sand and gravel, 8; gray pebbleless silt, 15; blue till (Kansan), 42.
M. T. Evans	1½ miles south of Roscoe.	98	55	Rock	Head, 30 feet below curb.
J. Mehmken	Roscoe	24	20	Limestone.	35 feet below railway station. Yield, 3 gallons per minute. Heads 5 feet above curb.

HENRY COUNTY.

By W. H. NORTON.

TOPOGRAPHY.

Henry County lies almost wholly on the Kansan drift plain of southeastern Iowa. This upland, which once had a nearly level surface, retains its original features over much of the northern and central portions of the county, where the drainage is still imperfectly developed and the tabular divides present the appearance of level plains, scored only by shallow swales of little-concentrated wash. In the southern townships the deep-cut valleys of Skunk River, Cedar Creek, and Big Creek permit a much greater dissection of the adjacent uplands, and here the interstream areas are cut to a maze of ridges with narrow level crests whose even sky line marks the common level of the ancient upland plain.

The southeastern townships, Baltimore and New London, are ridged with the low long swell of the terminal moraine, which marks the limit to which the Illinoian ice here invaded Iowa from the east.

A wide channel excavated by glacial waters in the Kansan drift lies along the northern border of the county and turning abruptly south follows the west county line, along which it has been occupied and deepened by the waters of Skunk River and Cedar Creek, passing thence through Lee County by Grand Valley and the valley of Sugar Creek to the Mississippi. Both Cedar Creek and Skunk River are bordered by wide flood plains where they hold to this ancient channel, the entire width of the Skunk River bottoms here ranging from three-fourths to 1¼ miles. Over the remainder of their courses these two streams, like the others of the county, flow through comparatively narrow valleys destitute of any flood plains of sufficient width to be of importance in this investigation.

GEOLOGY.

The Nebraskan, the lowest and earliest drift in Henry County, is not exposed so far as known, but is encountered in different wells as a dark-blue stony clay or till, resting on bedrock or separated from it by thin inconstant streaks of sand and gravel. The upper stony clay, the Kansan, is parted from the Nebraskan by sheets of sand and gravel or by old soils, peat, and forest beds (Aftonian interglacial deposits). The Kansan drift includes over nearly all the county both the yellow till immediately underlying the loess and the unweathered blue till from which the yellow till has been derived by long leaching and oxidation. On and east of the north-south ridge passing through New London and recognized as a terminal moraine a third till appears, the yellow stony clay of the Illinoian.

Over the entire county, except the river flood plains, has been spread the thin mantle of the loess, a friable siliceous silt. In color the loess is gray on the level prairies where overlain with deep humus, but yellow on hill slopes or where it attains some thickness.

The bedrock of Henry County, with the exception of small and negligible outliers of Pennsylvanian shales and sandstones, belong to the Mississippian series. (See Pl. XIII.) Immediately beneath the drift the driller finds from 60 to 100 feet of limestones, sandstones, and shales belonging to the "St. Louis limestone." The succession from above downward is light-gray limestones, variable beds of sandstones, shales, broken or brecciated, limestones, and massive impure magnesian limestones. Below these lies the Osage group, the uppermost formation of which, as exposed in the county, is the Keokuk limestone, consisting of geode-bearing limy shales 30 feet thick, underlain by about 25 feet of limestone interleaved with bands of bluish shale. No lower rocks than the Keokuk are exposed within the county, but the drill of the well driller has explored to some depth the underlying formations of the Mississippian. Beneath the Keokuk lies the white Burlington limestone, composed in part of crinoidal remains and seamed by water-bearing porous beds and crevices. The deeper wells pass through the Burlington and reach the heavy shale of the Kinderhook, which forms the base of the Mississippian series.

UNDERGROUND WATER.

SOURCE.

The flood plains of Skunk River and its larger tributaries, such as Cedar Creek, afford abundant water to shallow wells from stream-laid sands and gravels. In Skunk Valley above Rome the alluvium is of agricultural importance owing to the breadth of the flood plains. In the narrower valley below Rome it is important chiefly for supplying towns and villages. Thus the village of Lowell obtains water from open and driven wells in the alluvium, although the rock bottom of the narrow valley is reached at from 20 to 30 feet from the surface, the water being found in a sheet said to be 2 feet deep on the rock.

On the flat divides ground water stands high, and collecting in the porous silts at the base of the loess and in the reddish sands and gravels which occur in seams and lenses in the Kansan till, usually affords a supply to shallow, open, bored, and driven wells. Larger and more permanent supplies are drawn from the sands overlying the Nebraskan drift and those which part it from bedrock.

From these strata most of the wells in the county are supplied. In places the lower drift sources lie deep below the surface. Wells in sections 1 and 11 of Marion Township pierced the drift to depths of 190 and 250 feet without reaching either bedrock or the sands and gravels which overlie it, indicating a channel cut in deep rock by some preglacial river and afterwards filled with drift; the course of this buried valley is, however, entirely uncertain.

Even on the wider tabular divides the drill or auger may find the water-bearing drift sands absent or too thin to convey enough water for stock wells, and the well must then be sunk into solid rock. Bedrock must also be probed where the drift is thin, and where, owing to the dissection of the region by the streams, ground water readily drains out to the lowest levels. The sandy layers of the "St. Louis limestone" and also the strata between its shale beds form water beds of value. The chief resource, however, is the white porous and creviced Burlington limestone of the Osage group. Drillers report that the main water bed is a white porous and spongy but hard limestone separated from the Kinderhook below by some 20 feet of blue-gray limestone. The Kinderhook no doubt acts as an impervious floor on which water accumulates in the overlying strata where porous or in passages opened up by solution.

At Mount Pleasant the Kinderhook was found a little less than 250 feet below the surface and was about 300 feet thick. On reaching this dry shale drilling should stop for all ordinary farm wells.

CITY AND VILLAGE SUPPLIES.

Mount Pleasant.—The succession at Mount Pleasant (population, 3,874) is shown by the following records of the wells drilled for the State Hospital for the Insane:

Well No. 1 has a depth of 1,125 feet. The curb is about 719 feet above sea level, and the head 30 feet below curb. The tested capacity is 165 gallons a minute, the water coming from 990 feet. Temperature, 62° F. Date of completion, 1862. The well was abandoned years ago because the water was so corrosive that it destroyed a battery of boilers and all the steam radiators of the institution.

Driller's log of well No. 1, Iowa Hospital for Insane.

	Thickness.	Depth.
	Feet.	*Feet.*
Limestones	295	295
Shales, soft, passing into hard	300	595
Limestone	295	890
No samples	100	990
Sandstone	135	1,125

Well No. 2 has a depth of 1,267 feet and a diameter of 12 inches to 123 feet, 10 inches to 723 feet, and 6 inches to bottom; casing, 12 inches, 123 feet to rock, 10 inches to 733 feet, 6 inches to 1,153 feet; packing ring at junction of 10-inch and 6-inch casing. The curb is about 719 feet above sea level, and the head 70 feet below curb. Pumping capacity, 70 gallons a minute. The well was completed in 1898 by L. Wilson & Co., of Chicago. From it 40,000 to 50,000 gallons a day are now pumped without exhausting its supply.

Well No. 3 has a depth of 1,203 feet and a diameter of 12 to 6 inches; casing, 71 feet of 12-inch, 610 feet of 9-inch, 635 feet of 6-inch. The head is 71 feet below curb and the tested capacity 70 gallons a minute. The water comes from 250 feet and is very good for drinking but destructive to boilers; other water-bearing strata were not recorded. The yield is 70 gallons a minute. Date of completion, 1903; cost

$4,700. From this well 120,000 gallons a day are now pumped. Except for boiler water, which is supplied from a reservoir, the entire institution is supplied by wells Nos. 2 and 3.

Driller's log of well No. 3, Iowa Hospital for Insane.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil, clay, and some sand	68	68
Slate	7	75
Limestone	29	104
Slate	4	108
Limestone (6 inches of slate at 125 feet)	107	215
Slate	10	225
Limestone	20	245
Slate	360	605
Rock ("Trenton")	511	1,116
Rock (St. Peter)	87	1,203

Record of strata in well No. 3, Iowa Hospital for Insane (Pl. XIII, p. 526).

	Thickness.	Depth.
Pleistocene (68 feet thick; top, 719 feet above sea level):	*Feet.*	*Feet.*
Drift, no sample	68	68
Carboniferous (Mississippian):		
"St. Louis limestone" and Osage group (182 feet thick; top 651 feet above sea level)—		
Shale, light blue, calcareous	7	75
Limestone, yellow; drillings chiefly foreign sand	5	80
Limestone, light blue, highly argillaceous; rather hard in chips	10	90
Chert, white; much sand in drillings	10	100
No record	4	104
Shale, blue, plastic, calcareous	4	108
No record	2	110
Limestone, light gray, nonmagnesian, soft, earthy	4	114
Limestone, as above; also bluish-gray, highly calcareous shale and considerable dark flint	4	118
Limestone, mottled dark gray and white, crystalline, encrinital; residue arenaceous and cherty; some white chert; 3 samples	22	140
Chert, light-blue cherty limestone, and light-blue shale	10	150
Chert, white; in small chips	10	160
Limestone, light yellow and white; encrinital, earthy to crystalline; some chert; 4 samples	40	200
Chert, white; some cherty limestone	10	210
Chert, white; includes chips of dense, subtranslucent opaque-white and blue-white cryptocrystalline silica with conchoidal fracture; also irregularly shaped cuttings of a dull-white, earthy chert, or less friable; limestone, light yellow gray	5	215
Shale, light buff, calcareous; in concreted powder	5	220
Shale (driller's log); no sample	5	225
Dolomite, blue gray, rather hard, subcrystalline, vesicular	5	230
Limestone, magnesian; moderately rapid effervescence, drab, earthy	20	250
Kinderhook group (360 feet thick; top, 469 feet above sea level)—		
Shale, blue, hard; highly siliceous with minute quartzose particles; calcareous; 2 samples	20	270
Sandstone, blue, fine grained, argillaceous and somewhat calciferous, composed of minute angular particles of quartz in chips; 4 samples	40	310
Shale, blue, calcareous	10	320
Shale, blue, and sandstone, argillaceous; thinly laminated, 2 samples	20	340
Shale, blue, calcareous; 7 samples	70	410
Shale, blue, and sandstone, yellow-gray; grains up to 1 millimeter in diameter; calcareous cement	10	420
Shale, blue and gray; 2 samples	20	440
Shale, olive gray; yellow and reddish chert in coarse sand, perhaps foreign	10	450
Shale, blue; 15 samples	160	610
Devonian and Silurian (210 feet thick; top, 109 feet above sea level):		
Limestone, crystalline, buff and gray; rapid effervescence; in fine sand; 3 samples	30	640
Limestone, blue, argillaceous, soft, highly fossiliferous; rapid effervescence; in small chips	10	650
Limestone, yellow-gray and blue-gray; rapid effervescence; in sand	10	660
Limestone, light blue-gray, dense, fine grained, laminated; in flaky chips; fossiliferous, containing fragments of crinoid stems and small brachiopods; 3 samples	30	690
Limestone, white, fine grained, rather hard, and blue-gray with some shale	10	700
Limestone, light yellow-gray, nonmagnesian; in fine sand; 2 samples	30	730
Anhydrite; some siliceous gray limestone in powder, and snow-white granules easily friable to crystalline powder; some anhydrite in chips of pure mineral; 2 samples	20	750

Record of strata in well No. 3, Iowa Hospital for Insane—Continued.

	Thickness.	Depth.
Devonian and Silurian (210 feet thick; top, 109 feet above sea level)—Continued.		
Limestone, drab, nonmagnesian; a few chips of anhydrite and of anhydrite and limestone	*Feet.* 10	*Feet.* 760
Anhydrite, white, and limestone, drab; in meal and powder	10	770
Limestone, gray, nonmagnesian; some anhydrite; in meal; 2 samples	20	790
Anhydrite and gypsum, white, and shale, dark drab, hard, noncalcareous, and siliceous; all in chips and sand; 3 samples	30	820
Ordovician:		
Maquoketa shale (40 feet thick; top, 101 feet below sea level)—		
Shale, blue, hard, siliceous, slightly calcareous; some minute grains of crystalline quartz; 2 samples	20	840
Shale, light blue, hard, calcareous; 2 samples	20	860
Galena dolomite and Platteville limestone (256 feet thick; top, 141 feet below sea level)—		
Dolomite, mostly in buff, fine crystalline sand; 25 samples	240	1,100
SAMPLES FROM WELL NO. 2.[a]		
St. Peter sandstone (136 feet thick; top, 397 feet below sea level)—		
Sandstone, white, fine grained; grains about 0.3 millimeter in diameter	20	1,120

[a] Samples of the drillings of this well were shipped in open wooden trays and became much mixed. The compartments of the trays were marked as St. Peter from 1,120 to 1,250, and all of these contained quartz sand of St. Peter facies; some contained green shale and brown bituminous shale, assumed to be foreign and perhaps Platteville. Samples marked 1,250 to 1,267 show chiefly sand of dolomite.

Minor supplies.—Information concerning local village water supplies is presented in the following table:

Village supplies in Henry County.

Town.	Nature of supply.	Depth of wells.			Depth to rock.	Depth to water bed.	Head below curb.	
		From—	To—	Common.			Shallow wells.	Deep wells.
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Hillsboro	Bored and drilled wells	15	150	35	60	40–100		− 30
Lowell	Open and driven wells.	15	35	25	25	25	−18	− 28
Mount Union	Open bored, and drilled wells	20		32	70	30		− 20
New London	Open and drilled wells.	15	300	25	100–200			−100
Alds	Bored wells	16		25		25		− 5
Salem	Wells	28	300	35	35	40	−20	
Swedesburg	Dug, bored, and drilled wells	40	200	100	60	200	−20	− 20
Winfield	Drilled and bored wells	30	100	40	50		−30	− 30

WELL DATA.

The following table gives data of typical wells in Henry County:

Typical wells in Henry County.

Owner.	Location.	Depth.	Depth to rock.	Depth to water bed.	Source of supply.	Head below curb.	Remarks (logs given in feet).
T. 70 N., R. 7 W. (SALEM.)							
	Near Hillsboro.	*Feet.* 318	*Feet.* 104	*Feet.* 260		*Feet.* 265	Yellow clay, 45; soft light-blue till, 27; dark hard till, 32; limestone, 154; soft white sandstone, water bearing, 41; limestone, 19.

Typical wells in Henry County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Depth to water bed.	Source of supply.	Head below curb.	Remarks (logs given in feet).
T. 70 N., R. 7 W. (SALEM)—Con.		*Feet.*	*Feet.*	*Feet.*		*Feet.*	
F. McNeely	S. ½ sec. 15	270	60		Limestone		Rock all limestone except some shale; flinty rock below the shale.
Thos. Campbell	E. ½ sec. 26	190	35		do		Upland drift, 35; limestone, 55; limestone alternating with shale, 100; limestone cherty.
T. 70 N., R. 6 W. (JACKSON).							
John Abraham	SW. ¼ NW. ¼ sec. 24.	290	80	180-200	Limestone		First rise above Skunk River. Drift, 80; limestone, 55; shale, 35; limestone, 70; shale, 20; limestone, 25; shale, 5 (Kinderhook?).
—— Beckwith	Sec. 19	290	80	270	Limestone	40	Drift, 80; limestone, 60; shale, 35; limestone, 115; shale. Pumping 15 gallons per minute reduces water level to 140 below surface.
T. 71 N., R. 5 W. (NEW LONDON).							
—— Greenlee	New London	135		132	Sand		3-foot sand bed at 100, weak water; another at 110, some water; third at 132, yields 2 gallons per minute.
Andrew Johnson	1½ miles south of New London.	55					Loess, 6; yellow till, 20; sand, 3; blue till, 12; peat and wood, 4; gray gummy clay with few pebbles, 10.
John Shipley	New London	220	200		Rock		
William Orndauf	do	260					
T. 72 N., R. 5 W. (CANAAN).							
John A. Wicks	SE. ¼ sec. 15	224	80	204	White porous limestone.		Drift, 80; limestone, 35; shale, 25; limestone, 84.
T. 72 N., R. 6 W. (MARION).							
August Wicks	SE. ¼ sec. 28	100	14		Limestone	30	Drift, 14; limestone, 7; blue shale, 25; limestone with water in crevice, 54.
E. June	SE. ¼ sec. 1	190					All in drift, well failure, struck bowlder at 190 feet and bore hole abandoned; black cement clay, 160 to 190.
	Sec. 11	250					All in drift; abandoned.
T. 72 N., R. 7 W. (TRENTON).							
Oscar Fitch	NE. ¼ sec. 20	260	150	240-260	Limestone	80	Drift clays, etc., 145; dry blue sand, 5; blue limestone, 20; shale, 25; gray limestone, white toward bottom, 65.
T. 73 N., R. 6 W. (WAYNE).							
	1 mile east of Swedesburg.	85					Lower 50 feet blue till.

Typical wells in Henry County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Depth to water bed.	Source of supply.	Head below curb.	Remarks (logs given in feet).
T. 73 N., R. 5 W. (SCOTT).							
		Feet.	*Feet.*	*Feet.*		*Feet.*	
....	Winfield or Fairground.	123	115	....	....	......	Loess and yellow till, 40; hard blue till, 30; gravel, 30; hard blue till, 15; white sandstone, 3; shale, 4; cherty limestone at bottom.
J. England........	3½ miles east of Winfield.	110	100	....	Sand........	......	Sand on rock 60 feet thick.
—— Lehart........	8 miles northwest of New London.	200	....	....	.....do........	......	Drift clay, 30; sand, 170.
Alda Delashmitt..	.....do.........	120	105	....	Rock........	......	
T. 70 N., R. 7 W. (SALEM).							
....	Salem.........	52	....	....	Sand........	......	Yellow clay, 35; light-blue clay, 15; sand, 1; blue-black clay, 1.
T. 71 N., R. 6 W. (CENTER).							
Chas. Leedham...	4½ miles southeast of Mount Pleasant.	70	69	....	....	......	Yellow clay; blue clay; rock at bottom; water on rock.

JEFFERSON COUNTY.

By W. H. NORTON.

TOPOGRAPHY.

The surface of Jefferson County is a plain of ancient drift dissected by streams from 50 to 150 feet below a once level surface, remnants of which remain throughout the county in tabular divides whose flat surfaces have been estimated to constitute about one-fourth or one-fifth of the entire area. These remnants are naturally widest along the main divide between the two master streams, Skunk River and Cedar Creek, where they form a featureless prairie plain extending diagonally across the county from northwest to southeast. Before the settlement of the country wet-weather marshes and shallow ponds occupied slight original depressions, but these, for the most part, have disappeared with the lowering of ground-water level consequent on sod cultivation.

Near the larger streams the country is deeply ravined, and here, as throughout southeastern Iowa, the intimately dissected areas are known as "breaks."

The maturely developed valley of Skunk River affords bottom lands more than a mile in average width. The flood plain of Cedar Creek varies in width from a mile where cut in easily eroded glacial drift and one-half or one-fourth mile where cut in the shales of the Pennsylvanian and to a narrow gorge bearing all the marks of youth where the valley is incised in the more resistant limestones of the Mississippian.

GEOLOGY.

Beneath the dark soil or later humus of the surface lies a mantle of fine yellow silt—the loess—which on the uplands has a thickness of 12 to 15 feet or more. On the slopes it is somewhat thinner, owing to rain wash.

The loess rests on the Kansan drift, which is normally a blue stony clay, but which has been changed, under the oxidizing influence of long weathering, to yellow, and is known to drillers as "true red hardpan." The upper surface of the Kansan may be modified to a sticky noncalcareous clay—the gumbo—through which water can not pass, or in places may consist of pervious sands.

Beneath the Kansan, and separated from it in places by layers of sand and gravel (Aftonian), is a lower stony clay, the Nebraskan drift, a tough dark-bluish deposit, which is rather difficult to drill and which generally contains splinters and bits of wood and fragments of coal.

Over most of Jefferson County the rock beneath the drift sheets belongs to the Pennsylvanian series (coal measures) of the Carboniferous, and consists of a variable succession of shales and sandstones, with an occasional thin bed of limestone and some seams of coal. (See Pls. X, XIII.) The thickness of these strata ranges from a few feet to 150 feet and attains its maximum in the southwestern part of the county. In the northeastern part of the county, in Walnut and in parts of Penn townships, the coal measures have been stripped off by the tributaries of Skunk River, and the underlying "St. Louis limestone" of the Mississippian series is exposed to view. The total exposed thickness of the "St. Louis" amounts to 80 feet.

Beneath the "St. Louis limestone" lies the Osage group, 30 feet or more thick. The most easily recognized of the different beds of the Osage are the basal white limestone and the overlying flinty cherts ("Montrose cherts"), both of which belong to the Burlington limestone.

The Osage rests on shales of the Kinderhook group, here about 150 feet thick. The rock formations of the area below the Kinderhook have not been penetrated by the drill within the county.

UNDERGROUND WATER.

SOURCE.

On the bottom lands of Skunk River and of its larger branches river-laid sands and gravels, saturated with water, are encountered near the surface. On these open wells and driven wells suffice, and in places plenty of water is obtained within 10 to 20 feet of the surface.

Water in greater or less quantity is obtained at the base of the loess, in the yellow Kansan drift, especially near its base, and in or at the base of the Nebraskan drift.

On the level ill-drained uplands, where the run-off is small and much of the storm water is either evaporated or sinks to feed the stores of water underground, the base of the loess silt is in many places saturated, and under favorable conditions water may still be obtained by wells of moderate capacity at depths of 25 feet or less. These conditions obtain especially in Polk and the west half of Blackhawk townships. On the tabular divides, where the loess is dry, water may in many places be found by the well borer in the less clayey portions of the Kansan drift, especially at or near its base. In Fairfield and Locust Grove townships, along the flat divide extending northwest from the town of Fairfield, a large number of wells find water above the blue stony clay within 40 feet of the surface. In the town of Fairfield many house wells do not exceed 30 feet in depth, but the well borer can not depend on striking water at this depth. Here, as elsewhere in the county, the ground-water surface has gradually lowered and shallow wells must now be bored 10 to 15 feet deeper than was necessary in the early history of the town. On the level prairies, where 15 years ago water could almost universally be obtained with a 40-foot auger, it must now be sought at deeper horizons. On the breaks or belts of dissected country along the streamways shallow wells have quite generally failed. Well borers lose an increasing number of holes, and the driller who is able to carry his quest for water into solid rock has an ever-increasing advantage.

Water-bearing sands and gravels are encountered in the yellow Kansan drift. The sand may be but a pocket, in which case it is easily pumped out, or it may be a seam or bed sufficiently thick and extensive to supply a good stock well. No layer of sand and gravel within the blue stony clay is marked enough to impress the memories of well makers, though the water-bearing sands resting on bedrock at its base are often mentioned. In the west half of Penn Township, and in the northeastern part of Des Moines Township, water is found beneath the blue stony clay at about 100 feet from the surface. Two wells drilled in the town of Fairfield are said to have found abundant water in fine sand lying on bedrock at a depth of 195 feet but were abandoned as the sand could not be screened out. In general, however, the sands beneath the Nebraskan drift are not reliable in this county.

The Pennsylvanian series is extremely variable in character. Beds of sandstone thin out rapidly and may be replaced by shales. The succession of strata in one township or even in one section may not be maintained in the one adjacent. For these reasons each well drilled in the coal measures is largely experimental, and the experience derived from other wells serves only as a general guide indicating probabilities. In places the Pennsylvanian contains considerable bodies of sandstone and supplies a soft but often highly mineralized and usually sulphurous water.

In many of the rock wells of the county it has been necessary to go through the coal measures to the water-bearing limestones and interstratified sandy beds composing the "St. Louis limestone." The distance to which the drill must go to reach these beds in any locality is difficult to foretell. The overlying coal measures vary greatly in thickness, for they were laid on the deeply eroded surface of the "St. Louis limestone" and have also an uneven eroded upper surface of their own, now deeply buried beneath the drift.

In some part of every township except Fairfield and Locust Grove the Pennsylvanian has been entirely swept away, usually along the streamways; in Walnut Township it is found only over about 6 square miles in the southwestern and the northwestern parts. The following township data from Udden,[1] giving the average thickness of the coal measures in each township, may be of some help to drillers if it is remembered that in any section their thickness may be several times that given, or, again, may be much less than the average stated for the township.

Thickness of Pennsylvanian rocks in Jefferson County townships.

	Feet.		Feet.
Polk	20	Penn	30
Locust Grove	80	Buchanan	20
Des Moines	50	Cedar	20
Blackhawk	15	Walnut	10
Fairfield	75	Lockridge	40
Liberty	50	Round Prairie	20

SPRINGS.

Few noteworthy springs are reported from the county. In the southwest corner of sec. 1, Walnut Township, a number of springs emerge from glacial or preglacial gravels resting on bedrock. Large springs are said to occur near Merrimac on Skunk River. Near Perlee in Penn Township some sulphur springs, rising from the coal measures, yield 5 to 10 gallons per minute.

CITY AND VILLAGE SUPPLIES.

Fairfield.—The city supply of Fairfield (population, 4,970) is drawn from ponds and is not satisfactory. The distribution is both direct and from standpipe, the domestic pressure being 24 pounds and the

[1] Ann. Rept. Iowa Geol. Survey, vol. 12, 1902, p. 414.

fire pressure 140 pounds. There are 15 miles of mains, 55 fire hydrants, and 440 taps. The daily consumption is estimated at 250,000 gallons.

In forecast of artesian possibilities it may be said that the shales of the Kinderhook group should be found about 350 feet from the surface. Any highly mineralized water found in connection with them should be carefully cased out, although it may be potable. The thickness of these heavy shales is variable and can not be forecast with any certainty, but it probably will not exceed 200 feet. The Devonian limestones and shales below the Kinderhook may contain water, and water will in all probability be found in the underlying Silurian limestones and sandstones. Before leaving the Silurian strata the water of the well should be analyzed, as the Silurian may include beds of gypsum which may have added a large lime sulphate content to the water. Should such beds of gypsum or anhydrite be disclosed, it would be well to case out all Silurian waters. The Maquoketa shale should next be reached, lying within 950 feet of the surface.

Water will be found probably in the Galena and Platteville limestones, underlying the Maquoketa, and its quality should also be tested by analysis. The St. Peter sandstone should be reached within 1,260 to 1,350 feet of the surface and should contain a liberal supply of water. If the supply should fall short of the probable needs of the city, the well may be sunk several hundred feet deeper to a depth of at least 2,000 feet in order to obtain more water.

The water in such a well will probably stand about 100 feet below the curb. Its quality will depend largely on the care with which the upper waters of the Mississippian and Silurian formations are cased out, and would probably be improved by going deeper than the St. Peter sandstone.

Minor supplies.—Information concerning the water supplies of other towns and villages is presented in the following tables:

Town and village supplies in Jefferson County.

Town.	Nature of supply.	Depth of wells.		Depth to rock.	Depth to water bed.	Head below curb.	
		From—	To—			Shallow wells.	Deep wells.
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Abingdon	Wells	25	45		45	15	20
County Line	Open, bored, and drilled wells	12	300				
Germanville	Wells and cisterns	25	250	100		10	
Glendale	Bored and drilled wells	20	130			3	
Lockridge	Cisterns, bored wells						
Merrimac	Dug wells	16	18	16		10	
Packwood	Open wells	12	50		25	12	
Perlee	Springs, cisterns, and wells	20	250	50–150		6–20	50
Pleasant Plain	Open and bored wells	28	40		35	20	
Veo	do	15	75			10	
Woolson	Open wells	18	30			10	

WELL DATA.

The following table gives data of typical wells in Jefferson County:

Typical wells in Jefferson County.

Owner.	Location.	Depth.	Depth to rock.	Depth to water bed.	Source of supply.	Remarks (logs given in feet).
T. 72 N., R. 8 W. (LOCK RIDGE).						
		Feet.	*Feet.*	*Feet.*		
G. B. Parsons	1½ miles west of Glendale.	125	....	115	Sand	Yellow clay, 35; blue clay, 60; black "cement" clay, darker and harder than blue clay with few pebbles and no sand, 20; sand, grayish yellow, 10.
—— Kaliff	5 miles north of Glendale.	290	....	....	Limestone	
M. R. Cullins	Salina	79	....	....	Sand	Soil and yellow clay, pebbly, 45; blue clay, 20; dry sand, 5; blue clay, 3; blue sand, 3; shale and coal, 3.
T. 71 N., R. 8 W. (ROUND PRAIRIE).						
Thomas Raines	3½ miles southwest of Glasgow.	317	80	300	Limestone	Drift, 80; rock, 40; shale, 30; limestone, 167. Heads 175 feet below curb.
—— Spratt	SE. ¼ SW. ¼ sec. 8	319	130	317	Sandstone	Drift, 105; drift, gravel, and sand, 25; white limestone with bands of shale, 187; sandstone, 2. Heads 85 feet below curb.
....	SE. ¼ sec. 28	246	100±	....	....	Yellow clay, 40; dark clay, 50; not known, 12; limestone, 98; chert, ⅔; 2 feet of shale in other materials, 15; hard yellow sand rock with balls of hard material, 40.
T. 71 N., R. 9 W. (CEDAR).						
—— Hosette	SE. ¼ SW. ¼ sec. 26	230	105	....	....	About 30 feet above creek. Drift, 105; shale, 3; limestone, 119; sandstone, 3; lime rock.
T. 71 N., R. 10 W. (LIBERTY AND PART OF FAIRFIELD).						
L. Howard	Sec. 1	185	115	....	....	
G. P. Spratt	NW. ¼ sec. 11	265	70	....	....	Upland. Joint clay, 20; blue till, 50; shell rock, bastard limestone and coaly shale, 38; limestone, 152; sandstone, 5.
E. R. Smith	SW. ¼ NW. ¼ sec. 2	306	95	....	Sandstone	Red till, 45; blue till, 50; coal and slate, ⅙; white limestone, 100; brown limestone, 20; sandstone, with a little water, 2; white limestone, 85; sandstone yielding 10 barrels an hour, 4; water soft and a little salt. Heads 67 feet below curb.

Typical wells in Jefferson County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Depth to water bed.	Source of supply.	Remarks (logs given in feet).
T. 71 N., R. 10 W. (LIBERTY AND PART OF FAIRFIELD)—Contd.						
		Feet.	*Feet.*	*Feet.*		
Charles Webb	1 mile east of Libertyville.	368	....	....	....	Water salty.
P. H. Heston	NE. ¼ sec. 9	438	50	420	....	Water also in sandstone, 70; water lowers on pumping to —170. Well 4 inches in diameter; capacity, 10 gallons per minute.
T. 71 N., R. 11 W. (DES MOINES).						
E. McCleary	NW. ¼ sec. 1	230	64	....	....	Sandy loess, 20; till, yellow and blue, 44; limestone, 2; shale?, 32; limestone, 4; gritty shale, 20; yellow arenaceous rock, 108. Water salty.
T. 72 N., R. 11 W. (LOCUST GROVE).						
....	Brookville	241	95	....	....	Yellow till and blue till, 85; sand, water-bearing, 10; limestone with beds of sandstone, 142; sandstone, hard, 4.
W. C. Ball	NW. ¼ NE. ¼ sec. 25.	172	50	172	Sandstone	Loess, 25; blue till, 25; "blue granite" (siliceous rock), 12; brown sandstone, 93; limestone and sandstone, 17. Water soft.
T. Z. Gillett	SW. ¼ sec. 3	218	140	....	....	Loess and yellow till, 60; dark till, 80; black shale with much pyrite, 40; bluish black carbonaceous material, 8; sandstone, shale, and fine clay, 30.
T. W. Gobble	NE. ¼ sec. 5	188	108	....	Gravel	Yellow drift, 30; dark till, 60; gravel, 18; black shale, 80.
L. A. Patterson	NE. ¼ sec. 10	160	120	....	....	Loess, 10; gumbo, 10; yellow till, 40; dark till, 60; sandstone, mostly fine, but somewhat coarser below, 40.
T. W. Hill	Batavia	200	(?)	....	....	Creek bottom; marl at 60; coal at 115; hard sandstone at bottom.
T. 72 N., R. 10 W. (PART OF FAIRFIELD).						
Patrick Kennedy	SW. ¼ SW. ¼ sec. 9	76	....	....	Sand	Valley. Flowing well. Water from sand below blue clay.
F. J. Shearer	NW. ¼ SW. ¼ sec. 14.	165	90	....	....	Loess, 10; joint clay or gumbo, 20; red till, 30; dark till, 30; white shale, 20; some arenaceous material.

Typical wells in Jefferson County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Depth to water bed.	Source of supply.	Remarks (logs given in feet).
T. 72 N., R. 10 W. (PART OF FAIRFIELD)—Con.		*Feet.*	*Feet.*	*Feet.*		
J. W. Wilson	Sec. 17	143	95			Joint clay, 10; red hardpan, 3; blue till, 82; limestone, 48, with crevice in which drill dropped 4 feet. Water contains sulphureted hydrogen; laxative, soft. Heads 60 feet below curb.
J. F. Seahill	Near center sec. 17	145	110			Loess and yellow till, 60; sand and gravel, 10; dark till, 40; sandstone, in bottom. Mineral water.
G. W. Ball	SW. ¼ sec. 19	186	95			
L. Snider	SW. ¼ SE. ¼ sec. 21	146	90			"Soil," 10; red till, 80; white and brown limestone, 50; "slate," black, 2; coal, 4.
S. Sackett	NW. ¼ NW. ¼ sec. 23	200	200		Sand and gravel.	Loess, 10; red till, 30; blue clay, 155; sand and gravel, 5; resting on bedrock.
B. T. Raines	Fairfield	151	151		do	Loam, 5; brown "joint clay," 10; yellow till, 30; dark till, 78; gravel and sand, 28, resting on shell rock.
C. W. Whitam	NE. ¼ SE. ¼ sec. 28	230	120			Drift, 120; black shale, fire clay, and several small coal seams alternating, 45; coal, 6; alternations of shale, sand rock, and fire clay with dark sandstone below, 59.
J. B. Steever	SE. ¼ sec. 28	185	80			Drift, 80; shale and fire clay with thin seams of coal, 50; sandstone, 20; coal, 4; limestone at bottom.
D. W. Manning	SE. ¼ sec. 31	200	100			Drift, 100; dark sandstone, 20; common sandstone, 80.
T. 72 N., R. 9 W. (BUCHANAN).						
M. Fordyce	SE. ¼ SW. ¼ sec. 23	237	97		Sandstone	Loess, 20; yellow till, 25; blue till, 50; sand and a little water, 2; limestone, 88; sandstone, 2; yielding 2 barrels of water per hour; limestone, 46; brown sandstone, 4.
Wayne Green	3 miles west of Salina.	97	97			Joint clay, 6; yellow till, 40; black hardpan, hard and irony, 20; dark till, 24; old soil with wood, 3; sand with water, 4; limestone.
T. H. Clover	SW. ¼ sec. 27	186				Loess and gumbo, 25; yellow till, 20; dark till, 141.
J. P. Manatry	SW. ¼ SW. ¼ sec. 35	240	129			Drift, 129; limestone, 30; bastard rock and sandstone, 51; limestone, 30.

Typical wells in Jefferson County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Depth to water bed.	Source of supply.	Remarks (logs given in feet).
T. 73 N., R. 11 W. (POLK).						
		Feet.	*Feet.*	*Feet.*		
....	1 mile west of Abingdon.	165	165	....	Gravel......	Loess, 20; yellow till, 20; brown soft clay sandy streaks, 117; gravel, 8, on bedrock. Heads 40 feet below curb.
....	Abingdon...........	250	140	....	Sandstone...	Loess, 30; yellow till, 30; dark till, 80; bedrock with pyrites, 10; black shale, 4; coal, 6; fire clay; white limestone to 247; coarse sandstone, 3.
L. K. Wallace......	SW. ¼ SW. ¼ sec. 2...	300	160	....	....	Drift, 160; dark shale, 30; cherty limestone, 110.
Geo. E. Estes......	W. ½ sec. 16.........	186	....	....	....	Limestone with some chert at 104; sandstone from 144 to 186.
T. R. Smith........	SE. ¼ sec. 20........	79	76	....	....	Drift, 76; shale, 3.
A. T. Downey.....	Sec. 33..............	75	70	....	....	Drift, 70; shale and coal in bottom.
T. 73 N., R. 10 W. (BLACKHAWK).						
T. A. Webb........	NW. ¼ sec. 6........	160	130	....	....	Upland. Loess and yellow till, 60; dark till, 70; red shale, 10; some black shale.
....	SW. ¼ sec. 27.......	161	85	....	Sandstone...	Yellow till, 50; dark till with inclusions of sand, 35; shale; sandstone, 4, to bottom.
A. Freshwater.....	SW. ¼ sec. 28.......	....	165	....	Limestone..	Loess, 25; yellow till, 20; dark till, 115; red ocherous clay, 5; sandstone? 12; shell rock, 2; shale, 4; limestone with crevice, 1½ feet deep, 44. Water contains sulphureted hydrogen.
J. L. Knight.......	SW. ¼ sec. 37.......	170	....	....	Gravel......	Loess, 20; soft sandy yellow till, 140; gravel, 10.
T. 73 N., R. 9 W. (PENN).						
J. Pascha..........	Sec. 1...............	130	100	....	....	Loess and yellow till, 60; some sand; dark till, to 100 from curb; limestone with some sandstone, 30.
M. Polus...........	NW. ¼ sec. 24.......	106	....	....	....	Loess and yellow clay, 50; dark till, 53; gravel, 3.
T. 73 N., R. 8 W. (WALNUT).						
C. Shaffer..........	E. ½ sec. 26.........	240	60	....	....	Drift, 60; "rock and shale," 180; "hard rock" (limestone) in bottom.

KEOKUK COUNTY.

By W. H. Norton.

TOPOGRAPHY.

The surface of Keokuk County is an upland plain scored with the channels of numerous converging streams. The sky line as seen from the summits of the divides is everywhere even and horizontal. Extensive remnants of the ancient level surface, which must have been singularly flat and featureless, still exist on the main divides and extend to the rather steep slopes of the valleys of the larger streams. Even in the southern part of the county, where North and South branches of the Skunk flow in parallel and adjacent courses and where the upland is most dissected by their tributary streams, there are remnants of the original plain 3 or 4 miles wide, with a maximum relief of less than 12 feet. In this part of the county the valleys of the major streams have been worn to a depth of 100 to 200 feet below the upland level and have been widened by long lateral erosion and the action of the weather. The valley of the Skunk, for example, has been planed and filled to a flat alluvial floor 2 to 6 miles wide.

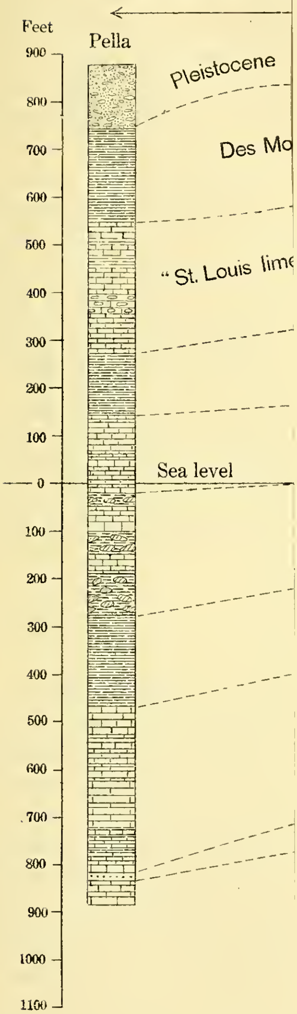
GEOLOGY.

The surface deposit over the entire county, except on the river flood plains, is the yellow or ashen pebbleless silt known as the loess. It mantles valley slopes as well as level uplands and is in few places more than 8 or 10 feet thick.

Below the loess is a yellow clay that is distinguishable from the loess by its brighter tint, by the presence in it of sand and gravel, and by its greater hardness. This yellow stony clay or till is the weathered upper portion of the Kansan drift sheet, the unaltered portion being normally bluish gray in color.

Beneath the Kansan lies another tough stony clay, the Nebraskan. It is hardly to be distinguished from the Kansan in well drilling, unless it should be separated from it by ill-smelling soils, by peat and forest beds, or by the more welcome water-bearing sands and gravels which not infrequently mark this horizon. The Nebraskan till rests either on bedrock or on thin sand and gravels which separate it from the rock.

The rocks of Keokuk County belong to two great series of the Carboniferous system, the Pennsylvanian and the Mississippian. (See Pl. XIV.) The Pennsylvanian is exposed to view or is found by the drill immediately below the drift over large areas in the western townships and in several scattered outliers over the remainder of the county. The rocks of the Pennsylvanian series consist of shale (''soapstone'' or ''slate''), with seams of coal and beds of fire


Feet
Pella
Pleistocene
Des Mo
"St. Louis lime
Sea level
900
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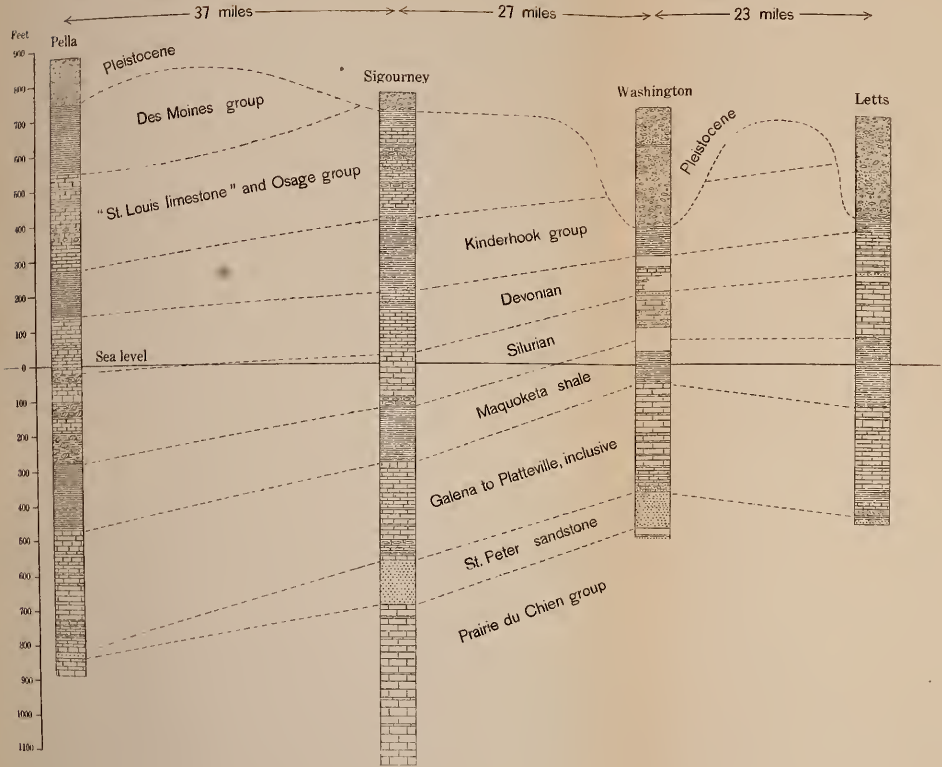

GEOLOGIC SECTION BETWEEN PELLA AND LETTS, IOWA
By W. H. Norton

THE NORRIS PETERS CO., WASHINGTON, D. C.

clay, and lenticular bodies of sandstone. These rocks lie on a deeply eroded surface of Mississippian strata.

The outcrops of the Mississippian series in this county present only its higher subdivisions. The "St. Louis limestone," with its variable beds of limestone (some fine grained and compact, some magnesian, some sandy, some interbedded with sandstone layers, and some made up of angular fragments) and of sandstone which in places may attain a thickness of 40 feet, underlies the greater portion of the area. The total thickness of the "St. Louis" may reach 150 feet.

The Osage group underlies the "St. Louis limestone." Its exposures in the county show a subcrystalline limestone locally made up of crinoidal fragments in many places pure white. It occurs in layers commonly less than a foot thick, separated by bands of chert or of clay. The Osage underlies the drift northeast of a line drawn diagonally across the county from a point 3 miles south of Keota through South English. The thickness of the Osage in the deep well at Sigourney is 168 feet.

The Osage rests upon the heavy shales of the Kinderhook. Everywhere throughout the county these shales lie too deep to be shown by even the deepest valleys. Some of the deeper wells of the county reach them, however, and their total thickness, shown by the Sigourney boring, measures 229 feet.

UNDERGROUND WATER.

SOURCE AND DISTRIBUTION.

On the broad bottom lands of Skunk River "sheet water" is found in river sands and gravels at a depth of 24 to 30 feet. The water derived from this formation by some wells is said to have a slight odor of organic matter.

The chief water supply of the county is obtained from the drift. Ground water beneath the level prairies stands high. Under favorable local topographic conditions the basal silts and sands of the loess yield a supply sufficient for house use, and in certain localities, at least in wet years, sufficient for stock wells. Thus near Richland a well 33 feet deep, dug in 1906, struck water at 12 feet, the quantity increasing to the bottom; this well, which supplies 30 head of cattle, probably obtains water from sands in Kansan drift as well as from the basal loess.

There are several well-marked water-bearing beds in the drift. At Sigourney these are reached at depths of 25 and 55 feet in loose gravelly beds, and at varying depths in gravels immediately overlying the "St. Louis limestone," which here occurs 35 to 70 feet from the surface. The following section of the drift at Sigourney is given by a driller:

Section of drift at Sigourney.

	Thickness.	Depth.
	Feet.	*Feet.*
Joint clay, without pebbles (loess)	16	16
Clay, sandy, loose, yellow, pebbly, caving; containing water toward base	22	38
Clay, blue, with streaks of yellow; hard, with small pebbles, many of them white in color; penetrated to a sufficient distance for reservoir	To rock.	....

At Delta, in Warren Township, the section of the upper portion of the drift is given as follows:

Section of drift at Delta.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil, black	5	5
Clay, yellow, with black streaks	15	20
Clay, yellow, caving, soft; with sand streaks; water bearing in basal portions	15	35

On the upland about South English a different section is given:

Section of drift near South English.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, yellow (loess)	12	12
Soil, ashen, dry (Kansan)	5	17
Clay, blue, tough, with small white pebbles	10	27
Soil, old, ill smelling, and wood	1	28
Sand, clean, coarse, white, with water	....	....

In Steady Run Township, on the flat prairie about Martinsburg, the succession is said to be as follows:

Section of drift near Martinsburg.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil, black	5	5
Clay, yellow, ashen at bottom	20	25
Clay, yellow	12	37
Clay, blue, stony	40	77
Sand, with water.		

Other sections showing drift deposits and water sources, as noted by the drillers, will be found in the list of wells (pp. 554–555). These sections seem to show that the upper weathered zone of the Kansan till is still water logged under favorable topographic conditions, and that it furnishes water at very moderate depths from its sandy beds; they show also, however, that a more dependable source of supply is to be found in the sands beneath a sheet of blue till which in many places is probably the unweathered Kansan, the sands being those which immediately overlie the Nebraskan drift.

The thickness of the drift and the depth to its different water beds varies greatly. In the town of Sigourney the depth to bedrock ranges from 35 to 70 feet; a mile north of town, wells 190 feet deep find water in gravels without reaching rock. In the southeastern sections of Lafayette Township rock is struck within 30 feet of the surface; in the western sections the drift is 130 to 160 feet thick and in the northeastern sections from 100 to 130 feet. On the uplands in the vicinity of South English the average thickness of the drift is about 100 feet; about Webster it is from 90 to 100 feet thick. In the area about Haysville rock is struck in wells 50 and 60 feet deep.

Until the series of dry years in the nineties it was rarely necessary to sink wells into the indurated rocks for water, except in the well-dissected areas where drift is thin and ground water normally stands low.

The Pennsylvanian supplies good water in but few localities, a fact which causes serious difficulty in the mining regions of the western townships, where most of the water obtained is drawn from the drift.

The "St. Louis limestone" usually yields a good supply of water from the soft sandstones that lie between the limestone beds, as, for example, in the wells at Keswick. Where the Osage group forms the country rock, as in Liberty and Lafayette townships, wells which fail of finding water in the drift are drilled a considerable distance in this limestone before finding water. Of the wells reported from these townships, more than one-half exceed 200 feet in depth.

In the southeastern townships, Richland and Jackson, a number of deep wells have been sunk. The deepest of these, 548 feet deep, passed through 150 feet of drift, 8 feet of flinty, pyritiferous rock, and 50 feet of "clay" (shale), which may be either coal measures or "St. Louis limestone"; then 200 feet of solid limestone (the Osage and perhaps the lower part of the "St. Louis"); and finally 140 feet of shale, evidently the Kinderhook. Whenever the thick and dry shale of the Kinderhook is struck, drilling should cease unless the owner is prepared to sink his well to the much-deeper formations reached by the deep well at Sigourney (p. 551). In other counties where like conditions exist the experiment of shooting a well with nitroglycerin at the top of the shale when water has not been found above it is successfully made as a last resort.

SPRINGS.

Only in the western townships are noteworthy springs reported. A number of unfailing springs, the water of which is said to rise from gravel and from sandstones, emerge along Richland Creek north of Richland, the measured discharge of one being 3 gallons per minute. Other springs are reported northeast of Harper in Lafayette Township.

CITY AND VILLAGE SUPPLIES.

Keota.—The water supply of Keota (population, 988) is taken from a well 180 feet deep. The amount used daily is 13,500 gallons. The water is distributed from a tank having a capacity of 68,000 gallons. The fire and domestic pressure is 65 pounds. There are $1\frac{3}{4}$ miles of mains, 21 fire hydrants, and 150 taps.

The well reached rock at 70 feet. To this distance it was excavated to a diameter of 10 feet, to serve as reservoir, the casing of the drilled well occupying the center. The supply, however, is insufficient for the needs of the town, and at times of greatest consumption the well can be pumped dry several times each day.

Sigourney.—The water supply of Sigourney (population, 2,032) is drawn from a well 14 feet in diameter and 20 feet deep, situated $1\frac{1}{2}$ miles from the town on the flood plain of Skunk River and about 150 feet from the river bank. The water is distributed by gravity from a tank holding 50,000 gallons. The domestic pressure is 50 pounds; the fire pressure, 100 pounds. There are 7 miles of mains, 41 fire hydrants, and 100 taps.

Besides supplying water for its own use the town furnishes water to the Chicago, Rock Island & Pacific and the Chicago, Milwaukee & St. Paul railways for use in their engines. The amount of water consumed by these companies and the objectionable qualities of the water of the deep well for use in boilers, may, it is said, have had something to do with the abandonment of the deep well drilled for the city by Hopkins & Gordon in 1882. (See Pl. XIV.)

The depth of the well is 1,888 feet and the diameter, 6 inches to 1,091 feet, and $4\frac{1}{2}$ inches to bottom; casing to 1,091 feet. The curb is 756 feet above sea level, and the head 30 feet below curb. At 1,320 feet, in the St. Peter sandstone, mineral water with strong odor was found; at 1,360 feet, a crevice was encountered in which the drill dropped 2 feet and a current of water carried off the cuttings. The supply of water increased to 1,388 feet, when it flowed over the top of the well while the drill was in and stood within 30 feet of curb when the drill and rods were removed. No water was found below 1,388 feet.

On account of the poor quality of the water the well has never been used. It is also stated that its capacity was insufficient, but if any pumping tests were ever made they have not been reported.

Record of strata in city well of Sigourney (*Pl. XIV, p. 548*).

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene:		
Drift	50	50
Carboniferous (Mississippian):		
"St. Louis limestone" and Osage group (306 feet thick; top, 706 feet above sea level)—		
Shale, blue; a few drift pebbles fallen from above	18	68
Clay, brown, fine, noncalcareous; in flakes; disaggregates in water with about ten times the difficulty of blue till; quartzose and cherty residue; some glacial pebbles	30	98
Limestone, brown-gray, arenaceous	22	120
Limestone, gray, arenaceous, cherty; 2 samples	15	135
Shale, calcareous; much gray flint in flakes	20	155
Limestone, highly siliceous, highly argillaceous; much flint and blue shale; drillings largely chert	10	165
Limestone, bluish gray; drillings mostly chert of the same color	5	170
Limestone, bluish gray, or shale, highly cherty, quartzose, and argillaceous	17	187
Shale, blue, calcareous, highly siliceous	3	190
Limestone, blue-gray, highly cherty	5	195
Limestone, soft, blue-gray	10	205
Limestone, blue-gray; much chert	5	210
Limestone, light bluish; earthy luster, in large flakes, highly siliceous	15	225
Limestone, blue-gray	15	240
Limestone, drab, granular	10	250
Limestone, brown, somewhat cherty	6	256
Chert, blue-gray	14	270
Limestone, brown, somewhat cherty	15	285
Limestone, light gray, soft, angular, crystalline	25	310
Shale, hard, greenish, calcareous, microscopically siliceous; in fragments; 2 samples	20	330
Shale, dark greenish; in large fragments; calciferous; so highly siliceous with microscopic particles of limpid quartz that it might perhaps be called sandstone; 3 samples	12	342
Limestone, light and darker blue-gray; in flaky chips; argillaceous and microscopically arenaceous	14	356
Kinderhook group (198 feet thick; top, 400 feet above sea level)—		
Shale, greenish, soft, slightly calcareous, fine grained; 4 samples	198	554
Devonian (171 feet thick; top, 202 feet above sea level):		
Limestone, green-gray, argillaceous	31	585
Shale, indurated, calcareo-siliceous	21	606
Shale, calcareous, or limestone, argillaceous, highly fossiliferous; drillings largely fragments of Spirifer, Orthis, and perhaps other brachiopods, and of crinoid stems	12	618
Limestone, blue-gray; earthy luster; fossiliferous	12	630
Limestone, brown and buff; earthy luster; fossiliferous	13	643
Limestone, soft, yellow; earthy luster; 4 samples	25	668
Limestone, gray, cherty	5	673
Limestone, white; in powder	52	725
Silurian (146 feet thick; top, 31 feet above sea level):		
Limestone, magnesian, buff; in sand; 2 samples	5	730
Dolomite, gray buff; in chips; subcrystalline, much white chert; 2 samples	56	786
Dolomite, yellow, buff, and gray; mostly cherty; 5 samples	79	865
Limestone, magnesian; mostly white and translucent chert, with interbedded cubes of pyrite, and a large number of minute rounded grains of limpid quartz	6	871
Ordovician:		
Maquoketa shale (159 feet thick; top, 115 feet below sea level)—		
Shale, blue, green, gray, and drab; 7 samples	159	1,030
Galena and Platteville limestones (283 feet thick; top, 274 feet below sea level)—		
Dolomite, brown, hard, argillaceous	25	1,055
Limestone, light, yellow-gray	34	1,089
Dolomite, brown	....	....
Limestone, magnesian, cherty, white, gray, buff, and brown; all effervesce more rapidly than Galena dolomite	149	1,238
Chert	17	1,255
Limestone, light yellow-gray, cherty	5	1,260
Limestone; a little shale	15	1,275
Shale, green, soft, calcareous	6	1,281
Limestone, gray	9	1,290
Limestone, magnesian, brown	25	1,315
St. Peter sandstone (115 feet thick; top, 557 feet below sea level)—		
Sandstone, fine grained; white and light gray in mass; mostly angular fragments with some rounded grains; 7 samples	115	1,430
Prairie du Chien group (458 feet thick; top, 674 feet below sea level)—		
Dolomite; 2 samples	398	1,828
Same (reported)	60	1,888

Minor supplies.—Information concerning the water supplies in the smaller towns and villages is presented in the following table:

Village supplies in Keokuk County.

Town.	Nature of supply.	Depth.	Depth to water bed.	Depth to rock.	Head below curb.	
					Shallow wells.	Deep wells.
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Delta	Dug and drilled wells	22–470	100–300	50	12	50
Gibson	Wells				4–15	
Haysville	Dug, drilled, and bored wells	16–40		55	15	
Hedrick	Wells	15–55	25		12	45
Kinross	Open wells					
Nugent	Dug, bored, and drilled wells	18–180	90–180	20–60	20	40
South English	Open and drilled wells	10–60			20	
Tallyrand	do	20–230		50–75	15	55
Thornburg	Open wells	20–50	35			8
Webster	Bored wells	15–30	10 and 18		5	
What Cheer	Wells and cisterns	18–45	25	90	8	35

WELL DATA.

The following table gives data of typical wells in Keokuk County:

Typical wells in Keokuk County.

Owner.	Location.	Depth.	Diameter.	Depth to rock.	Depth to water bed.	Source of supply.	Head above or below curb.	Remarks (logs given in feet).
T. 77 N., R. 10 W. (LIBERTY).								
		Feet.	*Inches*	*Feet.*	*Feet.*		*Feet.*	
W. Oliver	SE. ¼ sec. 6	253		230				20 feet of sandstone and some gray soapstone below drift.
Daniel Coffman	NW. ¼ sec. 31	290		170				All limestone below drift.
——— Graham	SW. ¼ sec. 31	232		160				
Casper Troutman.	SE. ¼ sec. 32	240		155				
Albert Dill	Southeast of Kinross.	220		130				
T. 77 N., R. 12 W. (ADAMS).								
J. O. McBride	NE. sec. 13	41	2		40	Gravel	+1	Foot of hill.
	SW. ¼ NE. ¼ sec. 32.							Soil and yellow clay, 20; yellow pebbly clay, a little water at bottom, 30; hard, black pyritiferous shale, 16.
T. 76 N., R. 10 W. (LAFAYETTE).								
Ephraim Bouzloz.	NE. ¼ sec. 5	220		155				
John Curtis	NW. ¼ sec. 5	325		160				
Creamery	Harker	92				Sand	−16	Soil and loess; yellow pebbly clay, 12; hard blue clay with wood, 60; sand.
Cook	NE. ¼ sec. 6	208		150				
Simon Herr	NE. ¼ sec. 7	260		160				
David Clyde	NW. ¼ sec. 9	150		120				
E. A. Kennell	SE. ¼ sec. 11	147		97				
Scott Kirkpatrick.	SW. ¼ sec. 12	202		130				
——— Klein	NE. ¼ sec. 13	175		120				
Frank Holmes	SE. ¼ sec. 2	110		109		Sand		Shale 1 foot, at bottom.
Ed. Van Fossen	SE. ¼ sec. 36	70		30				

Typical wells in Keokuk County—Continued.

Owner.	Location.	Depth.	Diameter.	Depth to rock.	Depth to water bed.	Source of supply.	Head above or below curb.	Remarks (logs given in feet).
T. 75 N., R. 11 W. (PARTS OF GERMAN AND LANCASTER).		*Feet.*	*Inches*	*Feet.*	*Feet.*		*Feet.*	
J. F. Doensing	NW. ¼ sec. 6	156						
	NE. ¼ sec. 2	60±				Sand		Yellow clay, 40; blue clay, 20; sand.
Charles Brallier	Sec. 34	224	4½	120	175		−90	Capacity, 1½ gallons per minute.
——— Teuscher	SE. ¼ sec. 14	230		180				
H. Brain	SW. ¼ sec. 26	190		120		Limestone		
T. 76 N., R. 11 W. (PART OF GERMAN).								
	About 1 mile southwest of Harper.	180		134				
	About 1 mile northwest of Harper.	130						Ends in quicksand; abandoned.
	Near township line northeast of Sigourney.	170						
	SE. ¼ NE. ¼ sec. 36.	54				Gravel	−50	Loess, 20; yellow clay, 15; blue clay, 16; fine gravel, 3.
E. W. Mohne	Southwest part.	156		141				Rock outcrops on neighboring creek 65 feet lower than curb.
T. 75 N., R. 10 W. (CLEAR CREEK).								
Rufus Carris		120		60				
John Wright	NE. ¼ sec. 5	180		105				
A. D. Conrad	SE. ¼ sec. 11	170		130			−75	
T. 74 N., R. 10 W. (RICHLAND).								
John W. Lemly	Sec. 18	302	6	70	70		−70	Capacity, 1 gallon per minute.
F. H. Heilman	do	213	6	26			−30	Capacity 30 barrels a day; easily lowered to −100 feet.
Jerry Reddig	Sec. 29	113	48		105	Gravel	−78	Soil, 2; yellow clay, 10; yellow joint clay, 48; blue till, 35; yellow sandy clay, 9; gravel 8; soapstone, 1.
Samuel A. Altman.	Sec. 30	548	5½ to 3½	150	400	Limestone	−92	Water lowers to −200 feet. Drift, 150; flinty rock, pyritiferous, 8; clay, 50; solid rock (limestone), 200; shale, Kinderhook, 140.
T. 74 N., R. 11 W. (JACKSON).								
John Altenhofen	Sec. 1	418	6	85	102		−60	Capacity, 3½ gallons a minute; lowers to −275 feet. Drift, 102; limestone, 58; flint, slate, pyrite, 65; soapstone, 193 with water at 410.
Isaac Brown	Sec. 12	118	6	50			−106	Mostly limestone; some sandstone and a little black rock.
Isaac Shelly	Sec. 13	105	6	48	103	"St. Louis"	−40	Capacity, 12 gallons a minute; can not be lowered. Drift, 48; sandstone, 10; hard, white flint rock, 47.
C. C. Bottyer	2½ miles from Ollie.	125	6	38	125		−40	Can not be lowered.
Pierce Hollingsworth.	Near Ollie	250	4	60			−60	

LEE COUNTY.

By W. H. Norton.

TOPOGRAPHY.

Lee County, occupying the southeast corner of the State, and bounded on the southeast by the Mississippi, on the northeast by the Skunk, and on the southwest by the Des Moines, may be described as an upland overlooking its boundary rivers from a height of 100 feet and more. From Montrose to Keokuk the Mississippi flows through a narrow rock-bound valley. From Montrose north to Fort Madison a wide, crescentic flood plain on the right bank has been opened in the drift on either side of the lower course of Sugar Creek, and north of Fort Madison a still broader alluvial plain has been opened on either side of Skunk River. These two patches of the Mississippi flood plain and a plain of similar character along the Des Moines at Sand Prairie are the only lowlands within the county.

A low ridge, sufficiently prominent to give name to Pleasant Ridge Township, rises above the general level of the upland plain and extends nearly north and south from the Henry County line through West Point to Sugar Creek. East of this broad swell—the terminal moraine of the Illinoian ice sheet—the upland is overlain with Illinoian drift; west of it the upland is formed of the older drift sheet, the Kansan. A broad shallow depression, a temporary drainage channel of Pleistocene times, entering from Henry County on the north, is known as Grand Valley until, trending to the southeast, it is occupied by Sugar Creek. With these exceptions the entire upland may be regarded as a plain once nearly level and now etched with the valleys of a drainage system as yet immature. The divides are in the main tabular and are still so wide as to allow a high ground-water surface.

GEOLOGY.

The lowest drift sheet of Lee County is the Nebraskan, a dark stony clay, in places separated from bedrock by outwash sands and from the overlying Kansan drift by forest beds, old soils or still more commonly by sands and gravels of special importance to the well driller. The Kansan drift sheet is a dense, tough stony clay, weathering to reddish yellow, but bluish in its unweathered deeper portions. East of a line drawn north and south through West Point from the Henry County line to Sugar Creek is a third drift sheet, deposited by a still later ice invasion, the Illinoian. Over the area of the Illinoian drift an old soil (Yarmouth) in many places separates it from the underlying Kansan.

The rocks under the drift in Lee County belong entirely to the Pennsylvanian and Mississippian series of the Carboniferous. (See Pl. XII.)

The rocks of the Pennsylvanian series or coal measures lie on an ancient land surface eroded in the rocks of the underlying Mississippian series. They consist chiefly of drab clay shales, not commonly associated here with coal, and yellow friable sandstones. As outliers of the Iowa coal field they occur in the western part of the county and are found in four tracts, occupying more or less of Pleasant Ridge, Marion, Franklin, Cedar, Harrison, and Van Buren townships.

The Mississippian series of this area includes the "St. Louis limestone" and the Osage and Kinderhook groups. The term "St. Louis limestone" of the Iowa State Survey reports and as employed in this report includes the upper part of the Warsaw limestone, the lower part of the Warsaw being included in the underlying Osage group. The Osage group of the United States Geological Survey, however, excludes the Warsaw limestone.

The "St. Louis limestone" forms the country rock over perhaps one-third of the county, with a thickness of hardly more than 30 feet. It is variable, including magnesian and nonmagnesian limestones, sandy limestones, and blue sandstones. Much of it consists of breccia, a rock that has been broken into angular fragments. The sandstone beds of the "St. Louis" should yield a moderate amount of water.

The "St. Louis limestone" rests on the Osage group, which includes as its basal formation the Burlington limestone, the lower part of which is characterized by its brilliant whiteness, its crystalline texture, and its numerous fragments of crinoid stems and plates. Upon the lower division of the Burlington lie the "Montrose cherts," well exposed along the Mississippi from Montrose to Keokuk, where their resistance to corrasion has given rise to the Lower Rapids of the Mississippi. This chert constitutes the upper division of the Burlington limestone. As flint or chert is considerably harder than steel it might be supposed that these beds of chert would be difficult to drill, but the thin, brittle layers break easily under the heavy stroke of the drill and the chips do not pack. The Osage group also includes the Keokuk limestone, the lower part of which is bluish and cherty, about 25 to 40 feet thick, and the upper part is a shale about 40 feet thick containing many geodes lined with banded chalcedony or crystals of quartz. The lower part of the Warsaw limestone, consisting of alternating sandy limestones and sandy shales, about 30 feet thick at Keokuk, is, for convenience, also included in the Osage group. The Kinderhook group underlies the entire area but is exposed in a few places only.

UNDERGROUND WATER.

SOURCE.

The river-laid sands and gravels of the broad Mississippi bottom lands and those of the narrower flood-plain strips along Skunk and Des Moines rivers yield abundant water of excellent quality to shallow open or driven wells.

The uplands of the county are mantled by the loess, a soft friable silt that is too fine to be called sand and too coarse to be called clay, and that furnishes water to shallow wells that reach its base wherever conditions bring ground water near the surface.

Water is obtained from thin sandy streaks in the Illinoian drift, and especially from sandy layers of the interglacial deposits separating the Illinoian and the Kansan drift sheets. These interglacial beds, known as the Yarmouth, from their occurrence at the village of that name, comprise not only sandy beds in places but also old soils that contain wood and beds of peat or muck. The water from the Yarmouth is therefore likely to be ill smelling and available only for stock.

The depth to the Yarmouth ranges from 20 to 40 feet in the northeastern part of the county. Along the ridge of the terminal moraines of the Illinoian drift sheet the increased thickness of this drift increases this depth to 40 to 70 feet.

The deeper water beds in the drift are sands in Kansan and Nebraskan tills, water-laid interglacial deposits (Aftonian) which separate them, and sand and gravels which overlie the bedrock. None of these horizons are altogether dependable. In Washington and Green Bay townships, for example, little or no water is found from the top of the blue till (unweathered Kansan and Nebraskan to its base, although at Fort Madison it reaches a thickness of 260 feet. The quicksand below it, however, about 100 feet deep at Fort Madison, yields generously. On the thick drift of the Illinoian terminal moraine water is found within 70 feet of the surface. An ancient drift-filled channel of the Mississippi contains 300 feet of Pleistocene deposits, including heavy sands and gravels. At Mount Clara and west and north of Summitville, wells in this old channel encounter 50 to 125 feet of sand containing more or less driftwood and in places overlain with an ancient soil. In one well dry reddish sand above was succeeded by gray sand underlain by water-bearing gravel. In northern Lee County, in the area from Denmark to St. Paul, the drift is comparatively thin. Water is commonly found on or above the rock, but many wells seek deeper sources.

The water from the Pennsylvanian is likely to be highly mineralized and sulphurous. The sandstones yield some water, but as dry clay shales form the bulk of the series and as the lenses of sandstone are exceedingly variable and rapidly thin out laterally, the occurrence of sandstone water-bearing beds at any given point within the area of the coal measures can not be predicted.

Water occurs in the Mississippian limestones in quantity ample for house supply, and is utilized by a large part of the population. The geologic horizon of the strata that yield the strong flows at depths ranging from 700 to 800 feet below the surface remains in some doubt. Local drillers, as at Burlington and at Fort Madison, speak of the water bed as the "St. Peter sandrock," a term as easily applied to a water-bearing dolomite which is cut by the drill into sparkling crystalline sand as to a true sandstone. If the samples of the Young Men's Christian Association well at Keokuk are reliable, this well and all others of like depth find their water far above the St. Peter sandstone. No sandstone of any kind appears in the drillings of the Young Men's Christian Association well, the basal stratum and water bed being a brown dolomite, belonging to the Silurian or to the Ordovician (Galena). According to several logs it is sandy, as the Silurian is known to be at Washington and Centerville. By the log of the Hubinger wells at Keokuk a shale referable to the Maquoketa and separated from the St. Peter by the Galena and Platteville limestones is found beneath it. On the other hand, supporting the reference to the Galena is the facies of the brown dolomite itself. At Mount Pleasant, where alone in southeastern Iowa there is a complete record of samples to below the St. Peter, dolomite is absent from the Silurian, whereas precisely such a brown dolomite constitutes the bulk of the Galena. At Fort Madison a similar brown dolomite, covered by the Maquoketa, forms the water bed. If the water bed is the Galena, the Maquoketa is absent and the shale of the Hubinger wells found below the water bed is difficult to account for.

In other counties of similar geologic structure the "Montrose cherts" (upper part of Burlington limestone) yield considerable water, but the main water bed in the Osage group is the lower part of the Burlington limestone, especially the part near its base, where descending ground water finds its farther downward progress stopped by the impervious shale floor of the Kinderhook. The water occurs in irregularly spaced and quite unpredictable crevices and passages dissolved along bedding planes by percolating underground water. Hence, a well may be drilled even to the Kinderhook and fail to find an adequate supply because it has missed a channel, perhaps by only a few feet or yards. In this event, access to any near-by channels in the limestones may be gained by "shooting" the well with nitroglycerin a short distance above the top of the shale. If this experiment is a failure, it remains to try the chances at some other place. The shale of the Kinderhook group underlies the entire area but for several hundred feet below the top carries no water. The deeper water-bearing strata have been tested at a number of points, as at Fort Madison, Keokuk, Mount Clara, Mooar, and Montrose.

On the whole, the larger supply of the county is still drawn from the drift, and that, too, from its higher horizons, but as these have been found less and less adequate, more and more wells of recent years have been drilled to the water beds of the country rock.

SPRINGS.

Good springs occur in almost every township of the county, those which issue from the Mississippian limestones along the escarpments fronting the larger streams being especially copious. Small springs of highly sulphated waters occur in areas underlain by coal measures rocks. Springs and oozes are also numerous in the drift. The springs on the east bank of Sugar Creek, near its mouth, issue from sands and gravels interbedded between blue and yellow tills. Large springs are reported from near Belfast, Overton, West Point, and Augusta.

CITY AND VILLAGE WATER SUPPLIES.

Denmark.—The following information in regard to Denmark (population, 350) is taken mainly from notes by Frank Leverett:

The R. B. Quinton well, located 1½ miles northwest of Denmark, has a depth of 1,715 feet. The curb is 715 feet above sea level and the head 54 feet below curb. The supply is stated by driller to be "plenty." Drift continues to 80 feet. The first sandstone, at 900 feet, was rather fine and was called by driller the St. Peter. A second sandstone was reached, but no change in head of water was noticed. Date of completion, 1890.

The Isaac Bell well, located in sec. 21, Cedar Township, has a depth of 1,220 feet. The curb is 700 feet above sea level and the head 28 feet below curb. Date of completion, 1890.

Record of strata in Isaac Bell well at Denmark.

	Thickness.	Depth.
	Feet.	*Feet.*
Loess	7	7
Gumbo, gray	4	11
Yellow till	79	90
Cemented crust	2	92
Sand	18	110
Coal, thin bed of shale, limestone, etc	706	816
Sandstone, white, water bearing; water overflowed for nearly a day and then dropped to about 23 feet below surface; a few feet thick at		816
Limestone, mainly		1,200
Sandstone, yellow		
Sandstone, white, to		1,220

Fort Madison.—Fort Madison (population, 8,900) is supplied by a water system owned by the Fort Madison Water Co. Water is drawn from the Mississippi and pumped to a reservoir with a capacity of

6,000,000 gallons. The consumption amounts to 1,500,000 gallons a day. The domestic pressure is 60 pounds and the fire pressure from 120 to 130 pounds. There are 130 fire hydrants and 750 taps.

The geologic horizon of the chief water bed at Fort Madison is doubtful. (See Pl. XII.) The rock is called by drillers of southeastern Iowa the "St. Peter sandrock," but all samples submitted are a sparkling brown dolomite sand. Such cuttings have often been supposed to represent sandstone, even when, as at Fort Madison, quartz sand is entirely absent. The rock yields a bountiful supply of water, and probably on this account was designated the St. Peter by drillers. In this part of the State, however, few wells reach that famous sandstone aquifer.

The water-bearing dolomite has the characteristics of the Galena. It is overlain by a shale which, when compared with the sections of neighboring deep wells, appears to represent the Maquoketa. For these reasons it is assumed to be the Galena. The large yield may be compared with that from the same bed at Davenport.

It is not impossible, however, that the dolomite is Silurian and that the so-called Maquoketa shale is really a basal shale of the Devonian. In support of this theory is the fact that Silurian rocks yield largely at Keokuk and supply the less deep wells at Burlington. The limestones above the so-called Maquoketa are nondolomitic, but at Burlington the Silurian contains little dolomite.

Artesian water at Fort Madison is exceptionally destructive to casings, so that the wells soon lose pressure and cease to flow because of leakage. The latest well drilled, however, registered 30 pounds in 1908, indicating that the local field is still far from depletion. Assuming that the water bed supplying the wells is the Galena, there remain untouched the large stores of water in the St. Peter and underlying formations.

The S. Atlee well is 740 feet deep and 6 to 4½ inches in diameter; 6-inch casing to rock at about 110 feet and 4½-inch to water bed near bottom. The curb is 553 feet above sea level. The original head was 85 feet above curb and the present head is stated to be the same. The temperature of the water is 64° F. Date of completion, 1889. The water is so corrosive that the casing lasts only a few years. Thus, in 1901, the well had ceased to flow, but a pressure of 35 pounds was reestablished by recasing. It was recased again in 1904. The water supplies a fountain at Mr. Atlee's residence, a public fountain in the city park, and a drinking fountain on one of the principal streets.

The S. and J. C. Atlee lumber mill well is on ground about 20 feet lower than the house well of Mr. S. Atlee and is 20 feet shallower. In other respects the wells are apparently similar.

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The Ivanhoe Park well is 670 feet deep and 6 inches in diameter. The curb is approximately 563 feet above sea level and the head more than 12 feet above the curb. The well was completed in 1888 by Tweedy Bros., of Keokuk. In 1896 the well had stopped flowing. It was then recased with 4-inch pipe and the flow was restored. Still later it became clogged, but on treatment discharged considerable black muddy sediment and flowed freely as before. In 1905 it was plugged up.

The Brown Paper Co. well No. 1 is 689 feet deep and 6 inches in diameter; casing, 175 feet. The curb is 528 feet above sea level. The original head was 20 feet above curb and the head in 1895 was the same; head in 1905, at curb. The original flow was 600 gallons a minute, the water coming from about 680 feet. Temperature, 62° F. Date of completion, 1888. Drillers, G. W. Adams & Co. In 1894 a 4-inch casing, inserted as the outer casing, had given way. Some time after 1905 the casing again gave way, the well caved in, and was abandoned.

The Brown Paper Co. well No. 2, located 12 feet from well No. 1, has a depth of 689 feet and a diameter of 8 to 6 inches; cased to bedrock. The head in 1905 was 20 feet above curb. The water comes from depths of 100 and 679 feet. The well was completed in 1903 by Haggerty & Skog, of Keokuk.

The Brown Paper Co. well No. 3 has a depth of 681 feet, and a diameter of 8 inches to 153 feet, 7 inches to 165 feet, and 5 inches to bottom. The curb is 528 feet above sea level. The head is variously reported at 20 and at 80 feet above curb and flow variously reported at 200 and 600 gallons per minute. The water is from a depth of 607 feet; temperature, 65° F. The well was completed in 1907 by Haggerty & Skog, of Keokuk.

To obviate the difficulty experienced in well No. 1 from the rusting of the casing and the caving of the alluvial sands through which the well passes, a method of casing hitherto unused in Iowa was employed. The well was cased with an 8-inch casing to bedrock at 153 feet. A 5-inch pipe was then inserted to the base of the 7-inch hole, 165 feet from the top, and there packed with rubber spring packing. To hold the inner pipe, central stud bolts, extending out so they barely slipped inside the outer casing, were placed on the inner pipe at intervals of 30 feet. Cement, composed of one-half pure Portland and one-half sharp sand, made thin enough to flow through an inch pipe was then poured into the space between the inner and the outer casings, the pipe being gradually withdrawn as the filling progressed. To the depth, then, of 153 feet the well is lined with a shell of Portland cement 1½ inches thick, held between two iron casings.

Drillers' log of Brown Paper Co. well No. 3, Fort Madison.

	Thickness.	Depth.
	Feet.	*Feet.*
Sand	23	23
Clay, blue	39	62
Sand and coarse gravel	81	143
Flint rock, white	20	163
Limestone, gray	40	203
Flint, blue	12	215
Limestone, brown	47	362
Sandrock	6	368
Shale, black	86	454
Reddish rock, very hard	135	589
Flint, blue	10	599
Shale, blue	8	607
Sandrock, water bearing	74	681

The Atchison, Topeka & Santa Fe Railway hospital well had a depth of 764 feet, but was deepened in 1903 to 865 feet. Diameter 6 to 4 inches; 6-inch casing to 184 feet; 200 feet of 4-inch casing. The curb is approximately 553 feet above sea level. The head in 1905 was 6 feet above curb; head in 1908, a few inches above curb. The well was completed in 1892 by Tweedy Bros., of Keokuk. The pressure was originally sufficient to carry the water to the third floor of the hospital. In 1902 there was a sudden loss of head, and the deepening and recasing of the well in 1903 made but slight improvement. The well discharges through a fountain into an artificial lake on the grounds of the hospital.

Drillers' log of railway hospital well at Fort Madison.

	Thickness.	Depth.
	Feet.	*Feet.*
Sand	50	50
Clay, black	62	112
Sand	65	177
Limestone	7	184
Shale	5	189
Limestone	39	228
Shale	266	494
Limestone, white	167	661
Shale	8	669
Limestone	23	692
Sandstone (St. Peter)	64	756

The Atchison, Topeka & Santa Fe Railway shops well is 700 feet deep and 8¼ to 6¼ inches in diameter; 8¼-inch casing to rock at 80 feet; 150 feet of 6¼-inch casing. The curb is 522 feet above sea level and the original head and head in 1908, 69 feet above curb. The flow is 300 gallons per minute, water coming from about 650 feet. The well was completed in 1906 at a cost of $1,500 by Haggerty & Skog. The water flows into a tank over the well, the top of the pipe being 38 feet above the ground; thence it is piped to the various buildings and the yard of the Santa Fe shops.

Record of strata in railway shops well at Fort Madison (Pl. XII, p. 514).

	Thickness.	Depth.
Pleistocene in old channel of Mississippi River (148 feet thick; top, 522 feet above sea level):	*Feet.*	*Feet.*
Clay, brown, sandy	18	18
Sand, gray, coarse, and gravel	6	24
Till, drab, predominantly clayey	42	66
Sand, coarse, yellow	36	102
Sand, as above, and gravel	46	148
Carboniferous (Mississippian):		
Osage group (62 feet thick; top, 374 feet above sea level)—		
Sandstone, blue, argillaceous; minute, angular, quartzose particles	8	156
Limestone, white, soft, nonmagnesian; some chips of blue shale	14	170
Limestone, drab, nonmagnesian; in fine sand	30	200
Limestone, light gray, fossiliferous, with blue, laminated shale	10	210
Kinderhook group (268 feet thick; top, 312 feet above sea level)—		
Shale, blue, calcareous, plastic	268	478
Devonian and Silurian (142 feet thick; top, 44 feet above sea level):		
Limestone, drab, earthy; rapid effervescence	6	484
Limestone, soft, blue gray, nonmagnesian, argillaceous; 3 samples	70	554
Limestone, blue and yellow gray, soft, earthy luster; rapid effervescence; in thin flakes	26	580
Limestone, light brown gray, soft, compact, fine-grained; in minute chips	20	600
Limestone, light yellow gray, compact; fracture subconchoidal; lithographic; effervescence rapid; in flaky chips	20	620
Ordovician:		
Maquoketa shale (18 feet thick; top, 98 feet below sea level)—		
Shale, blue, somewhat calcareous	18	638
Galena dolomite (62 feet penetrated; top, 116 feet below sea level)—		
Dolomite, light buff; in fine sand; 2 samples	62	700

The State penitentiary (439 inmates) is supplied from a well 100 feet deep and 4 inches in diameter. One hundred thousand gallons are used daily for all purposes. The maximum supply which can be drawn is 400,000 gallons in 24 hours. The water does not corrode the boilers, but gives some trouble where hot and cold water come together in pipes.

The well was drilled in 1905 and is cased with 4-inch wrought-iron pipe to the water bed, quicksand at 98 feet. Water rises within 18 feet of the surface, which is 21 feet above the level of Mississippi River. The temperature of the water in August is 54° F. Water is lowered on continuous pumping to 21 feet below the surface.

Keokuk.—Keokuk (population, 14,008) is supplied with water drawn from Mississippi River and filtered, the system being owned by the Keokuk Waterworks Co. The daily consumption is 900,000 gallons. The distribution is direct; the fire pressure is 140 pounds, and the domestic pressure 60 pounds. There are 28 miles of mains, 142 fire hydrants, and 1,700 taps.

The well of the Kertz Brewery is 700 feet deep. Its curb is 600 feet above sea level. Temperature, 65° F. This was the first artesian well drilled in Keokuk and it is still flowing, but has not been used for about 25 years.

The J. C. Hubinger & Co. well No. 1 is 2,230 feet deep and 10 inches in diameter. The curb is 637 feet above sea level. The original head was 30 feet above curb; the present head is unknown. The original discharge was 300 gallons a minute. Temperature, 65° F.

The J. C. Hubinger & Co. wells Nos. 2, 3, and 4 are 2,000 feet deep and 12 to 10 inches in diameter. The curb is 637 feet above sea level. The original head was 30 feet above curb; present head, about at curb. The original discharge of the three wells combined is 1,700 gallons a minute.

These wells are situated on a bluff overlooking Mississippi River and discharge into an artificial lake which covers the top of at least two of the wells. From this lake the water was originally carried in a chute down the face of the bluff about 130 feet and was utilized in running two dynamos for furnishing electric light to the city. In 1894 the discharge of the four wells had fallen from the original amount of 2,000 gallons to 1,500 gallons a minute and in 1894 to 900 gallons. At an unknown date, but earlier than 1905, well No. 1 had ceased to flow and had been closed. The other three wells still supplied the artificial lake in 1905, the surface of the water being practically on a level with the top of the casing of one of the wells. In 1908 it was reported that the water level of the lake was gradually falling. The head of water necessary to supply the lake is somewhat more than 140 feet above high-water level of Mississippi River at Keokuk, so that wells of this depth drilled on low ground would still develop enormous pressure.

Record of strata in Hubinger wells (Pl. XII, p. 514).[a]

	Thickness.	Depth.
Pleistocene (28 feet thick; top, 637 feet above sea level):	*Feet.*	*Feet.*
Bluff (loess)	25	25
Bowlder clay	3	28
Carboniferous (Mississippian):		
"St. Louis limestone" and Osage group (262 feet thick; top, 609 feet above sea level)—		
Limestone	5	33
Sandstone	5	38
Limestone	12	50
Shale	58	108
Limestone	62	170
Shale	10	180
Limestone	110	290
Kinderhook group (270 feet thick; top, 347 feet above sea level)—		
Shale, calcareous	65	355
Limestone	10	365
Shale	195	560
Devonian and Silurian (177 feet thick; top, 77 feet above sea level):		
Limestone	65	625
Sandstone	20	645
Limestone, sandy	55	700
Sandstone	37	737
Ordovician:		
Maquoketa shale (63 feet thick; top, 100 feet below sea level)—		
Shale	63	800
Galena and Platteville limestones (140 feet thick; top, 163 feet below sea level)—		
Limestone; sandy below	140	940
St. Peter sandstone (110 feet thick; top, 303 feet below sea level)—		
Sandstone	110	1,050
Prairie du Chien group and underlying Cambrian ? (755 feet penetrated; top, 413 feet below sea level)—		
Limestone, alternating with sandstone	755	1,805

[a] Gordon, C. H., Am. Geologist, vol. 4, 1889, p. 238; assignment of strata to formations by author.

The Hubinger Tile Works well is 800 feet deep and 6 inches in diameter. The curb is 620 feet above sea level and the original head 47 feet above curb. Temperature, 50° F.

The Rand Park well is 1,800 feet deep and 5 inches in diameter. The curb is 637 feet above sea level. The temperature of the water is 60° F. This well seems to have been drilled earlier than the Hubinger wells and on their completion it nearly ceased to flow. It is now pumped by a Rider-Ericsson engine.

The Keokuk Pickle Co. well is 710 feet deep and 4 inches in diameter; casing to 611 feet, packed with rubber. The original and the present head are 35 feet above curb, and the original discharge was 250 gallons a minute. Water comes from 530 feet, flowing from 635 feet. Temperature, 64° F. Date of completion, 1892.

The Keokuk Poultry Co. well is 700 feet deep and 6 inches in diameter; casing 60 feet, with rubber packing at base; repaired in 1900, replacing casing which had rusted out. The curb is 541 feet above sea level; the original head was 4 feet above curb; the present head is reported to be 40 feet. The original flow was 250 gallons a minute; present flow, 1,000 gallons. Date of completion, 1895. Drillers, Tweedy Bros., Montrose.

Record of strata in Keokuk Poultry Co. well.[a]

	Thickness.	Depth.
	Feet.	*Feet.*
Drift, promiscuous material	5	5
Limestone, magnesian	2	7
Dolomite (magnesian limestone) in which lime carbonate predominates	5	12
Dolomite, cherty	5	17
Dolomite, in which magnesium carbonate predominates	18	35
Limestone, slightly siliceous	15	50
Limestone, rather highly siliceous	18	68
Limestone, light colored; rather pure; slightly siliceous	30	98
Limestone, gray; rather highly siliceous	23	121
Limestone, gray; slightly mixed with shale	14	135
Dolomite; large amount of chert	11	146
Chert, mostly, and fossil limestone	19	165
Limestone and white sand (siliceous limestone)	17	182
Limestone with chert; slightly siliceous	5	187
Shale, almost pure	10	197
Shale, blue; highly siliceous	6	203
Shale, almost pure	5	208
Limestone, gray, quite pure	17	225
Dolomite, in which magnesium carbonate greatly predominates	46	271
Limestone, light colored, almost pure	19	290
Shale, blue, would weather into a tenacious clay	73	363
Shale, bituminous	39	402
Shale, gray; would weather into a tenacious clay	94	496
Limestone, light colored; almost pure; two samples	25	521
Limestone, gray; almost pure	60	581
Limestone, siliceous	47	628
Sandstone, gray, calcareous; yields traces of iron	73	701

The Young Men's Christian Association well has a depth of 769 feet and a diameter at top of 6 inches; casing to 56 feet. The curb is 580 feet above sea level and the head 50 feet above curb. The original discharge was 350 gallons a minute; discharge in 1905, 60 gallons a min-

[a] Record made by Mr. George M. Crofts, Keokuk.

ute. The principal water bed is at 700 feet. Temperature, 64° F. The well was completed in 1902 at a cost of $1,600, by D. W. Haggerty, of Keokuk. The water is used for drinking and to supply a swimming pool.

Driller's log of Young Men's Christian Association well at Keokuk.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay	15	15
Soil, light	15	30
Soapstone, blue	20	50
Limestone, gray	10	60
Limestone, black	16	76
Limestone, white	6	82
Flint; solid bed	8	90
Flint and blue lime	26	116
Lime, white, and flint	46	162
Lime, gray, and flint	38	200
Lime, blue	15	215
Lime, black	5	220
Shale, blue	4	224
Sand, black	8	232
Lime, white	28	260
Sand, gray, and flint	42	302
Shale, blue	12	314
Shale, black	90	404
Shale, white or light brown	125	529
Limestone, black	16	545
Limestone, gray	100	645
Sandrock with water	30	675
St. Peter	94	769

Record of strata in Young Men's Christian Association well at Keokuk.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, somewhat sandy yellow, noncalcareous	15	15
Sand, yellow, clayey	5	20
Shale, light blue, calcareous, some broken pieces of milky quartz in concreted powder	10	30
Shale, blue; in fragments; flint, white, in angular chips; limestone, very soft, white	20	50
Limestone, white, soft, crystalline, in large flaky chips; cuttings of shale	10	60
Limestone, as above; 2 samples; encrinital	16	76
Chert; sand of light-yellow limestone	4	80
Limestone, light yellow; moderately slow effervescence; soft, earthy, in large chips; much blue-gray flint	8	88
Limestone soft, nonmagnesian, white and drab mottled; earthy to crystalline; encrinital; some flint	12	100
Chert, white; some crystalline quartz	16	116
Chert, white; light yellow limestone	6	122
Chert, bluish white; sand of light colored nonmagnesian limestone	10	132
Limestone, white, encrinital, cherty; 3 samples	18	150
Limestone, white, minutely granular, soft; composed of minute loosely cemented calcite crystals; some chert	12	162
Limestone, white, encrinital; much chert	14	176
Chert, blue-white; some white limestone	6	182
Chert, white, and siliceous limestone; 2 samples	23	205
Limestone, soft, white; earthy to crystalline	10	215
Limestone, drab, nonmagnesian, soft; encrinital	5	220
Shale, calcareous, blue, plastic	4	224
Sandstone, blue-drab, earthy, fossiliferous, slightly calcareous; composed of microscopic angular quartzose particles	8	232
Limestone, white, soft, nonmagnesian, earthy; residue siliceous; some darker limestone and shale	36	268
Sandstone, drab, argillaceous, calcareous, soft; in flaky chips, chiefly composed of microscopic angular particles of quartz	34	302
Shale, blue-gray, hard, siliceous, calcareous; in chips	12	314
Shale, brown, somewhat calcareous, bituminous	76	390
Shale, blue-gray, plastic, calcareous	30	420
Limestone and shale; small chips and sand of nonmagnesian limestones, some crystalline and yellow or drab, some dark and argillaceous, many fragments of blue-gray and olive-gray shale in large flaky chips; pyritiferous, fossiliferous; driller's log: "404–529, white or light-brown shale"	112	532
Limestone, light blue-gray, nonmagnesian, compact, fine grained; in thin small cuttings	108	640
Dolomite, brown, hard, crystalline; in coarse sand but containing no quartz grains; "sandrock" of driller's log; 2 samples	60	700

The S. C. Carter Co. well has a depth of 661 feet and a diameter of 6 inches; casing, 12 feet. Rock at 16 feet. The flow is 5 gallons a minute, and the pumping capacity 30 gallons a minute. Water was found at 130 feet, but the main horizon was in basal in sandrock. Temperature, 61° F. The water is unfit for use in boiler. Date of completion, 1903. Driller, D. W. Haggerty, of Keokuk.

Driller's log of S. C. Carter Co. well at Keokuk.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay and soil	16	16
Shell rock	6	22
Limestone, blue	20	42
Limestone, brown	10	52
Limestone, white	8	60
Lime, blue, and flint	26	86
Lime, white, and flint	46	132
Lime, gray, and flint	38	170
Lime, blue	20	190
Sandrock, dark, yielding 5 gallons of water a minute	5	195
Shale, blue	4	199
Sandrock, dark	8	207
Lime, white	42	249
Shale, blue and black	117	366
Shale, white	135	501
Lime, black	35	536
Lime, gray or light	112	648
Sandrock	13	661

The log of the Popel-Miller Brewing Co. well, 3 miles south of Keokuk, is given to assist in the elucidation of the difficult geologic section in southeastern Iowa. The information was secured by J. A. Udden. The curb is about 523 feet above sea level.

Log of Popel-Miller Co. well, Warsaw, Ill.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and clay drift	40	40
Limestone, blue, and shale	15	55
Lime rock, blue	50	105
Lime and grit	25	130
Grit and fire clay	10	140
Limestone, gray	45	185
Soapstone, blue	30	215
Sandstone	19	234
Lithograph rock, light	46	280
Lithograph rock, dark	10	290
Limestone, bastard	6	296
Soapstone	69	365
Shale, brown	40	405
Shale	99	504
Limestone	126	630
Sandstone	182	812

Montrose.—At Montrose (population, 708) water is obtained from driven wells ranging in depth from 20 to 50 feet. At Bluff Park is a well 1,960 feet deep. The curb of the well is 680 feet above sea level and the water originally rose 9 feet above the curb; in 1896, the water stood 10 feet below the curb. The original discharge was 200 gallons a minute, the water coming from a depth of 800 feet.

Mooar.—At Mooar (population, 250) the E. I. du Pont de Nemours Powder Co. well is 800 feet deep and 6 inches in diameter; casing to

600 feet. Water from 110 feet, heads 3 feet below curb; from 240 feet, 5 feet below curb; and from 800 feet, overflows. The discharge, original and present, is 165 gallons a minute. Temperature, 67° F. Date of completion, 1901. The well is about 5 miles northwest of Keokuk and no doubt draws its copious supply from the same bed that yields so generously to the Keokuk wells of the same depth. It is said to deliver a good stream of water, which is used for watering stock on the farms through which it passes for 4 miles to Des Moines River.

Mount Clara.—The W. J. R. Beck well at Mount Clara is 939 feet deep and 6 inches in diameter. The curb is 679 feet above sea level. The original head was above curb; the present head is 12 feet below curb. Original discharge was 200 gallons a minute, capacity being limited to that of the pumps. The main water bed extends from 889 to 939 feet, the water being sufficient for farm purposes by pumping; other beds are from 250 to 343 feet, 660 to 793 feet, and at deeper levels. The well was completed in 1890.

Record of strata in well at Mount Clara (Pl. XII, p. 514).

[Based on drillers' log.]

	Thickness.	Depth.
Pleistocene (305 feet thick; top, 679 feet above sea level):	*Feet.*	*Feet.*
Clay	250	250
Sand	55	305
Carboniferous (Mississippian):		
Osage group (38 feet thick; top, 374 feet above sea level)—		
Limestone, white	25	330
Shale, white	8	338
Limestone	5	343
Kinderhook group (325 feet thick; top, 336 feet above sea level)	325	668
Devonian, Silurian, Ordovician (?):		
Limestone	115	783
Do	10	793
Limestone, flinty	25	818
Limestone	40	858
Limestone, hard	5	863
Samples washed away	76	939

Minor supplies.—Information concerning water supplies in the smaller towns and villages in Lee County is presented in the following table:

Village supplies in Lee County.

Town.	Nature of supply.	Depth of wells.		Depth to rock.	Depth to water-bearing stratum.	Head below curb.	
		From—	To—			Shallow wells.	Deep wells.
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Belfast	Dug and drilled wells	16	275	30		6	45
Charleston	Wells and cisterns	20	200			15	
Cottonwood	Wells	25	225				
Croton	Wells and springs	14	20	12	20		
La Crew	Bored or drilled wells	15	500	95		6–20	30–90
Overton	Open wells	18	300	20	30	16	20
Primrose	Open and bored wells	20	50		18	13	20
Sawyer	Bored and drilled wells	14	200	100	50	4–20	50
Summitville	Open wells	20	60			6	20
Warren	Wells	18	400	70–100		12	60
West Point	Bored and drilled wells	20	350	90		12	20

WELL DATA.

The following table gives data of typical wells in Lee County:

Typical wells in Lee County.

Owner.	Location.	Depth.	Depth to rock.	Depth to water bed.	Source of supply.	Head below curb.	Remarks (logs in feet).
T. 65 N., R. 5 W. (JACKSON).		*Feet.*	*Feet.*	*Feet.*		*Feet.*	
—— Hollingsworth.	Sandusky	160	36				
—— Merritt	West Keokuk	54	53		Sandstone	14	Bluff, about 150 feet above Des Moines River.
Keokuk Cooperage Co.	Soap Creek, Keokuk.	420	10	250	Crevices in limestone.		Diameter, 5⅝ inches; soil, 10; limestone, 180; white hard rock (cuts drill, could drill but 3 feet in 10 hours), 34; limestone; sandstone, shale (Kinderhook), from 380 to 420.
Pechstein & Nagel	Keokuk	215		200	Sandstone		
L. Nelson	do	114		95	do		
Baker Medicine Co.	do	300	20	260		60	Capacity, 8 gallons per hour(?); diameter, 6 inches; soil, 20; brown limestone; white limestone and shale; white limestone (at bottom), 20.
H. H. Trimble	1 mile northwest of city limits, Keokuk.	118	100				
James Jones	3 miles northwest of Keokuk.	140		45	Gravel	45	Blue clay; sand; coarse gravel.
H. H. Trimble	3 miles north of Keokuk.	272	90	50		50	Clay; sand; limestone; flint; sandstone.
Joseph Bloundies	5 miles northwest of Keokuk.	200			Gravel and sand.	80	Clay; sand and gravel.
L. E. McCrary	NE. ¼ sec. 15	110					
—— Applebaum	NW. ¼ sec. 10	225					
	SE. ¼ NE. ¼ sec. 33.	116	16				Des Moines River bottoms.
	SE. ¼ SE. ¼ sec. 27	265	98				
Henry Rein	SW. ¼ NE. ¼ sec. 23.	265	165				
	SE. ¼ NE. ¼ sec. 16.	136			Sand		Sand from 100 to 136.
Henry Reters	NW. ¼ SE. ¼ sec. 28.	250	100				
—— Hinman	NW. ¼ SW. ¼ sec. 27.	254	115				
	NE. ¼ SE. ¼ sec. 19.	154			Sand		
	SW. ¼ NW. ¼ sec. 20.	130			do		
	SW. ¼ NW. ¼ sec. 27.	244	126				Hill.
	NE. ¼ NE. ¼ sec. 29.	175			Sand		Valley.
County farm	½ mile southeast of Summitville.	300			Sand and gravel.	100	Diameter, 6 inches; capacity, 20 gallons per minute; yellow clay; blue clay; sand and gravel.
Do	do	212			Gravel		Yellow and blue clay to 125; dry, reddish sand, 125-212; gray sand; gravel; water soft.
T. 65 N., R. 6 W. (PARTS OF JACKSON AND DES MOINES).							
	NE. ¼ SE. ¼ sec. 14	120					

Typical wells in Lee County—Continued.

Owner.	Location.	Depth.	Depth to rock.	th to water bed.	Source of supply.	Head below curb.	Remarks (logs in feet).
T. 66 N., R. 6 W. (DES MOINES).							
		Feet.	*Feet.*	*Feet.*		*Feet.*	
A. J. Walters	NE. ¼ NE. ¼ sec. 12.	208					
——— Lowry	SE. ¼ NW. ¼ sec. 22.	190					Sand and clay, 20; alternate strips of sand and blue till, 40; sand at 140; ended in sand.
T. 66 N., R. 5 W. (MONTROSE).							
Tweedy Brothers.	Sec. 22	235	50	215	Limestone		Water comes in gradually in 20 feet of limestone at bottom of well.
William Fowler	NW. ¼ SE. ¼ sec. 6.	112			Sand		Foot of bluff.
	NW. ¼ SE. ¼ sec. 17.	145			do		Upland.
	NE. ¼ SW. ¼ sec. 20.	265	200				Creek bottom.
	NW. ¼ SW. ¼ sec. 15.	240	120				About 50 feet above Mississippi River.
Thomas Joyce	12 miles north of Keokuk.	272			Sand and gravel.	172	Blue clay; sand and gravel.
T. 67 N., R. 4 W. (MADISON).							
High School	Fort Madison	134		132	Sand and gravel.		Loam and sand, 24; blue till, 108; sand and gravel, 2.
Canning factory	do	181	95	77			Diameter, 4 inches; sand, 20; blue clay, 57; quicksand with water, 4; blue clay, 14; rock to bottom.
State Penitentiary.	do						Till, 10; sand, gravel, and blue till, 65; sand and gravel, 25.
——— Hoffmaster.	Near penitentiary, Fort Madison.	152	141				Soil and sand, 12; blue till, 123; gravel and sand, 6; limestone at bottom, 11.
Mrs. Heitz	Fort Madison	315			Gravel		Yellow drift, 27; blue till, continuous with the exception of one thin sand bed, 260 feet; gravel, 28; on bluff.
T. 68 N., R. 4 W. (WASHINGTON).							
John Cook	2 miles south of Denmark.	418	100				Drift, 100; limestone, 155; alternate limestone and shale, 10; shale (Kinderhook), 153.
T. 69 N., R. 4 W. (DENMARK).							
James Conaro	Denmark	49					Loess, 9; brown till, 10; old soil, 5; yellow till, 25.
William Sloat	do	56			Sand		Loess, 6; yellow till (Illinoian), 20; gray mucky clay, 15; yellow till (Kansan), soft; dark blue till with beds of sand, bearing water, 5.
Mill	do	55	55		Gravel		Loam, 2; yellow clay, 38; dark-blue hard till, 14; gravel, 1, to limestone.
S. Van Tuyl	Sec. 30	59	55				Loess, 7; Illinoian till, 28; mucky soil with wood, 2; yellow and blue till (Kansan), 18; limestone, 4.
Dr. Randall	South Augusta	438	80	90		60	Drift, 80; limestone and flint, 85; shale (Kinderhook), 273.

Typical wells in Lee County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Depth to water bed.	Source of supply.	Head below curb.	Remarks (logs in feet).
T. 69 N., R. 4 W. (DENMARK)—Continued.		*Feet.*	*Feet.*	*Feet.*		*Feet.*	
Ed. Marsh	3 miles east, 1 mile south of Denmark.	230	94	124	Sandstone		Drift, 94; limestone, 30; sandstone, 9; limestone, 84; shale, 13; well a failure.
G. Adimeier	3 miles north of Denmark.	82	14		Limestone		Skunk River bottom near high-water level; dry sand and gravel, 14; limestone, 68.
D. Klophenstein	3 miles northwest of Denmark.	265	60		do		Drift, 60; limestone, 205.
T. 68 N., R. 5 W. (WEST POINT).							
Axhandle factory	West Point	375	115	200 and 300	Limestone	65	Yellow clay, 40; blue till, 40; sand and gravel, 20; hard, dark-blue till, 15; limestone, 260.
T. 69 N., R. 6 W. (MARION).							
	St. Paul	165	94		Limestone		Yellow clay, 65; dark-blue till, 29; limestone and flint, 71.
John Cook	1 mile east of St. Paul.	85	35		do		Yellow clay, 33½; "hardpan" from cement, 1½; limestone, 50.
Henry Schindstalk.	2 miles east, ¾ mile north of Houghton.	105			Sand		Yellow clay, 45; light-blue clay, 45; sand, 1½; dark-blue till, 13½.
Garrett Sanders	½ mile east of Houghton.	95			Sand		Yellow clay, 94; sand bed with abundant water, 1.
T. 69 N., R. 5 W. (PLEASANT RIDGE).							
S. Kennedy	3 miles west, 1 mile north of Denmark.	40			Old soil		Yellow clay, 37; old soil, wood and leaves, 1½; blue hard till, 1½; water in old soil, ill-smelling, used only for stock.
Andrew Foggy	Sec. 16	131	119				Loess, 6; old soil, 4, yellow till, 20; sand affording weak vein of water, 6; blue till; 33; sand and peat underlain by fine gravelly sand, 50; limestone, 12.
T. 69 N., R. 7 W. (CEDAR).							
	Cottonwood	52½			do		Yellow clay, 40; light-blue clay, 12; sand on dark-blue clay, 1½.
Geo. Woolman	5 miles southwest of Cottonwood.	72			do		Yellow clay, 36; light-blue clay, 35½; sand on hard dark-blue clay, ½.
Thaddeus Church.	3 miles south of Laurel.	102	100	90		60	Yield, 2 gallons per minute; rock, limestone; diameter 5 inches.

Typical wells in Lee County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Depth to water bed.	Source of supply.	Head below curb.	Remarks (logs in feet).
T. 68 N., R. 6 W. (FRANKLIN).							
		Feet.	*Feet.*	*Feet.*		*Feet.*	
Chas. Blocksuth..	3 miles west of West Point.	100	32	70	Limestone ..	60	Yield, 2 gallons; water lowered 20 feet when pumped at that rate; yellow clay, 32; limestone, 68.
....	2 miles east of Locheen.	110	50	80	.....do......	30	Yield, 10 gallons per minute; yellow clay, 50; shale on fire clay, 20; limestone, 38.
Henry Tempsay..	1½ miles north of Franklin.	120	40	98	....	60	Yield, 2 gallons per minute; water lowered 12 feet when pumped at that rate; yellow clay and sand, 40; limestone, 80.

LOUISA COUNTY.

By W. H. NORTON.

TOPOGRAPHY.

Louisa County includes on the east a continuous belt of lowland, the Mississippi flood plain, from 1 mile to 5 miles wide. A second lowland, traversed by Iowa River and for a short distance by the Cedar, crosses the county diagonally from its northwest to its southeast corner where it joins the Mississippi bottoms. The second lowland is more than 6 miles wide at Wapello and more than 4 miles wide at Columbus Junction; it comprises the present flood plains of the rivers and also a broad alluvial lowland, which stands 20 to 40 feet above the river flood plains and is built of sand and gravel covered with a thin mantle of loess.

The flood plain of the Iowa has been cut in the once continuous upland of the county and divides it into two areas, the eastern upland and the western. The surface of the former consists entirely of loess-capped Illinoian drift; that of the latter consists of both Illinoian and Kansan drift, each veneered with loess. The two drift sheets of the western upland are divided in part by a marked topographic feature—a flat-floored valley 1 to 3 miles wide and 40 feet deep, cut in Kansan drift from Columbus Junction to the southwest corner of the county, and standing at an average height of 120 feet above the higher terraces of the flood plain of Iowa River.

The gently undulating surface of the eastern upland is diversified by the shallow troughs of the minor streams and by a few long, low swells whose major axes run northwest and southeast. A singularly straight and unbroken escarpment, as much as 150 feet high, overlooks the Mississippi flood plain.

The western upland, about equal in height to the eastern, is ridged by two parallel broad swells which run north and south near Cairo and are believed to be the terminal moraines of the Illinoian ice sheet.

GEOLOGY.

The Pleistocene deposits of the county comprise the loess—a yellow silt which covers the uplands and the higher parts of the river plains—and beneath the loess three massive sheets of stony clay. The Kansan, a thick, tough blue stony clay, weathered deeply to yellow and reddish, rests on a bed of sand and gravel 2 to 10 feet thick, known as the Aftonian, which separates it from the dense dark-bluish stony clay of the underlying Nebraskan drift. The uppermost stony clay—the Illinoian drift sheet—appears on the eastern upland, where it is separated from the underlying Kansan drift by sands and old soil beds of the Yarmouth interglacial stage. The upper surface of the Illinoian drift sheet may be either weathered to a reddish yellow or, where overlain by the decaying vegetable matter of ancient soils, may be bleached to a whitish clay. Unlike the drift sheets on which it rests, the loess is soft and very easily drilled, and is quite devoid of pebbles and larger stones. In passing from the loess to the weathered stony clays the color distinctly changes to a brighter yellow.

The Pleistocene deposits are underlain by rocks belonging to the Mississippian series of the Carboniferous, except over an area covering about 15 square miles in the northeastern corner of the county, where Devonian rocks may be expected beneath the superficial deposits. (See Pl. XIV, p. 548.)

The highest beds outcropping consist of a succession of limestones and cherts and alternating beds of shale and limestone—the Osage group—the thickness of the whole reaching 50 feet. The limestones belong chiefly to the Burlington limestone and form persistent beds recognized by the driller by their clean white color. The lowest beds outcropping belong to the Kinderhook group and comprise (1) limestones 15 feet thick which form a natural highway for ground water, (2) a less pervious, soft, bluish, fine-grained sandstone 16 feet thick, and (3) a blue-green basal shale or soapstone, practically impervious, the total thickness being as much as 180 feet.

In the southwestern part of the county wells have encountered sandstones belonging to small outliers of the Pennsylvanian series.

UNDERGROUND WATER.

SOURCE AND DISTRIBUTION.

On the lowlands bordering Mississippi River water is obtained from driven wells ending in heavy alluvial sands and gravels. Sand points sunk 15 to 20 feet find abundant soft water in what is called the first sand, and if bored or jetted to about 50 feet, enter a second sand. So abundant is the water drawn from these sands that at Wapello 5-inch driven wells about 20 feet deep are used as fire hydrants.

Wells on the uplands draw water from several beds. The eastern upland, south of Letts, is traversed by a number of low east-west loess ridges with sandy nuclei that furnish water to wells of very moderate depth which supply near-by farmsteads. Locally, on ill-drained areas on both uplands shallow wells find water in the basal layers of the loess, but as a rule these beds are wholly unreliable and inadequate. Interglacial gravels underlying the Illinoian drift, the Kansan drift, and the Nebraskan drift constitute the main aquifers of both uplands, the most important being the Aftonian, which underlies the Kansan drift. On the eastern upland these interglacial gravels are the only source of water supply for deep wells. Here rock lies far below the surface and no wells are known to have reached it. A wide, buried valley underlies the eastern upland and both lowlands, the rock bed of which does not rise higher in places than about 400 feet above sea level. The deepest drift wells on this upland exceed 200 feet in depth and show a succession of as many as three tills or stony clays parted by old soil beds and water-bearing sands and gravels. At only one point on the eastern upland, at its southern end, near Toolsborough, has rock been reported, and this one was at a depth of about 212 feet below the surface or 443 feet above sea level.

On the western upland the same drift aquifers occur, but by no means continuously. In the southern tier of townships and in Marshall and Elm Grove and parts of Columbus townships the drift is relatively thin, rock outcropping in many ravines and being reached by the drill on the divides at 40 to 120 feet. Some wells which show much deeper drift are supposed to indicate ancient buried valleys, though none of these have been definitely traced. It is suggested by Leverett that the lower course of preglacial Washington River may probably cross the western tier of townships north of Columbus Junction. On the bluffs about Columbus Junction wells range in depth from 80 to 140 feet and find water in glacial gravels without reaching rock. Two or three miles west of town the drift is about 140 feet thick, and in the extreme northwest section of Columbus Township wells from 135 to 150 feet deep end in water-bearing sands.

In the southern townships many wells find water in the limestones overlying the impervious floor of the shales of the Kinderhook group. The limestones of the Osage group are exceptionally pure and readily dissolved by seeping waters. Sinkholes on different outcrops, as north of Morning Sun, indicate well-defined underground waterways along joints and bedding planes. The perfection of the underground drainage and its confinement to definite channels renders the finding of such a channel by the drill somewhat uncertain. Several wells not finding water above the Kinderhook have gone deep into the dry shale of that group, reaching total depths of 300 and 400 feet. Where a well enters the shale without finding water it would probably be less expensive in the end and give better results to abandon the drill hole and sink another well at a convenient location near that of the first well.

Where the limestones are lacking owing to erosion, and the shales form the bedrock, the case is far more difficult, and a careful search is necessary for the best location for a drift well. This may in some places be found where the converging of ravines brings an unusual amount of seepage.

The succession of strata and the probability of obtaining water from the deeper formations is indicated by the record of a prospect hole for gas on the land of W. W. Wagner, one-half mile west of Letts. (See Pl. XIV.) The depth of this hole was 1,135 feet, and the elevation of its curb 698 feet above sea level. Water was noted at depths of 818 and 850 feet, heading 65 feet below curb; at a depth of 1,025 feet the water raised the tools in the well, heading 42 feet below curb. The well was completed in 1903.

Record of strata in deep boring at Letts (Pl. XIV, p. 548).

	Depth in feet.
Quaternary (285 feet thick; top, 698 feet above sea level):	
Old soil, brown, clayey; empyreumatic odor	90
Sand, white, coarse; grains mostly quartz; a few of limestone and green rock	100
Sand and gravel	140
Sand and clay, drab; in powder and compact lumps	175
Sand, buff; most grains less than 1 millimeter in diameter	206
Sand, orange, moderately coarse; gravel pebbles of chert, greenish quartzite, brownish quartzite, and shale	247
Gravel; pebbles large, of brownish limestone, greenish quartzite, and a black siliceous rock	250
Sand and coarse gravel	280
Carboniferous (Mississippian):	
Kinderhook group (41 feet thick; top, 413 feet above sea level):	
Shale, brown, rather hard, laminated, slightly calcareous, somewhat bituminous; in flaky chips	285–290
Shale, blue, calcareous	306

	Depth in feet.
Carboniferous (Mississippian)—Continued	
Kinderhook group (41 feet thick; top, 413 feet above sea level)—Continued.	
Shale, as above; drillings mostly of coarse yellow sand; small pebbles of Archean rocks	308–310
Sand, quartz, bright buff; finer than above	312
Shale, blue, calcareous, siliceous	315
Sand, coarse, buff; with chips of compact, hard, dark reddish-brown limestone of slow effervescence, apparently pre-Cambrian	318
Shale, green, calcareous, rather hard; in chips	319
Same as at 318 feet	320–325
Devonian (137 feet thick; top, 372 feet above sea level):	
Limestone, blue-gray, porous; effervescence moderate; nests of calcite	326–332
Limestone, mottled gray, crystalline earthy, rather soft; brisk effervescence; much sand	342
Limestone, gray, fossiliferous; rapid effervescence; soft crystalline to earthy	357
Limestone, buff, highly fossiliferous; brisk effervescence	359–362
Limestone, light gray, highly fossiliferous, soft	373
Limestone, white and blue-gray; soft; crystalline to earthy	378
Limestone, blue-gray, hard; in flaky chips; nonmagnesian, dense, earthy luster; fine-grained; slightly siliceous	383
Limestone, light gray, fossiliferous; fragments of Brachiopods, Bryozoa, and a few crinoid stems	388
Limestone, light drab, nonmagnesian, hard, crystalline	425
Limestone, blue-gray, hard, argillaceous, pyritiferous	435–440
Sandstone, light yellow-gray; calciferous; grains fine, of crystalline quartz	446
Limestone, yellow-gray, cherty	443
Silurian (157 feet thick; top, 235 feet above sea level):	
Limestone, buff, magnesian; in fine sand	463
Limestone, magnesian or dolomite; brown, crystalline; in sand	468
Limestone; as above, very hard, siliceous	480
Dolomite, white, and light blue-gray; crystalline, vesicular; four samples	500–578
Ordovician:	
Maquoketa shale (198 feet thick; top, 78 feet above sea level):	
Shale, drab; in rounded cuttings, with fine yellow quartz sand (from above)	620
Shale, olive-gray; in hard, siliceous, calcareous cuttings	657
Shale, olive-gray, hard, calcareous, siliceous; at 790 feet brown, green, and highly siliceous	720–810
Galena dolomite to Platteville limestone (317 feet thick; top, 120 feet below sea level):	
Dolomite, buff, crystalline; in fine sand; four samples	818–855
Dolomite, light buff, cherty; rounded grains, moderately fine, of clear quartz, apparently native	875

Ordovician—Continued.

Galena dolomite to Platteville limestone (317 feet thick; top, 120 feet below sea level)—Continued.

	Depth in feet.
Limestone, light buff, cherty	918–935
Limestone, magnesian, dark buff	950
Limestone, dark and light yellow-gray; rapid effervescence	960
Limestone, gray, earthy, and brown, crystalline; rapid effervescence; cherty	1,000
Limestone, light brown; rapid effervescence; crystalline	1,025
Shale, brown, highly bituminous	1,048
Shale, green, and limestone, gray, fossiliferous	1,063
Limestone, gray; nonmagnesian; hard; in sand	1,088
Limestone, buff, hard, with rounded grains of crystalline quartz in drillings	1,095
Sandstone; clear quartz, fine grains, many well rounded; but an unusual number ill-rounded or chipped; some gray limestone	1,105
Shale, green, hard, fissile, noncalcareous	1,125
St. Peter sandstone (top, 437 feet below sea level):	
Sandstone; grains well rounded, largest 0.75 millimeter in diameter; drillings red from superficial staining grains with ferric oxide	1,135

Analyses of rock from boring near Letts.[a]

	At 833 feet.	At 545 feet.
$CaCO_3$	51.93	52.42
$MgCO_3$	42.02	41.85
$CaSO_4$		.21
SiO_2	3.24	2.68
FeO	1.20	
Fe_2O_3		.37
Al_2O_3	.69	2.34
H_2O	1.42	.16
	100.50	100.03

[a] Made in chemical laboratory of Cornell College, Mount Vernon, Iowa.

SPRINGS.

As the chief water-bearing formations are cut by the major stream ways, springs are by no means uncommon in the county. The alluvial gravels underlying the abandoned flood plains of Cedar and Iowa rivers discharge large amounts of ground water into the rivers and their tributary creeks by means of springs and seepages. Strong springs emerge from glacial gravels along the bluffs bordering the river valleys. In the southern tier of townships the creeks are fed by springs discharging from the country rock, the leading horizon here being the top of the shale of the Kinderhook group.

CITY AND VILLAGE SUPPLIES.

Columbus Junction.—At Columbus Junction (population, 1,185) water for the city supply is obtained from a well 16 feet in diameter and 20 feet deep, sunk in the sand and gravel of the flood plain of Iowa River a short distance below its junction with the Cedar. Although distant about one-fourth mile from the channel, the water of floods overflows the area of the well. The supply is large and a distinct inflow is noticed from the up-valley side. The pumping does not affect two wells about 200 feet away. When the well was dug water could not be pumped out through a 6-inch pipe as fast as it came in. The water is found in a bed of clean gravel and is pumped to a tank with a capacity of 57,000 gallons. The gravity pressure is 95 pounds and the fire pressure 140 pounds. There are 2 miles of mains, 15 fire hydrants, and 120 taps. The consumption is 18,000,000 gallons a year, the Chicago, Rock Island & Pacific Railway being a large consumer. The waterworks are owned by the town.

Wapello.—Water for domestic supply of Wapello (population, 1,326) is obtained from city wells from points driven 20 feet in the sands and gravels of the flood plain on which the town is built. So large is the supply that driven wells placed at intervals along the streets afford fire protection, being pumped by steam as from so many hydrants. Five drive points are attached by a 5-inch pipe along the top.

The depth of the principal water-bearing formations below Wapello (588 feet above sea level) can not be closely predicted because of the deformation of the strata. The southward dip of the strata is uninterrupted to the north county line, but south of this line the dip is reversed and the deeper strata are so upwarped that at Burlington they stand higher than at any point south of Cedar County. The limit of the southward dip, the position of the bottom of the trough, at which the ascent toward Burlington begins, has not been determined. The dip of the St. Peter sandstone from West Liberty to Letts is 11 feet a mile. If the dip continues at this rate as far south as Wapello the St. Peter should lie about 615 feet below sea level, or 1,203 feet below the surface; but it is possible that the dip is reversed north of Wapello and that the St. Peter may be found 100 to 200 feet nearer to the surface. The depth of the old drift and alluvium-filled valley in which the channel of Iowa River lies is unknown. Possibly it may cut deep into the shales of the Kinderhook group, whose base here should be about 200 feet above sea level provided the southward dip continues this far south of Muscatine County. Between the base of the Kinderhook and the top of the next heavy shale, the Maquoketa, there are about 300 feet of Devonian and Silurian limestones in whose crevices water may be found should the drill fortunately strike them. Beneath the Maquoketa shale, the base of which lies here about 298 feet below sea level, are limestones with some shales (Galena to Platteville), which will probably yield some water. The yield will be increased by water from the St. Peter sandstone, which in this area seems to be exceptionally thick and may afford a supply adequate for the town. If it should not it may be necessary to sink the well to formations lying 500 to 600 feet below the summit of the St. Peter, or to a total depth of 1,800 or 2,000 feet, in order to augment the supply materially.

The waters will probably be strong in sulphates, though by no means beyond the limits of potability. The waters of the St. Peter and the deeper formations should be better in quality than those of higher strata. The closed pressure of the well should be 20 to 30 pounds.

Minor supplies.—Information concerning minor village supplies in Louisa County is presented in the following table:

Minor village supplies, Louisa County.

Town.	Nature of supply.	Depth of wells.			Depth to water bed.	Depth to rock.	Head below curb.	
		From—	To—	Common.			Shallow wells.	Deep wells.
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Cotter	Drilled wells	25	100	75–100	75			
Elrick	Driven and bored wells	8	52	9–15	50		−8	
Fredonia	Driven wells	16	22	16–20	18		−16	
Grandview	Dug and bored wells	45	55	45	36		−33	
Morning Sun	Wells	18	26					
Newport	Drilled and open wells	18	120	80–120	20	40	−10	−40
Wyman	Bored wells	20	200	25	75	70–200	−10	

WELL DATA.

The following table gives data of typical wells in Louisa County:

Typical wells of Louisa County.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Remarks (logs given in feet).
T. 73 N., R. 2 W. (PARTS OF JEFFERSON, ELLIOT, AND WAPELLO).		*Feet.*	*Feet.*		
W. Clark	Sec. 8	60		Sand	Slope of bluff of Iowa River. Yellow clay, 30; sand 30.
John Hays	Sec. 11	127		do	Upland. Yellow clay, 40; blue clay, 80; sand.
J. Parson	Sec. 11	210			Upland. Yellow clay, 30; sand, 6; blue clay, 80; sand, 14; blue clay, 25; sand, 25; blue clay, 30; rock at bottom.
Dr. Parsons	Sec. 23	107		Sand	Second bottoms, loam, sand, and gravel, 31; blue clay, 60; wood and black loam, 10; sand with water, 6.

Typical wells of Louisa County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Remarks (logs given in feet).
T. 73 N., R. 3 W. (PARTS OF WAPELLO AND MORNING SUN).					
		Feet.	*Feet.*		
Concord School	NE. ¼ sec. 18	300	8		Upland ravine. Drift, 8; limestone, 15; "soapstone," 148; dark shale, 30; "soapstone," 99.
H. Harris	NE. ¼ sec. 20	140	135	Sand	Upland. Drift, 135; shale, Kinderhook, 5.
W. D. Jamison	NW. ¼ sec. 22	300			Drift, 90; shale, 210.
Cyrus Hewitt	NW. ¼ sec. 29	76	73		Drift, 73; limestone, 3.
T. 73 N., R. 4 W. (PARTS OF MORNING SUN AND MARSHALL).					
	NE. ¼ NE. ¼ sec. 2.	152		Sand	Yellow clay, 22; blue clay, 116; sand, 14.
D. C. Marshall	NW. ¼ sec. 9	126	95		Drift, 95; limestone, 31.
	SW. ¼ NE. ¼ sec. 12	110	104	Limestone	Yellow clay, pebbly, 25; dry yellow quicksand, 5; blue clay, 74; broken limestone, 6.
J. K. Brown	SE. ¼ SE. ¼ sec. 16.	141	118	do	Drift, 118; limestone, 23.
James Chilson	SW. ¼ sec. 20	126	40		Drift, 40; rock, 86.
Town	Morning Sun	162	65	Limestone	Drift, 65; limestone, with some shale, 97.
T. 74 N., R. 2 W. (PARTS OF JEFFERSON AND PORT LOUISA).					
P. B. Stetson	E. ½ sec. 31	70		Sand	Yellow clay, 8; blue clay, 42; sand, 5; blue clay, 10; sand, 5.
T. 74 N., R. 3 W. (PARTS OF WAPELLO, PORT LOUISA, GRAND VIEW, AND JEFFERSON).					
Joseph Schofield	Sec. 24	247		Sand	Yellow clay, 10; blue clay, 8; old soil, 3; blue clay with sand at 70 and old soil at 160; sand at bottom.
Average of several wells.		123		do	Low upland. Soil 4; loess and yellow clay, 40; blue clay, 76; sand, 3.
T. 74 N., R. 4 W. (PARTS OF WAPELLO, MARSHALL, AND COLUMBUS).					
	NW. ¼ NW. ¼ sec. 35.	150		Sand	Yellow clay, 80; blue clay, 58; sand, 12. Water head, 110.
Lyman Bluff	SE. ¼ sec. 8	176		do	Upland; all drift.
Jesse Van Horn	SW. ¼ SW. ¼ sec. 27.	180		do	All drift.
	Cairo	124		Gravel	Soil, 8; yellow clay, 25; blue clay, 83; gravel, 8.
H. Freeman	SW. ¼ sec. 29	180	150		Drift, 150; with sand at 120; shale, 30.
R. S. Cummings	SW. ¼ sec. 32	120	45	Limestone	Drift, 45; limestone, 75.
Jos. Bates	E. ½ sec. 33	209			Yellow clay, 70; blue clay, 68; sand, 1; blue clay, 25; sand and clay, 23; dark drift, 22.
T. 74 N., R. 5 W. (ELM GROVE; PART OF COLUMBUS).					
L. M. Sampson	SE. ¼ SE. ¼ sec. 20.	60	53		Loess, 10; bowlder clay, 40; sand 3; rock, 7.
Evan Paris	NE. ¼ sec. 28	115	95		Drift, 95; sandstone, 20.

Typical wells of Louisa County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Remarks (logs given in feet).
T. 75 N., R. 3 W. (PART OF GRAND VIEW).		*Feet.*	*Feet.*		
....	NE. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 3..	265	....	Sand........	Ridge. Yellow clay without pebbles, 28; red sand, 30; blue clay, 38; quicksand with water 4; blue, pebbly clay, 158; sand with water, 7.
Joseph Wagner.....	Sec. 6............	137	....	.....do.......	Yellow clay and sand, 15; blue clay, 60; coarse gravel, 2; sticky blue clay with wood below, 47; sand, 13.
W. W. Wagner.....	SW. $\frac{1}{4}$ sec. 6.......	80$\frac{1}{3}$	....	.....do.......	Loess, 2; yellow sand, 16; bowlder clay, 40; quicksand, 20; old soil and wood, 4 inches; dark blue stony clay, 2; sand with gas and water.
M. A. Gray.........	N. $\frac{1}{2}$ sec. 22........	173	....	.....do.......	Soil, 6; yellow clay, 50; quicksand, 40; white and blue clay mixed, 74; sand with gas and water.
L. S. Gresham......	W. $\frac{1}{2}$ SW. $\frac{1}{4}$ sec. 27.	150	....	.....do.......	Loess, 12; peat, 3; blue clay, 65; quicksand, 1; blue clay, 3; quicksand, 1; blue clay, 55; sand, 10.
....	NE. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 9.	45	....	.....do.......	Yellow clay, 20; blue clay clear of pebbles, 14; peat, 1; quicksand, 4; blue clay, 6. Head of water, 16.
....	SE. $\frac{1}{4}$ sec. 14......	84	....	.....do.......	High knoll. Loess, 22; yellow sand and pebbles, 42; blue clay, 1; gray sand with water, 19.
Roy Letts..........	SE. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 19.	100	....	.....do.......	Yellow clay, 20; blue clay, 60; sand with water and gas, 20.
	NE. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 24.	78	....	.....do.......	Foot of Mississippi bluff. Yellow clay, 4; blue clay, 28; white sand, 26; red clay, 1; red sand with water, 19.
B. W. Haff.........	SE. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 35	153	....	.....do	Yellow clay, 34; yellow sand 8; blue clay, 96; sand with water and gas, 15.
John Sneider.......	Near Letts........	300	....	.....do.......	Yellow clay, 18; quicksand, 3; blue clay, 70; yellow clay and gravel, 20; blue clay and gravel 30 (?); sand to bottom.
T. 75 N., R. 4 W. (CONCORD; PARTS OF COLUMBUS AND OAKLAND).					
C. Estle.............	SW. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 3.	150	....	Sand........	Water and gas in basal sand.
M. A. Turkington...	S. $\frac{1}{2}$ sec. 10.........	215	....	.....do.......	Loess, 5; yellow till, 16; yellow sand, 3; blue "sand," 26; white sand, 80; dark bluish hard "sand," 45; light soft sand, 40.
D. Overholt........	SE. $\frac{1}{4}$ sec. 29.......	164	....	.....do.......	Bottom. Alluvium, 8; blue pebbly clay, 72; sand, 2; blue clay, 14; sand, 68.
T. 75 N., R. 5 W. (PARTS OF COLUMBUS AND UNION).					
General section.....	Near Columbus Junction.	....	....	....do.......	Yellow clay, pebbly, 15–20; blue pebbly hard clay, sand 2–15 at from 125 to 150 feet from surface, with water; blue clay.
Ruben Stapp.......	Sec. 16............	400	150	....	Drift, 150; shale, Kinderhook, 250.
....	Cotter Station.....	136	133	....	Drift, 133; sandstone, 3.
J. W. Garner.......	Columbus City....	170	....	Sand........	Loess, 13; blue till, 157; sand.
D. W. Overholt.....	SE. $\frac{1}{4}$ sec. 25.......	166	....	Sand and gravel.	Loess and yellow till, 35; blue till, 125; sand and gravel, 6.
Martin Schaum.....	Sec. 27............	68	65	....	Drift, 65; sandstone, 3.
T. 76 N., R. 5 W. (PARTS OF OAKLAND AND UNION).					
Edward Murdock...	NW. $\frac{1}{4}$ sec. 6......	152	....	....	All drift.
J. Lucky...........	NW. $\frac{1}{4}$ sec. 18.....	133	....	....	Do.

MAHASKA COUNTY.

By Howard E. Simpson.

TOPOGRAPHY.

Topographically Mahaska County comprises an upland plain, sloping from an elevation of about 900 feet in the northwest to about 800 feet in the southwest, across which Des Moines, Skunk, and North Skunk rivers flow southeastward in approximately parallel courses and into which they have carved their valleys to depths ranging from 100 to 200 feet. Between these valleys broad, flat, remnants of the former rolling drift plain remain. In places the streams are bordered by sharp rock terraces, but as a rule they have gradually sloping valley sides which rise from floors half a mile to 3 miles wide.

Only near the borders of the larger valleys, and particularly near the Des Moines Valley, is the topography rough and broken, but the tributary streams extend into all parts of the area, draining it so completely that ponds and lakes exist only on the flood plains.

GEOLOGY.

The bottom lands of all the larger streams are covered with alluvial deposits consisting of alternating layers of sands and silts that afford an abundant supply of water to drive point wells, few of which exceed 30 feet in depth. The water is usually good, though in some wells it has a slight odor or taste due to organic matter deposited in the silts.

Except on the flood plains of the streams, the entire surface is covered, in places to a depth of 10 feet, with the light yellow clay called loess; and everywhere beneath the loess is a deposit of unconsolidated clay and gravel in heterogeneous mixture, though showing in many places definite layers and lenses of stratified sand and gravel, the whole forming the glacial drift of Kansan age. Old soils, peat, and forest beds found locally beneath the Kansan drift, accompanied by well-defined layers of sand and gravel and in places resting on till, give evidence of an older drift, the Nebraskan. The whole drift commonly rests on layers of coarse sand and gravel immediately overlying the bedrock. The drift yields moderate quantities of water to dug and bored wells from 15 to 30 feet deep; small pockets of sand at depths ranging from 100 to 200 feet supply many wells, the largest supplies being obtained from the thick deposits of gravel at or near the base of the drift. These gravels can not be traced as a distinct bed over large areas, but wherever found they yield an unfailing supply of water which is generally hard but is satisfactory for domestic and farm use. In many places large open wells are dug down into the shale below in order to form a reservoir for water from gravels resting on the shale and thus maintain a large supply. Such wells should be carefully protected from pollution by surface drainage.

From southwestern Oskaloosa an old preglacial valley extends northwest and southeast, crossing Spring Creek Township and entering Harrison Township about the middle of its north line. The H. Crookham well (E. ½ SW. ¼ sec. 29, Spring Creek Township) passes through 40 feet of soil and till and then 80 feet of fine yellow sand, which changes to coarser sand and gravel below without striking rock. Water began to come in at 45 feet and increased downward. Abundant good soft water stands 85 feet below the curb of the well. To the northwest this old valley passes underneath the farm of J. B. Cruzen (NE. ¼ sec. 34, Madison Township), whose well passes through 196 feet of drift, chiefly sand, to bedrock. Across the road, T. J. Ferree's well reaches bedrock at 172 feet after passing through 90 feet of drift and 82 feet of sand. At a depth of 167 feet woody matter was found mixed with the sand.

The rock underlying the drift consists chiefly of Carboniferous shale, with a few beds of sandstone, limestone, and coal belonging to the Des Moines group of the Pennsylvanian series. (See Pl. XIII.) In narrow strips along the three principal streams, however, the rocks have been eroded away, and the underlying hard Mississippian limestone ("St. Louis limestone") becomes the country rock. The "St. Louis limestone" unconformably underlies the Pennsylvanian coal measures throughout the county and is readily distinguished in drilling by its hardness, its thin, soft, interbedded marly layers, and its thickness, 20 to 40 feet being common.

The shales of the Des Moines group are comparatively dry; only the coal and sandstone layers are water bearers, and the coal waters are always, and sandstone waters usually, impregnated with iron, sulphur, and other minerals. In a few places, however, thick local lenses of sandstone furnish excellent water. Chief among these is the brownish red sandstone underlying New Sharon and other portions of the northeastern part of the county, from which the New Sharon Electric Light Co. well and several farm wells in the vicinity draw their supply. The granular white sandstone of the "St. Louis" yields water of such quantity and quality as to give it locally the name of the "white water sandrock." Even above this thin sandy layers alternating with heavy limestone beds in many places yield a moderate quantity of water, which as a rule is hard but is rarely mineralized if the water from the coal measures is properly cased out. On the whole, the "St. Louis" is the most satisfactory aquifer in the county.

Only a few wells passing the upper limestone have failed to find the sandstone, but three such have been reported; two in Scott Township—that of Fred Oswandle (SW. ¼ sec. 2), 250 feet deep and that of the Williams Brothers (sec. 13), 317 feet in depth—and one at the Allandale stock farm (NE. ¼ sec. 22, Union Township). These wells probably all draw their supply from the limestone which immediately underlies the "St. Louis limestone;" and two of the three, the Oswandle and Allandale wells, yield water that is very strongly mineralized. Unless the deep aquifers are to be sought, drilling below the sandrock layer of the "St. Louis limestone" is to be discouraged.

In general, the upper limestone of the "St. Louis" is reached about 120 feet below the uplands, and the sandstone about 20 to 40 feet deeper. The depth, however, varies greatly. Between Skunk River and the Des Moines the "white water sandrock" is found at depths ranging from 150 to 250 feet, and the water is everywhere reported good. South of Des Moines River it lies somewhat deeper and in many wells is strongly mineralized. Between Skunk and North Skunk rivers, many wells draw from this bed at depths of 150 to 175 feet. The bed thus rises to the north and east, though perhaps not so often drawn upon in that direction, owing to the fact that the drift waters there are better and that there are numerous sandstone layers in the overlying Des Moines group.

The quality of all these waters unfits them for use in boilers, for which purpose it is, as a rule, necessary to impound rain water.

UNDERGROUND WATER.

SHALLOW FLOWING WELLS.

In Mahaska, as in the adjoining counties, the drill used in coal prospecting may strike a vein of water under such pressure as to cause it to flow from the top of the hole, though, as a rule, without much force. Most of these holes are located in low valleys or draws, and the aquifer is ordinarily a gravel layer low in the drift or a sandstone or coal seam of the Des Moines group. Many of these holes are abandoned and forgotten, but when advantageously located with respect to pasture lands they are cased and retained for stock supplies.

Such are the two flowing wells on the farm of C. A. Coryell, 1 mile southeast of Olivet, Scott Township. One well, 80 feet deep, yields about two-thirds gallon per minute of strong mineral water flowing from a coal vein; the other well, one-fourth mile south, is 52 feet deep, enters sandrock at 40 feet, and yields 6 gallons per minute of excellent water; the water rises 8 feet above the surface. A third well, 167 feet deep, also in Scott Township, on the farm of Con Ellis, 1½ miles southeast of Tracy, is drilled on a valley side, and reaches its aquifer in rock described as "dark limestone with flint" in the Des Moines group; the water has a strong mineral taste.

On the farm of Ed De Long (NE. ¼ sec. 26, Scott Township) a 47-foot well yields a 2½-gallon flow with head 18 feet above the surface; the aquifer is a heavy bed of sand beneath the till. This is an excellent stock well.

SPRINGS.

Many springs issue on valley sides, most of them flowing from the Des Moines group, but a few from drift deposits. The impervious stratum which collects the downward percolating waters and brings them to the surface, where it outcrops on the valley sides, is commonly a shale bed. Many of these waters are mineralized, and some of the springs yield sufficient water to form a permanent supply for stock. If such springs are advantageously located in pasture land they are piped into tanks.

The most interesting spring reported is on the farm of Edward Edris, 2½ miles northeast of Oskaloosa. This spring is said to have formed 10 or 12 years ago after the closing of a coal mine in the vicinity, where underground waters gave so much trouble that the mine was abandoned. It flows about 75 gallons per minute, and the water has a local reputation for its medicinal properties.

CITY AND VILLAGE SUPPLIES.

New Sharon.—The public supply of New Sharon (population, 1,122) is obtained from a well drilled to a sandstone horizon in the Des Moines group. Three wells have been drilled, all reaching the same aquifer, but only one is now used. The well, which is 9 inches in diameter and cased 80 feet to the sandstone bed, has yielded 35 gallons per minute.

The water is pumped by a gasoline engine into an elevated tank, having a capacity of 43,000 gallons, and is distributed by gravity through 2 miles of mains under pressure of about 45 pounds. Twenty-one fire hydrants and 160 taps utilize about 15,000 gallons daily.

Shallow drift wells are common in the city, but an excellent water, like that used by the city, may be found in the same or similar lenses of reddish-brown sandstone near the base of the Des Moines group at depths ranging from 40 to 175 feet. The water is very pleasant to taste, neither hard nor soft nor mineral. Should the drill pass through shales of the Des Moines without finding this water, the sandstone horizon of the "St. Louis limestone" might be found 40 to 50 feet below.

Oskaloosa.—The public supply of the city of Oskaloosa (population, 9,466) is owned by the Oskaloosa Water Co. and is operated under a 20-year franchise, dating from November 12, 1899.

The supply is obtained from 15 driven wells, 6 inches in diameter and about 50 feet deep, put down to bedrock in the alluvium and sands underlying the flood plain on the north side of Skunk River, 3½ miles north of the city. Each casing carries a 7-foot Cook strainer and is connected with piping in such a way that all siphon into an open well, 34 feet deep and several feet in diameter, in the bottom of which are 11 other drive points. The wells on the north and farthest from the river end in coarser sand and supply much more water than those nearer the river.

The pumping station is on the south river bank immediately opposite the wells. A cable from this plant runs a centrifugal pump in the main well, raising the water to a cistern from which it is forced into the mains by two steam pumps. A large open reservoir has been cut into the bank on the south side in such a way as to impound some storm waters, and into this water from the river is pumped directly in order that sedimentation may take place. In emergencies water can be pumped from this reservoir. An ordinary pressure of 110 pounds is maintained at the plant, and a fire pressure of 185 pounds is obtainable.

A large main leads from the pumping station to the filtration plant at the north edge of the city, where six Hyatt filters (two with a capacity of 250,000 gallons and four with a capacity of 150,000 gallons), and one Jewell filter (capacity 500,000 gallons) are utilized to filter the water through sand before it passes into the standpipe and mains of the city. It is estimated that about 1,300,000 gallons a day are filtered, and only in case of emergency is the water passed directly into the mains. The ordinary pressure on the mains from the filter plant is 35 pounds, but a pressure of 100 pounds or more may be had for fire engines.

A standpipe 20 feet in diameter and 130 feet high connected with the city mains stores the reserve and equalizes the pressure and flow. The greatest objection to the use of this water is that the mains are flooded with unfiltered water with every serious fire.

An artesian well, 2,517 feet in depth, was sunk by the city in the center of the city square about 1875, partly for the purpose of obtaining a flowing well for city supply and partly to prospect for coal and other mineral. No record has been preserved and little is now known of the well, save that at 800 feet a strong aquifer was reached which gave a head only 40 feet below the curb. This was tested by a steam pump throwing a 4-inch stream for 48 hours without lowering, but the water was so strongly mineral as to be unfit for drinking. The well has never been utilized.

Some time previous to 1888 a well was sunk to a depth between 2,800 and 3,000 feet. Two or three companies were engaged in drilling this well, litigation ensued, and the well was abandoned after a cost to the city of $2,800 or $3,000—an extraordinarily small sum for so deep a well, if the depth is correctly reported.

Record of strata to 1,200 feet in city well at Oskaloosa (Pl. XIII, p. 526).

[Based on drillers' logs. Assignments to formations by W. H. Norton.]

	Thickness.	Depth.
Quaternary (50 feet thick; top, 843 feet above sea level):	*Feet.*	*Feet.*
Soil, black	5	5
Clay, joint	33	38
Sand and gravel	3	41
Clay, blue	9	50
Carboniferous:		
Pennsylvanian series—		
Des Moines group (111 feet thick; top, 793 feet above sea level)—		
Fire clay	13	63
Slate, black	34	97
Coal	10	107
Sulphur (pyrite)	½	107½
Limestone	19½	127
Soapstone	12	139
Sandstone, gray	9½	148½
Plumbago, traces (?)	½	149
Sandstone, gray	12	161
Mississippian series—		
"St. Louis limestone" and Osage group (449 feet thick; top, 682 feet above sea level)—		
Flint	4	165
Limestone	15	180
Sandstone	9	189
Plumbago, traces (?)	1	190
Sandstone	10	200
Slate, black	50	250
Slate, white	20	270
Porous rock	10	280
Limestone	330	610
Kinderhook group (110 feet thick; top, 233 feet above sea level)—		
Slate	110	720
Devonian and Silurian (356 feet thick; top, 123 feet above sea level):		
Marble, hard	150	870
Limestone, very dark, hard; with streaks of saudrock, and mica; also fossils at 935 feet	100	970
Sandstone, hard, gray	7	977
Gypsum and magnesia	5	982
Feldspar (calc-spar?)	15	997
Sandrock, porous	5	1,002
No samples	74	1,076
Ordovician:		
Maquoketa shale (124 feet penetrated; top, 233 feet below sea level)—		
Slate, black	19	1,095
Slate, blue	20	1,115
Limestone	25	1,140
Slate, blue	60	1,200

Outside of the city water, which is generally used, the chief supply comes from shallow drift wells, which, with few exceptions, are unfit for domestic use, owing to unavoidable contamination from the surface, cesspools, coal mines, and open wells.

WELL DATA.

The following table gives details of typical wells in Mahaska County:

Typical wells of Mahaska County.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head below curb.	Remarks (logs given in feet).
T. 75 N., R. 16 W. (GARFIELD AND PART OF SPRING CREEK).		*Feet.*	*Feet.*		*Feet.*	
Sewer Pipe Manufacturing Co.	Oskaloosa.....	217	....	Sandstone ("St. Louis").	35	6 inches diameter; good clear water. Clay, yellow and blue, and slate and soapstone shale, 100+; gravel, some water, 5; limestone, solid, 60+; sandstone, white porous, water-bearing, 50+; limestone, shaly, 2; test 1½-inch stream one-half day; curb 5 feet below Minneapolis & St. Louis R. R.
Oskaloosa Light & Power Co.	Oskaloosa.....	360	63	.....do...........	60	Unused account mineral. Yields 6 to 8 gallon flow under pump. Clear; pleasant taste.
Blake Wilson...	SE. ¼ sec. 28...	182	40	.....do...........	143	Test 154+ barrels per day.
J. W. Hunt.....	4½ miles southwest Oskaloosa.	179	25	Sandstone (Des Moines).	59	
J. K. Hook......	SE. ¼ sec. 29...	140	27	Sandstone ("St. Louis").	......	Slightly mineral. Soil and clay and sand, red, 27; slate, chiefly coal, fine clay, limestone, 46; sandstone "white water rock," 37; soft porous sand, 30.
T. 75 N., R. 15 W. (PARTS OF SPRING CREEK AND ADAMS).						
H. Crookham...	Sec. 29.........	120	....	Drift sand.......	85	Good water in 80-foot beds; sand and gravel.
Spring Creek Coal Co.	SE. ¼ sec. 11...	220	38	Sandstone ("St. Louis").	100	4 inches diameter. Pumps 2½ gallons only.
A. H. Rogers....	NW. ¼ sec. 3..	124	30	Sandstone (Des Moines).	......	
T. 76 N., R. 15 W. (PARTS ADAMS AND SPRING CREEK).						
Moses Barr......	SE. ¼ sec. 19...	170	134	Sandstone (Des Moines?).	......	Bowlder clay, 60; blue clay, soft, 65; wood fragments common, log 1 foot thick at bottom; sand and gravel, 9; white sandstone, 35+.
W. G. W. Anderson.	SW. ¼ sec. 19..	600	85	Chiefly "St. Louis."	100	Clay, yellow, bowlder, 35; clay, blue, bowlder, 50; shale, 23; coal "blossom," 1; clay shale, red, 18; limestone and white clay interbedded, 38; sandstone (fine water), 10; limestone, 331; clay shale, light colored, 4; shale, thin, 2; limestone and shale, 88. Head, 100 feet; lowered to 180 feet on heavy test; 4-inch casing to sandstone, which is fine water bearing and yields 45 barrels in 24 hours. All water united below. Probably ends in Kinderhook.
J. N. Allgood....	NE. ¼ sec. 35..	135	80	Sandstone ("St. Louis").	......	
J. A. Reynolds..	Sec. 15........	128	128	Sand............	73	

Typical wells of Mahaska County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head below curb.	Remarks (logs given in feet).
T. 76 N., R. 16 W. (MADISON).		*Feet.*	*Feet.*		*Feet.*	
Ben Cruzen	S. ½ sec. 28	216	50	Sandstone ("St. Louis"?).	......	Soft water; yields 3 gallons per minute.
J. B. Cruzen	SE. ¼ sec. 34	196	19[illegible]	Sand	......	
T. J. Ferree	Madison	172	......	do	......	To bedrock. Wood in sand at base.
Bert Stiger	SW. ¼ sec. 5	225	150	Limestone or sandstone.	85	Good, hard water.
C. W. Bartlett	NW. ¼ sec. 9	120	......	Sand	......	
Mrs. R. H. Davis	......	282	195	Sandstone ("St. Louis").	92	Good water. Strong test.
W. B. Stiger	NE. ¼ sec. 8	175	115	"St. Louis"	90	Strong test without lowering.
C. L. Steddon	Lacey	198	85+	Sandstone ("St. Louis").	......	Strong well.
T. 74 N., R. 15 W. (HARRISON).						
Pekay Mine	NW. ¼ sec. 20	225	35	Sandstone ("St. Louis"?).	......	4 gallons per minute on test.
Miss Lullis	6 miles southeast Oskaloosa.	225	26	Sandstone ("St. Louis").	......	
Owen Mobley	5 miles southeast Oskaloosa.	188	20	Limestone	135	
T. 74 N., R. 17 W. (PART OF JEFFERSON).						
Walter Jones	5 miles east Bussey.	105	15	Sandstone (Des Moines).	......	
W. T. Knowles	......	203	20	do	......	
Catherine Strain	SE. ¼ sec. 14	100	24	Sandstone ("St. Louis").	......	Good hard water.
T. 75 N., R. 17 W. (SCOTT; PART OF JEFFERSON).						
J. H. Evans	W. ½ sec. 25	171	90	Sandstone ("St. Louis").	......	Soil and clay, 38; sand, 4; blue clay, 48; slate, 10; limestone, 40; sandstone, 31. Cased to limestone.
E. S. Godfrey, jr.	1½ miles southeast Tracy.	167	15	Limestone	......	Flows mineral.
J. J. Henry	SE. ¼ sec. 13	177	19	Sandstone ("St. Louis").	......	Soft water. Strong well. Clays, 19; slate, 51; coal, 3½; soapstone, etc., 64½; limestone, 16; sandstone, 23. Cased 142 feet to limestone.
W. R. Lacey	NE. ¼ sec. 1	198	......	"St. Louis"	120	Strong well, test 348+ gallons per minute. Surface, 50; blue clay, 6; slate, gray, 8; sand, 2; sandstone, 1½; coal, ½; bowlder (?), ⅜; coal, ⅝; fire clay, 1; gray slate, 9; fire clay, ¼; slate, black, 50; sandstone, 2; limestone, 27; sandstone, 39.
Wm. Velthuzen	NW. ¼ sec. 1	102	......	Drift sand	......	Plenty of good water.
Abe Bartlows	SW. ¼ sec. 23	145	21	"St. Louis"	......	
T. 74 N., R. 14 W. (CEDAR).						
R. Parsell	NW. ¼ sec. 5	207	......	Sandstone ("St. Louis").	......	Base of Des Moines at 97 feet.
T. 74 N., R. 16 W. (DES MOINES).						
D. M. Covey	SE. ¼ sec. 3	215	40	Sandstone ("St. Louis").	......	Good soft water.
Fred Oswandle	SW. ¼ sec. 2	250	38	Osage (?)	......	Soil and clay, 38; slate, 22; limestone, 20; slate and soapstone, 110; hard blue limestone, 60; sand. Water very salty and mineral. Head varies with rainfall and pumps down rapidly. "White water rock" (sandstone in "St. Louis").

Typical wells of Mahaska County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head below curb.	Remarks (logs given in feet).
T. 74 N., R. 16 W. (Des Moines)—Continued.						
		Feet.	*Feet.*		*Feet.*	
D. D. Davis	SW. ¼ sec. 29	118	32	Sandstone ("St. Louis").	95	Surface, 32; slate, 8; coal, 2; slate, 28; limestone, 25; sandstone, 23. Water stands at top of sandstone. Cased to limestone.
Williams Bros	Sec. 13	317	42	Osage (?)		Surface, 42; slate, 58; coal, 5; slate, limestone, and shale alternating, 212. Gradual increase of water in limestone layers. Weak head, may be pumped out.
T. 77 N., R. 16 W. (Prairie).						
Town of New Sharon.		155	80	Sandstone (Des Moines).	80	Test, 35 gallons per minute. Soil, 2½; clay, yellow above, blue below, 77½; sandstone, red and white, 70; shale, black and gray, 5. Test 35 gallons per minute, 9-inch casing to sandstone.
Minneapolis & St. Louis R. R.	New Sharon	246	123	Drift sand		Water scanty.
New Sharon Electric Light Co.	New Sharon	150	110	Sandstone (Des Moines).	54	Soil and yellow clay, 25; sand, 50; shales, 22; coal, 2; fire clay, 3; shales, 8; light shales, 25; sandstone, white shales, 40. Pumped 23½ hours per day for six weeks during drought, yielding constantly 5 gallons per minute without lowering. Water from white sandstone at 135 feet. Used chiefly for boilers.
C. G. Tice	Sec. 19	170		do		White sandstone with FeS_2 concretions.
W. Hite	Southwest of New Sharon.	256	100+	Drift sand		Plenty of water in sand over shale.
T. 77 N., R. 15 W. (Union).						
Allan Bros	NE. ¼ sec. 22	222	75	Osage (?)	58	Clay and sand, 75; limestone, solid, 20; slate, 12; limestone, thin layers, 100; sandstone, 15. Tastes very strongly of mineral salts. Pouring in test: 7 barrels without rise of head.

VAN BUREN COUNTY.

By W. H. Norton.

TOPOGRAPHY.

Van Buren County consists of a once continuous and well-nigh level plain modeled by glacial ice, now deeply and intricately carved by running water so that only remnants of the initial surface remain in the broad flat and imperfectly drained prairies of the northern part of the county and in the narrow flat-topped divides which separate the more closely spaced streamways of the south.

Des Moines River has trenched the upland to a depth of 100 feet or more, crossing the country diagonally from northwest to southeast. Fox and Little Fox rivers hold courses parallel with that of the Des

Moines and have widened their valleys to a greater degree proportionately than has the larger river.

GEOLOGY.

The lowest beds exposed in the county belong to the Osage group of the Mississippian series. They include at the base the upper part of the Burlington limestone, consisting of chert with a few thin beds of limestone or of limy shale (the "Montrose cherts" of Iowa Survey reports). The chert, although too hard to be cut by the drill, is fortunately brittle and is readily broken by the impact of its blows. On this chert rests the lower division of the Keokuk limestone, a blue-gray, coarse, subcrystalline, and thinly bedded limestone. Next in ascending order comes a bed of shale 40 feet thick, distinguished by the geodes which it carries. Broken by the drill, these hollow balls furnish to the slush bucket crystals of quartz or calcite and chips of milky white translucent chalcedony. Hardly to be distinguished from the geode-bearing shales in well records is a bed of overlying blue shale and interbedded limestone layers.

The Osage group is overlain by the "St. Louis limestone," which consists of sandy magnesian limestones, shattered limestones made up of sharp angular fragments, and compact granular limestones, the total thickness reaching nearly 90 feet. The larger part of the county is covered by the Pennsylvanian series, with its beds of shale, sandstone, and coal, underlying fine clay.

Not exposed within the county, but underlying the "Montrose cherts" is the lower part of the Burlington limestone, which forms a valuable water bed. This limestone rests on heavy shales (Kinderhook group), which are entered by some of the deeper wells. Near Utica these shales lie about 400 feet below the surface of the upland.

Resting on bedrock or separated from it by stratified sands and gravels lies a massive, tough, blue, stony clay, known as the Nebraskan drift. Upon the Nebraskan lies another stony clay, known as the Kansan drift. These two drifts may be parted by sands and gravels (Aftonian). The Kansan in its unweathered portions is a blue hard till hardly to be told in drillings from the Nebraskan except that the latter is usually of a darker tint. In its weathered portions the Kansan is a yellow or reddish stony clay, in places 40 to 50 feet thick. Both drift sheets contain lenses of sand and gravel laid down by water from the melting ice.

The entire county, with the exception of the present flood plains of the rivers, is covered with loess, a yellow or gray silt 2 to 10 feet thick.

UNDERGROUND WATER.

SOURCE.

Sheet water is found so near the surface in river sands and gravels on the flood plains of the larger streams that it is tapped by driven and open wells. Such wells form the chief domestic supply for the towns located on Des Moines River. On Fox River the alluvial area is still more extensive in proportion to the size of the stream.

In places the base of the loess supplies house wells. The chief water beds of the drift, however, are sands interbedded between the successive sheets of stony clay, beneath the earliest till, parting it from bedrock. These beds supply very many wells on the more level uplands.

Where drift sands fail to furnish sufficient water there is a good prospect of finding it at moderate depths in some of the Mississippian limestones or cherts. A number of wells to the Mississippian are reported, however, which range from 270 to something more than 400 feet in depth. The deepest of these are sunk a few feet into the Kinderhook, but so far as known no wells in the county have failed to find water above this heavy shale.

CITY AND VILLAGE SUPPLIES.

Bonaparte.—The waterworks at Bonaparte (population, 597), owned by the town, are used for fire protection and street sprinkling only. Water is pumped from Des Moines River to a standpipe. The pressure is from 65 to 125 pounds. There are 2 miles of mains and 28 fire hydrants.

Bonaparte (and also Keosauqua) is about 644 feet above sea level and hence the base of the Kinderhook should be reached at 275 to 300 feet above sea level. The drill will then pass into 200 to 300 feet of Devonian and Silurian limestones, the latter possibly including a water-bearing sandstone near its base. The underlying dry Maquoketa shale rests on heavy limestones (Galena and Platteville), in which water should be obtained above the bituminous shales which here occur near the base of the Platteville limestone. The St. Peter sandstone should be reached at about 500 feet below sea level or 1,100 feet below the surface. A well 1,300 feet in depth should obtain an adequate supply of water of fair quality with a head of perhaps 50 feet. As security against the possibility of the St. Peter sandstone failing to yield enough for a city supply, the contract should provide for drilling, if necessary, to 1,600 feet.

Farmington.—Farmington (population, 1,165) draws its public supply from Des Moines River. Water is pumped raw into a reservoir with a capacity of 300,000 gallons and distributed thence under a pressure of 80 pounds. There are 16 fire hydrants and 2 miles of mains. The water is not used for domestic purposes, open or driven house wells being still utilized for this purpose. The waterworks are owned by the town.

A flowing well, 705 feet deep, is reported by C. A. White[1] at Farmington (elevation, 567 feet). Its depth would take it to the Silurian sandstone beds, and it was probably from these that the flow occurred. Large flows may be expected here from about 350 feet below sea level or about 920 feet below the surface, and a well for city supply should be sunk to this depth not only to get more water but also to improve its quality. This depth would take it to either the crystalline Galena dolomite (which in this area is often erroneously called by drillers the St. Peter sandstone) or to the St. Peter sandstone. The water should head at from 670 to 700 feet above sea level, and should be entirely potable. although its mineral content will not be low.

Minor supplies.—Supplies of minor villages are summarized below:

Town and village supplies of Van Buren County.

Town.	Nature of supply.	Depth.	Depth to rock.	Depth to water bed.	Head below curb.	
					Shallow wells.	Deep wells.
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Birmingham	Wells	20–65	150–200	60		25
Cantril	Wells and cisterns	20–60		30		
Douds Leando	Driven, bored, and open wells	15–20	20	20	12	
Kilbourne	Cisterns, open, and drilled wells	20–112	40	112	15	6
Milton	Open wells	15–30			15	
Mount Sterling	Cisterns and bored wells	15–60			8	
Mount Zion	Wells and cisterns	70–100	100		40	60
Stockport	Wells	10–40	45	40		

WELL DATA.

The following table gives data of typical wells in Van Buren County:

Typical wells in Van Buren County.

Owner.	Location.	Depth.	Diameter.	Depth to rock.	Depth to water bed.	Source of supply.	Head below curb.	Remarks (logs given in feet).
T. 67 N., R. 10 W. (PART OF DES MOINES).								
		Feet.	*In.*	*Feet*	*Feet.*		*Feet.*	
William Teter	Sec. 8	83	12		65	Gravel and sand.	35	Yields 50 barrels a day.
W. C. Fritz	5 miles southeast of Cantril.	82	4		62	Sand	40	Yields 20 barrels a day; water iron bearing.
T. 67 N., R. 11 W. (PART OF JACKSON).								
A. U. Benson	NW. ¼ sec. 12	290	4	280(?)	290	Sandstone	40	Yields 2 gallons a minute; water sulphur bearing.

[1] White, C. A., Rept. Iowa Geol. Survey, vol. 2, 1870, pp. 272, 355.

Typical wells in Van Buren County—Continued.

Owner.	Location.	Depth.	Diameter.	Depth to rock.	Depth to water bed.	Source of supply.	Head below curb.	Remarks. (logs given in feet).
T. 68 N., R. 10 W. (PART OF DES MOINES).		*Feet.*	*In.*	*Feet.*	*Feet.*		*Feet.*	
Edwin De Ford	Sec. 27	350	4	200	270	Limestone	80	Yields 5 gallons per minute.
J. M. Silver	NW. ¼ sec. 29	290	5	240	250	do	80	Yields 2 gallons per minute.
—— Manning.	NW. ¼ sec. 31	151			110	Gravel and sand.		Yellow clay, 50; blue till, 60; water-bearing gravel and sand, 41.
T. 69 N., R. 10 W. (PART OF VAN BUREN).								
L. R. Plowman.	Kilbourne	112	6	(?)			4	Hill slope; water salty, flowing when first drilled.
Siegel	SE. ¼ sec. 28	153	6	63	150	Limestone	60	Upland. Yellow clay, reddish clay, light-blue clay, dark-blue clay, all without sand, 63; limestone, 87; shale, 3.
	NW. ¼ sec. 13	213		60		do		A little caving yellow sand under yellow clay, with a little water. Rock hard limestone with some flint.
—— Britt	SE. ¼ sec. 32	409		90		do	60	Drift clays, 80; black sand with foul water, 10; shale, black, 30; limestone and shale, 100; limestone, shale at bottom. Water pumps down 6 to 200 feet.
—— Drummond.	Pittsburg	110		16		do	15	Des Moines River bottoms. Alluvium, 16; shale, 10; limestone; shale at bottom.
T. 70 N., R. 10 W. (LICK CREEK).								
	SE. ¼ NW. ¼ sec. 26.	194		110		Limestone		Creek bottom. Drift, 110; limestone, 84.
T. 70 N., R. 11 W. (VILLAGE).								
S. E. McGrew	SW. ¼ sec. 21	405	5	40			25	Water lowers under pumping to 47 below curb.
James Elerick	Sec. 20	400	4	100	375	Siliceous rock.	75	Upland. Yields 5 gallons per minute. Mostly limestone, except 4 feet of water-bearing stone at 250, and siliceous rock ("quartz rock") near bottom.
T. 68 N., R. 11 W. (PART OF JACKSON).								
—— Holland.	SW. ¼ sec. 8	217½			205½	Gravel	52	Yellow clay, 23; dark-blue clay with some sand 65 feet from top, 181; "rock," rather soft, 1½; water-bearing clay and sand with some gravel, 12.
T. 69 N., R. 8 W. (HARRISBURG).								
—— Cresswell	SW. ¼ sec. 11	132		92		Limestone		Yellow clay, 92; limestone, yellowish to white, 6; limestone, white, in thin strata, water bearing, 34.
Enderby	SE. ¼ sec. 12	121		120				Yellow clay, 50; blue clay with gravel 90 feet below curb, 70; limestone, 1.

Typical wells in Van Buren County—Continued.

Owner.	Location.	Depth.	Diameter.	Depth to rock.	Depth to water bed.	Source of supply.	Head below curb.	Remarks. (logs given in feet).
T. 69 N., R. 8 W. (Harrisburg)—Con.		*Feet.*	*In.*	*Feet.*	*Feet.*		*Feet.*	
C. Davis	Sec. 8	318		85				Yellow clay with some sand, 35; blue joint clay, 5; yellow clay with layers of sand and some water, 16; hard blue till, 29; coal measure shales, 17; white limestone, 15; blue limestone with some pyrite, 70; shale, 58; limestone, cherty and sandy, 3; limestone, gray, pink, and black, 38; rock, hard, gray, cuts the drill, 32.
T. 69 N., R. 9 W. (Washington, parts of Henry and Van Buren).								
C. Miller	1½ miles northeast of Keosauqua.	162		42				Gray clay, 8; sand, 32; gravel with water, 2; coal, 3; white limestone, 8; lime and sand, 8; gray limestone, 30; reddish sandstone, 3; gray sandstone, 12; blue shale, 56.
H. B. Edmunson.	SE. ¼ sec. 26	224		111				Yellow clay, no sand, 90; blue clay into 3 inches of sand at base, 21; blue shale, 55; ocher, 3; brown limestone, 10; shales alternating with limestone, 41; rock, very hard, dark, could not penetrate it (most all chert?) 4.
T. 70 N., R. 8 W. (Cedar).								
George Watson.	1½ miles north of McVeigh.	50				Sand		Water from white sand beneath light-blue clay.
William Brooks	Utica	400					65	Yellow clay, 56; light-blue clay, 23; dark-blue clay, 29; limestone, 257; alternate shale and limestone, 25; shale (Kinderhook), 10.

WAPELLO COUNTY.

By Howard E. Simpson and W. H. Norton.

TOPOGRAPHY.

Wapello County lies about midway between the center and the southeast corner of the State. Owing to the deep dissection of the Kansan till plain by the tributaries of Des Moines River the surface is generally rough and irregular, the only notable exception being in the northeast quarter, where the upland plain is but slightly rolling. This area is drained by Cedar Creek and its tributaries into Skunk River. These master streams conform to the general southeasterly trend of the more important streams in the eastern part of the State. The Des Moines enters at Eddyville, in the northwest corner of the county, and leaves just below Eldon, in the southeast corner, flowing the entire distance through a broad, deep valley of preglacial origin, on the floor of which it has developed a flood plain a mile or two in width. The drainage is complete. The relief, though broken, varies only from about 625 feet in the Des Moines Valley at its point of exit from the county to about 900 feet near the southwest corner.

GEOLOGY.

Save where removed by stream erosion, the surface of the entire county is covered with a fine light-gray clay, in few places more than a few feet thick, which is easily identifiable with the southern loess. On the floors of the deeper stream valleys this loess is replaced by darker alluvial silts. These are especially prominent on the bottoms of the Des Moines Valley, where they cover not only the present flood plain, known as the "bottom," but also form several terraces, the most conspicuous of which is known as the "second bottom."

Underneath the loess and resting unconformably on the country rock is a thicker layer of Kansan drift, composed of mixed clay, sand, and gravel.

The country rock consists chiefly of Carboniferous shale, including some beds of sandstone and coal, and belongs to the Des Moines group of the Pennsylvanian series. (See Pl. X, p. 374.) In the deeper valleys in the northeast corner of the county, and in the Des Moines Valley for more than half the distance across the county, the streams have cut through the Pennsylvanian shales and sandstones to the "St. Louis limestone" of the Mississippian series. Below the upper limestones of the "St. Louis" a soft sandstone, belonging to the same division and popularly known in this region as the "white water sandrock," occurs in a few places. All the strata have a very slight southern dip, and in working for coal gentle folds and a few small faults have been noted.

UNDERGROUND WATER.

SOURCE.

Water in Wapello County is obtained from the alluvium, the drift, the Des Moines group, the "St. Louis limestone," and from deeper rocks. Each is an important source of water in some localities, though the first three vary greatly in both quantity and quality. The only distinct water province is that formed by alluvial deposits of the Des Moines Valley and its chief tributaries.

In the belt of alluvium half a mile to 2 miles wide lying along the Des Moines River valley floor and in very much narrower strips in the lower ends of the tributary valleys bands or belts occur, in which water may be found in sandy or gravelly layers, usually within a few feet of the surface. Such water is commonly obtained by means of drive points, though dug and bored wells are numerous.

The most common source of water in the county is the drift. Rarely are any wells now found which secure a supply of water from the loess, though in earlier years the sand near the base of the deeper portions of loess yielded a supply sufficient for the scanty needs of the pioneer. The drift wells are generally dug or bored to 20 to 30 feet, though some reach 120 to 130 feet before striking abundant water. The shallower wells find a meager supply in sand pockets and small veins in the bowlder clay. The most prolific source is, however, in a heavy layer of sand and gravel at or near the base of the drift. This layer, when found directly overlying the shale, is in some places cemented into a ferruginous conglomerate and is so similar to the Aftonian gravel as to suggest an older drift sheet.

The drift waters when uncontaminated are of good quality and, being comparatively easy of access and comparatively free from deleterious mineral matter, are generally used for domestic purposes. Most of them contain carbonate of lime, and occasionally a ferruginous precipitate forms in them when they are exposed to the air, but neither of these is particularly baneful.

In villages and in the vicinity of the coal mines these shallow waters are subject to pollution and should be used with caution. The quantity supplied from the gravel bed at the base of the drift is in some places sufficient for all demands of even large stock farms, but generally the drift wells are insufficient except for household use or for small farm supplies. Large open wells must be dug to increase inflow, and to form suitable storage reservoirs, or the drill must be resorted to and a rock well be tried.

The Des Moines group (or "Lower Coal Measures," as it is popularly called) is composed chiefly of shales with a few beds of sandstone and coal. The shales are of no value as water bearers, as they are very impermeable and therefore comparatively dry. Water is commonly found in the coal beds, but it is not potable, owing to the abundance of iron and sulphur compounds it carries in solution, this being characteristic of most of the waters of this group. Some sandstone lenses are so free from mineral as to afford satisfactory supplies, but these are local and uncertain.

Many of the best farm wells of the northern and western portions of the county penetrate the coal measures and enter the "St. Louis limestone," the upper part of which consists of a compact, even-bedded white limestone 20 to 30 feet thick, with cherty and marly layers. In some wells a good supply of hard water is found in the joints, and in the underlying calcareous sandstone of the "St. Louis," known as the "white water sandrock," a supply of good hard water is obtainable in quantities sufficient for all wells for stock. This water is rarely mineralized, and it will probably prove to be the most satisfactory source in the county. It is not much used except in the northwest corner on account of the depth at which it lies and the expense of drilling to it.

Whatever doubt may exist as to the correlation of the deeper sandstones (see p. 605) there is fortunately no doubt as to the abundant store of water in the upper of the two. It supplies the wells of the Ottumwa Iron Works and the first well drilled by the Morrell Co., whose initial flow is reported at 800 gallons per minute with a 5⅝-inch bore through the water bed. The Young Men's Christian Association well did not reach this horizon if its depth is correctly reported. In the Morrell well No. 4 a small flow was obtained from 975 to 1,190 feet; when the well pierced the lower strata of this aquifer from 1,190 to 1,240 (1,260? feet), a flow of 1,100 gallons was tested.

DISTRIBUTION.

At Larson (formerly Marysville) bored wells draw their supply from the sand and gravel layers of the drift at depths ranging from 20 to 40 feet, though at one point a mile south of the village a drift well 130 feet deep is reported.

A typical deep drilled well is reported by J. P. Hawthorne, 2 miles southeast of Larson. This well penetrates about 100 feet of drift and at 200 feet found a strong water-bearing sandstone. The water tastes of sulphur, but is a good stock water, yielding strongly to windmill with only slight lowering below the 30-foot level. It probably draws from a sandstone lens in the Des Moines group.

One of the deepest stock wells of the county is on the farm of Norman Reese, 4 miles south and 2 east of Larson. The record as reported by A. G. Leonard is given to show the relations of the drift, the Des Moines group, and the "St. Louis limestone."

Record of well of Norman Reese.

	Thickness.	Depth.
	Feet.	*Feet.*
Drift clay	60	60
Sand	3	63
"Soapstone"	15	78
Shale, gray	30	108
"Soapstone"	20	128
Shale, black carbonaceous	7	135
Coal	3½	138½
Shale, blue	15	153½
"Soapstone"	10 to 15	167
Shale	8	175
Soapstone	10 to 14	188
Shale, black	100	288
Limestone ("St. Louis") alternating with thin, blue layers of "sandstone"	182	470

The record shows the characteristic sand horizon at the base of a 60-foot layer of drift. No sandstone lenses are reported in the Des Moines group (coal measures), of which 222 feet were penetrated; the Mississippian was entered to a depth of 182 feet.

Highland wells about Dahlonega are chiefly bored and dug in the drift from 20 to 40 feet. The well of George D. Robertson (sec. 19) is typical. It is 40 feet deep and 4 feet in diameter and does not reach bedrock. The water enters from sand at 18 feet and stands ordinarily about 10 feet below the surface, but in dry weather the well may be pumped out by the windmill. The best drift aquifer evidently lies very deep here, for in several places in the northeastern part of the township the heavy sand layer at the base of the drift is reached only at 120 feet.

On the farm of F. J. Remir, 2 miles northeast of Dahlonega, several wells indicate two quite persistent water beds. The composite section follows:

Record of wells on farm of F. J. Remir, near Dahlonega.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	2- 3	2- 3
Clay, yellow, and loess with light-colored sand	10-12	12-15
Clay, black, with gravel; drift	10-20	22-35
Sand and gravel	....	....

Temporary hillside springs not uncommonly issue from the sand at the base of the loess.

A few wells are drilled into rock. Among these the most noted is that at the county farm in the SE. ¼ sec. 32, Highland Township (T. 73 N., R. 13 W.), 462 feet in depth, which reached limestone of the "St. Louis" at 200 feet and its water-bearing sandstone at about 230 feet. The head is very low, standing about 200 feet below the surface and requiring a gasoline engine and force pump.

The J. Haines farm well, a mile southwest of the village of Kirkville, draws its supply from the "St. Louis" at a depth of 177 feet. A strong flow of water was procured in sandstone of the Des Moines group at a depth of 110 feet, though caving prevented its utilization. The average well about Kirkville is 20 to 40 feet deep in drift, though wells are drilled deeper on stock farms.

Shallow drift wells are common in the vicinity of Eddyville and many in the valley utilize the sand and gravel underneath the alluvium. Good rock wells are, however, more common than in any other part of the county, owing to the proximity to the surface of the sandstone of the "St. Louis," the best water bed of this region. The limestone of the "St. Louis" is quarried in the bluffs a mile south of Eddyville and the sandstone is exposed immediately underneath.

Among these rock wells may be mentioned that of A. J. Gardiner on the upland (SW. ¼ sec. 19, T. 73 N., R. 15 W.), 220 feet in depth, which enters the rock at 55 feet and the sandstone at 214. The well of G. F. Glass, 3 miles southeast of Eddyville on the river bottom, enters rock at 25 feet and the sand rock at 50 feet, the total depth being 75 feet. The C. H. Leander well, 3 miles north of Dudley, 185 feet deep, reached coal measures at 24 feet and the sandstone of the "St. Louis" at 157, after passing but 7 feet of limestone. The well of George Stevens, 2 miles northwest of Dudley, is 205 feet in depth; that of James Harris, 1½ miles southwest of Kirkville, is 177 feet; and that of Joe Johnson, 2½ miles south of Eddyville on the river bluff, is but 120 feet.

One of the most interesting wells in this vicinity is that of Stephen Lewis, just south of Eddyville (sec. 7, Columbia Township). It is a characteristic blowing well. As stormy weather approaches the water becomes turbid and the well rumbles and roars with a rush of air which jars and rattles the pump. Although the water is derived from the sandstone of the "St. Louis" at a depth of 80 feet, the air apparently issues from the limestone at a depth of perhaps 60 feet. The well was drilled in 1903, and at that time the phenomenon was most pronounced, but it has gradually decreased since.

A. J. Leonard, 2 miles northeast of Munterville (sec. 9, Polk), reports water at a depth of 124 feet, beneath 24 feet of limestone. Another well 1½ miles east of Munterville reached the "St. Louis" at 210 feet and penetrated it 20 feet, when an abundant supply was found. Near Blakesville the limestone was struck at a depth of 360 feet. A well in the NW. ¼ sec. 27, Green Township, reached the "St. Louis" at 350 feet and its water-bearing sandstone at 370 feet.

Owing to the thickness of the drift, the slight probability of securing satisfactory water in the coal measures, and the depth to the "St. Louis," few wells have been drilled in the southeastern part of the county. In the vicinity of Agency some bored wells reach a depth of 100 feet or over, though depths of 20 to 35 feet are most common. A small flowing well was secured in the SE. ¼ sec. 24, Agency Township, the flow coming from the Des Moines group at 44 feet.

CITY AND VILLAGE SUPPLIES.

Eddyville.—Eddyville is 676 feet above sea level and wells there should find the same artesian waters as at Ottumwa, but at greater depths. The water-bearing sandstone found at 417 feet below sea level at Ottumwa was presumably the St. Peter and should be found at Eddyville at about 550 feet below sea level or about 1,225 feet below the surface. The logs of the Ottumwa wells are conflicting and no set of drillings has ever been preserved. It is possible that the lower sandstone is the St. Peter, and this would be found at Eddyville at about 1,375 feet from the surface. It is quite probable that a well 1,500 feet deep would suffice for the town, but more copious flows can be had by drilling deeper, the supply increasing to 2,000 feet at least.

The static level is such as to bring the water to the surface with a probable pressure of 20 pounds. In quality it should be a good potable water of the sodic-magnesic sulphated class, provided that the upper waters of the Carboniferous and Silurian are cased out. In all probability gypsum or anhydrite will be found in the Silurian, and water-tight casing should be driven to the Galena.

Eldon.—The location of Eldon (elevation, 630 feet) in the Des Moines Valley gives it an elevation so low that artesian water will be found within moderate distance of the surface and will rise to the curb under a good pressure. The Des Moines Valley extends here approximately along the line of strike of the strata, and the Ordovician dome of southeastern Iowa causes a slight rise toward the southeast, the dip from Keokuk to Ottumwa measured on the St. Peter being 1.6 feet to the mile. At this rate the water bed supposed to be the St. Peter at Ottumwa (Pl. X) would be encountered at Eldon at 400 feet below sea level, or about 1,030 feet below the surface; but the absence of complete and reliable data both at Ottumwa and at Keokuk makes accurate estimates impossible. Above the supposed St. Peter, water may be expected in the limestones of the Devonian and Silurian; below the St. Peter, for several hundred feet, the flow should be largely increased from creviced and porous dolomitic beds and intercalated sandstones.

If the upper Mississippian waters are cased out the well should supply a potable water of fair quality of the sodic-magnesic sulphated class. Sodium sulphate may be the chief mineral in solution, but some sodium chloride, or common salt, will also be found. The pressure of the water at the curb may reach 20 to 25 pounds.

Ottumwa.—The public water-supply franchise for Ottumwa (population, 22,012) was granted to the Public Water Co. in December, 1903, for a period of 25 years. The water was formerly drawn from a power canal leading from Des Moines River opposite Turkey Island down past the main pump house in the city, 1½ miles below. Dams across the two channels of the river connected with a levee divert the water into the canal, and this still furnishes the greater part of the power necessary to operate the plant.

The water is now obtained in part from a well 20 feet in diameter and 25 feet deep, sunk on the island just above the levee. An infiltration gallery, 250 feet long and 7 by 8 feet in cross section leads into the well. As this supply is inadequate the additional amount necessary is taken direct from the river through an 8-inch intake pipe.

A pumping station at the well on the island is equipped with two electrically driven pumps, each having a capacity of 5,000,000 gallons a day, which force the water against a head of 44 pounds through the two 24-inch pipes leading to the main pumping station. To avoid danger of accident during high water these pumps are set in a steel tank 18 feet square and 15 feet deep, the top being well above high-water level, and the suction of both connected with a header through which water may be drawn from the well, the river, the sedimentation basin, or all of them.

The main pumping plant is in a modern fireproof station 67 by 90 feet. Water and steam are both provided for power, the former through the canal, which operates five turbines under a head of 7½ feet. These furnish sufficient power for most of the year. Four horizontal boilers supply the steam power. Two water-power pumps, one having a capacity of 2,000,000 and the other of 3,000,000 gallons, are connected with a 125-horsepower Corliss engine in such a way that they may be operated by steam if necessary. There is also a steam turbine pump having a capacity of 5,000,000 gallons. Two electric generators, one driven by water and the other by steam, generate the current needed to operate the pumps on Turkey Island and the pumps at the auxiliary station at the reservoir and light the company's buildings.

The city is built on two levels, the business district being on the "second bottom" of Des Moines River and the modern residential district on the bluffs, about 180 feet above. It therefore requires two waterworks systems. The lower level is supplied with water under a head of 210 feet, from a reservoir of 2,000,000 gallons capacity, receiving its supply directly from the pumps of the main station. The higher part of the city is supplied with water under the same head by a motor-driven pump located at the reservoirs.

Two standpipes, each 56 feet in height and 6 feet in diameter, located on the 24-inch mains, one at either pumping station, regulate the flow in the pipes and give head to operate an old series of Jewell filters when the river water is in such condition as to require filtering.

A new sedimentation basin at the island station and a clear-water reservoir at the nearer station are contemplated at an early date.[1]

On the "second bottom" of Des Moines River, a terrace about 20 feet above low water, driven wells have generally replaced the older open dug wells. These average between 15 and 20 feet in depth between Main Street and the river and have a maximum of about 30 feet in the vicinity of the fair ground. The water occurs in alluvial sand so fine that ordinary screens are of no use, and 60 to 120 gauze is required with large exposure.

[1] Eng. Record, vol. 53 (1906), No. 13, p. 430. Fire and Water Eng., Feb. 3, 1906, p. 54.

Between Main Street and the foot of the bluffs bored wells fitted with 6-inch drain tiles are common. The fineness of the alluvial silt and sand causes the water to be somewhat turbid.

On the bluff dug wells are still used though the supply there is from the drift and is meager and of poor quality. Cisterns are frequently used for domestic supply.

A spring worthy of mention is that of William Wheaton in the northeastern portion of the city, from which 75 to 100 barrels per day flow. The water is stored in a tank by means of wind and gas engines and sold for household use throughout the city.

On the south side of the river practically all the wells are driven, the only exceptions being in the west end where the sandstone of the "St. Louis" is found within 15 or 20 feet of the surface and is occasionally utilized; the well of B. A. Williams enters it to a depth of 80 feet. The average well is about 24 feet in depth. The water-bearing sand is here overlain by 10 to 12 feet of yellow clay and is generally coarser than on the north side. The water is generally good though hard, and is inexhaustible. After a time the point is coated over with sand cemented into a conglomerate with lime and iron. The fact that but a few feet of loamy clay separates the city from its water supply makes this sand a questionable source of supply.

The Wabash Railroad Co. uses for boiler supply a battery of 17 driven wells which reach the rock. The water is pumped into a 30,000-gallon tank, from which about 10,000 gallons a day are used without ever running short. Though somewhat hard, the thin scale which forms breaks easily and the water does not cause foaming.

Similar results are obtained at the Dain Manufacturing Co. plant, where all of the water used comes from the alluvial sands. In the open heater a slight yellow iron precipitate is formed and a thin flaky scale forms. The water stands 10 to 12 feet below the surface.

The country rock at Ottumwa is the Des Moines group. (See Pl. X, p. 374.) For the nature and thickness of the deeper formations dependence must be placed entirely on the identifications of the driller's logs, in the absence of any drillings from any of the wells. In a number of important points these logs are in substantial agreement, and correlations may be made with considerable assurance. But the real natures of several strata and their places in the geologic column remain in doubt because of the total lack of direct lithologic evidence.

After passing through thin superficial deposits the drill penetrates the rapidly alternating limestones, cherts, shales, and sandstones of the "St. Louis limestone" and the Osage group. The shales of the Kinderhook are reached at about 200 feet above sea level and apparently extend to about 40 feet above sea level or even lower. Leaving the Kinderhook, the drill passes into a complex of limestones with more or less shales interbedded at different horizons, the whole attaining a thickness of 300 to 375 feet. The lower 125 to 150 feet of this complex is described by one log as "limestone," as "caving rock" by a second, and as "shale" by a third. The drill next encounters a sandy limestone from 75 to 125 feet thick. As at least some of the drillers seem to have had wide experience, and as they speak of the arenaceous dolomites of the Prairie du Chien group in the same terms it is quite probable that it is here a true arenaceous limestone rather than a limestone which crushes under the drill into crystalline sand. All logs agree that this sandy limestone rests on a water-bearing sandstone from 75 to 100 feet thick, whose top may be reckoned at about 430 feet below sea level by an average of probabilities, although variously placed in the logs. Below this lies 100 feet of limestone from which the drill passes into 20 feet of green shale overlying a white sandstone 40 feet thick whose summit stands at about 630 feet below sea level.

Either the first or the second of these sandstones is the St. Peter, but which of the two it is must be left in doubt, although the question could be settled at once by inspection of cuttings if these had been preserved. Favoring the theory that the lower sandstone is the St. Peter is the fact that it is called a white sandstone and that it is overlain by a shale definitely stated to be green. We seem to have here the association of the St. Peter sandstone and the green shale of the Platteville found in all near-by deep wells, as indeed it is found in almost all the deep wells of the State. The fact that no shale is reported overlying the upper sandstone favors this reference. The upper sandstone and the sandy limestone which rests upon it, then, fall to the Silurian and may be taken as the equivalent of the water-bearing Silurian sandstones found at Centerville and Washington and certified at these two stations by cuttings of the strata.

Bearing against this reference is the thinness of the beds intervening between the two sandstones, which must represent the entire thickness of the Maquoketa, Galena, and Platteville. At Centerville these beds are about 290 feet thick, at Washington about 450, and at Pella upward of 500 feet thick, and at Ottumwa the logs allow for them only about 120 feet. (See Pl. X, p. 374.) The fact that the Maquoketa is absent from the section, as no shale underlies the upper sandstone, is not decisive, since it is also absent at Centerville, although present in force at points north and west of Ottumwa.

If the upper sandstone is assumed to be the St. Peter, the shale reported in one well at from 137 to 307 feet below tide must be referred to the Maquoketa, but as this rests directly upon the "sandy limestone" and as less than 150 feet intervene between the shale and the sandstone the same difficulty recurs as to the thinning out of the Galena and Platteville.

If it be assumed that the lower of the two sandstones is the St. Peter, the drill at about 1,300 feet passes out of it into the Prairie du Chien group, with perhaps still lower terranes undistinguished from it with the evidence at hand, the whole forming a complex of limestones, sandy limestones, and sandstones extending, according to the logs, to the bottom of the deepest well, 1,562 feet below sea level. The description of these strata as given in the Ottumwa well logs is altogether similar to that given of the Prairie du Chien wherever found. In a general way the Prairie du Chien at Ottumwa tallies with the beds below the St. Peter at Centerville. From 800 to 1,250 feet below sea level these beds are generous in their yield.

The Ottumwa Iron Works well is 1,150 feet deep and 6 inches in diameter; casing to 600 feet packed with lead at bottom. The curb is 648 feet above sea level. The original head was 50 feet above curb; the present head is above curb. Water comes from 1,040 feet. Temperature, 62° F. The well was completed in 1888, at a cost of $3,000.

This well has shown loss of pressure. It still overflows and is used to supply water-closets at the works. The lessened flow is attributed to defective packing and to the loss in the well of a smaller pipe that was being inserted. The sinking of other wells has not affected the discharge. The strata penetrated are said to be mostly limestone to the water bed at 1,040 feet, and below that sandstone.

The Artesian Well Co. well No. 1 has a depth of 2,047 feet and a diameter of 8 inches; cased to 1,200 feet. The curb is about 648 feet above sea level. The original head was 108 feet above curb by pressure; the present head is 103 feet above curb. The original and present flow is about 700 gallons per minute. Water comes from 1,015 feet. The temperature is variously reported as 70° F. and 67° F. Date of completion, 1889. In 1904 the well was repaired by recasing to 30 feet below the curb, where a leakage was found to occur.

Driller's log of Artesian Well Co. (well No. 1) at Ottumwa.

	Thickness.	Depth.
	Feet.	*Feet.*
Loam	21	21
Limestone	21	42
Shale	14	56
Sandstone	30	86
Limestone	60	146
Shale	19	165
Sandstone, flinty	41	206
Sandstone	30	236
Limestone	195	431
Shale	160	591
Limestone	380	971
Limestone, mixed with sand	96	1,067
Sandstone, white	110	1,177
Shale and limestone	200	1,377
Slate	19	1,396
Limestone	319	1,715
Limestone, water-bearing	332	2,047

The Artesian Well Co. well No. 2 is 1,552 feet deep and 8 inches in diameter; cased to 1,200 feet; packed down 100 feet with concrete. The curb is about 648 feet above sea level and the head about 76 feet above curb. The flow is about 300 gallons a minute, the water coming from 1,250 feet. Temperature, 70° F. The well was completed in 1897 by J. F. Kearns, of Ottumwa.

The Young Men's Christian Association building well is 800 feet deep. The curb is about 648 feet above sea level and the head, by pressure, 9 feet above curb. The flow is 33 gallons a minute; temperature, 65° F. The well is used to supply a swimming pool and baths.

The packing house well No. 1 of John Morrell & Co. (Ltd.) has a depth of 1,110 feet. The curb is 643 feet above sea level. The first flow came in at 280 feet, and increased at 710 feet, the main flow being struck at 1,015 feet. The well was completed in 1888. It was reamed out in 1892 by the original drillers, J. P. Miller & Co., to a diameter of 12 inches to 19 feet, 8 inches to 518 feet, and 5⅝ inches to bottom. The flow was then 800 gallons a minute. The pumping capacity in 1908 was 207 gallons a minute. The head in 1895 was 35 feet above curb; in 1896, 32 feet above curb. The loss of flow was gradual and was attributed to filling with sediment. No repairs have been made since 1892.

Driller's log of packing-house well No. 1 of John Morrell & Co., Ottumwa.

	Depth in feet.
Surface	80
Slate	100
Slate and lime	110
Lime and sand	215
Solid lime	255
Water flowed	280
Lime	312
Lime and streaks of sand	330
Lime	360
Shale	440
Solid rock	625
Flow increased	710
Sandstone (water bearing)	1,015
Sandstone	1,100

Packing-house well No. 2 of John Morrell & Co. (Ltd.) has a depth of 1,554 feet and a diameter of 10 inches to 25 feet, 9⅝ inches to 97 feet, 8 inches to 540 feet, 6 inches to 994 feet, 5 inches to 1,320 feet, and 4 inches to bottom; casing, from surface to 25 feet, from 437 to 540 feet, from 842 to 994 feet, from 1,244 to 1,320 feet. The curb is 643 feet above sea level. The original head was 57 feet above curb; the head in 1893, 49 feet above curb. The original flow was

1,000 gallons a minute, and the tested capacity in 1908, 214 gallons a minute. No repairs. Loss attributed to filling with sediment. The water comes from 1,085 feet. Temperature, 64° F. The well was completed in 1892 by J. P. Miller & Co., of Chicago.

Driller's log of packing-house well No. 2 of John Morrell & Co., Ottumwa.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface	17	17
Limestone	8	25
Shale	71	96
Limestone	344	440
Caving rock	90	530
Sandy limestone	150	680
Shale	35	715
Limestone	140	855
Caving rock	130	985
Limestone	65	1,050
Sandstone	65	1,115
Limestone	110	1,225
Sandstone	15	1,240
Shale and sand	70	1,310
Limestone	170	1,480
Sandstone	50	1,530
Sandy limestone	24	1,554

Packing-house well No. 3 of John Morrell & Co. (Ltd.) has a depth of 1,702 feet and a diameter of 10 to 6⅝ inches; casing, 8 inches from surface to 1,360 feet, later, 10 inches from surface to 76 feet; from 1,360 to 1,702 feet uncased. The curb is 643 feet above sea level and the original head was 50 feet above curb. The original flow was 1,500 gallons a minute; pumping capacity, in 1908, 244 gallons a minute. No repairs. Temperature 67° F. The well was completed in 1898 by J. P. Kearns, of Forrestville, N. Y. It was first bored to 1,702 feet with a diameter of 8 inches below 425 feet. As some trouble was experienced with caving rock at from 1,210 to 1,360 feet, and as the well yielded only 900 gallons a minute, it was reamed to 10 inches to a depth of 1,360 feet and an 8-inch pipe inserted to this depth, when the discharge was increased to 1,500 gallons a minute.

Packing-house well No. 4 of John Morrell & Co. (Ltd.) has a depth of 2,205 feet and a diameter of 12 to 6⅝ inches; casing to 1,310 feet, with hemp packer. The curb is 643 feet above sea level. The head, in 1905, was 46 feet above curb. The original flow was 1,450 gallons a minute; tested capacity in 1908, 1,500 gallons a minute. A small flow came in at 1,190 feet; a flow of 1,100 gallons, tested, at 1,260 feet, and of 1,450 gallons, tested, at 1,896 feet; all rocks were water bearing between 1,451 and 1,896 feet; no increase at 2,205 feet. Temperature, 70° F. The well was completed in 1905 by J. P. Miller & Co., of Chicago.

Driller's log[a] of packing-house well No. 4 of John Morrell & Co., at Ottumwa (Pl. X, p. 374).

	Thickness.	Depth.
	Feet.	*Feet.*
Surface	22½	22½
Small stone and rock	63½	96
Limestone and shale, mixed	334	430
Shale and limestone	205	635
Limestone, solid	35	670
Streaks of shale and stone	50	720
Limestone	60	780
Shale	170	950
Sandy limestone	125	1,075
Sandstone and limestone, small flow	115	1,190
Water rock (1,100 gallons flow)	50	1,240
Limestone (water bear ng)	20	1,240
Shale, green	16	1,276
Sandstone, white	38	1,314
Limestone, with streaks of shale	11	1,325
Sandstone, white	5	1,330
Limestone	25	1,355
Sandstone	10	1,365
Limestone	58	1,423
Sand or sandy limestone	28	1,451
Limestone with crevices	34	1,485
Sandstone, white	58	1,543
Limestone with streaks of sandstone	22	1,565
Limestone	57	1,622
Limestone, sandy	10	1,632
Limestone	33	1,665
Sandstone, white	15	1,680
Limestone, sandy, with crevices	65	1,745
Limestone	45	1,790
Limestone, sandy, or hard sandstone	45	1,835
Limestone	15	1,850
Limestone, sandy, or hard sandstone	27	1,877
Sandstone	19	1,896
L mestone, hard	129	2,025
Sandstone, with streaks of limestone	73	2,098
Same as above, but thicker streaks (15 to 20 feet)	62	2,160
Limestone, hard	30	2,190
Limestone, sandy	15	2,205

[a] Log below 1,240 feet sent by driller to the Survey. Log above this depth supplied by the company, probably from the log of another driller.

WELL DATA.

The following table gives data of typical wells in Wapello County:

Typical wells of Wapello County.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head below curb.	Remarks.
John Curtis	3½ miles east of Eddyville.	165	91	Sandstone ("St. Louis").	100	Hard water.
James Harris	1½ miles southwest of Kirkville.	177	9	do	125	
George Stevens	2 miles northwest of Dudley.	205	20	do		A good well.
C. H. Leander	3 miles north of Dudley.	185	40	do		Good soft water.
Joe Johnson	2½ miles south of Eddyville.	120	16	Sandstone (Des Moines?).	60	Good water.
S. H. Lamis	2½ miles east of Eddyville.	80	25	Sandstone ("St. Louis").	40	A blowing well.
A. J. Gardiner	3½ miles south of Eddyville.	220	55	Sandstone (Des Moines).		Hard water.
J. P. Hawthorne	2 miles south of Farson.	217	100	do	30	"Sulphur taste."
G. F. Glass	3 miles southeast of Eddyville.	75	25	Sandstone ("St. Louis").	8	

WASHINGTON COUNTY.

By W. H. Norton.

TOPOGRAPHY.

Washington County is situated in the third row of counties north of the Missouri line and in the second west of Mississippi River. Its relief is due almost wholly to the dissection of an ancient plain of glacial drift molded by a continental glacier to a well-nigh flat and even surface. The rivers of the area have cut their valleys in this once continuous upland to depths of 175 feet and more. Bordering the larger streams the country is "broken" into a succession of ridges and closely spaced ravines. The interstream areas, however, are still largely uncarved by any sharp or well-marked channels and form tabular divides traversed by shallow swales that mark the beginnings of the tributary streams. The area may thus be divided into flat uplands, called "prairies," and slopes, called "breaks" where somewhat rugged. Iowa River forms part of the eastern boundary of the county, but as it saps the right-hand valley bluffs its bottom lands lie outside the county limits. Skunk River flows over a wide alluvial floor. English River has developed a flood plain $1\frac{1}{2}$ miles wide for nearly 6 miles from the western county line.

GEOLOGY.

Washington County lies wholly within the area of outcrop of the Mississippian series, of which the Kinderhook group, the Osage group, and the "St. Louis limestone" are exposed to view. The lowest group, the Kinderhook, includes heavy shales overlain by earthy magnesian limestones and gritstones, the total thickness being estimated at 200 feet. Upon the Kinderhook rests the Osage group, made up of massive coarsely crystalline limestones. In the southern and southwestern parts of the county the Osage is overlain by the "St. Louis limestone," consisting of limestones, shale, and sandstones. Some of the limestone is a breccia; that is, it is composed of angular fragments cemented together. Small isolated patches of coal measures are also found in this county—outliers of the coal fields of the Des Moines group. (See Pls. X, XIV.)

The Pleistocene of Washington County includes but two drift sheets. Immediately upon the country rock lies the Nebraskan drift sheet—a tough, hard, dark-blue stony clay, in many places containing small fragments of coal and bits of wood, and in some places at its base glacial gravels. Directly upon the Nebraskan or separated from it by stratified sands and gravels and in a few places by an old soil or forest beds—interglacial deposits known as the Aftonian—lies the Kansan drift sheet. This stony clay is normally blue in color but is oxidized and turned yellow for a considerable distance below its surface. Upon the Kansan lies the loess—a thin, yellow, or gray gritless silt or dust deposit, which everywhere mantles the uplands of the county. The average depth of the Pleistocene over the county probably exceeds 100 feet.

UNDERGROUND WATER.

SOURCE AND DISTRIBUTION.

The water-bearing beds of Washington County consist of the alluvial sands and gravels of the flood plains of the rivers, the glacial sands and gravels of the Pleistocene, and the limestones of the Mississippian. The first named are limited to portions of the valleys of Skunk and English rivers and their larger affluents. The second forms a province as wide as the entire county. The third, or Mississippian, also includes all the county with the exception of a deep buried river channel extending from northwest to southeast through the town of Washington, and hence designated the Washington channel. Along the line of this ancient river valley the limestones have been cut away to great depth and water is sought and found in glacial sands.

On the flat uplands ground water stands high, and house wells and wells adequate for small farms with little live stock may be obtained in many places within 50 feet of the surface.

A soft gray silt, underlying the yellow loess and attaining in places a thickness of 15 feet, supplies many shallow wells. A second water bed, consisting of streaks of reddish sand and gravel varying in thickness from 2 to 3 feet up to 20 and even 30 feet underlies the yellow pebbly clay of the area. A portion of this sand is often cemented to "hardpan"; and a good roof of hardpan overlying water-bearing sand and gravel may be reckoned as distinct good fortune to the well maker.

A third water bed is found in layers of reddish sand and gravel underlying the blue pebbly clay of the drift (either the Nebraskan or the unaltered Kansan) and resting on the country rock. This sand is said by drillers to be thin and seldom supplies water in adequate amount.

Washington channel supplies many deep wells from its buried sands. In the town well of Washington a large amount of water was struck at 235 feet in these sands, and a number of farm wells tap them at depths exceeding 200 feet.

The chief water beds of the county are those of the bedrock. The upper rock layers broken by preglacial weathering into spalls, called "shelly rock" by drillers, constitute a waterway of much importance.

The limestone of the Osage group, which is found immediately underlying the drift over the larger part of the county, yields copious supplies from porous layers and from seams separating massive beds. Some drillers report that the cherts and flinty beds interleaved with the limestones of the Osage are especially reliable as water carriers. Water-bearing crevices, where the drill drops a foot or more, are said not to be uncommon in this easily soluble limestone.

Water may also be found in the "St. Louis limestone" which forms the country rock over the southwestern part of the county.

The thick shales of the Kinderhook group will be found dry. When they are reached without obtaining a sufficient supply of water the question of going deeper should be carefully considered. If this is decided against, the well may be shot with nitroglycerin at the top of the shale, the well having been filled up to this height if the drilling has been continued below it. The well of Mr. L. Stout, in Brighton Township, reached a depth of 425 feet, having been sunk 215 feet in the Kinderhook. The well was then plugged at the top of the shale and shot with nitroglycerin, the flow being trebled in amount by the operation. In case this heroic treatment is not successful, the only course remaining is to abandon the drill hole and drill again in some other place, as torpedoing a well makes it impossible to sink it deeper.

Some notes may be added as to conditions in different townships. In Brighton Township wells about Verdi are from 80 to 120 feet in depth and draw their water from a blue flinty limestone with some streaks of shale which may be referred to the Osage. In Marion Township a highly mineralized corrosive water is found in drift sands and gravels, rock not being reached. In West Franklin, Duck Creek, and Seventy Six townships wells find the rock usually at about 100 feet, and obtain water in the "shelly rock" immediately beneath the drift. In the latter township, however, a strip of "deep country" extends from the Keokuk County line for 5 or 6 miles on the north side of Crooked Creek and parallel with it. There rock is said to lie from 200 to 400 feet from the surface and most wells are "sand wells."

CITY AND VILLAGE SUPPLIES.

Ainsworth.—At Ainsworth (population, 408) the waterworks are owned by the town. Distribution is made by compressed air under a pressure of 65 pounds. There are three-fourths of a mile of mains, 7 fire hydrants, and 60 taps. The capacity of the system is 12,000 gallons daily and the consumption is but 4,000 gallons.

Washington.—The town of Washington (population, 4,489) draws its supply from deep wells. The consumption per diem is 200,000 gallons. The domestic pressure is 47 pounds and the fire pressure from 90 to 100 pounds. There are 9 miles of mains, 73 fire hydrants, and 600 taps. The waterworks are the property of the city.

Record of strata of a well drilled in Washington previous to 1888 (Pl. X, p. 374; Pl. XIV, p. 548).[a]

	Depth in feet.
Pleistocene (350 feet thick; top, 738 feet above sea level):	
Sand, gravel, blue clay; forest bed with peaty matter and cones of *Abies nigra* at 115 feet	115
Carboniferous (Mississippian):	
Kinderhook group (108 feet thick; top, 388 feet above sea level):	
Shales, dark; in part calcareous; samples to	432
Devonian (74 feet thick; top, 280 feet above sea level):	
Limestones and shales; at 458 feet, limestone light colored magnesian, with fragments of *Atrypa reticularis* Linn. and *Athyris vittata* Hall; samples to	500
Silurian (170 feet thick; top, 206 feet above sea level):	
Sandstone; calciferous at 532 feet; purer at 585 feet; continuing to	632
Ordovician:	
Maquoketa shale (101 feet thick; top, 36 feet above sea level)—	
Shale; bluish or greenish, some with sand; some with calcareous matter; samples continuing to	793
Galena and Platteville limestones (297 feet thick; top, 65 feet below sea level):	
Limestone, grayish; samples	803–963
Limestone and dark fine-grained, carbonaceous shale	1,020
Limestone; facies of Platteville	1,059
Sandstone	1,082
Shale, arenaceous	1,084–1,095
St. Peter sandstone (128 feet thick; top, 362 feet below sea level):	
Sandstone, pure white, granular; resembling refined sugar; some drillings changed to reddish or brownish by atmosphere and moisture; samples from	1,100–1,200
Shale, bluish	1,228
Prairie du Chien group:	
Shakopee dolomite (2 feet penetrated; top, 490 feet below sea level):	
Sandstone, gray	1,230

City well No. 1 has a depth of 1,611 feet and a diameter of 10 to 4½ inches; casing, 10-inch to 244 feet, 6¼-inch to 461 feet, 5½-inch from 563 to 818 feet, 4½-inch from 1,400 to 1,468 feet. The original head was 44 feet below curb; head in 1896, 54 feet below curb; head in 1907, 133 feet below curb. The well is now pumped with air lift; capacity, 95 gallons per minute. The temperature is variously reported as 72° and 74° F. The well was completed in 1891 by J. P. Miller & Co., of Chicago.

City well No. 2 (Pls. X, XIV) has a depth of 1,217 feet and a diameter of 12 to 6 inches. The head is 58 feet below curb. Water was found at 300 feet, but was cased out, the present supply coming from 1,105 feet; capacity, 62 gallons per minute. The well was completed in 1897 by O. G. Wilson.

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[a] Adapted from report by Calvin: Am. Geologist, vol. 1, 1888, pp. 28-31.

City well No. 3 has a depth of 1,808 feet; casing, 14 inches to 256 feet, 10 inches to 610 feet, and 8 inches to 1,470 feet. The curb is 738 feet above sea level; the initial head was 100 feet below the curb; head in 1911, 70 feet below curb. The capacity under compressed air is 300 gallons per minute. The water comes chiefly from 1,808 feet. The well was completed in 1908 by C. B. Brant, of Indianapolis, Ind., at a cost of $10,000.

Water levels in Washington city well No. 3 while well was being drilled.

Geologic division.	Depth.	Head below curb.
Devonian	500	200
Silurian	563	120
St. Peter sandstone	1,215	110
New Richmond sandstone	1,365	95
Jordan sandstone	1,670	83
St. Lawrence formation	1,808	80

Description of strata of city well No. 3 at Washington.

	Depth in feet.
Quaternary (235 feet thick; top, 738 feet above sea level)	235
Carboniferous (Mississippian?):	
Sandstone, buff and reddish buff; microscopic angular grains; flint of same color	242
Carboniferous (Mississippian):	
Kinderhook group (198 feet thick; top, 503 feet above sea level):	
Shale, light blue, plastic, gritless	265
Shale, hard, brownish drab, fissile	360
Shale, hard, green gray, calcareous; in rounded chips; washed	385
Devonian (101 feet thick; top, 305 feet above sea level).	
Silurian (29 feet thick; top, 204 feet above sea level):	
Dolomite, light buff; siliceous, with microscopic quartzose particles, and cherty, with white calciferous sandstone; grains fine, imperfectly rounded; chips show microscopic quartz crystals	534
Dolomite, dark drab mottled; light-gray, pyritiferous, slightly quartzose residue; with white chert; some quartz, as above	563
Ordovician:	
Maquoketa shale (147 feet thick; top, 175 feet above sea level):	
Shale, light green, plastic; noncalcareous; in molded masses	563
Shale, drab, hard noncalcareous	615
Shale, green, hard, noncalcareous	620
Galena dolomite to Platteville limestone (398 feet thick; top, 28 feet above sea level):	
Dolomite, dark brown, granular crystalline, argillaceous, of Galena facies; and yellow, earthy; 3 samples	710–790
Limestone, light gray; rapid effervescence; cherty; 7 samples	900–980
Limestone, light drab and yellow-gray; with brown, and highly inflammable shale	1,030

Ordovician—Continued.

Galena dolomite to Platteville limestone (398 feet thick; top, 28 feet above sea level)—Continued.

	Depth in feet.
Shale; as above; with light brown and gray limestone	1,037
Shale; hard green; and limestone as above	1,043
Limestone, light yellow-gray and brown; rapid effervescence; 4 samples	1,050–1,085
Dolomite, brown, hard, crystalline	
Shale, hard, green, fissile; and sandstone; white rolled noncalcareous grains; larger grains about 0.8 millimeter diameter (in log of earlier well this horizon is given as sandstone 2 feet, arenaceous shale 16 feet)	1,090
St. Peter sandstone (103 feet thick; top, 370 feet below sea level):	
Sandstone, white; well rounded grains, larger up to 1 millimeter diameter; 2 samples	1,115–1,117
Sandstone, fine; grains imperfectly rounded, rusted, native color, white; 7 samples	1,150–1,208
Prairie du Chien group:	
Shakopee dolomite (142 feet thick; top, 473 feet below sea level):	
Shale, light green; in hard molded masses; some quartz sand	1,211
Dolomite, gray, cherty; some oolitic, highly arenaceous chert; drillings largely sand; grains reach 1 millimeter in diameter; 2 samples	1,215–1,230
Dolomite, light yellow-gray, crystalline; considerable quartz sand and green shale	1,235
Dolomite, gray-buff, arenaceous; some chips show embedded grains	1,250
Dolomite, light gray, arenaceous; some embedded grains; some sand	1,280
Sandstone; as at 1,165 feet; sample misplaced	1,310
Dolomite, light drab, arenaceous; some sand and embedded grains	1,320
New Richmond sandstone (27 feet thick; top, 615 feet below sea level):	
Sandstone, white; grains imperfectly rounded, secondary enlargements; larger grains of 0.8 millimeter diameter	1,360
Dolomite, pink; considerable quartz sand in drillings	1,370
Sandstone; as at 1,360 feet; cherty; some oolitic chert	1,380
Oneota dolomite (210 feet thick; top, 642 feet below sea level):	
Dolomite, pink, and buff; a large part of drillings quartz sand	1,390
Dolomite, light gray-buff	1,415
Chert, white; in large chips, some oolitic; 2 samples	1,420–1,425
Dolomite, light gray, clean of sand; and whitish, pink, and brown; with siliceous oolite in places; 2 samples	1,445–1,590

Cambrian:
Jordan sandstone (150 feet thick; top, 852 feet below sea level):

	Depth in feet.
Sandstone, white, fine; grains imperfectly rounded; 2 samples	1,595–1,600
Sandstone, white; larger grains reach 1 and 1.2 millimeters diameter	1,612
Sandstone, fine, white	1,620
Sandstone, white, hard; in chips and detached grains; secondary enlargements; 2 samples	1,625–1,650
Dolomite, gray; much sand	1,670
Sandstone, white, fine	1,705
Sandstone, as above, and light-gray dolomite	1,730

St. Lawrence formation (68 feet penetrated; top, 1,002 feet below sea level):

Dolomite, light gray and whitish; drusy pyrite at 1,745; 2 samples	1,745–1,770
Dolomite, light pink	1,808

Driller's log of city well No. 3 at Washington.

	Thickness.	Depth.
	Feet.	*Feet.*
Subsoil, white and blue clay	65	65
Quicksand	5	70
Clay, blue	35	105
Quicksand	12	117
Clay, blue	118	235
Quicksand	7	242
Shale, white	118	360
Shale, brown	25	385
Shale, blue	50	435
Limestone, brown	40	475
Limestone, gray	52	527
Limestone, brown	7	534
Limestone, gray	29	563
Shale, blue	42	605
Shale, brown	15	620
Shale, blue	80	700
Shale, brown, sandy	35	735
Shale, blue	28	763
Limestone, brown, shelly	27	790
Limestone, brown, hard	10	800
Limestone, gray	228	1,028
Limestone, brown, hard	22	1,050
Limestone, gray	40	1,090
Limestone, blue, and sandstone	18	1,108
Sandstone, white, hard	103	1,211
Shale, blue	4	1,215
Limestone, red, shelly, hard	15	1,230
Limestone, gray, hard	123	1,353
Sandstone, white, soft	12	1,365
Limestone, red	10	1,375
Sandstone, white, soft	5	1,380
Limestone, gray	20	1,400
Limestone, gray, soft	80	1,480
Limestone, white, hard	110	1,590
Sandstone, white, soft	80	1,670
Limestone, gray, hard	30	1,700
Sandstone, white, soft	40	1,740
Limestone, gray, hard	63	1,803
Limestone, pink, hard	5	1,808

Wellman.—The public supply of Wellman (population, 724) is drawn from eight 3-inch wells 70 feet deep, located 50 feet apart and joined to a single steam pump. Their combined yield more than equals the capacity of the pump—225 gallons per minute. The two best wells yield 149 gallons per minute and one of these alone can supply

80 gallons. The wells are situated about 10 feet above the level of Smith Creek and head 4 inches below the curb. Rock was here reached at 30 feet from the surface. Water is distributed from a tank, whose capacity is 3,500 barrels, through more than a mile of mains. There are 12 fire hydrants and 54 taps. The domestic pressure is 60 pounds and the fire pressure 100 pounds. The daily consumption is 6,500 gallons. The works are the property of the town.

Minor supplies.—The water supplies of minor villages are described in the following table:

Minor village supplies in Washington County.

Town.	Nature of supply.	Depth.	Depth to water bed.	Depth to rock.	Head above or below curb.	
					Shallow wells.	Deep wells.
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Crawfordsville	Dug, bored, and drilled wells	15–140		60–100	−10	−20
Haskins	Bored wells	20–150	100	55	− 6	
Nira	Wells	20– 62				+ 6
Rubio	Driven, bored, and drilled wells	30–190		50	−20	
Riverside	Open wells	18– 55		25	−35	−30 to −60
West Chester	Dug wells	18– 50		35	−10	−30

WELL DATA.

The following table gives data of typical wells in Washington County:

Typical wells in Washington County.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Remarks.
T. 77 N., R. 9 W. (PART OF LIME CREEK).					
		Feet.	*Feet.*		
George G. Sigler	SW. ¼ NW. ¼ sec. 25.	92	78	Limestone	Valley. Diameter, 2½ inches. Water also in sand at 60 feet; discharge ⅓ gallon per minute. Heads 2 feet above curb.
——— Carris	NW. ¼ sec. 32	168	140	Sandstone	
	1½ miles south of Nira.	180	179		Ends in shale.
	1 mile south of Nira	90	89		Creek bottom. Flowing well; now failing.
T. 76 N., R. 9 W. (SEVENTY SIX).					
O. K. Stoutner	Northeast of Keota		100		
——— Stamp	do		125		
	SE. ¼ sec. 18	450			"Depth of drift, 450 feet."
——— Tallman	SW. ¼ sec. 17	450			Do.
P. H. Tallman	Sec. 19	551			Joint and dark brown clay, 60; sand, 10; clay, 70; rock, ½; clay, yellow and brown, and changeable, mixed with some gravel, 60; shale light gray, gritless, with a bed of bluish rock 30 feet thick, and bed of rock in the middle, 250; sulphur, very hard, 4; rock, softer, to 551 feet, where water was struck; water salty and laxative.
——— Mickle	SW. ¼ sec. 34	136	100		
D. Monroe	SE. ¼ sec. 35	113	100		
D. Fisher	SE. ¼ sec. 27	270	170	Limestone	Heads 70 feet below curb.
D. Fisher	NE. ¼ sec. 27	130	114	do	Same level as preceding well. Heads 30 feet below curb.

Typical wells in Washington County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Remarks.
T. 76 N., R. 9 W. (SEVENTY SIX)—Continued.		*Feet.*	*Feet.*		
....	2½ miles southwest of Lexington.	330	....	....	No rock except a shell of soapstone at 100. No water.
William Hamilton..	....	130	100	Limestone..	
Charles Kreger......	NW. ¼ sec. 31......	130	105	....	
A. S. Tuft..........	SW. ¼ sec. 30......	90	75	....	
William Stoutner...	SW. ¼ sec. 5......	160	120	Limestone..	
....	2 miles southwest of Lexington.	100	100	....	Plenty of water in shell rock.
T. 75 N., R. 9 W. (PART OF DUTCH CREEK).					
Curtis Wells........	S ½ sec. 12........	140	....	....	
James Brinning.....	NW. ¼ sec. 35.....	220	130	....	
J. W. Augustine....	NE. ¼ sec. 32......	....	....	....	Drift, 110.
W. Horning........	About 2 miles southwest of Grace Hill.	230	80	....	Drift; limestone; shale; limestone. Heads 90 feet below curb.
B. Engle...........	About 1 mile southwest of Grace Hill.	130	100	....	
W. W. Wells.......	Sec. 13............	....	220	....	
T. 76 N., R. 8 W. (CEDAR; PART OF FRANKLIN).					
D. Monroe..........	NW. ¼ sec. 31.....	90	....	Gravel	
——— McCurdy....	NE. ¼ sec. 31......	162	161	....	
T. 75 N., R. 8 W. (PARTS OF FRANKLIN AND WASHINGTON).					
Charles Guy........	SW. ¼ sec. 6.......	....	....	....	Drift, 190.
Alexander Houk....	3 miles west of Washington.	....	110	....	
T. 75 N., R. 7 W. (PART OF WASHINGTON).					
County poor farm..	Sec. 7.............	236	....	....	Wood and seeds at 236, below blue clay.
John Graham.......	1½ miles east of Washington.	....	250	....	
T. 74 N., R. 8 W. (BRIGHTON; PART OF MARION).					
L. Stout...........	Sec. 22........ ...	425	20	Limestone..	Foot of bluff, Skunk River bottoms; clay, 20; limestone, 190; shale, 215.
T. 74 N., R. 7 W. (PART OF MARION).					
William Hamilton..	Sec. 6.............	150	....	Sand and gravel.	Upland. Red clay, 30; bastard shale, a blue clay with few if any pebbles, 100; sand and gravel, 20.
T. 76 N., R. 7 W. (JACKSON).					
George Foster......	Sec. 23............	313	....	Sand........	Ends in sand under 200 feet of soft blue clay.
....	Sec. 26............	....	125	....	Same altitude and place as preceding.
T. 75 N., R. 6 W. (OREGON).					
Livery stable.......	Ainsworth........	....	50	....	20 feet above railway station.
C. Pearsons........	2 miles south of Ainsworth.	....	113	....	
T. 74 N., R. 9 W. (CLAY; PART OF DUTCH CREEK).					
John Fleig..........	Richland..........	168	37	Limestone..	Water in rock at 165. Heads, 120 feet below curb.
Henry Lewers......	NW. ¼ sec. 3......	240	160	....	Heads 100 feet below curb.

CHAPTER XI.

NORTH-CENTRAL DISTRICT.

INTRODUCTION.

By W. H. Norton.

The north-central district comprises the 11 counties of Butler, Cerro Gordo, Floyd, Franklin, Hancock, Humboldt, Kossuth, Mitchell, Winnebago, Worth, and Wright. The predominant dip of the Paleozoic strata is southward. (See Pl. VII, p. 272.) In the northern part of the area the strata dip gently toward the east, the axis of the trough lying apparently in Floyd County. In Floyd and Butler counties a strong southwestward dip is evident. The gradient of the St. Peter southwest from Osage to Fort Dodge is about 9.5 feet per mile and from Mason City south to Hampton is nearly 20 feet per mile.

The rocks immediately underlying the drift in Mitchell, Worth, and Floyd and most of Butler and Cerro Gordo counties are Devonian; in the remainder of the area, except in western Kossuth County, where Cretaceous formations appear, the rocks are Mississippian.

The geologic and artesian conditions in the eastern half of the area are fairly well known through the records of wells at Osage (Pl. VII, p. 272), Charles City, Mason City (Pl. V, p. 238), and Hampton; but in the western half the only well reaching the Paleozoic sandstones is that at Algona, of which practically nothing is known.

The Paleozoic rocks thin rapidly toward the west and north, and some of the formations probably disappear. Thus, at Emmetsburg, a few miles beyond the western boundary of the area, from the bottom of the Cretaceous to the top of a rock called granite by the drillers, is but 632 feet. (See Pl. XVI, p. 672.) If the Algonkian or Archean rocks were really reached at this depth, the entire Paleozoic is here comprised within little more than 600 feet, though at Des Moines it exceeds 3,000 feet; if the bottom of the well is in dolomite, as the drillings indicate, and this belongs to the Prairie du Chien group, the same narrow limit is set to a body of rock which in eastern and central Iowa ranges in thickness from 1,700 to 2,000 feet.

Pennsylvanian rocks appear only in a few townships of Humboldt County. The Niagara is probably present only in greatly attenuated beds, and the Devonian may thin out before it reaches Kossuth County. The Maquoketa may persist throughout the area, and the Galena and Platteville probably underlie it all, although they seem to become increasingly shaly toward the west. If the deeper sandstones have been correctly correlated, the St. Peter maintains a thickness of about 100 feet to the extreme northern and western boundaries of the area—a fact of prime importance in the matter of artesian supplies. In the eastern counties the divisions of the Prairie du Chien group are well marked, and the Jordan, St. Lawrence, and Dresbach formations are also distinguishable. In the southwestern counties the dolomites of the Prairie du Chien group may become increasingly arenaceous and give place in part to sandstones.

If the Minnesota well records are correctly interpreted, the St. Peter sandstone should be found in the northern tier of counties at about 600 feet above sea level, and in the southern tier, along the south line of Wright and Franklin counties, at about 300 feet below sea level. Thus, it is so near the surface that its waters, together with those of the limestones and sandstones immediately below, can be exploited at no very great expense over the entire area with fair chances of success. Wells carried 400 or 500 feet below the base of the St. Peter will in most places tap the water beds of the Prairie du Chien and Jordan or their western equivalents, and should reach the shales of the St. Lawrence formation. It will hardly be advisable to drill through these shales to the Dresbach sandstone. The red clastic beds (Algonkian ?) found in Minnesota may occur also in this area, but as these beds yield little water their exploitation is hardly more warranted than is that of granite or quartzite.

The artesian waters of this area are of high grade. (See pp. 139–141, 145–147.)

BUTLER COUNTY.

By M. F. Arey.

TOPOGRAPHY.

In Butler County the soil is everywhere fertile and tillable and agriculture is the principal occupation. There is no large city in this county, but there are eight or nine towns and villages, with population ranging from 400 to about 1,150. With two exceptions, Allison and Bristow, which are on the prairie level, the towns are in the valleys of the principal streams.

The area is crossed from the north and west by three tributaries of Cedar River. Shell Rock River traverses the northeast corner for a distance of 20 miles or more, its drainage area comprising about three-eighths of the county. West Fork of Cedar, draining an equal area, flows in a somewhat more easterly course through the south-central part of the county for more than 30 miles. The rest of the county, embracing principally the south row of townships, is drained to Beaver Creek. These streams and their larger tributaries, with two or three minor exceptions, have broad flood plains of alluvium, which constitute fully one-third of the area of the county.

Between West Fork of Cedar and the Beaver is a ridge of Kansan drift, which begins in the southern part of Madison Township (T. 91 N., R. 18 W.) and the northern part of Washington Township (T. 90 N., R. 18 W.), and extends to nearly the central part of Monroe Township (T. 90 N., R. 17 W.). Another ridge begins in the west-central part of Albion Township (T. 90 N., R. 16 W.) and extends east on through Beaver Township (T. 90 N., R. 15 W.), reaching its maximum height about 80 feet above the valley of the Beaver, not far from New Hartford. There is also a beautiful cluster of wood-crowned hills of Kansan drift in secs. 26, 27, and 35, Madison Township.

The Iowan drift plain is 10 to 15 feet above the valleys of the smaller streams and 30 to 40 feet above the valleys of the larger streams. The natural drainage is better developed than in most counties where Iowan drift prevails.

GEOLOGY.

Throughout the northern and eastern portions of the county, comprising three-fourths of its area, the drift rests on the Cedar Valley limestone of the Middle Devonian series (Pl. VII, p. 272); in nearly three-fourths of the remainder it lies on the Lime Creek shale of the Upper Devonian; in scarcely more than one township in the southwest corner is it shown by outcrops to rest on the Kinderhook group of the Mississippian series.

The Cedar Valley limestone in this county shows at the top a layer characterized by thin plates with conchoidal surfaces. Predominantly and characteristically, however, it consists of an inferior lithographic rock which is much jointed, shows numerous thin clay partings, and usually yields no water. At the base of the lithographic layers is a soft, earthy limestone which shows water-worn channels of considerable size.

The outcrops of the Lime Creek shale, so far as observed in the county, belong chiefly to its upper beds, described by Calvin as the Owen substage,[1] the lower part (Hackberry substage of Calvin) being seen in but one locality. The upper beds in the main are readily pervious to water, as are the sandstone and much-jointed limestone of the Kinderhook group.

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[1]Ann. Rept. Iowa Geol. Survey, vol. 7, 1897, pp. 162-166.

UNDERGROUND WATER.

SOURCE.

Water is obtained from the Buchanan gravel, from the sandstone of the Kinderhook group, from the base of the upper division of the Lime Creek shale (Owen substage of Calvin), from the shelly rock layers of the Cedar Valley limestone, and from the earthy limestone just below the lithographic beds of the Cedar Valley limestone.

DISTRIBUTION.

In the part of the county northeast of the valley of the Shell Rock, and including all of Fremont and the northeast halves of Butler and Dayton townships, the drift is everywhere thin and rock reaches the surface in many places. Several kettle holes and small ponds occur along the northern border. Little trustworthy information concerning the wells of this district could be obtained, but a drilled well in the north half of Fremont (sec. 22, T. 93 N., R. 15 W.), which was completed in 1904, is believed to be typical. The well is 5 inches in diameter and 87 feet deep and ends in soft limestone underlying the lithographic beds. The water is medium hard and plentiful.

Log of well in Fremont Township.

Material.	Thickness.	Depth.
	Feet.	*Feet.*
Soil and drift (Iowan), followed by gravel (Buchanan)	7	7
Clay, yellow, and shelly stone	20	27
Limestone (Cedar Valley); some clay partings	60	87

In the valley of Shell Rock River, a tract about 20 miles long and 2 to 3 miles wide, the wells range in depth from 10 to 30 feet, are dug or driven, and obtain an abundance of good water in the Buchanan gravel, which everywhere and to an unusual depth underlies the alluvium. The towns of Greene, Clarksville, and Shell Rock are in this district. Part of Greene is on an elevated bench where the wells are about 50 feet deep, but the wells in the plain have an average depth of 25 feet and are mostly driven. Greene has a public well located one-half mile north of the railroad station, on top of a gravel ridge 30 feet or more above the river plain; this well is wholly in sand and gravel and is 25 feet deep; water stands in it constantly to a depth of 10 or 12 feet. At Clarksville many wells enter the shelly rock about 5 feet, although many stop in the gravel. At Shell Rock, at a point where rock is found in the river bed, wells are drilled to a depth of 50 to 80 feet, 50 to 60 feet being in rock. The water is hard as compared with that in the driven wells in the southeast part of the town, which are 20 to 30 feet deep. The water is of excellent quality.

In the northeastern part of the elevated Iowan plain lying between the Shell Rock and West Fork of Cedar the drift is thin, but in the southwestern part it ranges from 100 to 200 feet. The wells on this upland range in depth from 65 to 207 feet. The shallower wells end in drift, the deeper penetrate rock to distances ranging from 15 to 140 feet.

In West Point Township (sec. 32, T. 92 N., R. 17 W.) a well 200 feet deep is 40 feet in rock; water is plentiful but hard. Most wells in this vicinity are 160 to 180 feet deep. In east half of sec. 22, same township, a well 80 feet deep wholly in drift, yields good water in abundance.

In Bennezette Township, in the NE. ¼ sec. 19, T. 93 N., R. 18 W., is a well 207 feet deep. The owner reported 60 feet of drift, 39 feet of loose rock, and bottom of well in solid rock. The loose rock is believed to belong to the upper division of the Lime Creek shale. The owner reports a little water in this material. A part of the material below this is believed to belong to the lower division of the Lime Creek shale, the well ending in Cedar Valley limestone. Another well one-half mile south gives good water at a depth of 189 feet. Another a mile north is but 75 feet deep.

In Pittsford Township, in the NE. ¼ sec. 5, T. 92 N., R. 18 W., is a well 106 feet deep, the lowest 6 feet in loose rock, believed to be the Cedar Valley limestone. At Dumont driven wells find water at 15 to 50 feet. Rock occurs at 60 feet in the town, but on a hill to the north the drift is 95 feet deep.

On the alluvial plain of West Fork of Cedar River is a tract 2 to 3½ or 4 miles wide and about 30 miles long, on which water is obtained by driven or dug wells ranging in depth from 10 to 30 feet, the differences being due largely to the great thickness of the Buchanan gravel, any part of which ordinarily yields water.

The western end of the upland region between the plain of the West Fork of Cedar and that of Beaver Creek is wide and is more varied in elevation and character than are other parts of the county. This district narrows toward the east until it is occupied almost exclusively by the Kansan morainic hills. Accurate data for wells in the western part were not generally obtained, but it is reported that most wells in this region are shallow and end in gravel. Two miles north of Austinville, in sec. 10, T. 90 N., R. 18 W., a well 40 feet deep, 3 feet in limestone of the Kinderhook group, yields a plentiful supply of hard water. A broad valley of a tributary of the Beaver shares with the latter the most of the northern area of Monroe Township (T. 90 N., R. 17 W.) in which the wells are all driven and shallow.

In the eastern third of this district the ridge of loess-crowned Kansan drift hills dominates the topography almost wholly. Wells in this area range in depth from 55 to 190 feet and most of them end in gravel.

Near the center of sec. 27, Beaver Township, a drilled well, 101 feet deep, penetrates rock to an unknown extent. In the NW. ¼ sec. 27 a drilled well on top of a hill 70 feet above the creek valley is 190 feet deep and obtains a plentiful supply of water in gravel beneath blue clay. In sec. 15 a drilled well 122 feet deep passes 10 feet into limestone.

The alluvial plain of Beaver Creek is narrower than the other valley plains but is in other respects similar, except that in the first 2 or 3 miles of the course of the creek through the southwest corner of the county it is much constricted by steep stony bluffs which are held up by limestone of the Kinderhook group. Most of the wells in this valley are driven to depths of 10 to 16 feet. The deeper gravels are more heavily stained with iron and give to the water a taste so disagreeable that many prefer the shallower wells. New Hartford, Parkersburg, Aplington, and Austinville, towns on the Illinois Central Railroad, are situated wholly or in part in this valley, and obtain their water supply largely from the gravels just below the alluvium.

In the narrow strip of upland south of Beaver Creek water is obtained by drilled or driven wells.

In the southeast part of Parkersburg, at an elevation of 30 or 40 feet above the railroad station, a well 142 feet deep ends in gravel just above the rock. In South Parkersburg a drilled well gives the following section:

Section of drilled well in South Parkersburg.

	Thickness.	Depth.
	Feet.	*Feet.*
Drift	142	142
Limestone; water bearing, but not sufficiently so	28	170
Soapstone; described by driller as a greasy, solid clay	87	257
Limestone; firm; water plentiful, good, but hard	5	262

No rock outcrops in this vicinity. The nearest exposure is a limestone belonging to the upper division of the Lime Creek shale (Owen substage of Calvin), 3 miles northeast. It is believed that the limestone above the "soapstone" belongs to this upper division and that the "soapstone" belongs to the lower division of the Lime Creek shale (Hackberry substage of Calvin). The limestone in which the well ends must be the Cedar Valley limestone.

Three miles due west of Parkersburg a drilled well is 65 feet deep, the last 5 feet being in rock, undoubtedly the upper division of the Lime Creek shale.

In the east half of sec. 32, Washington Township, a drilled well 30 feet deep is 14 feet in rock. This well is in the Kinderhook area and the surface is at least 40 feet above the creek level. The water is somewhat iron tainted. The nature of the rock could not be ascertained.

SPRINGS.

Small springs are not uncommon in some portions of the county, many having their source in the drift and issuing from slopes where the interglacial gravels or sands chance to be exposed. A few springs issue from limestone or sandstone beds, exposed by stream erosion. Such a spring is in the SE. ¼ sec. 11, Pittsford Township, near a quarry in the Cedar Valley limestone. Another is near the center of sec. 31, Washington Township. The rock is limestone of the Kinderhook group. Yet another spring is in the SW. ¼ sec. 28 of the same township. The rock is sandstone of the Kinderhook group. Springs of the type first mentioned are in the SW. ¼ sec. 29, Fremont Township, and in the NE. ¼ sec. 11 and the SW. ¼ sec. 15, West Point Township. Several springs in Shell Rock Township afford water for the stock in the pastures. A. Best, of Clarksville, obtains a good supply of excellent water from a hillside spring piped to his buildings.

CITY AND VILLAGE SUPPLIES.

Allison.—Allison (population, 495) pumps its supply by gas engine from an 8-inch well drilled to 180 feet, reaching rock at 40 feet. The water bed is limestone. The well was completed in 1899. A deep well would probably reach the St. Peter sandstone at 1,000 feet (50 feet below sea level), and a well 1,100 feet deep should give a supply ample for the town.

Greene.—Greene (population, 1,150) pumps by steam from a dug well 20 feet in diameter and 25 feet deep, all in sand and gravel. The well is walled with limestone. The head is 10 feet below the curb and does not lower on pumping. The well was completed in 1900.

New Hartford.—New Hartford (population, 482) obtains a supply by windmill from a driven well 2½ inches in diameter and 28 feet deep, wholly in gravel. The curb is on a slope 10 feet above the river. The well was completed in 1896.

Shell Rock.—The town of Shell Rock (population, 741) obtains its supply from a dug well 10 feet in diameter and 15 feet deep, 5 of which is in limestone. A force pump run by water power is used. The water is used for washing and for stock. There are 35 taps.

The curb of the well is 10 feet above the river level. It was completed in 1900.

WELL DATA.

The following table gives data of typical wells in Butler County:

Typical wells of Butler County.

Owner.	Location.	Date of completion.	Elevation of curb.	Diameter.	Depth.
			Feet.	*Inches.*	*Feet.*
R. H. Stewart	Bristol; on Iowan drift plain	1906		5	122
Chicago Great Western Railway.	....do	1906		10	300
Private	Dumont; on alluvial plain				15-50
Electric Light, Heat & Power Co.	Parkersburg; in valley	1898	10 feet below railway station.	8	90

Owner.	Depth to rock.	Source of supply.	Casing.	Head below curb.	Pumped by—	Use.
	Feet.		*Feet.*	*Feet.*		
R. H. Stewart	48½	Limestone	48.5	52	Hand	Domestic.
Chicago Great Western Railway.	40				Gasoline	Locomotives.
Private						
Electric Light, Heat & Power Co.	14	Limestone	20	76	Steam; Bell pump; lowers slightly.	General; 120 taps.

CERRO GORDO COUNTY.

By O. E. Meinzer and W. H. Norton.

TOPOGRAPHY AND GEOLOGY.

Cerro Gordo County is divisible into two distinct topographic provinces. An area nearly coextensive with the western tier of townships shows a thick deposit of Wisconsin drift, typical morainic topography, poor drainage, and numerous lakes, ponds, and swamps; the rest of the county shows a much thinner layer of drift (Iowan) and a smoother topography. The drainage system in the Iowan area is, however, well developed, many of the streams having cut into the bedrock.

The formations exposed in the county [1] include glacial drift (Wisconsin and older), Mississippian limestone, and Devonian strata consisting of limestone at the top, shale in the middle, and limestone at the base. The rock formations dip gently to the southwest; hence, if the drift were removed, they would outcrop in parallel bands crossing the county with a northwest-southeast trend. Thus the Devonian shale lies next below the drift in a belt that extends

[1] Calvin, Samuel, Geology of Cerro Gordo County: Ann. Rept. Iowa Geol. Survey, vol. 7, 1897, pp. 144 et seq.

through Mason City (Pl. V, p. 238); toward the southwest it passes beneath younger strata of limestone, and farther northeast it is absent and the underlying older Devonian strata are found immediately below the drift.

UNDERGROUND WATER.

SOURCE.

Water is obtained from the glacial drift, the limestone above the Devonian shale, the limestone immediately below the shale, and deeper limestone and sandstone formations. The Wisconsin drift is so imperfectly drained that where it occurs the ground-water table is near the surface and nearly all the porous beds are saturated. Many of the wells are very shallow, but some draw from beds of sand and gravel at greater depths. Where the Wisconsin drift sheet is absent (Pl. III), the drift is too thin and well drained to be a reliable aquifer. In the western part of the county, the limestones above the Devonian shale will furnish large supplies, but farther northeast, where the shale is near the surface, these limestones fail as a source of water, and the Devonian limestone that lies stratigraphically below the shale constitutes the most important water bearer.

In the western tier of townships dug and bored wells are common but there are also numerous drilled wells, which either end in drift or enter rock. Elsewhere in the county drilled wells are the dominant type, and several have been sunk to considerable depths.

HEAD.

Water from the Galena dolomite and the St. Peter sandstone rises at Mason City to a little over 1,100 feet above the sea, which is slightly above river level, but at that place is about 140 feet below Clear Lake, 130 feet below Burchinal, and 90 feet below Thornton. Drilling by the municipality and by the Chicago, Milwaukee & St. Paul Railway at Mason City seems to show that the water in the still deeper sandstones is under less head.

In the west, the water from the limestone immediately underlying the drift will probably rise considerably higher than 1,100 feet above sea level, but if a deep well were drilled the head would probably be lowered as greater depths would be reached. In the relatively low area at the east base of the high morainic belt, the water from drift and from the limestone below the drift is under good pressure and will flow in certain tracts, as along West Fork of Beaver Creek.

CITY AND VILLAGE SUPPLIES.

Clear Lake.—At Clear Lake (population 2,014) about one-half of the residents depend on the city waterworks, the supply for which is taken from the lake; the rest use private wells, most of which are shallow and end in drift. The distribution system consists of a standpipe, more than 3 miles of mains, 35 fire hydrants, and about 140 taps. The average daily consumption is estimated at 60,000 gallons.

Dougherty.—The railway well at Dougherty (population, 171) is 417 feet deep and ends in shale which probably is the Maquoketa. It is reported to have been pumped at 90 gallons a minute and to have a normal water level of 135 feet below the surface.

Emery.—The well at Emery, owned by the electric railway company, was drilled into shale, but gets its supply from higher horizons. In this well the water stands only 5 feet below the surface and the yield is large.

Section of electric railway well at Emery.

	Thickness.	Depth.
	Feet.	*Feet.*
Drift	25	25
Limestone	30	55
Sandy transition bed	5	60
Shale (entered)	15	75

Mason City.—The public supply in Mason City (population, 11,230) is furnished by flowing wells that discharge into 2 large underground reservoirs. City well No. 1, which was drilled in 1892 by Henry F. Miller, of Chicago, is 1,350 feet deep and 8 inches in diameter. The elevation of the curb is 1,077 feet above sea level, water level at curb. The water beds are variously reported at 426 and at 537 feet above sea level. As the supply at 426 feet above sea level was far from sufficient, drilling was continued to 1,350 feet, where the drill encountered a crevice in the St. Lawrence formation and the flow was lost. The well was then plugged at 651 feet.

City wells Nos. 2, 3, and 4 are 651 feet deep and 5 inches in diameter. The curb is 1,077 feet above sea level and the water level is at curb. Water is obtained at a depth of about 600 feet in a porous limestone, said to be 40 inches thick, lying above the Decorah shale. The temperature of the water is 49° F.

City wells Nos. 5 and 6, located about 500 feet from the reservoir, are 616 feet deep and 10 inches in diameter, and are cased to a depth of 50 feet. Normally the water flows above surface, but is lowered 80 feet by pumping.

City wells Nos. 2, 3, and 4 were drilled in 1892 at the corners of a parallelogram 60 feet long and 40 feet wide, the other corner being occupied by city well No. 1. This space, excavated in rock to the depth of 16 feet, forms the reservoir into which the wells discharge. The natural flow of wells 1 to 4 combined was 60 gallons a minute.

In 1894 the wells were cased and an air lift was installed, 200 feet below the surface, increasing the discharge to 150 gallons a minute. from the four wells. All six wells still flow and furnish under compressed air an average of 400,000 gallons a day with a maximum of 650,000 gallons.

The water is pumped from the reservoir directly into the mains, the combined capacity of the three pumps being 2,100 gallons a minute. There are 15½ miles of mains, 108 fire hydrants, and about 1,000 taps. Approximately one-half of the people are supplied from the city waterworks; the other half depend on private wells, most of which are drilled only a short distance into rock and furnish only small amounts of water.

Record of strata in Mason City waterworks well No. 6.

	Thickness.	Depth.
Devonian and Silurian (?):	*Feet.*	*Feet.*
Dolomite, light yellow-gray, subcrystalline; in sand	10	10
Dolomite, brown, crystalline; in small chips	40	50
Limestone, blue-gray, rapid effervescence; crystalline; much yellow-gray flint	30	80
Dolomite, brown, crystalline; considerable calcite	30	110
Limestone, light gray and blue mottled; rather slow effervescence; some brown dolomite	30	140
Limestone, brown; rather slow effervescence; considerable calcite	10	150
Dolomite, light gray, crystalline, vesicular, fossiliferous	17	167
Limestone, blue-gray, crystalline; of rapid effervescence; and dolomite, light yellow, hard, in small chips and sand	8	175
Dolomite, crystalline, brown; 2 samples	25	200
Ordovician:		
Maquoketa shale—		
Limestone, brown; of rapid effervescence; dark-brown inflammable shale; and blue-gray limestone of rather slow effervescence	15	215
Shale, medium dark blue-gray, highly calcareous; in large chips	5	220
Limestone, blue-gray, argillaceous; rather slow effervescence; some brown dolomite	6	226
Limestone, medium dark blue-gray, argillaceous; in fine chips; 2 samples	39	265
Shale, medium dark blue-gray, highly calcareous; in chips; 2 samples	35	300
Galena dolomite to Platteville limestone—		
Limestone, light gray and whitish, dense, fine-grained; rapid effervescence; in large flakes	15	315
Dolomite, gray, crystalline; chips of drab clay shale	5	320
Dolomite, dark brown, vesicular, cherty; 2 samples	25	345
Chert and dark-gray dolomite	15	360
Limestone, as at 315 feet	4	364
Chert, gray; and dark-gray dolomite; 2 samples	21	385
Dolomite, brown; much chert	33	418
Limestone, yellow-gray, earthy; rapid effervescence	15	433
Limestone, blue-gray; and chert	7	440
Limestone, earthy, whitish, and light-yellow; Trenton facies; 16 samples	140	580

City well No. 7 has a depth of 865 feet and a dimeter of 10 inches; casing, 10 inches from surface to 50 feet, 8 inches from 620 to 750 feet. The curb is 1,109 feet above sea level; the head at a depth of 220 feet was 40 feet above the curb; after passing the St. Peter it was about the same as in the wells in the reservoir. The only water bed mentioned is at 70 feet. The well is 470 feet from the wells in reservoir and 700 feet from well No. 6. It was completed in 1910 at a cost of $2,579 by W. L. Thorn, of Platteville, Wis.

Description of strata in well No. 7, Mason City waterworks.

	Depth in feet.
Devonian (and Silurian?) (210 feet thick; top, 1,109 feet above sea level):	
Limestone, cream-yellow, finest grain; subconchoidal fracture; rapid effervescence; in large chips	25
Limestone; as above; and dark blue-gray compact, nonmagnesian limestone; in small chips	50
Dolomite, drab, crystalline; in flaky chips; light-gray limestone of rapid effervescence; some dark-blue fissile shale.	75
Limestone, brown-gray; subcrystalline; rather slow effervescence; in large chips	100
Limestone, light gray; rather slow effervescence; in sand	110
Limestone, drab, subcrystalline, vesicular; rather slow effervescence; 3 samples	140
Dolomite, light brown-gray; in sand	150
Limestone, buff, vesicular, with molds of fossils; rather slow effervescence, with lighter nonmagnesian limestone	160
Dolomite, buff, compact	170
Limestone, drab, brownish, compact; rather slow effervescence; with limestone of lighter tint and rapid effervescence	190
Dolomite, drab and brown; in coarse sand	200
Ordovician:	
Maquoketa shale (90 feet thick; top, 899 feet above sea level):	
Shale, light blue-gray, calcareous, laminated; in large chips; also some buff dolomite	210
Dolomite, buff, saccharoidal	220
Shale, light blue-gray, calcareous; in chips; 2 samples.	240
Dolomite, drab and brown, vesicular; some brown inflammable shale	250
Shale, blue-gray, highly calcareous; in large chips; 4 samples	290
Galena dolomite to Platteville limestone (450 feet thick; top, 809 feet above sea level):	
Dolomite, gray; in coarse sand	300
Limestone, gray and buff; considerable calcite; rapid effervescence	310
Limestone, gray, soft; in large chips; rapid effervescence	320
Limestone, fine saccharoidal, greenish gray; rapid effervescence; in sand with powder of shale	330
Dolomite, gray, vesicular; in places cherty, crystalline; 5 samples	380
Chert, light gray; and blue-gray shale	390
Chert, light gray; shale; and hard argillaceous dark-gray limestone	400
Dolomite, dark gray, vesicular; and chert	410
Dolomite, dark buff-gray; disk of crinoids	420
Limestone, dark gray, saccharoidal; moderately rapid effervescence; in large flakes; 3 samples	450
Limestone and shale; limestone of Trenton facies, earthy, grayish-buff; in chips; fossiliferous; effervescence rapid	460

Ordovician—Continued.

Galena dolomite to Platteville limestone (450 feet thick; top, 809 feet above sea level)—Continued.

	Depth in feet.
Limestone, buff, nonmagnesian	470
Limestone, whitish or light gray, earthy, nonmagnesian; in flaky chips often of considerable size; in places fossiliferous; 12 samples	590
Limestone, as above, but blue-gray	600
Limestone, green-gray; and shale	610
Limestone, cream-colored	620
Limestone, blue-gray; crystalline; in coarse sand	630
Limestone, blue and yellow-gray; in flaky chips; 2 samples	650
Shale, green; in molded masses, calcareous; 2 samples.	670
Shale, as above; some chips of hard dark limestone of rapid effervescence	680
Shale, green; in molded masses; 2 samples	710
Shale, green; fine, gritless, noncalcareous; in splintery chips	720
Limestone, blue-gray; rapid effervescence; some hard noncalcareous green shale	730
Shale, hard, green, noncalcareous; in large chips; some limestone	740
St. Peter sandstone (77 feet thick; top, 359 feet above sea level):	
Sandstone, white; rounded grains, rarely exceeding 0.7 millimeter in diameter; 2 samples	760
Sandstone, as above, but slightly finer; 2 samples	780
Sandstone, as above; largest grains attain 0.8 millimeters in diameter; some light-yellow limestone and green shale; 2 samples	800
Sandstone, clean; as at 780 feet	810
Sandstone, white; with calcareous cement	820
Prairie du Chien group:	
Shakopee dolomite (40 feet penetrated; top, 285 feet above sea level):	
Dolomite, light gray and light brown; in fine sand; considerable quartz sand; 3 samples	824–850
Sandstone, calciferous; or limestone, highly arenaceous; grains fine, about 0.6 millimeter in diameter; white, well rounded	860

Driller's log of city well No. 7, Mason City.

	Thickness.	Depth.
	Feet.	*Feet.*
Sand	4	4
Lime, white	26	30
Lime, blue and white	19	49
Lime, gray	40	89
Lime, white	6	95
Lime, brown	5	100
Lime, brown, and shale	5	105
Lime, gray bluish	10	115
Lime, brown and gray	8	123
Shale in soft thin layers	....	....
Lime, brown	22	145

Log of city well No. 7, Mason City—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Lime, brown, and shale	15	160
Lime, gray	22	182
Lime, brown and gray	28	210
Lime, brown and gray, and shale	15	225
Lime, blue	13	238
Lime, blue, with shale	7	245
Lime, blue	64	309
Lime, blue and gray	14	323
Lime, gray and white	23	346
Lime, gray, and shale	61	407
Rock, gray brown	135	542
Rock, gray and white	46	588
Lime, gray and white	6	594
Lime, gray and bluish	31	625
Shale and clay	93	718
Shale, clay, and brown lime	20	738
Shale and clay	9	747
Sandstone (St. Peter)	73	820
Lime, gray and white	44	864

The Lehigh Portland Cement Co. has two wells located in sec. 33, Lime Creek Township, just north of city limits. They have a depth of 405½ feet and a diameter of 12 inches to 14½ feet and 10 inches to 405½ feet. The head is within 10 feet of the surface. On bailing with sand pump for 1 hour at a rate of about 45 gallons a minute the water fell to 30 feet below surface. The well was completed in 1911 by J. B. Lowe & Co., of Mason City. These wells were sunk as a reserve supply in case the Calamus Creek reservoir supply proved inadequate.

Description of strata, well No. 2, Lehigh Portland Cement Co., at Mason City.

	Depth in feet.
Soil, black; no sample	4
Devonian (and Silurian?):	
Limestone, light colored; no sample	20
Limestone, light buff and blue-gray compact; rapid effervescence; in large chips	20
Limestone, light gray, dense; earthy luster; rapid effervescence	30
Dolomite, crystalline, buff; in sand	40
Dolomite, drab, crystalline; in small chips	50
Dolomite, darker drab; rather slow effervescence; with drab fissile shale and some nonmagnesian light-colored limestone; 2 samples	70–80
Dolomite, dark gray, hard, vesicular; with casts of fossils; in large chips	90
Limestone, nonmagnesian, yellow-gray, compact, lithographic; conchoidal fracture	100
Limestone, gray buff, hard; rather slow effervescence; subcrystalline; in sand and small chips	110
Dolomite, blue gray, crystalline; in small chips	120
Limestone, light brown-gray; in thin flakes; moderately rapid effervescence	130

	Depth in feet.
Devonian (and Silurian ?)—Continued.	
Limestone, light brown-gray; in sand at 140 feet; in large flakes at 150 feet; rather slow effervescence; 2 samples....	150
Limestone; rather slow effervescence; gray buff at 160, 180, and 190 feet; drab at 170 feet; hard; in small chips; 4	190
samples Dolomite, brown, crystalline; 2 samples	210
Limestone, light yellow, lithographic; nonmagnesian conchoidal fracture	220
Ordovician:	
Maquoketa shale:	
Limestone, brown; moderately rapid effervescence; considerable brown and black inflammable shale.........	230
Dolomite, drab, hard; some blue shale; 2 samples.....	250
Shale, blue, pyritiferous; highly calcareous; in sand; 4 samples............	290
Limestone, highly argillaceous; or shale, highly calcareous, blue............	300
Galena and Platteville limestones:	
Limestone, drab; rapid effervescence; 2 samples......	320
Limestone, light buff, saccharoidal, minutely vesicular; moderately slow effervescence; in large chips.......	330
Limestone, as above, but cherty; 3 samples............	360
Chert, white............	370
Chert, white, with hard drab dolomite; 3 samples.....	400

The well of Jacob E. Decker & Sons has a depth of 604 feet and a diameter of 10 inches. The elevation is about 1,092 feet above sea level and the head 8 feet below the curb; cased to 18½ feet. The capacity is 225 gallons a minute, the water coming from a depth of 100 feet; temperature, 50° F. The well was completed in 1911 at a cost of $1,850 by W. L. Thorn, of Platteville, Wis.

Description of strata in Jacob E. Decker & Sons' well at Mason City.

	Depth in feet.
No samples............	220
Limestone, hard, fine grained, brown, nonmagnesian............	220
Maquoketa shale:	
Shale, blue-gray, laminated; in large chips; some brown inflammable shale	230
Limestone, light blue-gray, argillaceous; 2 samples.........	250
Shale, and highly argillaceous blue-gray limestone; 5 samples............	300
Galena dolomite to Platteville limestone:	
Limestone, brown, crystalline, nonmagnesian..............	310
Shale, blue; some white macrocrystalline nonmagnesian limestone	320
Dolomite, blue-gray; 3 samples............	350
Chert; some limestone and shale; 5 samples...............	400
Limestone, yellow-gray, crystalline; mostly of slow effervescence, with chert and shale; 2 samples..................	420
Limestone, nonmagnesian, yellow-gray and whitish, earthy; 16 samples............	600

The Chicago & North Western Railway well, located 1 mile north of the station, has a depth of 862 feet and a diameter of 10 inches to 53 feet, 8 inches to 650 feet, and 6 inches to bottom; casing, over the shale of the Platteville from 660 to 749 feet. The curb is 1,124 feet above sea level and the head 24 feet below the curb. The tested capacity is 6,500 gallons an hour after 10 hours' continuous pumping with cylinder set 200 feet below the surface. Water comes from 650 feet, above the shale, rising within 16 feet of the surface and supplying 1,000 gallons an hour, and from 746 feet, with rise of water 2 feet in tube and testing (at 756 feet) 1,440 gallons an hour. The main supply is in the St. Peter at 862 feet. The head of this lower water is reported at 117 feet below the curb. Date of completion, 1900.

Driller's log of railway well, near Mason City.

	Thickness.	Depth.
	Feet.	*Feet.*
Loam, clay, and gravel	16	16
Limestone	660	676
Shale	89	765
Sandstone	94	859
Mud	3	862

The Chicago, Milwaukee & St. Paul Railway well No. 1 has a depth of 1,473 feet and diameter of 8 to 6 inches. The curb is 1,128 feet above sea level. The original head was 2 feet below curb and the head in 1896 was variously reported at 30 and 75 feet below curb. The capacity is small, being insufficient to keep a small steam pump running. The well was completed about 1879 by Swan Bros., of Minneapolis. The well has long been abandoned; in 1896 it was used—or misused—as a depot sewer. The water was not found inadequate in quantity, but its quality as a boiler water was inferior to that supplied by the city.

Record of strata in Chicago, Milwaukee & St. Paul Railway well No. 1 (Pl. V, p. 238).

	Thickness.	Depth.
Pleistocene and Recent (28 feet thick; top, 1,128 feet above sea level):	*Feet.*	*Feet.*
Black loam	2	2
Clay	26	28
Devonian and Silurian (276 feet thick; top, 1,100 feet above sea level):		
Limestone, brown, soft, argillaceous	70	98
Dolomite, hard, light bluish gray, granular, subcrystalline; some lighter and softer, briskly effervescent limestone	119	217
Dolomite or magnesian limestone, hard, brown	87	304
Ordovician:		
Maquoketa shale (57 feet thick; top, 824 feet above sea level)—		
Shale, blue	57	361

Record of strata in Chicago, Milwaukee & St. Paul Railway well No. 1 (Pl. V, p. 238)—Continued.

	Thickness.	Depth.
Ordovician—Continued.		
Galena dolomite (350 feet thick; top, 767 feet above sea level)—	*Feet.*	*Feet.*
Limestone, magnesian, hard, pale buff	50	411
Limestone, magnesian, flinty, impure, bluish gray; earthy luster	300	711
Platteville limestone (75 feet thick; top, 417 feet above sea level)—		
Shale, green, slightly gritty; with chert and particles of magnesian limestone	55	766
Dolomite, highly arenaceous, yellow	20	786
St. Peter sandstone (85 feet thick; top, 342 feet above sea level)—		
Sandstone, fine, white; grains rounded and ground	85	871
Prairie du Chien group (308 feet thick; top, 257 feet above sea level)—		
Shakopee dolomite—		
Dolomite, white	113	984
New Richmond sandstone—		
"Mixed lime and sandstone" (no sample)	50	1,034
Oneota dolomite—		
Dolomite, light gray	145	1,179
Cambrian:		
Jordan sandstone (70 feet thick; top, 51 feet below sea level)—		
Sandstone, buff and white	70	1,249
St. Lawrence formation (174 feet thick; top, 121 feet below sea level)—		
Dolomite, hard, gray; flakes of rather hard, green shale	116	1,365
Shale, greenish, highly arenaceous; fragments of dolomite	58	1,423
Dresbach sandstone (45 feet thick; top, 295 feet below sea level)—		
Sandstone, gray; larger grains, rounded; many smaller angular fragments; with some greenish shale	45	1,468
Cambrian or pre-Cambrian (?) (5 feet penetrated; top, 340 feet below sea level):		
"Granite." The sample so labeled consists of sandstone similar to the above, rounded grains about 0.25–0.35 millimeter in diameter, with some dolomite, chert, and shale; none of the constituents of granite are present except quartz	5	1,473

The Chicago, Milwaukee & St. Paul Railway well No. 2 has a depth of 816 feet and a diameter of 6 inches. The curb is 1,135 feet above sea level. The original head was 30 feet below curb; head in 1908, 126 feet below curb. The tested capacity is 120 gallons a minute.

Driller's log of Chicago, Milwaukee & St. Paul Railway well No. 2, near Mason City.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay	36	36
Limestone	659	695
Shale	30	725
Limestone	35	760
Sandstone	56	816
Shale.		

The American Brick & Tile factory has a well 207 feet deep, and the Mason City Brick & Tile factory one 304 feet deep. The water rises within about 20 feet of the surface in the former and about 30 feet in the latter, or to about 1,100 feet above sea level in each. Both wells yield large supplies.

Rockwell.—The city well at Rockwell (population, 700) passes through glacial drift, limestone, and shale, and ends at a depth of 236 feet in limestone beneath the shale. The water stands 20 feet below the surface, or 1,110 feet above the sea, lowering about 25 feet on pumping for 12 hours at 60 gallons a minute. The water is pumped into an air-tight cylinder from which it is delivered by air pressure. The total length of mains is one-half mile, and there are 10 fire hydrants. Only a few homes have service connections, and the total daily consumption probably does not exceed 5,000 gallons.

FLOYD COUNTY.

By O. E. Meinzer and W. H. Norton.

TOPOGRAPHY AND GEOLOGY.

The smooth surface of the Iowan drift plain extends over Floyd County but is moderately dissected by a number of small parallel streams which flow southeastward The thickest drift is found in the northeast in an area which includes the eastern and central parts of Cedar, nearly all of Niles, and the extreme eastern or northeastern part of St. Charles townships. Here many wells have penetrated more than 200 feet of drift, and in one well (NW. ¼ sec. 29, T. 97 N., R. 15 W.) a thickness of 365 feet is reported. Throughout most of the remainder of the county the drift is relatively thin, the average thickness probably being less than 50 feet, and along the streams rock outcrops are common. The numerous irregularities in the rock surface on which the drift rests account for the radical differences in the thickness of the latter noted in drilling wells at points not far apart and on nearly the same level.

The rock which lies immediately below the drift is probably all Devonian in age and consists for the most part of indurated but somewhat cavernous limestone. (See Pl. V, p. 238; Pl. VII, p. 272.) In the southwestern part of the county, including the southern part of Scott and the southwestern part of Union Township, the distance to limestone is commonly 75 to 100 feet, but it is not clear from the data at hand whether this depth is due entirely to glacial drift or in part to the Devonian shale, which is known to be well developed in the next county to the west.

UNDERGROUND WATER.

SOURCE AND DISTRIBUTION.

Water is obtained from (1) alluvial and outwash gravels, which are practically restricted to the valleys, where they yield freely to some shallow wells; (2) glacial drift, which in most parts of the county is too thin and well drained to be a satisfactory source of supply; (3) Devonian limestone, which constitutes the best and most largely utilized aquifer; and (4) lower formations reached in at least one well—the deep well at Charles City.

In Cedar and Niles townships there are many shallow open wells that end in the upper part of the drift, and perhaps even more drilled wells that extend to an average depth of nearly 200 feet and draw unfailing supplies of good water from the lower part of the drift or from the limestone. In many of the deepest wells the water level is low, in some being 100 feet below the surface. In St. Charles and Floyd townships some wells end in alluvial sand and gravel and some in porous drift beds, but the best penetrate the limestone and have an average depth of more than 100 feet. In Riverton Township, where the drift rarely exceeds 60 feet in thickness and is in some localities very thin, most of the satisfactory wells penetrate limestone and are commonly between 120 and 160 feet in depth. In Pleasant Grove Township, where the drift ranges in thickness from less than 10 feet to more than 140 feet, the wells are generally drilled into limestone and have an average depth of perhaps 100 feet. In Rock Grove and Rudd townships the rock is near the surface and is penetrated by practically all wells. The most common depths are between 50 and 150 feet, but in the northern part of Rock Grove Township wells approaching 300 feet in depth are reported. Many of the shallowest wells, such as those common in the village of Nora Springs, do not yield much water, but abundant supplies are usually found if the rock is penetrated some distance. In Rockford and Ulster townships the drift is also thin and in many places wells must be sunk many feet into the rock before obtaining large and dependable supplies. Depths ranging from 30 to 180 feet were reported. In the northern parts of Scott and Union townships, where the limestone is generally near the surface, most of the wells are between 50 and 125 feet deep, but in the southern parts, where the distance to limestone is greater, most of them are between 100 and 200 feet deep.

From the head of water in deep wells at Mason City and at Charles City it appears probable that flows with slight pressure could be obtained from deep wells on the lowest levels in the valley at Marble Rock, Rockford, Nora Springs, and elsewhere, but so much excellent water can be obtained by drilling a few hundred feet into the limestone that it would seem unnecessary to sink to greater depths even for municipal or industrial supplies.

SPRINGS.

The largest springs issue from crevices in the limestone at places where the streams have removed the overlying drift. A good example is afforded by the spring of C. F. Beelar, in the valley of Shell Rock River, at the south edge of the village of Marble Rock, where a stream of several hundred gallons per minute pours from a solution channel in the limestone.

CITY AND VILLAGE SUPPLIES.

Charles City.—The city water supply of Charles City (population, 5,892) is obtained from a well 1,587 feet deep (Pl. V, p. 238; Pl. VII, p. 272), drilled by J. F. McCarthy, of Minneapolis, in 1906, at a cost of $3,591. The well is 10 inches in diameter to 800 feet, 8 inches to bottom, and is cased from top to 250 feet and from 600 to 800 feet; no packing was used. The curb is about 1,013 feet above sea level and the head of water 10 feet above curb. The natural flow is 200 gallons per minute; with vacuum of 7 pounds, 900 gallons a minute. Temperature, 53° F. The strata penetrated are shown in the following table:

Record of strata of deep well at Charles City (Pl. V, p. 236; Pl. VII, p. 272).

	Thickness.	Depth.
Devonian (120 feet thick; top, 1,013 feet above sea level):	*Feet.*	*Feet.*
Limestone	14	14
Limestone, yellow; rapid effervescence	36	50
Limestone, light brown-gray, rather soft, fine granular, crystalline; moderately rapid effervescence	10	60
Limestone, yellow; rapid effervescence	10	70
Limestone, like that at 50–60 feet; some fragments of yellow, soft, argillaceous limestone, probably fallen in	10	80
Limestone, highly argillaceous, in light-blue chips, and limestone hard, gray, of moderately slow effervescence; 2 samples	20	100
Shale, blue, plastic, calcareous; 2 samples	20	120
Silurian? (180 feet thick; top, 893 feet above sea level):		
Limestone, gray, soft, granular, argillaceous; earthy luster; slow effervescence	10	130
Limestone, blue-gray, argillaceous; some nodules of pyrite; moderately slow effervescence; 3 samples	30	160
Shale, and soft, gray argillaceous limestone	10	170
Limestone, blue-gray, argillaceous; rapid effervescence; 3 samples	30	200
Limestone and shale, limestone yellow with slight quartzose residue; shale blue, calcareous; in chips	10	210
Dolomite, gray, porous, rather hard, with blue-gray shale; in chips	10	220
Dolomite, gray, hard, in part vesicular; with molds of fossils	20	240
Shale, blue, calcareous; in chips and powder; and limestone, blue-gray, some crystalline and of rapid effervescence, some hard, compact, and of slow effervescence	10	250
Limestone, blue-gray, rather hard; moderately slow effervescence; earthy luster	10	260
Limestone and shale, blue-gray; limestone varying in rate of effervescence	10	270
Dolomite, gray; earthy luster; 2 samples	20	290
Dolomite, gray, minutely saccharoidal; some yellow limestone, probably fallen from above	10	300
Ordovician:		
Maquoketa shale (110 feet thick; top, 713 feet above sea level)—		
Shale, blue, calcareous, in powder	10	310
Shale and limestone; shale blue; limestone gray, cherty; slow effervescence	20	330
Limestone, gray; moderately slow effervescence, rather hard; in sand	20	350
Shale, light blue-gray; calcareous; in powder with sand of gray dolomite; 4 samples	40	390
Limestone, light gray, hard; rapid effervescence; somewhat siliceous	10	400
Shale, blue-gray; with limestone of rapid effervescence	10	410
Galena limestone to Platteville limestone (380 feet thick; top, 603 feet above sea level)—		
Limestone, argillaceous, yellow-gray, somewhat siliceous; rapid effervescence	10	420
Limestone, gray, earthy luster; rapid effervescence; in thin flaky chips; 5 samples	50	470
Limestone, light yellow-gray, hard, somewhat siliceous, magnesian; cherty at 500 feet; 4 samples	40	510
Shale and limestone, gray	10	520
Limestone, light yellow-gray, crystalline, minutely porous, somewhat siliceous; slow effervescence	20	540
Limestone, yellow-gray and blue mottled; crystalline; rapid effervescence	10	550
Limestone, gray; moderately slow effervescence	10	560
Limestone, gray, soft; earthy luster; argillaceous; rapid effervescence; 4 samples	40	600
Dolomite, hard, crystalline, light gray; effervescence slow; cherty	10	610
Limestone, light gray; rapid effervescence; 2 samples	20	630
Shale, blue, calcareous; in masses of concreted powder; 3 samples	30	660
Shale, buff, calcareous; residue, ocherous, cherty, and minutely arenaceous	10	670
Shale, blue; as at 630 to 660 feet	20	690
Shale, hard, green, fossiliferous; in chips	30	720
Sandstone, highly argillaceous, gray, slightly calcareous; grains fine, rounded, of considerable diversity of size; the largest more than 0.5 millimeter in diameter; 8 samples	70	790

Record of strata of deep well at Charles City—Continued.

	Thickness.	Depth.
Ordovician—Continued.		
St. Peter sandstone (80 feet thick; top, 223 feet above sea level)—		
Sandstone, white; clean quartz sand grains well rounded and sorted; largest 1 millimeter in diameter	*Feet.* 10	*Feet.* 800
Sandstone and dolomite; quartz sand of rounded grains with much white chert and gray siliceous dolomite and green shale; granular; 4 samples	40	840
Sandstone, white; clean grains of quartz; fine grained	10	850
Sandstone, white; grains mostly 0.75 millimeter in diameter; calcareous cement	10	860
Sandstone, white	10	870
Prairie du Chien group (300 feet thick; top, 143 feet above sea level)—		
Shakopee dolomite:		
Dolomite, light yellow-gray; in meal; little quartz sand in drillings	10	880
Dolomite, blue-gray and yellow-gray; 2 samples	20	900
Sandstone and dolomite; sandstone white, moderately fine grained; dolomite blue-gray; in fine sand	10	910
Dolomite, blue; shale, white, in powder; and sandstone, white; largest grains 1.2 millimeters in diameter	10	920
New Richmond sandstone:		
Sandstone, white; finer than above; with admixture of dolomite in lower part; 2 samples	20	940
Sandstone, white; largest grains 1 millimeter diameter; 2 samples	20	960
Oneota dolomite:		
Dolomite, blue, and sandstone; drillings largely quartz sand; 2 samples	20	980
Dolomite, brown, drab, and gray; finely arenaceous and cherty; 7 samples.	70	1,050
Marl, white, calcareous; residue argillaceous and quartzose	10	1,060
Dolomite, white and gray; highly cherty at 1,070 feet; 11 samples	110	1,170
Cambrian:		
Jordan sandstone (80 feet thick; top, 157 feet below sea level)—		
Sandstone, clean, white; well-rounded grains; many 1 millimeter in diameter	30	1,200
Sandstone; as above, but finer	10	1,210
Sandstone; as above, coarser; largest grains 1.5 millimeters passing at bottom into highly arenaceous dolomite represented in drillings by blue-gray chips	10	1,220
Sandstone; as above; clean quartz sand; 2 samples	20	1,240
Sandstone, finer, calciferous	10	1,250
St. Lawrence formation (337 feet penetrated: top, 237 feet below sea level)—		
Shale, green-gray, calciferous, arenaceous; 2 samples	20	1,270
Sandstone, white, moderately fine grained; chips of dolomite	10	1,280
No samples	120	1,400
Shale, greenish, calcareous, glauconiferous, arenaceous; fine rounded grains of quartz; 4 samples	50	1,450
Shale, blue-gray, calcareous, glauconiferous; in easily friable concreted masses; arenaceous; 2 samples	20	1,470
Shale; as above; and greenish, fine-grained, argillaceous, and glauconiferous sandstone; 7 samples	70	1,540
Shale, green-gray, glauconiferous, calcareous, and arenaceous	10	1,550
Shale; as above; with flakes of hard, dark, greenish-drab shale, noncalcareous and nonglauconiferous; very slightly siliceous; 2 samples	20	1,570
Shale; green-gray, glauconiferous, calcareous, and arenaceous	17	1,587

The following chemical analyses of drillings from the deep well at Charles City were made in the chemical laboratory of Cornell College, Mount Vernon, Iowa:

Analyses of drillings from Charles City well.

	270–280 feet.	600–610 feet.
$MgCO_3$	39.45	35.29
$CaCO_3$	53.42	53.28
Fe_2O_3	.21	.75
Al_2O_3	.99	.23
SiO_2	4.50	9.89
H_2O	.54	.50
$CaSO_4$	.29	.11
Total	99.40	100.05

The waterworks system consists of a standpipe, 6 miles of mains, 56 fire hydrants, and about 450 taps. The water is used for domestic purposes by perhaps 1,800 people, or one-third of the population, and for boiler supplies by both railway companies and by other industrial concerns. The average daily consumption is estimated at 200,000 gallons.

Marble Rock.—The village well at Marble Rock (population, 480) is 154 feet deep, nearly all of which is in rock. It has been pumped for 12 hours at the rate of 65 gallons a minute without noticeable effect. The water normally stands about 60 feet below the surface. The system comprises an elevated tank, half a mile of mains, six fire hydrants, and about 35 taps. About one-fifth of the people use the public supply.

Nora Springs.—The public well at Nora Springs (population, 985) is 8 inches in diameter and 197 feet deep, nearly the entire depth being in limestone. It is pumped at the rate of 45 gallons per minute without appreciable effect. The water rises to a level 20 feet below the surface, or about 1,050 feet above the sea, and is pumped to an elevated tank, from which it is distributed through three-fourths of a mile of mains. There are 14 fire hydrants. Only a few of the inhabitants use the public supply; about 4,000 gallons are said to be consumed daily. According to Norton, a supply of good water could probably be obtained from a deep well sunk to the Galena and Platteville limestones, or from these and the St. Peter sandstone combined. The summit of the St. Peter should be found at about 300 feet above sea level, or at about 775 feet below the surface. A well 800 or 900 feet deep should be ample.

FRANKLIN COUNTY.

By O. E. Meinzer and W. H. Norton.

TOPOGRAPHY AND GEOLOGY.

Franklin County is divisible into two distinct topographic, geologic, and ground-water provinces, the area of Wisconsin drift occupying the western part, and the area of Iowan drift occupying the eastern part. The former has deep drift, a morainic topography, many undrained swamps and ponds, and numerous drift wells; the latter has thin drift, a nearly level but well-drained surface, and a predominance of rock wells. Except in certain localities, the dividing line between these two areas is well defined. It crosses the north boundary about 9 miles east of the west margin, trends southeast, and crosses the south boundary about 4 miles west of the east margin of the county.

The rocks upon which the drift rests are chiefly limestones belonging to the upper part of the Devonian and the lower part (Mississippian series) of the Carboniferous. Apparently they dip gently to the southwest, so that the oldest formations are found in the northeastern and the youngest in the southwestern part of the county. In the northeastern part of Franklin County and also in Cerro Gordo County a shale formation is interbedded between Devonian limestones.

UNDERGROUND WATER.

SOURCE.

Water is obtained from the glacial drift and underlying limestone, and in the deep well at Hampton from the lower sandstone formations. In the western morainic area the drift is in general between 65 and 150 feet thick, and because of the poor drainage the pervious portions are filled with water nearly to the surface. When this area was first settled, the water supply was nearly all obtained from shallow wells that ended in the upper part of the drift, but many wells have recently been sunk to the lower part of the drift and into the subjacent limestone, thus obtaining more sanitary, more plentiful, and more reliable supplies. In the eastern area, where the drift is thinner and a little more dissected by streams, it is generally necessary to drill into rock in order to obtain supplies that are at all dependable. Most of the wells end in the upper limestone at depths ranging from 30 to 100 feet, but a few pass through the Devonian shale and end in the underlying limestone at depths between 200 and 400 feet. In all wells that are sufficiently deep the supply is abundant and permanent. The water from all beds is hard, but is otherwise of good quality unless polluted from the surface.

SPRINGS AND FLOWING WELLS.

In the valley of Iowa River in the southwestern part of the county, in the valley of West Fork of Red Cedar River in the northeast, and in a number of low tracts especially at the east base of the high morainic area, the water in the ordinary drilled wells rises nearly to the surface or, in a few wells, overflows. In other localities east of the morainic belt, the water-bearing beds have been exposed by erosion or otherwise, allowing the water to escape in rather large springs. The head of the city well at Hampton indicates that the water from the deeply buried formations will remain at a lower level than that from the formations reached in ordinary drilling.

CITY AND VILLAGE SUPPLIES.

Hampton.—The public supply of Hampton (population, 2,617) comes from a group of springs and from a deep well. The springs discharge into two reservoirs at about 100 gallons a minute; and the well has been tested at 160 gallons a minute. There is a standpipe and system of mains with about 225 taps. The average daily consumption is about 150,000 gallons, the water being used for domestic purposes by over 1,000 people and for boiler supplies by both railway and industrial companies.

The well is 1,709 feet deep, is cased with 10-inch pipe from surface to 190 feet, 8-inch from 588 to 642 feet, 7-inch from 196 to 1,139 feet, and 6-inch from 1,139 to 1,191 feet; the casing is split to let in water. The curb is 995 feet above sea level. The normal head is 50 feet below curb; under pump the water stands 160 feet below curb. The principal water supply is obtained from a depth of 1,100 feet. The well was drilled in 1900 by J. P. Miller & Co., of Chicago. The strata penetrated are indicated by the following log and section:

Drillers' log of city well at Hampton.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface	52	52
Shale	153	205
Lime, hard	393	598
Shale, caving	77	675
Limestone	65	740
Shale	60	800
Mixture of lime and shale and coating material	40	840
Very hard rock, which batters drill	35	875
Mixture of rock and soapstone	140	1,015
Limestone	85	1,100
Sandy material	35	1,135
Shale	53	1,188
Sandstone	60	1,248
Limestone	152	1,400
Sandy limestone	75	1,475
Hard limestone	160	1,635
Sandstone	74	1,709

Description of strata in city well at Hampton.

	Depth in feet.
Pleistocene (52 feet thick; top 995 feet above sea level):	
Till, pale yellow	20
Sand, ocher-yellow; with ocherous clay	40
Carboniferous (Mississippian):	
Kinderhook group (108 feet thick; top, 943 feet above sea level):	
Shale, blue	60
Limestone, bluish gray, subcrystalline; of rapid effervescence; in coarse chips; fragments of calc spar and sparry surfaces indicate that the rock is geodiferous; platy fragments of drusy pyrite, in some of which the pyrite alternates with laminæ of black coaly shale	80
Shale, blue; 3 samples	100–140
Devonian (360 feet thick; top, 835 feet above sea level):	
Limestone, dark green-gray, earthy; brisk effervescence; argillaceous residue; in large chips; some fragments of white fine-grained, crystalline limestone	160

	Depth in feet.
Devonian (360 feet thick; top, 835 feet above sea level—Con.	
Limestone, dark drab, fine grained, crystalline, hard; residue black; moderately brisk effervescence; microscopic grains of crystalline quartz	180
Limestone, white, compact; earthy luster; also gray and cream-colored; saccharoidal, in small chips; much argillaceous admixture; effervescence moderate; residue large, argillaceous, and microscopically quartzose	200
Shale, greenish	220
Limestone, white, earthy; brisk effervescence; in fine sand; some cuttings of shale	240
Shale, greenish; 2 samples	260–280
Limestone, white; brisk effervescence; crystalline, in fine sand masked by argillo-calcareous powder	300
Limestone, varicolored, dark bluish, saccharoidal, with moderate effervescence, and argillaceous residue; and buff, subcrystalline, fine grained, compact, with brisk effervescence and little residue	320
Limestone, light gray, fine grained, subcrystalline, subtranslucent; rapid effervescence; in large flakes	340
Limestone, drab; large dark argillaceous residue; effervescence moderate	360
Limestone, light gray, dense, fine grained, subcrystalline; brisk effervescence; some chips of soft greenish saccharoidal limestone	380
Limestone, light buff, soft, compact, earthy; effervescence brisk	400
Limestone, light blue and light buff; hard; brisk effervescence	420
Limestone, light brownish, soft: earthy; brisk effervescence; argillaceous residue	440
Limestone, blue-gray; earthy luster; fine grained, compact; brisk effervescence, dark argillaceous residue	460
Limestone, blue-gray; effervescence rather slow; large clayey residue; fragments of fossiliferous green shale.	480
Limestone, gray, subcrystalline; in angular sand; effervescence brisk	500
Silurian (78 feet thick; top, 475 feet above sea level):	
Limestone, cream-colored, very soft; earthy; effervescence moderate; some drab, argillaceous	520
Limestone, light blue-gray, soft; rather large clayey residue; effervescence moderate	540
Limestone; as above, but with chips of chert siliceous limestone, and drab argillaceous limestone	560
Limestone, white, soft; rapid effervescence; subtranslucent	580
Ordovician:	
Maquoketa shale (172 feet thick; top, 397 feet above sea level):	
Shale, light chocolate brown, calcareous	600
Shale, reddish; no reaction for carbons or hydrocarbons in closed tube	620
Shale, light greenish, calcareous	640

	Depth in feet.
Ordovician—Continued.	
Maquoketa shale (172 feet thick; top, 397 feet above sea level—Continued.	
Limestone; moderate effervescence; much argillaceous powder	660
Gray chert, greenish shale, and red calcareous shale; probably fallen from above	700
Shale, greenish	720
Limestone, varicolored, in sand; brisk effervescence; much greenish shale	740
Shale, dark greenish, calcareous	760
Galena limestone to Platteville limestone (410 feet thick; top, 225 feet above sea level):	
Limestone, white; brisk effervescence; much shale	780
Limestone, buff, and shale, chocolate-brown; considerable yellow chert	800
Limestone, gray and white; brisk effervescence; much white chert and argillaceous powder; 2 samples	820–840
Shale, green and brown; gray chert	860
Limestone, gray; brisk effervescence	880
Limestone, cream colored; brisk effervescence; in fine sand; much argillaceous powder	900
Limestone, light yellow; highly argillaceous; 2 samples	920–940
Shale, light brownish, calcareous	960
Limestone, light gray; some fossiliferous; cherty; brisk effervescence; in chips; much argillaceous powder in some samples; 6 samples	980–1,080
Limestone, gray, brisk effervescence; 2 samples	1,130
Shale, green; and gray limestone	1,140
Shale, green, indurated; in fine chips	1,160
St. Peter sandstone (68 feet thick; top, 185 feet below sea level):	
Sandstone; white grains of clear quartz, well rounded, comparatively uniform in size, surfaces smooth, with green shale from above; 4 samples	1,180–1,240
Prairie du Chien group:	
Shakopee dolomite (172 feet thick; top, 253 feet below sea level):	
Dolomite, gray, hard, cherty	1,260
Dolomite, gray, cherty, arenaceous	1,280
Sandstone, fine grained, white	1,300
Dolomite, light buff and gray, cherty; 2 samples	1,320–1,340
Dolomite, light buff, arenaceous; considerable quartz sand in drillings	1,360
Dolomite, blue-gray	1,400
New Richmond sandstone (70 feet thick; top, 425 feet below sea level):	
Dolomite, blue-gray, and sandstone; large part of drillings quartz sand	1,420
Dolomite, gray; small fragments of arenaceous dolomite and some quartz sand	1,440

	Depth in feet.
Ordovician—Continued.	
Prairie du Chien group—Continued.	
New Richmond sandstone—Continued.	
Sandstone and dolomite; sandstone of St. Peter facies; dolomite gray	1,460
Sandstone, white, fine grained, hard	1,480
Oneota dolomite (145 feet thick; top, 495 feet below sea level):	
Dolomite, gray and white, cherty; 2 samples	1,500–1,520
Dolomite, gray; residue of cryptocrystalline quartz	1,540
Dolomite, blue-gray; residue as above	1,560
Dolomite, gray; 3 samples	1,580–1,620
Cambrian—	
Jordan sandstone (74 feet penetrated; top, 640 feet below sea level):	
Sandstone; of clean, white, well-rounded grains of pure quartz, of moderate size; 3 samples	1,640–1,680
Sandstone; as above, but somewhat harder, as indicated by larger number of fractured grains; 2 samples	1,700–1,709

Latimer.—The village well at Latimer (population, 378) is 6 inches in diameter and 150 feet deep, the last 50 being in limestone. The water rises within 45 feet of the surface, and the well is reported to have yielded 300 gallons a minute continuously during a 12-hour test.

The water is brought out of the well by an air lift and is then forced by a rotary pump into a cylindrical air-tight tank, from which it is carried through the mains by air pressure. The total length of the mains is less than half a mile, the number of fire hydrants 6, the number of taps 14, and the average daily consumption is estimated at 6,000 gallons. Only a small proportion of the inhabitants use the public supply.

HANCOCK COUNTY.

By O. E. Meinzer.

TOPOGRAPHY AND GEOLOGY.

The drift-covered surface of Hancock County is in most localities only gently undulating. It has been but little modified by stream erosion and consequently its natural drainage is imperfect. The glacial material forms a continuous blanket, 75 to 250 feet thick, beneath which the older rock formations are completely concealed. In the northwestern part of the county (Bingham, Crystal, Orthel, and part of Britt townships) the drift has its greatest development, depths of 200 to 250 feet being common; and in the southern tier of townships (Major, Amsterdam, Twin Lake, and Avery), it is also rather deep, ranging in general between 125 and 200 feet and averaging deeper in Twin Lake than in Avery Township; in parts of Britt, Garfield, Concord, Ell, German, Erwin, and Boone townships it is relatively thin, depths of 75 to 125 feet being common.

The bedrock upon which the drift rests consists of indurated limestone with a minor amount of interstratified shale, and probably belongs in part to the Mississippian series of the Carboniferous and in part to the Devonian system. The general succession of the upper formations is indicated by the following section of the village well at Britt:

Section of village well at Britt.

	Thickness.	Depth.
	Feet.	*Feet.*
Drift	127½	127½
Limestone	40½	168
Shale	17	185
Limestone (entered)	15	200

UNDERGROUND WATER.

SOURCE.

The water supply is derived from the glacial drift and the underlying limestones. On account of the poor drainage, the porous parts of the drift are usually filled with water nearly to the surface; hence there are many shallow wells which are liable to fail in dry seasons when the water level lowers. Better wells are drilled to deeper parts of the drift where they receive more dependable supplies from sand and gravel beds that contain water under pressure. The best drilled wells, however, pass through the sand and gravel beds and tap the limestones, from which are obtained copious supplies of water that is lifted by artesian pressure nearly or quite to the surface. The water from both drift and limestone is hard, but is otherwise good.

Throughout the county the blanket of drift, with its undrained surface and its water-bearing beds of sand and gravel, lies on top of the same kind of bedrock, with its large water supplies under good pressure. The two variable factors are (1) the thickness of the drift and consequent depth to rock, and (2) the altitude of the surface and the resulting depth at which the water remains in the wells.

HEAD.

In most parts of the county the water in drilled wells rises nearly to the surface and in some areas it overflows. The following table shows the head at several points:

Head of water in and near Hancock County.

Locality.	Altitude of surface above sea level.	Height to which the water rises.	
		Above or below surface.	Above sea level.
	Feet.	*Feet.*	*Feet.*
Forest City (Winnebago County)	1,180	Above.	1,180
Garner	1,220	−14	1,206
Klemme	[a] 1,210	−10	[a] 1,200
Belmond (Wright County)	1,180	Above.	1,180
Britt	1,230	−18	1,212
Hutchins	1,208	−18	1,190
Wesley (Kossuth County)	1,246	−80	1,166
Corwith	1,178	−20	1,158

[a] Approximate.

Flowing wells have been obtained along the several branches of Boone River in Magor, Amsterdam, Boone, and Erin townships, and also in the low tracts adjoining several creeks in Bingham and Orthel townships. They have also been obtained in the valley of Iowa River near the south line of the county, and, judging from the flowing well at Forest City, it seems not improbable that they could be obtained in parts of Lime Creek Valley near the Winnebago County line.

The deepest well reported is the Chicago, Milwaukee & St. Paul Railway well at Britt, which extends to a depth of 684 feet, and in which the water rises to 16 feet below the surface, or 1,220 feet above the sea level, this being practically the same head that is found in the ordinary drilled wells of the vicinity. At Algona to the west and Mason City to the east the water from the deeply buried formations does not rise much higher than 1,100 feet above sea level, and the general experience in deep drilling in this region indicates that the head tends to become lower with increasing depth. In view of the generous yield and good head of wells sunk relatively short distances into the rock, probably little or nothing would be gained by deep drilling.

In certain areas where the water in rock wells stands some distance below the surface, it may be feasible to drain small swampy tracts, remote from streams and large ditches, by conducting the water through wells into the cavities of the rock, but throughout the greater part of the county the head of the well water is too high to permit this method of drainage.

CITY AND VILLAGE SUPPLIES.

Britt.—The public well at Britt (population, 1,303) is 8 inches in diameter and 200 feet deep. The first limestone yielded 60 gallons a minute and the finished well, ending in the limestone beneath the shale, has been tested at the rate of 400 gallons a minute. The waterworks consist of an elevated tank, about 2 miles of mains, 16 fire hydrants, and approximately 200 taps. A majority of the people use the water, the average daily consumption being estimated as 30,000 gallons.

The Chicago, Milwaukee & St. Paul Railway well has a depth of 684 feet and a diameter of 7 inches. The curb is 1,236 feet above sea level. The head is 16 feet below the curb and the tested capacity is 125 gallons a minute.

Corwith.—The village well at Corwith (population, 455) is 125 feet deep and ends in limestone. The water stands 20 feet below the surface, or 1,158 feet above sea level, and has been pumped at the rate of 70 gallons a minute.

The distribution system comprises an elevated tank, somewhat more than half a mile of mains, 8 fire hydrants, and 17 taps. Only a small portion of the total population uses the public supply. The average daily consumption is reported to be approximately 10,000 gallons.

Garner.—The public water supply of Garner (population, 1,028) comes from two wells, one of which was dug to a bed of gravel at 48 feet, and the other was dug to 55 feet and thence drilled to 145 feet, where it ends in limestone. The water in each well rises within 14 feet of the surface, but pumping at the rate of 80 gallons a minute from the two combined lowers the water level about 25 feet.

The system comprises an elevated tank, about one-half mile of mains, 11 fire hydrants, and approximately 75 taps. It is estimated that less than one-fourth of the people are supplied from this source and that the average daily consumption is about 13,000 gallons.

HUMBOLDT COUNTY.

By O. E. Meinzer.

TOPOGRAPHY AND GEOLOGY.

Nearly all of Humboldt County is drift covered and much of it is poorly drained, but East and West forks of Des Moines River, which cross the county and unite near the south line, have in many localities cut into the bedrock, and, with their numerous short tributaries, have drained some of the swampy tracts. In the eastern part of the county the glacial drift forms an uninterrupted sheet, commonly between 100 and 200 feet thick, but in most of the central and western parts it is thinner and in some places is only a veneer over the rock surface. Near the northwest and southwest corners (Pl. XVI, p. 672) beds of loose sand, which are believed to represent the basal Cretaceous deposit, appear to lie immediately below the drift, but elsewhere, as far as is known, the drift rests on Carboniferous rocks which, according to T. H. Macbride,[1] consist of shale and sandstone belonging to the Des Moines group of the Pennsylvanian and of the "St. Louis limestone" and Kinderhook group of the Mississippian. The shale and sandstone are probably not widely distributed, for in most sections limestone constitutes the first rock recognized by drillers. The succession is indicated by the following section of the Chicago & North Western Railway well at Renwick:

Section of railway well at Renwick.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil, yellow and blue clay	40	40
Clay, hard, blue	100	140
Sand	10	150
Shale, red	20	170
Shale, white	4	174
Limestone	38	212

UNDERGROUND WATER.

SOURCE.

Most of the water used in Humboldt County is obtained from the glacial drift and the Carboniferous limestones. In the eastern tier of townships relatively few wells have been sunk to rock, but many end in the lower part of the drift at depths of more than 100 feet. In the vicinity of Livermore the drilled wells average perhaps 100 feet in depth, and possibly half of them end in rock; in the vicinity of Humboldt they average somewhat deeper and a larger proportion enter rock. In the west-central part of the county limestone wells are also numerous, but in certain localities, especially near the northwest and southwest corners, all drilled wells end in sand.

In general the rock wells are the most satisfactory and yield the largest supplies, but where the drift is thin and the water level is low it is in some places necessary to drill considerable distances in the rock, and even where the latter lies entirely below the water level a generous yield is obtained only after a good crevice has been tapped. Although the upper part of the limestone is the most broken and fissured it occasionally happens that compact rock must be penetrated for many feet before an opening is found which will freely conduct water to the drill hole.

[1] Geology of Humboldt County: Ann. Rept. Iowa Geol. Survey, vol. 9, 1899, pp. 122 et seq.

HEAD.

In the eastern part of the county water in the drilled wells rises nearly to the surface, and several flows have been struck in the valley of Prairie Creek and elsewhere. In Boone Valley, immediately east of Humboldt County, flows are obtained over an extensive area, but in Des Moines Valley, which lies at a lower level, none exist. The difference is due to the fact that in the first valley there is a continuous thick blanket of bowlder clay which is so impervious that it acts as a confining bed, holding under pressure the water in the porous beds beneath; whereas in the second valley the stream has cut through the confining bed into the water-bearing strata, thus allowing the water to escape freely. The result is that one valley has flowing wells but practically no springs, and the other has numerous springs but no flowing wells.

In some localities in the western part of the county the water in the drilled wells remains at rather great depths and the conditions are unusually favorable for draining swamps into the underlying limestone.

No deep drilling has been done in Humboldt County, but the wells in Algona, Mallard, and Webster City indicate that the water from the deep formations will rise to approximately 1,100 feet above the sea and that wells may possibly flow with slight pressure in the Des Moines Valley. The highest head would probably be obtained within a few hundred feet of the surface; no additional pressure would be gained by sinking to still lower horizons.

SPRINGS.

Springs are abundant in the valley of West Fork of Des Moines River, and also in the valley of East Fork near the junction of the two streams. They issue mainly from the limestone, where the impervious cover of bowlder clay has been removed by erosion.

CITY AND VILLAGE SUPPLIES.

Humboldt.—About half of the people of Humboldt (population, 1,809) are said to use the public supply. The water comes from a spring that flows into a reservoir, from which the water is carried, by gravity, through a pipe that passes under the river into a second reservoir, and is then pumped into a standpipe and system of mains. The total length of mains is 3½ miles, the number of fire hydrants is 21, and the number of taps is about 180. Approximately 60,000 gallons of water are consumed daily.

At Humboldt the drill (according to Norton), after passing the Mississippian limestone and shales, will enter the limestones and shales of the Devonian, below which some Silurian limestones may possibly be found. Next are shales 100 to 200 feet thick, correlated with the Maquoketa, although they may in part represent the Galena. Probably some water will be found in the Galena limestone. Below the Decorah shale and the Platteville limestone the drill will enter the St. Peter sandstone, about 1,300 feet below the surface. This sandstone may easily reach 100 feet in thickness and should afford a good yield of excellent water. The supply may be largely increased by going deeper, say to 1,700 feet, to tap the stores held by the limestones and sandstones lying beneath the St. Peter.

Livermore.—The village well at Livermore (population, 578) is 163 feet deep, the last 31 feet of which are in limestone. The water is said to stand about 55 feet below the surface (or about 1,080 feet above sea level) and to have been pumped at the rate of 60 gallons a minute.

KOSSUTH COUNTY.

By O. E. Meinzer.

TOPOGRAPHY.

The surface of Kossuth County forms a north-south trough, the southern and central portions of which are drained southward through East Fork of Des Moines River and the northern portion northward through Blue Earth River. These two rivers are connected across the divide between the Des Moines and Minnesota River basins by a swampy area known as the Union Slough. The entire area is covered with glacial drift and exhibits a typical ground-moraine topography. The drainage is imperfect and swamps and ponds are numerous.

GEOLOGY.

If the layer of drift, which in most localities is over 100 feet thick, could be removed the surface on which it rests would probably comprise an erosional topography exposing a geologic section of considerable thickness and diversity. In the eastern and most of the central part of the county and also in a small area in the extreme southwest the drift lies upon indurated Paleozoic limestone, the age of which can not be definitely ascertained because outcrops are lacking. In a tract adjoining Des Moines River and throughout most of the western third of the county a wedge of soft shale and sandstone with a maximum known thickness of about 200 feet intervenes between the drift and the limestone. The upper beds of shale and sandstone are believed to be Cretaceous, but some of the lower beds probably belong to the Pennsylvanian series and possibly in part to the Permian. The following well sections, as reported by the drillers, show to some extent the character and relations of these strata:

Generalized well section for the vicinity of Wesley.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and yellow clay	8	8
Clay, blue	45	53
Clay, black, sand, and gravel with fragments of wood	5	58
Clay, blue	45	103
Clay, black, with fragments of wood	2	105
Clay, yellow, sandy	7	112
Clay, blue	83	195
Clay, yellow, and broken limestone	2	197
Limestone (entered).		

Section of well immediately north of Luverne.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, blue	80	80
Sand	10	90
Clay, red	50	140
"Flint"	6	146
Sandstone	20	166
Shale	10	176
Limestone (entered)	2	178

Section of well at the Algona steam laundry.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, blue	90	90
Sand Shale or clay, yellow Shale or clay, red Shale or clay, blue	125	215
Limestone	5	220
Sandstone	7	227
Limestone (entered).		

Section of abandoned village well at Whittemore.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, etc	115	115
Sand, etc	40	155
Shale	3	158
Sandstone (entered).		

The section at Wesley suggests three distinct drift sheets whose deposition occurred at intervals sufficiently long to enable a soil to form and some weathering to occur at the top of each before it was covered by the next. The section at Bancroft (p. 656) likewise suggests either two or three distinct drift sheets. The red clay or shale reported in a number of the sections in Kossuth, Humboldt, and Palo Alto counties may represent the red shale found in the vicinity of Fort Dodge.

UNDERGROUND WATER.

SOURCE AND DISTRIBUTION.

Water is obtained from glacial drift, Cretaceous sandstone, and Paleozoic limestones and sandstones.

In the northeastern part of the county, where the drift rests upon limestone at depths ranging from about 100 feet in the vicinity of Germania to much more in certain other localities, many drilled wells pass through the entire thickness of drift and find water after penetrating only a short distance into the limestone. Farther west, in the vicinity of Swea City, a few wells reach limestone at about 200 feet, but in general the rock lies much farther below the surface and the wells are finished either in the drift or in the Cretaceous sand.

Similar conditions prevail in the central portion of the county. Thus, at Ramsey post office, near the Union Slough, limestone occurs and is reached by many drilled wells at about 100 feet; at Bancroft it lies 240 feet below the surface and is reached by only a few wells; and at Ringsted, 3 miles west of the county line, it occurs at 364 feet and is almost never reached in drilling.

In the southeastern part of the county many bored wells end in the drift at depths of less than 100 feet but a large proportion of the drilled wells enter rock, although in some localities this lies at considerable depths. In a very general way it may be said that the most common depths of the drilled wells are between 150 and 190 feet in the region south of Titonka, between 200 and 230 feet in the vicinity of Wesley, about 175 feet in the vicinity of Sexton, between 200 and 260 feet in the high area surrounding St. Benedict, and between 75 and 200 feet in the vicinity of Luverne. In much of the region south of Wesley and east of Luverne the drift is deep and drilled rock wells are proportionately rare.

In the vicinity of Algona there is a wide range in the depth of wells, some of the drift wells being very shallow and some of the rock wells going down more than 300 feet. An average for drilled wells is probably between 150 and 200 feet. In the high area north of Whittemore the drilled wells range in general between 200 and 330 feet and end either in the drift or in the subjacent beds of sand. South of Whittemore the range in depth of wells is between 70 and 200 feet and most of the wells end in sand, except in a small area near the southwest corner of the county, where limestone is sometimes reached by the drill.

Of the several sources of water in this county the limestone is the most satisfactory. Its upper portion is generally creviced—a condition probably due to preglacial weathering—and hence it supplies water very freely. On the other hand, sand at higher levels causes much trouble by rising in the wells or by clogging screens. Only

6-inch wells should be sunk and, except in those areas where the depth to rock is great, drilling should be continued until limestone is reached or a satisfactory sand or gravel bed is encountered. As the ordinary rock wells yield generous quantities of good water, little if anything is to be gained by drilling to the deeper formations.

HEAD.

The upper part of the glacial drift is more or less porous and as a rule is saturated almost to the surface, the water table closely following the topographic irregularities. But the bulk of the drift consists of dense bowlder clay which appears to be quite impervious to water and which serves in a sense as a confining bed that holds under pressure the water in the creviced limestone, in the sand strata, or in the sand and gravel deposits within the drift itself. Hence, when a hole is drilled through the bowlder clay, the water from the underlying formations rises under pressure to a certain definite level, which is generally higher (above the sea) in elevated than in depressed regions, but which does not follow the topographic irregularities nearly as closely as does the surficial ground-water table. Hence it is that in the highest areas the water remains far below the surface and in the lowest areas it may rise above the surface.

The following tables shows the head of the water at several points in or near this county:

Head of water in and near Kossuth County.

Locality.	Altitude of surface above sea level.	Height to which water rises.	
		Above or below surface.	Above sea level.
	Feet.	*Feet.*	*Feet.*
Buffalo Center (Winnebago County)	1,183	− 14	1,169
Germania		Above.	1,145
Swea City	1,174	− 15	1,159
Armstrong (Emmet County)	1,240	− 68	1,172
Bancroft	1,210	− 60	1,150
Burt	1,170	− 30	1,140
Ringsted (Emmet County)	1,251	− 76	1,175
Wesley	1,246	− 80	1,166
Sexton	1,218	− 70	1,148
St. Benedict	1,266	−125	1,141
Algona	1,193	− 53	1,140
Whittemore	1,200	− 35	1,165
Corwith (Hancock County)	1,178	− 20	1,158
Luverne	1,169	− 40	1,129
Livermore (Humboldt County)	1,140	− 55	1,085
West Bend (Palo Alto County)		Above.	1,156

Wells obtain flowing water in a tract of considerable extent adjacent to Blue Earth River, chiefly in Hebron, Springfield, Ledyard, and Lincoln townships, and also in the valleys of Buffalo, Mud, Prairie, and Lotts creeks, all of which drain into Des Moines River.

Throughout the entire northeastern part of the county the water rises nearly to the surface, but in the high areas in the northwestern and west-central parts, and in the region about St. Benedict, it remains at considerable depths. To the south the head is lowered by the leakage that takes place farther south where the rocks outcrop along both forks of Des Moines River.

CITY AND VILLAGE SUPPLIES.

Algona.—The public water supply of Algona (population, 2,908) is taken from two deep wells: City well No. 1, drilled by S. Swanson, of Minneapolis, which is 1,050 feet deep, and city well No. 2, which is 818 feet deep. The curb of well No. 1 is approximately 1,202 feet above sea level, and the water level is 69 feet below curb. The driller's logs follow:

Driller's log of city well No. 1, Algona.

	Thickness.	Depth.
	Feet.	*Feet.*
Material	235	235
Sandrock	75	310
Limerock	125	435
Sandrock	300	735
Shale and streaks of sandrock	315	1,050

Log of city well No. 2.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	4	4
Clay, yellow	10	14
Clay, blue	77	91
Sand	50	141
Shale, blue; shale, white; flint shale, light blue	169	310
Limestone	508	818

The water in the first well lowers notably when pumped 50 gallons a minute; the second yields 150 gallons by the use of an air lift. There are a standpipe, about 5 miles of mains, and 39 fire hydrants. It is reported that about 1,600 people are supplied and that an average of 60,000 gallons is consumed daily.

Bancroft.—The public supply of Bancroft (population, 830) is taken from a rock well, 242 feet deep, which has been tested at 40 gallons a minute. The system comprises an elevated tank, about one-half mile of mains, eight fire hydrants, and 28 taps. Approximately 5,000 gallons of water is used daily and perhaps 125 people are supplied.

A well at one time drilled for the railway company is said to be 500 feet deep with the water rising within 2 feet of the surface, which would be 1,187 feet above sea level. The well stood a good test, but the water is so hard that it is not used in locomotives.

Section of village well at Bancroft.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and yellow clay	15	15
Clay, blue	50	65
Sand containing wood, snails, etc	6	71
Clay, blue	20	91
Sand	5	96
Clay, red and yellow	138	234
Gravel	6	240
Limestone, entered	2	242

Burt.—The village well at Burt (population, 495) is 175 feet deep and has been pumped at the rate of 40 gallons a minute. The water rises within 30 feet of the surface.

Waterworks with nearly a mile of mains and 10 fire hydrants have been installed.

Swea City.—The public well at Swea City (population, 402) is 117 feet deep and ends in sand from which the water rises within 15 feet of the surface (1,160 feet above sea level). It has been pumped at the rate of 30 gallons a minute. The water is pumped to an elevated tank and is to be distributed through a system of mains.

MITCHELL COUNTY.

By O. E. Meinzer.

TOPOGRAPHY AND GEOLOGY.

Mitchell County exhibits few topographic irregularities. The deep-drift area, however, is higher than the shallow-drift area, a fact that has an important bearing on ground-water conditions.

The bedrock in all parts of the county probably consists of limestone of Devonian age, upon the irregular surface of which rests a mantle of glacial drift. In the southeast the average thickness of the drift is perhaps 200 feet, and in certain localities it exceeds 300 feet. In much of the northeastern part it is also thick, but its average is less. Thus in the northern part of Jenkins Township and in much of Wayne Township the drift is only about 50 feet thick, though in the southern part of Jenkins and in some places in the northeastern section of Wayne it is much heavier, locally exceeding 200 feet. In the second tier of townships from the east the drift is thinner than in the first tier; in most places in the western half of the county it is less than 25 feet thick and limestone outcrops are abundant, especially along Red Cedar River.

UNDERGROUND WATER.

SOURCE AND DISTRIBUTION.

Water is derived from alluvial and outwash deposits, glacial drift, Devonian limestone, limestone below the Devonian, and St. Peter sandstone.

Deposits of alluvial sand and gravel occur locally in the valleys of the principal streams and afford large quantities of water to wells from 15 to 25 feet deep. Within the body of the glacial drift there are many water-bearing beds of sand and gravel, the shallowest of which can not, however, be relied on to yield water in dry years. The limestone everywhere yields an unfailing supply and is the most valuable water bed in the county. The city well at Osage extends through the St. Peter sandstone, which was encountered at a depth of 715 feet.

In the southeastern townships most of the drilled wells end in beds of gravel and sand far down in the drift, many wells being more than 200 feet and a few more than 300 feet deep. In the northeastern townships most of the drilled wells end in limestone at depths averaging about 100 feet in the localities of thinnest drift and about 200 feet in the localities of thickest drift. In the second tier of townships from the east drilled wells commonly range in depth between 100 and 150 feet, some ending in limestone and others in drift. In the western half of the county by far the greater number of good wells are drilled into rock and obtain an abundance of water at depths ranging from about 50 to 150 feet.

SPRINGS AND FLOWING WELLS.

In the western part of Mitchell County, especially in the valley of Red Cedar River, some rather large springs issue from the limestone, the spring in the park south of Osage being typical. In the eastern part of the county smaller seeps come from gravelly beds in the drift; the spring at Riceville may be cited as an example.

In a belt running north and south through the western part of Wayne, Jenkins, and Burr Oak townships the water in the drilled wells rises nearly to the surface and in some wells overflows with slight pressure; farther west it does not flow, even though the altitude is lower. The explanation of this distribution of flowing wells appears to be as follows:

Along the east margin of Mitchell County and the adjoining parts of Howard County the surface is relatively high and the pervious portions of the drift are filled with water nearly to the surface. To some extent these pervious members are in communication with the underlying limestone, which they thus keep supplied with water under considerable head. The limestone may be regarded as a continuous water-bearing formation, and consequently, if farther west, where the altitude is lower, a well is drilled into the limestone or into sand or gravel in communication with it the water will rise under pressure and a flowing well may result. The drift thus plays the double part of a porous formation through which the water enters and an impervious layer under which it is confined. A short distance farther west, however, no flows are obtained, although the surface is still lower, the rapid reduction of the artesian pressure evidently being due to leakage through the thin drift cover and through rock outcrops.

Altogether there are in this belt probably several dozen flowing wells grouped in clusters along streams or in depressions. The well on the farm of James McCarty, in the SW. ¼ sec. 9, T. 98 N., R. 15 W., is locally famous for its unusually strong pressure and flow. It ends in gravel at the depth of 174 feet and is reported to flow about 300 gallons a minute.

In the Osage deep well the water from the St. Peter sandstone rises to about 1,110 feet above sea level. According to the railway surveys the altitude at Osage is 1,168 feet above sea level; at Riceville, 1,229 feet; at McIntyre, 1,279 feet; at Stacyville, 1,208 feet, and at St. Ansgar 1,175 feet.

CITY AND VILLAGE SUPPLIES.

Osage.—At Osage (population, 2,445) it is reported that 40,000 gallons are pumped from the city well daily and about 1,500 people are supplied. The water is lifted into an elevated tank and thence distributed through nearly 4 miles of mains to 42 fire hydrants and about 400 taps.

The city well (Pl. VII, p. 272) is 780 feet deep, 12 to 10 inches in diameter, and is cased to a depth of 192 feet without packing; the curb is 1,168 feet above sea level, and the water stands 60 feet below curb. The tested capacity is 200 gallons a minute. Water horizons are reported at 110 feet, with water heading 70 feet below curb; and at 650 feet, heading 60 feet below curb; water is also reported at 780 feet. The temperature of the water is 48° F. The well was drilled in 1899 by J. F. McCarthy, of Minneapolis, and cost $2,400.

Driller's log of city well at Osage.

	Thickness	Depth.
	Feet.	*Feet.*
Drift	20	20
Limestone	160	180
Gumbo shale	20	200
Limestone (water at 650 feet)	460	660
Shale and sandstone mixed	60	720
Sandstone	60	780

Record of strata in Osage city well (Pl. VII, p. 272.)[a]

	Thickness.	Depth.
	Feet.	*Feet.*
No sample	490	490
Dolomite, light buff, crystalline; beginning at 490 feet; 4 samples	50	540
Limestone, light gray; effervescing freely in cold hydrochloric acid; 6 samples	85	625
Limestone, yellowish; with pyritic crystals and small nodules; 2 samples	15	640
Limestone, light gray; with pyrite; 1 sample	5	645
Limestone, dark gray; small chips of lighter gray from above; some grains of pyrite; 1 sample	10	655
Limestone, dark gray, shaly, pyritic; 1 sample	5	660
Limestone, dark gray; chips of green shale	10	670
Shale, greenish	5	675
Shale, slaty gray; some small flakes of limestone and crystals of pyrite; 2 samples	20	695
Shale, dark green; a few small bits of limestone and grains of clean water-worked quartz sand	20	715
Quartz sand, clean, clear, water worn; some chips of green shale from above; 3 samples; sand at 750 feet a little finer than that above	35	750
Sand, yellowish; finer than any in the above	10	760
Shale, greenish, marly; some sand grains and small chips of limestone	10	770
Sand, fine, gray; well-rounded grains; some shale	10	780

[a] Calvin, Samuel, Ann. Rept. Iowa Geol. Survey, vol. 13, 1903, p. 336.

Calvin refers the sandstones from 725 feet to the bottom of the well to the St. Peter, and all the rocks above it to the Galena, Decorah, and Platteville formations. The occurrence of water above the Decorah shale—the source of powerful springs in the northeastern counties of the State—should be noted.

Riceville.—The public supply of Riceville (population, 844) is taken from a spring which issues from a seam of sand in the drift at the bank of the river and yields about 20 gallons a minute. The water is allowed to flow into a reservoir from which it is pumped into an elevated tank and thence distributed through a small system of mains to 4 fire hydrants and 15 taps.

St. Ansgar.—The city well at St. Ansgar (population, 747), put down in 1902 by Emil Sedlacek, of Thief River Falls, Minn., is 240 feet deep and 10 inches in diameter. (See Pl. VII, p. 272.) The curb is 1,175 feet above sea level and the water stands 20 feet below the curb.

This well was in process of boring when the county was surveyed by the Iowa Geological Survey. The drill had then reached a depth of 160 feet, the last 60 feet being in the Maquoketa shale.

WINNEBAGO COUNTY.

By O. E. Meinzer.

TOPOGRAPHY AND GEOLOGY.

Winnebago County is covered with glacial drift to a depth, in most localities, of 100 to 200 feet. The upper layer is of Wisconsin age and has a gently undulating and poorly drained surface. The highest land and the deepest drift are found in a north-south belt which passes through the central part of the county. Beneath the drift is an irregular limestone surface not known to outcrop within the county.

UNDERGROUND WATER.

SOURCE.

Water is obtained from the glacial drift and from the underlying limestone. The drift is tapped by a large number of dug, bored, driven, and drilled wells, and furnishes the greater part of the supply; the limestone is reached by a smaller number of drilled wells, but the supplies are very satisfactory.

Driven wells are successful only over small tracts where coarse material has been deposited at the surface. Bored wells are common throughout the county, but many of them are filthy and their yield is frequently small and uncertain. Drilled drift wells penetrate deeper and reach beds of sand and gravel from which water is delivered under pressure. Where the water-bearing material is sufficiently coarse, they are satisfactory, but in some of them the sand is so fine that it rises when the water is pumped. Drilled rock wells extend through the entire thickness of the drift and communicate with the system of joints and solution passages which ramify through the limestone, and which are charged with abundant excellent though hard water that is everywhere under pressure. Drilled rock wells are most common in the western part of the county and least numerous in the central part where the drift is deep.

The good features of rock wells can be summarized as follows: (1) They contain no sand to cause trouble; (2) their yield is usually large and permanent; (3) the water is under enough pressure to rise high above the bottom of the wells, thus requiring a comparatively small lift; and (4) if they are properly cased their water is pure. As at all points the limestone is within easy reach of the drill, it is advised that, where the yield from the drift is not abundant or the sand causes trouble if not screened, drilling should be continued until limestone is penetrated and free communication is established with its water-filled crevices. It is poor economy to stop with an unsatisfactory sand well when a little deeper drilling would result in a good limestone well.

HEAD.

The water in the limestone and deeper parts of the drift is invariably under a pressure which lifts it far up in the wells. The lowest head, relative to the surface, is found in some of the highest areas in the central part of the county, but even here the lowest head reported was only 75 feet below the surface. Near the west margin of the county flows are obtained in the creek valleys and other low-lying areas. In the well at Forest City a light flow was struck in gravel at a depth of 80 feet and stronger flows were obtained at lower levels. Other flowing wells could probably be obtained in the valley of Lime

Creek. The following table shows the head of the water from the lower part of the drift or the subjacent limestone at several points:

Head of water in Winnebago County.

Locality.	Altitude of surface above sea level.	Height to which water rises.	
		Above or below surface.	Above sea level.
	Feet.	*Feet.*	*Feet.*
Lake Mills	1,265	−30	1,235
Forest City (in valley)	1,180	Above.	1,180
Thompson	[a]1,275	−75	[a]1,200
Buffalo Center	1,183	−14	1,169
Rake	1,154	−10	1,144

[a] Approximate.

Wells which, like the Forest City well and the Lake Mills railway well, have been sunk to some depth into the limestone, yield so generously, have so good a head of water, furnish such a fair quality of water, and are in every respect so satisfactory that it does not seem advisable to drill deeper even where large supplies are required. From the deep-well data in this region it may be inferred that the water from the lower sandstones would not rise so high as that in the imestone underlying the drift.

DRAINAGE WELLS.

Where the water in rock wells stands at some depth below the surface, it is possible to drain ponds and swamps through them into the rock, though it is not certain that this method of drainage can be made profitable. Where the water rises nearly to the surface, as along the west margin, drainage through wells is not feasible. In other sections of the State wells discharging into sand have not proved as successful as those which discharge into creviced limestone, and the same condition would probably exist in Winnebago County.

CITY AND VILLAGE SUPPLIES.

Buffalo Center.—The village well at Buffalo Center (population, 456) is 168 feet deep, the last 44 feet of which is in limestone. The water stands 14 feet below the surface, or 1,169 feet above sea level. There is an elevated tank, and new mains are being laid to replace the old ones which have become corroded. The people depend almost entirely on private wells, many of which are sunk only a short distance into the drift.

Forest City.—The well which furnishes the public supply at Forest City (population, 1,691) is 4 inches in diameter and 300 feet deep, the last 180 feet of which are in limestone. It is located in the valley, and the water rises a few feet above the surface, or to about 1,180 feet above sea level. It yields several hundred gallons per minute by natural flow at the surface and discharges into the bottom of an underground reservoir at a rate of about 800 gallons a minute when the water level in the latter is lowered to 7 feet below the surface. Approximately two-thirds of the inhabitants of Forest City are reported to use the public supply. The water is pumped into a standpipe and delivered through 3½ miles of mains to 33 fire hydrants and about 140 taps. It is estimated that an average of 90,000 gallons of water are consumed daily.

According to a forecast of artesian possibilities made by Norton, the St. Peter sandstone is estimated to lie only 700 or 800 feet below the surface, or between 400 and 500 feet above sea level. Water may be found in considerable quantity above the St. Peter, in the Galena limestone, and in the Platteville limestone above its basal shales. These basal green shales of the Platteville, which rest on the St. Peter, may be expected to be heavy and to need casing. The St. Peter sandstone should exceed 50 feet in thickness, and may be more than double that. The limestones and sandstones underlying the St. Peter would add largely to the supply, and sinking for less than 500 feet below the base of the latter would test their possibilities. The quality of the water should be excellent, its chief mineral ingredients being calcium and magnesium carbonates.

Lake Mills.—The well which furnishes the public supply at Lake Mills (population, 1,214) is 233 feet deep and enters limestone at 105 feet. The water rises to 30 feet below the surface, or about 1,235 feet above sea level, and has been pumped at 35 gallons a minute. The well of the Chicago & North Western Railway Co. at the same place is 334 feet deep, and enters limestone at 120 feet, with the water rising within 21 feet of the surface, or about 1,245 feet above sea level. In this well pumping at the rate of 125 gallons a minute for 10 hours did not perceptibly lower the water.

The public supply is pumped to an elevated tank, which connects with more than a mile of mains and 11 fire hydrants. Most of the people use water from private wells, but a few are supplied from the public waterworks. Approximately 17,000 gallons of water is used daily.

No deep wells have been drilled within a considerable distance of Lake Mills, but the dip of the strata, as estimated from the sections at Easton, Minn., and Mason City, indicates, according to Norton, that the St. Peter sandstone lies 500 to 600 feet above sea level, or about 700 to 800 feet below the surface. If any deep well is drilled it should be sunk to the bottom of this formation, which may be 100 feet in thickness.

Thompson.—The public supply at Thompson (population, 500) is derived from a drilled well 6 inches in diameter that ends in limestone at the depth of 300 feet, the water rising to a level 75 feet below the surface. The waterworks consist of an elevated tank with less than a quarter of a mile of mains and four fire hydrants. The people rely chiefly on private shallow drift wells, using only 2,500 gallons daily of the public supply.

WORTH COUNTY.

By O. E. Meinzer.

TOPOGRAPHY AND GEOLOGY.

The outer margin of the terminal moraine of the Wisconsin drift sheet crosses Worth County diagonally from northeast to southwest. West of this margin the topography is irregular and morainic and the drainage is poor; east of it an older drift lies at the surface, which, although only slightly dissected, has a well-developed drainage system.

The total thickness of the glacial drift is greatest in the northwestern morainic townships, where over extensive areas it measures between 100 and 200 feet, and in the extreme northeast, where in many places it exceeds 100 feet. Throughout the rest of the county its average thickness is probably 50 feet or less. The drift is for the most part underlain by Devonian limestone, which is exposed in many places along Shell Rock River and other streams.

UNDERGROUND WATER.

SOURCE.

The water supply of Worth County is obtained from alluvial and outwash deposits, glacial drift, and limestone of Devonian age or possibly older.

There are many drilled wells in all parts of the county, although shallow dug, bored, and driven wells are numerous in the morainic area and in the areas where alluvial and outwash sands and gravels lie at the surface. The drilled wells end in the lower parts of the drift or in the subjacent limestone, the average depth, as well as the proportion that end in drift, being greatest where the drift is thickest. In general the wells ending in limestone are the most satisfactory, and, as in nearly all parts of the county this rock is within easy reach of the drill, it is usually unwise to depend on the drift for either farm or village supplies.

One of the deepest wells in the county is that of the Chicago & North Western Railway, at Hanlonton, which enters limestone at a depth of 23 feet and extends to a total depth of 260 feet. The water in this well is reported to rise within 23 feet of the surface and to have been pumped at the rate of 100 gallons a minute.

CITY AND VILLAGE SUPPLIES.

Northwood.—The city well at Northwood (population, 1,264) is 10 inches in diameter and 92 feet deep, the last 50 feet being in limestone. The water rises within 18 feet of the surface, or to about 1,204 feet above the sea, and has been pumped continuously for 15 hours at 100 gallons a minute without noticeable effect. It is lifted from the well into an elevated tank and is thence distributed by gravity through about 1⅗ miles of mains to 20 fire hydrants and approximately 70 taps. It is estimated that 400 people are supplied and that about 18,000 gallons of water is consumed daily. Nearly all the private wells are less than 100 feet deep.

Northwood is 1,222 feet above sea level. According to a forecast of the artesian conditions of the locality made by Norton, the drill, after penetrating the cover of drift clays and sands, will pass through Devonian limestones and shales with possibly some Silurian limestones, the whole, however, being less than 175 or 200 feet thick. The Maquoketa shale, here rather thin, will then be penetrated, and below it several hundred feet of magnesian limestones may be expected. As these last are underlain by a heavy shale belonging to the Platteville limestone, considerable water will probably be found in their crevices and porous beds. A dependable supply will be found in the St. Peter sandstone immediately below the heavy shale mentioned, which may be expected at about 600 feet above sea level, or about 625 feet below the surface, although it may lie 100 feet deeper.

WRIGHT COUNTY.

By O. E. Meinzer.

TOPOGRAPHY AND GEOLOGY.

All of Wright County is covered with glacial drift. Extending across it, somewhat east of the center, with a general north-south trend, is a high morainic belt which contains several lakes and other undrained depressions and forms the divide between the basin of Iowa River, which flows through the eastern part of the county, and the basin of Boone River, which flows through the western part. In this belt is found the deepest drift, the average depth probably being not less than 200 feet; at one point, 2 miles south and 2 miles east of Clarion, a depth of 367 feet is reported. In much of the eastern part of the county, on the other hand, the depth of the drift is only about 100 feet, and in the Iowa Valley it is generally less. Throughout all or nearly all of the county the drift rests upon a surface of indurated Paleozoic limestone.

UNDERGROUND WATER.

SOURCE.

The water supply is derived from the glacial drift and the underlying limestone. The upper layer of drift, owing to its loosely consolidated and somewhat gravelly condition, is to a certain extent porous, and because of the poor drainage it is normally saturated nearly to the surface with water which it yields slowly to shallow dug or bored wells; but in times of protracted drought this surficial water largely disappears and leaves the wells without adequate supply. In certain small districts, where beds of sand or gravel lie at the surface, as in parts of the Iowa Valley, inexpensive wells with large yields are obtained by driving points only a short distance into these porous water-filled deposits. Deeper in the drift beds of sand and gravel are interbedded with dense blue bowlder clay, and these beds are almost invariably saturated with water under pressure. Numerous drilled wells are supplied from this source.

The limestone below the drift is hard and impervious but more or less broken and cavernous, and it is this condition, probably produced by preglacial weathering, that renders it an excellent aquifer. The openings in the rock are charged with water under considerable head, and when they are encountered by the drill the water surges into the well and rises rapidly to a level determined by the head. That large supplies can be obtained by drilling some distance into the limestone is shown by the village wells at Forest City, Britt, Latimer, and Clarion, each of which will furnish several hundred gallons a minute without any great lowering of the water level. Moreover, wells ending in rock do not give trouble as do so many of the sand wells, and the yield does not deteriorate with time as is frequently the case in wells ending in fine-grained unconsolidated material. Though it is not always necessary to drill to rock, yet there is much ill-advised economy in finishing wells in unsatisfactory sand beds when a little deeper drilling would reach rock and result in a much better and more permanent well. Another mistake frequently made, especially where large supplies are desired, is in stopping the drill before the limestone has been penetrated a sufficient depth. The farther the drill hole enters the rock the more water-filled crevices it taps and the more chances there are that a large fissure or cavern will be encountered. The village wells mentioned above penetrate rock to depths ranging from 20 to 180 feet.

HEAD.

The following table shows the head of the water from the limestone and lower parts of the drift at several points in or near Wright County:

Head of water in and near Wright County.

Locality.	Altitude of surface above sea level.	Height to which the water rises.	
		Above or below surface.	Above sea level.
	Feet.	*Feet.*	*Feet.*
Belmond	1,180	0	1,180
Galt	1,200	−50	1,150
Dows	1,140	0	1,140
3 miles east of Clarion	[a] 1,240	−97	[a] 1,143
Clarion	1,170	−28	1,142
Florence	1,130	0	1,130
Goldfield	1,108	Above.	1,120
Eagle Grove	1,109	Above.	1,120
Corwith (Hancock County)	1,178	−20	1,158
Luverne (Kossuth County)	1,169	−40	1,129
Renwick (Humbolt County)	[a] 1,130	−30	[a] 1,100

[a] Approximately.

In the high central belt the water in the drilled wells remains far below the surface, lifts of 50 to 100 feet being general. On the lower ground east of this belt the water usually rises near the tops of the wells, and in the lowest parts of the valley of Iowa River, at Belmond, Dows, and elsewhere, flows are obtained. West of this belt over an extensive area the water rises above the surface or remains only a few feet below, flows being obtained all along the immediate valley of Boone River and far up the valleys of Otter, Eagle, and White Fox creeks and their tributaries. James Rowe, an experienced driller in Eagle Grove, estimates that a flow can be obtained at some low point on approximately half of the farms in the western half of the county.

The table shows that the head of the water is relatively independent of the surface configuration, the water rising to nearly the same level above the sea in the high central area, where it remains far below the surface, as in the valleys, where flows are obtained, the wells being as truly artesian in principle in one area as in the other. The table shows, however, that the head gradually lowers toward the south and west, a condition due to leakage at rock outcrops in the Des Moines Valley to the west and in the Iowa Valley and other localities to the south.

Information gained from deep wells drilled at several places near Wright County indicates that the water from the sandstone formations below the limestone will rise to approximately 1,100 feet above the sea. The supply from the rock immediately beneath the drift is so satisfactory in quantity, quality, head, and other respects that nothing would probably be gained by drilling to the more deeply buried sandstones.

DRAINAGE WELLS.

In the high central area, where the water in rock wells remains a considerable distance below the surface, it is possible to drain swampy tracts by conducting the surface water into drainage wells, but in the lower parts of the county, where the water from the limestone rises nearly or quite to the surface, this method can not be employed. Where it is possible to drain into stream channels or large cooperative ditches, drainage into wells will probably not be profitable, but it is possible that, where conditions are favorable, small isolated swamps, remote from any ditch or stream channel, can be profitably reclaimed by wells. The two favorable conditions in the central part of this county are (1) the low head of the well water and (2) the creviced character of the limestone, both of which increase the capacity of a well for receiving water; the one unfavorable condition lies in the thickness of the drift, which, of course, increases the cost of the wells proportionately. Thus far drainage wells have not proved very successful even where the physical conditions are the best, the chief difficulty being the rapid deterioration in the capacity of the wells, which is believed to be due to the clogging of the pores and crevices in the rock by sediment carried in with the water. This deterioration takes place more rapidly in sand and gravel deposits, whose pores readily become sealed, than in the limestone which has larger openings that are not so easily clogged. If drainage into wells—even into limestone wells—is to be made successful, it will be necessary to devise methods for lengthening the life of the wells used for this purpose, and this can probably be accomplished only by preventing sediment from entering with the water. An experiment that might be worth trying is to excavate a reservoir of considerable size in which the water could stand for some time, thus allowing the suspended matter to settle before the water is taken into the well. Such a reservoir would also greatly augment the potential capacity of the well in that it would receive the water from a heavy rain and supply it to the well gradually, thus draining the land before the crops were damaged and yet allowing the well to be functional during a large part of the time. Where the drainage is effected by an underground system of tiles, the difficulty with suspended matter is much less than where the water is led to the wells in ditches.

CITY AND VILLAGE SUPPLIES.

Belmond.—The public supply at Belmond (population, 1,224) was until recently taken from a dug well 14 feet in diameter and 25 feet deep and from 8 driven wells 27 feet deep, the water coming from a surface layer of sand. There is an elevated tank, 1½ miles of mains, 16 fire hydrants, and 56 taps. It is estimated that about 225 people, or one-fifth of the population, are supplied and that about 18,000 gallons is consumed daily.

The city well recently completed has a depth of 500 feet and a diameter of 10, 8, and 6 inches; casing 10 inches to rock at 130 feet, 8 inches to about 250 feet. The curb is 1,180 feet above sea level and the head 16 feet below the curb. The depth to the principal supply is 500 feet; another water bed is at 25 feet. Date of completion, 1911; driller, W. L. Thorn, of Sparta, Wis.

Driller's log of city well at Belmond.

	Thickness.	Depth.
	Feet.	*Feet.*
Gravel and clay (drift)	130	130
Limerock (Mississippian)	100	230
Shale (Lime Creek, of Devonian)	40	270
Limerock	?	?
Shale	20–30	?
Limerock (to bottom)	?	500

The well penetrates deeply the Devonian and perhaps the Silurian limestones, but does not reach the Maquoketa shale, although that formation should be found within 100 feet of the bottom. The St. Peter sandstone is estimated by Norton to be about 1,150 feet below the surface.

Clarion.—The village well at Clarion (population, 2,065) is 280 feet deep and ends in limestone from which the water rises to 28 feet below the surface, or 1,142 feet above sea level. It has been tested at 500 gallons a minute. An elevated tank has recently been erected and a system of mains laid.

Clarion is 1,170 feet above sea level. According to Norton, a deep well passing through the cover of glacial drift should find limestone with some shales extending to a depth of about 750 feet, below which lies a bed of mud-rock shale, the Maquoketa (Ordovician), which effectually parts the waters above it from those below. The Maquoketa shale rests on 300 to 350 feet of dolomitic limestones (Galena), below which the drill will enter the heavy green Decorah shale and then the limestones and shales of the Platteville, which together may exceed 75 or even 100 feet in thickness. The top of the St. Peter should be reached at about 1,270 feet from the surface, but any contract for a deep well should provide for going to a depth of 1,500 or 1,600 feet if necessary in order to insure against contingencies.

Dows.—The public supply at Dows (population, 892) is taken from an 8-inch well 85 feet deep, in which the water rises to 15 feet below the surface, or to 1,146 feet above the sea. There are an elevated tank, five-eighths of a mile of mains, 9 fire hydrants, and 15 taps The water is used by only a small part of the population and the average daily consumption is reported to be approximately 5,000 gallons.

Eagle Grove.—Only a few people in Eagle Grove (population, 3,387) use the public supply; the rest have private wells, most of which overflow. The public supply is taken from two wells, one of which is a 20-inch bored well that ends in gravel and is cased with tile, the other a 6-inch drilled well with iron casing, extending to a depth of 168 feet and penetrating limestone, from which the water rises above the surface. The two wells will together discharge 500 gallons a minute into an underground reservoir through an orifice 25 feet below the surface. There are a standpipe, 3 miles of mains, and about 35 fire hydrants. It is estimated that approximately 40,000 gallons are consumed daily.

Norton estimates that if the dip of the strata from Mason City to Fort Dodge is uniform the St. Peter sandstone occurs at Eagle Grove at very nearly 1,300 feet below the surface, and that it and the formations immediately below it would yield a large quantity of wholesome water. In order to get the largest yield it is recommended to sink to 600 or 700 feet below sea level, or to 1,700 or 1,800 feet below the surface. As soon as the shales of the St. Lawrence formation appear, at 1,700 feet or lower, the drilling should be stopped except under expert advice to the contrary.

No special difficulties in drilling need be apprehended. Shales may be expected to occur among the limestones of the upper 800 feet, and heavy shales will be found between 800 and 950 feet, and again between 1,200 and 1,300 feet. These should be cased to insure against caving.

CHAPTER XII.

CENTRAL DISTRICT.

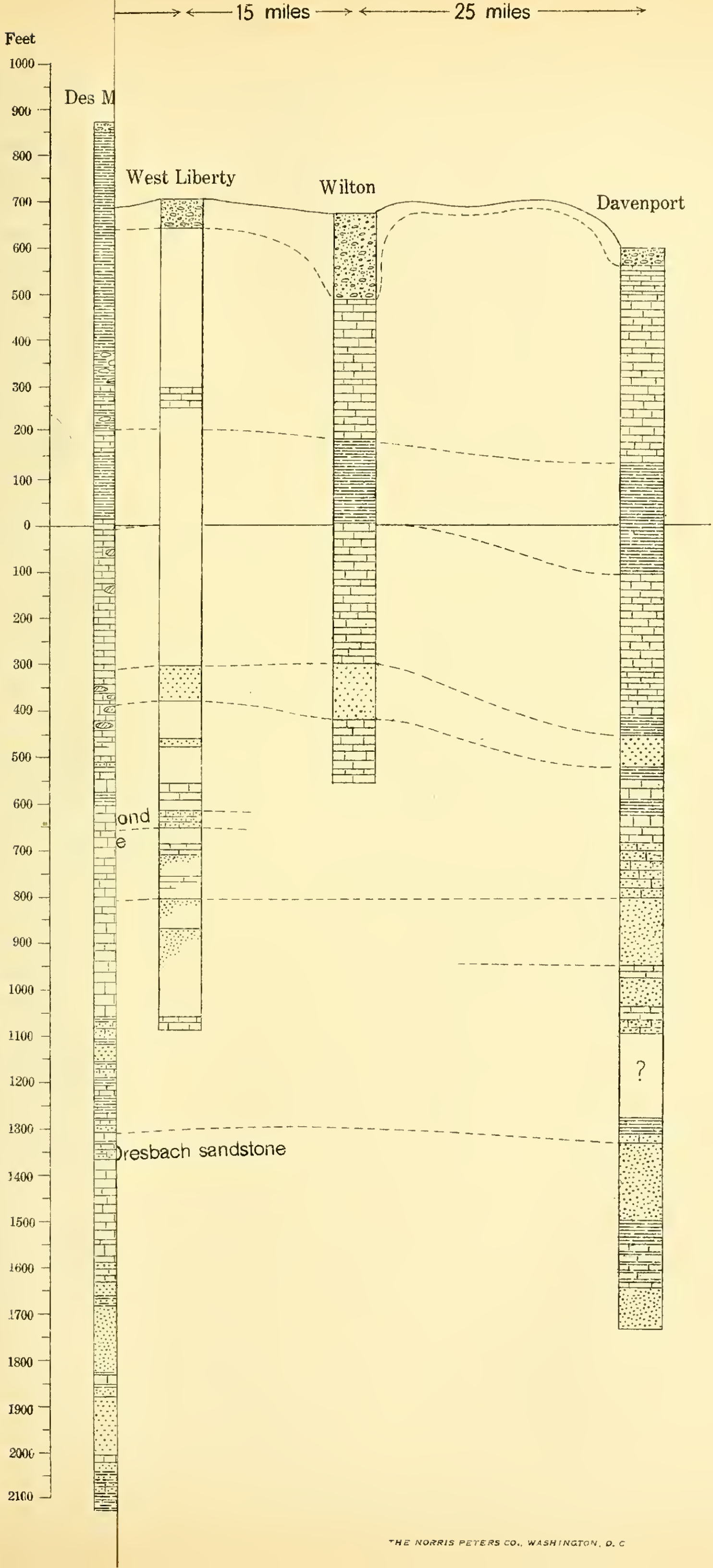
INTRODUCTION.

By W. H. Norton.

The central district comprises 12 counties situated in central Iowa—Boone, Dallas, Greene, Grundy, Guthrie, Hamilton, Hardin, Jasper, Marshall, Polk, Story, and Webster. By far its larger part, including all the central and western portions, is underlain by Pennsylvanian rocks, which here consist predominantly of shales; the eastern part is underlain by the Mississippian, which also includes heavy shale beds. The presence of these heavy beds of shale make the question of the deeper water supply of special importance.

The Paleozoic terranes continue their southwestward dip well toward the western part of the area. From Waterloo to Ackley the average fall of the St. Peter sandstone is 8 feet per mile; from Ackley to Fort Dodge the fall decreases to 2⅓ feet per mile (Pl. VI, p. 258). The section along the Chicago & North Western Railway shows a descent of the St. Peter from Belle Plaine to Boone averaging 4 feet to the mile (Pl. XI, p. 382), but this dip is interrupted by the Ames anticline, discovered by Beyer and demonstrated by his section of the deep well at the Iowa Agricultural College. By this singular upwarp the St. Peter at Ames stands 275 feet higher than at Boone, 15 miles farther west. From Boone a very gentle descent of about 3 feet to the mile continues to Ogden, but from Ogden the strata rise at the rate of 8⅓ feet to the mile as far as Jefferson. Along the main line of the Chicago, Rock Island & Pacific Railway the St. Peter dips west from Grinnell to a point 12 miles north of Des Moines at the rate of 6 feet to the mile. (See Pl. XV.) West of Des Moines the strata probably continue their westward dip through or nearly through Dallas County, beyond which a very gentle ascent probably occurs. From Waterloo to Des Moines the St. Peter descends 1,143 feet, or a little less than 12½ feet to the mile.

The deep-water beds of this district are the St. Peter sandstone, the Prairie du Chien group, and the Jordan sandstone. The Jordan, however, may not be found well defined in the southern and southwestern parts. In the sections at Boone and Des Moines the terranes



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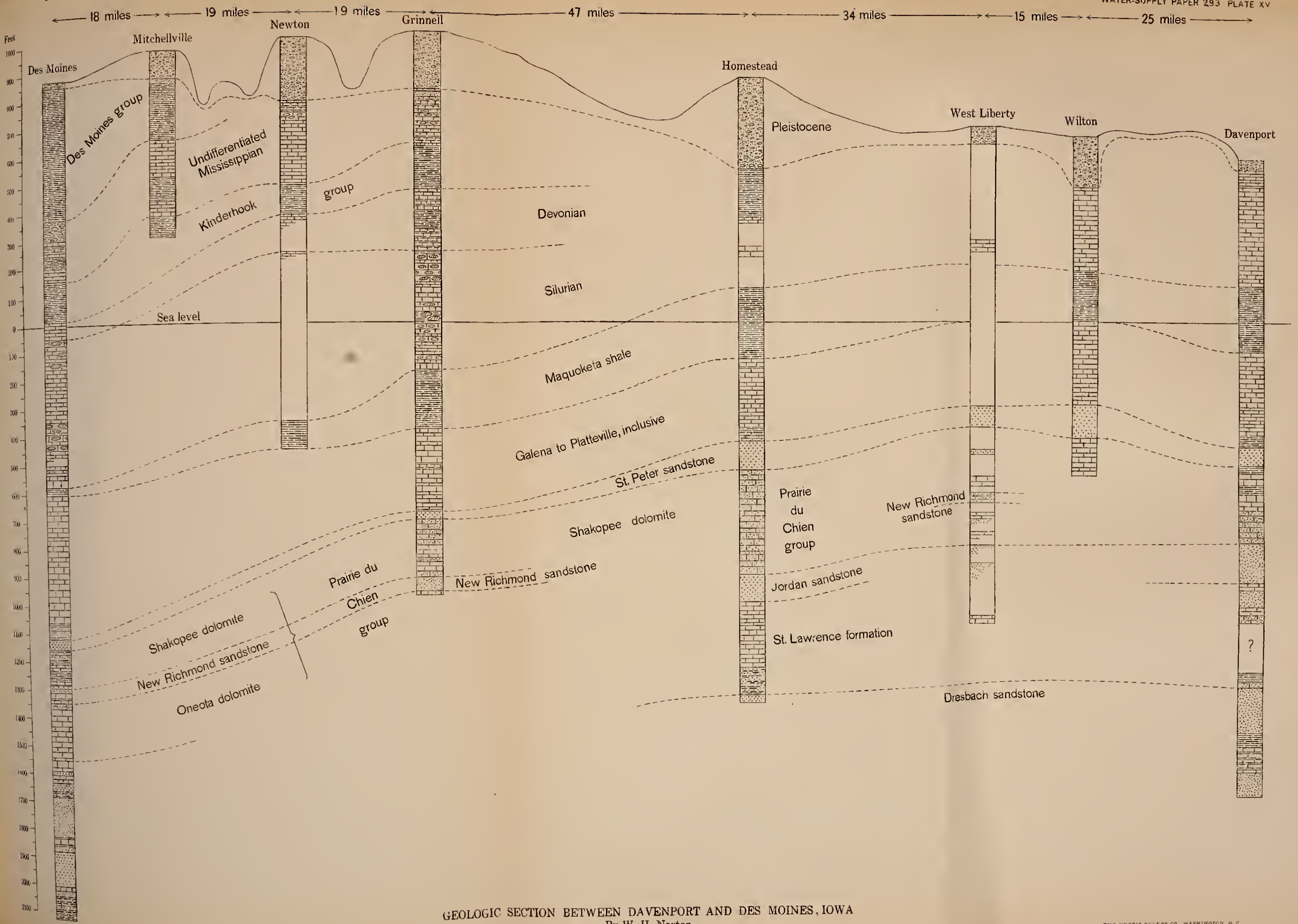


GEOLOGIC SECTION BETWEEN DAVENPORT AND DES MOINES, IOWA
By W. H. Norton

below the St. Peter are not well demarked, even the boundary between the Prairie du Chien and the Jordan being indistinct. Though water-bearing sandstones will undoubtedly be found below the St. Peter, their place can not be predicted and their correlation is not always determinable. In the central and southwestern parts of the district these sandstones are to be found only at great depths and the cost of reaching them should be well considered before a deep well is decided on. The history of the Boone wells is exemplary in this respect.

In the northern tier of counties the St. Peter seems to be unusually thick and the terranes immediately underlying it are apparently markedly arenaceous. They lie within profitable drilling distance of the surface and may be expected to yield exceptionally large supplies of water.

Moderate amounts of water may be found in the Galena and Platteville limestones, but generally wells should be carried through the St. Peter or the underlying water beds. The Herndon supply seems to come from the Galena, and it is quite possible that had the well been drilled a few score feet deeper the St. Peter would have been encountered.

The waters of the country rocks, especially those of the Pennsylvanian, are apt to be so highly mineralized as to be unpotable. The gypseous beds of the Silurian also furnish highly mineralized waters at a number of places. Special care should be taken to case out these upper waters from deep wells. The high mineral content of a number of the deep wells leads to a strong suspicion that their waters are derived in part from upper horizons, yet the lower waters—those of the St. Peter and the subjacent beds—have come far, they have sunk deep, their circulation has no doubt become sluggish, and they have had opportunity to take up far more minerals in solution than have the waters of the same beds farther to the north and east.

Taking all factors into consideration deep wells can not be recommended for the extreme southern part of the district, including the southern half of Guthrie, Dallas, Polk, and Jasper counties, except as experiments and where other sources are unavailable. The depth of the Ordovician formations along the axis of the downwarp from Boone southward renders deep-well drilling here also of doubtful expediency. Except in these parts of the district, however, wells may obtain water of fair quality without being carried to excessive depths. Other sources of supply should, however, be carefully considered before decision is made in favor of artesian wells.

BOONE COUNTY.

By W. J. Miller and W. H. Norton.

TOPOGRAPHY AND GEOLOGY.

The surface of Boone County is rather flat, although very gently rolling areas are not uncommon. The most striking modification of the general flatness is the broad, deep valley cut by Des Moines River from north to south across the middle of the county. A smaller depression is formed along Beaver Creek in the western part.

Wisconsin drift and Kansan drift are spread over the whole county except along Des Moines River, where both have been completely eroded. The drift appears to be thinner on the west side of the river than on the east. It rests immediately on the Des Moines group of the Carboniferous, which has been well exposed by erosion along Des Moines River

The drift formations show rapid variations in thickness, but are generally horizontal. The rock formations dip rather strongly to the west in the eastern part of the county and lie about horizontal in the western part. (See Pl. XI, p. 382.)

UNDERGROUND WATER.

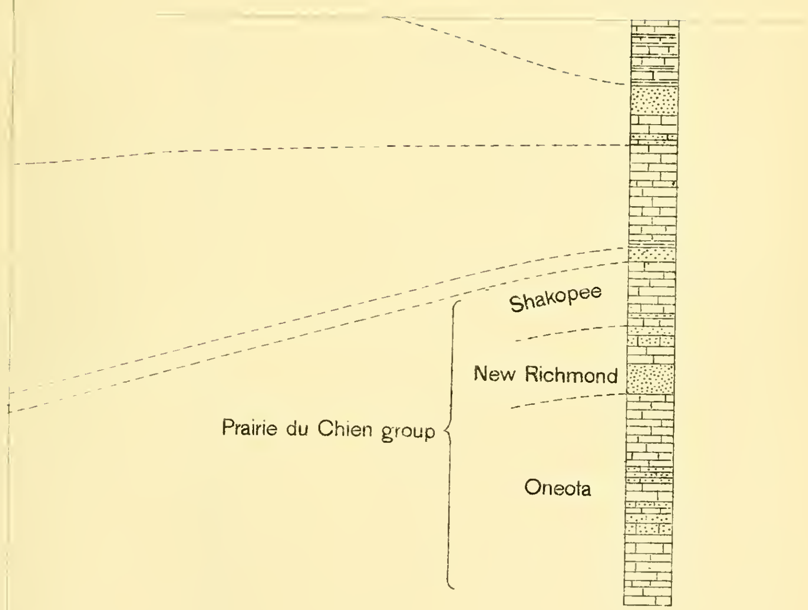
SOURCE.

Most of the wells in Boone County obtain water in the sand or gravel beneath the Wisconsin drift, at depths ranging in different districts from 50 to 120 feet. Where the gravels fail to yield sufficiently, deeper wells must be drilled. Along Des Moines River the Wisconsin is altogether absent, and it also appears to be absent or very thin along the other watercourses.

Where the Wisconsin drift is very thin or absent, especially along certain watercourses, first water is obtained in the sand or gravel beneath the blue clay of the Kansan drift, which affords a persistent and satisfactory supply and is tapped by a good many wells. Because of rather rapid and local thickening and thinning of the Kansan, the depth to this water varies greatly even in any one part of the county. Depths ranging from 100 feet to nearly 300 feet have been noted, the most common being 150 to 200 feet; the greatest depth appears to be in the vicinity of Boone. Along Des Moines River the Kansan has been completely cut through. Unless a well has been sunk into the underlying rocks, it may be difficult to tell whether the water comes from beds below the Kansan or below the Wisconsin.

Local good supplies are found in sandy layers in the blue clays of either the Wisconsin or the Kansan drift sheets.

A number of wells obtain water from Carboniferous sandstones (Des Moines group). A few very deep wells, as at Boone and Ogden, get water in Cambrian sandstone.



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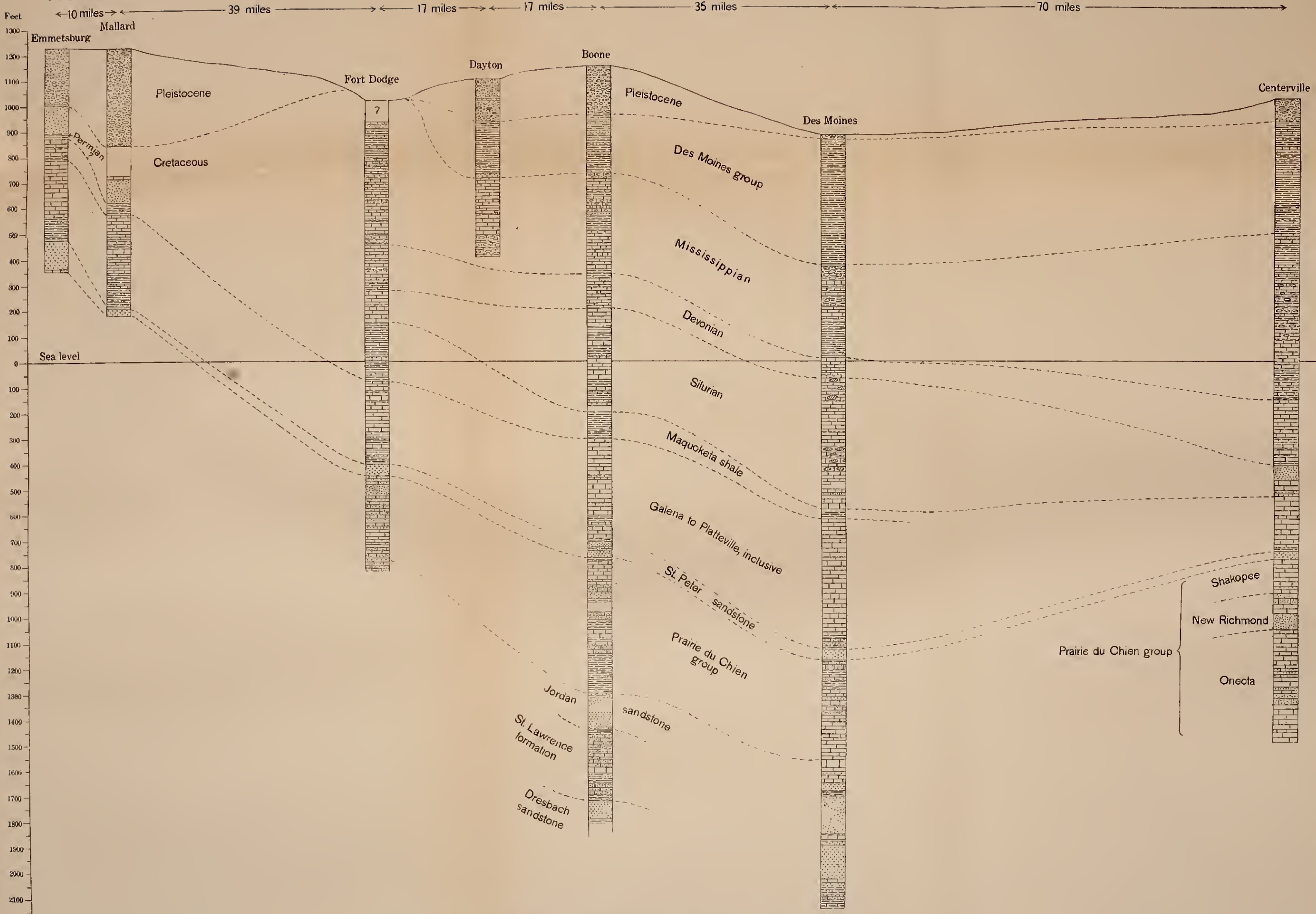

GEOLOGIC SECTION BETWEEN EMMETSBURG AND CENTERVILLE, IOWA
By W. H. Norton

THE NORRIS PETERS CO., WASHINGTON, D. C.

On the low lands along stream courses the water in the drift may be under sufficient head to overflow at the surface. The most important flowing basin in Boone County is along Beaver Creek and its branches. Flows are also obtained along Big Creek in the southeastern part of the county, and at least one flowing well exists in the northeastern part of the county in the valley of Squaw Creek. A flowing well has been reported in the northwestern part of Boone and another 5 miles north of Boone.

The available data are not sufficiently accurate to determine definitely the source of these flows, but the best evidence indicates that those along Beaver and Big creeks are derived from the gravels beneath the Kansan drift, and the others from the sand and gravel beneath the Wisconsin. The flowing well in the northwest part of Boone and the one 5 miles north of Boone are almost certainly from the Wisconsin.

SPRINGS.

A few springs are found along Des Moines River and some of the smaller streams, but none are of notable size.

CITY AND VILLAGE SUPPLIES.

Boone.—Boone (population 10,347) derives its water supply from four wells, 3,010, 2,900, 297, and 264 feet deep. (See Pls. XI, XVI.) The water is pumped by air lift to a reservoir and thence to an elevated tank, from which it is distributed by gravity with a domestic pressure of 40 pounds and a fire pressure of 100 pounds. Boone has 10½ miles of mains, 46 fire hydrants, and 500 taps. The system serves 2,500 people with 300,000 gallons a day. The water is plentiful but hard.

City well No. 1 has a depth of 3,010 feet and a diameter of 8, 5⅝, 4½, 3½, and 3 inches; casing, 5⅝ inches to 1,400 feet, 4½ inches from 1,300 to 1,875 feet, and smaller from 1,975 to 2,073 feet. The curb is 1,140 feet above sea level and the head 200 feet below the curb. The pump cylinder is set 276 feet below the curb; pumping at the rate of 70 gallons a minute produced no noticeable effect on water level. Water from depths of 45 feet and 195 feet rose to 35 feet below the curb and yielded 40,000 gallons a day; water from the St. Peter sandstone at 1,875 feet rose to 60 feet below the curb; water from beds at depth of 2,700 feet stood 200 feet below the curb but gave largest yield. Date of completion, 1890. Temperature, 68° F.

The water is corrosive and scale forming; new water pipes in boilers are eaten out sometimes in six months; scale deposits at the rate of about 1 inch a week in heater and one-sixteenth of an inch in boiler tubes.

Record of strata in well No. 1 at Boone.[1]

	Depth in feet.
Pleistocene (200 feet thick; top, 1,140 feet above sea level):	
Clay, yellow, sandy, variegated	10
Clay, light blue; mixed with angular gravel	24
Clay, light blue; gravel more conspicuous	34
Clay, yellowish gray, slightly arenaceous; and containing fragments of wood closely resembling red cedar; gravel persists but is less angular	45
Clay, gray blue; more even in texture than preceding, but still containing a considerable percentage of arenaceous material; strongly calcareous	60
Clay, yellow-gray; changes gradually to yellow at 140 feet; even textured, almost free from gravel, but slightly arenaceous throughout; 3 samples	100, 110, 140
Clay, grayish yellow; containing angular sand and gravel	150
Gravel, coarse; embedded in matrix of blue clay; gravel of quartzitic, cherty, and basic igneous rocks; many pebbles faceted	155
Clay, deep brown	165
Clay, blue, massive	175
Sand, quartz; fine uniform grain, containing a few grains of calcareous chert	185
Gravel, coarse; composed chiefly of granite, vein quartz, basic igneous rocks, quartzite, and nodules of clay ironstone. The latter two bespeak strongly a coal measure origin. The rounded forms of many of the constituents bear evidence of prolonged attrition	195
Pleistocene (?) (70 feet thick; top, 940 feet above sea level); may belong to Des Moines group of the Pennsylvanian:	
Shale, buff, arenaceous; containing a small amount of fine gravel probably carried down from overlying strata; slightly calcareous, loesslike in appearance, and with distinct soil odor; samples at 240 and 260 feet clay, drab, sandy, and pebbly; not molding readily when wet; sample at 230 feet effervesces freely in acid, and slightly calcareous below; appearance of old soil at 240 feet; a little wood at 250 feet; 7 samples	200–260
Carboniferous:	
Pennsylvanian:	
Des Moines group (175 feet thick; top, 870 feet above sea level):	
Shale, blue, compact, brittle	270
Shale, blue; a little coal; 2 samples	275, 308
Shale, blue, calcareous, and slightly arenaceous	325
Shale, light blue, strongly calcareous; more arenaceous than the preceding	335
Shale, black, bituminous, fissile; 2 samples	345, 353
Shale, bituminous, mixed with ash-colored fire clay, coal, iron pyrites, and clay ironstone	355
Shale, black, noncalcareous, brittle; containing an abundance of iron pyrites	370

[1] Adapted from Beyer, S. W., Geology of Boone County: Iowa Geol. Survey, vol. 5, 1896, pp. 194–198. The assignment to formations follows closely that of Dr. Beyer.

	Depth in feet.
Carboniferous—Continued.	
Pennsylvanian—Continued.	
Des Moines group (175 feet thick; top, 870 feet above sea level)—Continued.	
Shale, gray-blue; slightly arenaceous at 400 feet but practically noncalcareous thorughout; 4 samples	380, 390, 400, 415
Shale, ash colored, brittle, calcareous	430
Mississippian:	
"St. Louis limestone" and Osage group (155 feet thick; top, 695 feet above sea level):	
Shale, gray; a little black shale; much flint partly in the form of geodes; some limpid quartz; 2 samples	445, 450
Shale, grayish black, calcareous, and arenaceous	455
Limestone; rhombs of calcite	460
Limestone, slightly oolitic; 4 samples	470, 475, 490, 500
Shale, blue; strongly calcareous; 3 samples	515, 525, 540
Shale, gray-blue; more marly than preceding	550
Limestone, blue-gray, close textured, brittle; sharply angular	552
Limestone, conchoidal or hackly fracture	560
Limestone; abnormal amount of chert	562
Limestone, oolitic facies, slightly quartzitic; not angular	580
Sandstone, friable, fine grained	590
Kinderhook group (215 feet thick; top, 540 feet above sea level):	
Shale, green-gray, slightly arenaceous	600
Shale, slightly calcareous; 2 samples	610, 620
Shale, more marly	630
Limestone, gray; 2 samples	640, 650
Limestone, gray, marly	660–777
Limestone, blue, compact, brittle	790
Limestone, apparently brecciated	800
Shale, gray	805
Devonian and Silurian (520 feet thick; top, 325 feet above sea level):	
Limestone, subcrystalline, gray; 2 samples	815, 830
Limestone; shows numerous reddish-brown spots, probably due to oxidation of iron pyrites; 2 samples	849, 920
Limestone, magnesian, light buff; 2 samples	930, 1,015
Limestone, more or less argillaceous; fragments of a dark-colored shale; 2 samples	1,028, 1,040
Shale, sligntly calcareous	1,050
Limestone, magnesian, light buff; 2 samples	1,065, 1,070

	Depth in feet.
Devonian and Silurian (250 feet thick; top, 325 feet above sea level)—Continued.	
Shale, gray-blue, slightly calcareous; sand present; 3 samples	1,080 1,090 1,100
Shale, arenaceous; many sand grains larger than those above	1,120
Limestone, gray, dolomitic; bituminous shale at 1,130 feet; 3 samples	1,130 1,140 1,150
Limestone, magnesian, buff, saccharoidal; 3 samples	1,160 1,170 1,180
Limestone, magnesian; some quartz grains	1,190
Limestone, dolomitic, marly; 2 samples	1,200 1,210
Shale, greenish gray	1,220
Limestone, dolomitic, marly; 2 samples	1,240 1,250
Limestone, argillaceous	1,260
Quartz, varicolored, chalcedonic	1,280
Clay, residual; a red ocherous substance, charged with white calcareous grains	1,282
Sand, quartz, varicolored	1,290
Limestone, crystalline, purplish; some fissile green shale	1,298
Limestone, buff; considerable green shale	1,305
Dolomite, gray, fine even texture, brittle, reduced to fine sand by drill; 2 samples	1,315 1,325
Ordovician:	
Maquoketa shale (105 feet thick; top, 195 feet below sea level):	
Shale, green, soft, plastic, only slightly calcareous	1,335 1,385
Shale, black, carbonaceous	1,395
Shale, buff, magnesian; 2 samples	1,405 1,430
Galena dolomite and Platteville limestone (405 feet thick; top, 300 feet below sea level):	
Limestone, agrillaceous	1,440
Limestone, gray, magnesian; 2 samples	1,450 1,480
Limestone, argillaceous, marly	1,490
Limestone, gray, magnesian; 2 samples	1,500 1,510
Limestone, buff, magnesian, finely granular	1,537
Limestone, slightly cherty	1,545–1,560
Limestone, buff, magnesian, containing flakes of gray limestone and small cleavage plates of gypsum; 3 samples	1,580 1,590 1,600
Dolomite, brownish yellow, marly	1,610
Dolomite, becoming progressively lighter colored; 2 samples	1,620 1,630
Dolomite, buff	1,640
Dolomite, saccharoidal	1,650

	Depth in feet.
Ordovician—Continued.	
Galena dolomite and Platteville limestone (405 feet thick; top, 300 feet below sea level)—Continued.	
Dolomite, buff; 2 samples	1,660 1,680
Dolomite, shaly	1,690
Dolomite, bluish gray, marly, argillaceous	1,700
Dolomite, buff; 3 samples	1,710 1,720 1,730
Clay, residual, with some fine-grained quartz sand	1,740
Shale, greenish gray	1,750
Dolomite, brownish	1,760
Shale, greenish gray with dolomite sand	1,770
Dolomite, deep brown	1,780
Dolomite, color changes gradually from buff to greenish gray and texture becomes shaly	1,795–1,810
Shale, bluish gray	1,830
Shale, green, noncalcareous	1,835
Shale, bluish	1,840
St. Peter sandstone (55 feet thick; top, 705 feet below sea level:	
Sandstone, clear white, grains well rounded	1,845
Shale, green; small amount of sand	1,850
Shale, arenaceous; 2 samples	1,860 1,870
Sandstone, clear-white, even-grained quartz sand; 3 samples	1,880 1,890 1,895
Prairie du Chien group:	
Shale, arenaceous	1,900
Dolomite, gray; fine quartz sand	1,910
Dolomite, greenish gray, marly	1,915
Dolomite, gray; with quartz; sand finer and much more angular than that at 1,880 feet; 2 samples	1,940 1,950
Dolomite, cream-colored, slightly shaly	1,955
Dolomite, gray, shaly	1,975
Shale, red, noncalcareous	2,075
Shale, buff, highly calcareous, slightly arenaceous	2,165
Shale, green; 2 samples	2,200 2,250
Shale, dark-blue, and marl, light gray	2,310
Cambrian:	
Jordan sandstone:	
Sandstone, highly calcareous, buff, fine grained; 2 samples	2,510 2,515
St. Lawrence formation and earlier Cambrian strata:	
Shale, yellowish green, highly calcareous	2,560
Sandstone, yellowish, fine grained, mostly subangular or rounded; many angular grains	2,585
Sandstone, light bluff; grains fine, mostly angular; 2 samples	2,640 2,660
Sandstone, brown, calciferous, fine grained	2,700
Alternating bands of shale, red marl, and soft red sandstone, without limestone; 2 samples	2,700 3,000

City well No. 2 has a depth of 2,914 feet and a diameter of 16 inches to 195 feet, 12 inches to 294 feet, 10 inches to 500 feet, 6¼ inches to 1,973 feet, below this not reported. The curb is 1,140 feet above sea level; water at 195 feet rose to 35 feet below the curb; water at 1,870 to 1,885 feet rose to 100 feet below the curb; the largest yield came from 2,846 to 2,900 feet. The capacity of the pumping apparatus is 70 to 80 gallons a minute. Temperature, 62° F. The cost, including casing, was $15,000. The well was drilled by J. P. Miller & Co., of Chicago.

Both deep wells were abandoned in 1906 in favor of supply from shallower wells.

Driller's log of deep well No. 2 at Boone.

	Depth in feet.
Soil	0–4
Clay, blue	13–45
Sand; with water	60
Sea mud	86
Clay	98
Sand; with water	185–195
Clay	200
Stone, light blue	355
Shale, black	370
Sandstone	430
Gravel and slate	450
Fire clay	457
Hard rock, gas	471
Limestone	520
Soapstone	610
Limestone	642
Stone, red, hard	1,282
Marl, red, sticky	1,290
Hard limestone	1,315
Shale, blue	1,335, 1,435
Limestone	1,735
Rock, light brown	1,752–1,800
Shale, blue	1,840–1,868
Sandstone; well tested; amount of water small	1,870–1,895
Sand, shale, limestone	1,900–1,975
Crevice	2,075
Limestone	2,140
Chalk	2,190
Limestone	2,200
Shale and limestone	2,360, 2,650, 2,800
Shale, blue	2,815–2,835
Sandstone, water bearing	2,846–2,900
Shale, blue, soft and sticky	2,914

Record of strata (below 2,009 feet) in well No. 2, at Boone.

	Depth in feet.
Dolomite, cherty; much quartz sand	2,009
Dolomite, highly arenaceous, or sandstone, calciferous	2,035
Sandstone, brown; grains imperfectly rounded	2,045

	Depth in feet.
Dolomite, arenaceous; 2 samples	2,070 2,135
Dolomite, arenaceous; much shale	2,150
Shale, buff, highly calcareous, slightly sandy	2,165
Dolomite, arenaceous; much shale	2,170
Marl, drab, calcareous, argillaceous, and minutely arenaceous and cherty	2,190
Dolomite; with shale and sand; 2 samples	2,218 2,243
Shale, green	2,250
Dolomite, highly arenaceous	2,257
Marl, drab, calcareous, argillaceous, minutely arenaceous and cherty	2,285
Sandstone, calciferous	2,292
Shale, dark blue, and marl, light gray	2,300
Marl, greenish yellow and blue, 4 samples	2,315 2,360 2,365 2,395
Sandstone, fine grained; calcareous cement; glauconiferous; much argillaceous material; 2 samples	2,425 2,435
Sandstone; rounded grains; highly argillaceous; green fissile shale	2,445
Sandstone of minute angular grains held in calcareous cement, with some greenish cryptocrystalline silica, argillaceous	2,460
Sandstone; fine rounded grains, calcareous cement, glauconiferous; considerable green shale in the drillings	2,620
Shale, hard, slate colored; in chips; greenish yellow marl in concreted powder	2,685
Sandstone, buff, calciferous; disintegrating under acid into fine angular particles; much hard green laminated shale	2,700
Dolomite, glauconiferous; much shale	2,705
Sandstone, greenish, hard, fine grained, califerous, highly glauconiferous; in laminated chips; also chips of siliceous gray dolomite and much hard green shale	2,727
Shale, slate colored, hard; in chips; much greenish argillo-calcareous and microscopically quartzose powder	2,730
Marl, light green-gray, quartzose; constituents microscopic; slightly glauconiferous; 2 samples	2,750 2,755
Dolomite, arenaceous, glauconiferous; much shale	2,780
Dolomite; as above; in buff meal; marl in green-gray concreted powder	2,800
Marl, green-gray	2,811
Marl, green-gray, glauconiferous, and dark slaty shale	2,817
Marl, green-gray, glauconiferous, and hard shale	2,840
Sandstone, buff; clean quartz grains, imperfectly rounded, very diverse in size, the largest reaching or exceeding 1.5 millimeters; water bearing	2,846
Sandstone; as above, but coarser; many grains reaching or exceeding 1.5 millimeters	2,855
Sandstone; as above, but somewhat finer grained than at 2,846 feet	2,862

	Depth in feet.
Sandstone; as above; 3 samples	2,870 2,877 2,890
Shale, light drab, slightly calcareous; drillings highly arenaceous	2,900
Shale or marl; in concreted powder, highly arenaceous; and hard, drab laminated shale	2,914

Driller's log of well at Boone.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil, black, and yellow clay	20	20
Clay, blue, and pebbles	28	48
Sand, white, and water	67	115
Sand (cleaner and coarser than above) and water	10	125
Gravel and water	18	143
Clay, blue, and pebbles	67	210
Clay, gray, hard	20	230
Sand and lignite	50	280
Shale, gray	10	290
Shale, black	5	295
Shale, bluish black	2	297

Madrid.—Madrid (population, 1,191) pumps its water from a well 100 feet deep by a double-action electric motor. The supply is furnished by gravity, with a domestic pressure of 42 pounds; the fire pressure is greater. The town has 1¼ miles of mains, supplying 17 fire hydrants and 10 taps to 70 people. The water is plentiful, but fairly hard.

Driller's log, Madrid well.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil, black and yellow clay	16	16
Clay, blue	54	70
Clay, yellow, and sand; water	24	94
Clay, dark, hard (hardpan)	4	98
Gravel and water; light clay or shale	2	100

Ogden.—The town of Ogden (population, 1,298) draws its supply from a well 2,507 feet deep by steam pump and force pump combined. The water is distributed by gravity, with domestic pressure of 42 pounds and fire pressure of 42+ pounds. There are four-fifths mile of mains, 10 fire hydrants, and 26 taps. All business houses and four residences use the water, consuming 7,750 gallons daily. The supply is plentiful, but hard.

The city well (Pl. XI, p. 382) is 2,507 feet deep and 10 to 3 inches in diameter. The original head was 125 feet below curb. The head in 1905 was 140 feet below curb. The capacity is 26 gallons a minute, the water coming from 110, 1,650, and 1,820 to 1,851 feet. Date of completion, 1897. Drillers, J. P. Miller & Co., of Chicago.

Record of strata in city well at Ogden (Pl. XI, p. 382).

[Based on driller's log.]

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene:		
Clay	50	50
Sand	15	65
Carboniferous:		
Pennsylvanian:		
Des Moines group (top, 1,029 feet above sea level):		
Shale; with coal at 190 and 290 feet	345	410
Mississippian:		
"St. Louis limestone" and Osage group (top, 684 feet above sea level):		
Limestone	145	555
Kinderhook group (top, 539 feet above sea level)	95	650
Carboniferous? (Mississippian?), Devonian and Silurian (top, 444 feet above sea level):		
Limestone	615	1,265
Ordovician:		
Maquoketa shale (top, 171 feet below sea level):		
Shale and red marl	55	1,320
Galena dolomite (top, 226 feet below sea level)	440	1,760
Platteville limestone (top, 666 feet below sea level)	60	1,820
St. Peter sandstone (top, 726 feet below sea level)	31	1,851
Prairie du Chien group (649 feet thick; top, 757 feet below sea level):		
Limestone	234	2,085
Limestone and shale	75	2,160
Limestone and sand	340	2,500

It is also noted that the "lime rock had mud veins in it from 150 to 1,265 feet and was the same from 1,320 to 1,760 feet." "The rock caves more or less down to the top of the sand rock about 1,820 feet; from that down to 2,460 feet (depth when noted) the rock stands up."

WELL DATA.

The following table gives data of typical wells in Boone County.

Typical wells of Boone County.

No.	Owner.	Location.	Depth.	Depth of rock.	Source of supply.	Head above or below curb.	Remarks (logs given in feet).
			Feet.	*Feet.*		*Feet.*	
1	P. Miller	8 miles south and 4 miles east of Ogden.	102	(?)	Shale (?)	− 45	Bored well.
2	J. Phralin	Buckley	126		Sand	+ 30	Flowing well. No rock.
3	J. Wilson	Ogden	205	190±	Sandstone	− 30	Bored and drilled.
4	City	Boone	297	280	Shale(?)	− 55	Steam air lift used.
5	G. Tifler	do	75		Gravel	+	Bored well. No rock.
6	Charles Pilcher	3½ miles northwest of Boone.	371		Sandstone	−140	
7	Dodge Cooperative Creamery.	3½ miles southwest of Mackey.	101		Gravel	− 40	Pumped by steam for creamery uses.
8	W. Abraham	5 miles southeast of Luther.	108		Sand	+ 25	Black soil, 5; yellow clay and blue clay, 35; "sea-mud," so-called, 10; blue clay, 10; sandy layer and water (weak flow), 1; blue clay and "sea-mud," sand and water (flow), and fossil wood and gas, 47. No rock.

Typical wells of Boone County—Continued.

No.	Owner.	Location.	Depth.	Depth of rock.	Source of supply.	Head above or below curb.	Remarks (logs given in feet).
			Feet.	*Feet.*		*Feet.*	
9	G. B. Abraham	3 miles southeast of Luther.	160		Sand	− 4	Formerly flowed +6 feet. Black soil, 3; yellow clay, 12; blue clay, 45; sand (gray) and water, 1; blue clay, 15; soft blue clay or "sea-mud," 83; greensand and water, 1. No rock.
10	Town	Madrid	100	100	Gravel	− 36	Bored well.
11	Blake farm	½ mile south of Angus.	62		do	− 20	Bored well. No rock.
12	E. Ball	Near Napier	215		Sand	− 80	Black soil and yellow clay, 20; blue clay, 60; yellow clay, 20; blue clay (hard and dark), 111; sand and water, 4. No rock.
13	J. Nolan	7 miles northwest of Madrid.	135		Gravel	−118	Bored well. No rock.

DALLAS COUNTY

By O. E. Meinzer.

TOPOGRAPHY AND GEOLOGY.

Dallas County is just south and west of the center of the State. Along its south margin, principally south of Middle Raccoon River, the old loess-covered Kansan drift at the surface has been so profoundly eroded that the topography is rugged; but the rest of the county, including much the greater part of the total area, is covered with Wisconsin drift so recently deposited and so slightly eroded that it forms a typical youthful drift plain, with gently undulating topography and numerous undrained tracts. The entire drift mantle probably averages rather less than 100 feet in thickness and in certain localities is much thinner. Although the Wisconsin drift is superimposed upon the Kansan, it does not seem to increase the total depth to bedrock, probably because of the abrasion of a part of the Kansan drift by the Wisconsin ice sheet. Over extensive areas, especially in the northwestern part of the county, a layer of gravel lies between the drift and the bedrock. Thick accumulations of alluvial and outwash materials are found along the principal watercourses, not only below the flood plain levels but also underlying the terraces which border the valleys.

The rocks lying below the drift and outcropping at many points in the southern part of the county belong to the Des Moines group of the Pennsylvanian and consist of several hundred feet of alternating beds of shale, sandstone, and coal. (See Pl. XVI.) In Dallas County the predominant rock is shale, but sandstone seems to be more abundant than is usual for this series. If traced laterally the sandstone strata show rapid changes in thickness and porosity.

The approximate section shown by a well in the valley of South Raccoon River, on the farm of Calvin Marshall in the SE. ¼ sec. 7, T 78 N., R. 29 W., is reported by A. G. Leonard [1] as follows:

Section of the Marshall flowing well.

	Thickness.	Depth.
Pennsylvanian:	*Feet.*	*Feet.*
Shale, red and blue	65	65
Sandstone	6	71
Shale and slate, bituminous	200	271
Sandstone, white	20	291
Mississippian:		
Limestone, penetrated	8	299

UNDERGROUND WATER.

SOURCE.

In both the Wisconsin and the Kansan drift areas most of the wells are dug or bored and depend on seepage from the more or less porous seams in the drift. The wells in the Wisconsin area ordinarily yield the larger and more permanent supplies.

In much of the Wisconsin area the gravel at the base of the drift will furnish large amounts of water to drilled wells; and other beds of sand and gravel at different levels in the drift will also yield generously to drilled wells; but in some localities the drill passes into the bedrock before water in sufficient quantities is found. In the Kansan area drilled wells are much less successful, chiefly because of the radical difference in the head of the water, which results directly from the difference in the topography. In the Wisconsin area the surface is so nearly level and the drainage so imperfect that practically all porous deposits are saturated, and the water in the deeper beds is under sufficient pressure to rush forcibly into the wells that penetrate them and rise nearly or quite to the surface. In the Kansan area, on the other hand, the drift is deeply dissected and the porous deposits are either drained completely or their water is under such slight pressure that it will flow only sluggishly into wells. In accordance with this general difference, flowing wells are found in a number of low-lying tracts in the Wisconsin area and springs are plentiful in the valleys of the Kansan area.

[1] Geology of Dallas County: Ann. Rept. Iowa Geol. Survey, vol. 8, 1898, p. 75.

The Pennsylvanian sandstone strata are water bearing and furnish the supply for a number of wells within this county. They are, however, so inconstant in character that drilling into bedrock always involves some uncertainty. The Marshall well (p. 683) was drilled in 1879 and has overflowed ever since. The water comes from the sandstone at the bottom, and the natural flow at the time it was visited was about 3 gallons a minute. The diameter of the well is $1\frac{1}{2}$ inches. The flowing well in the valley at Redfield (p. 685) was carried to a total depth of 1,384 feet, but it is reported that the first flow was struck at the depth of 280 feet. In the wells located on higher ground the water does not rise to the surface, but it is generally under better head in the Wisconsin than in the Kansan area. In the former area it is not unusual for drilled wells to get their supplies from sandstone that lies a short distance below the bottom of the drift.

Two-inch sand wells require screens, which give trouble by becoming incrusted, but most wells of larger diameter, if not pumped rapidly, can be finished without screens and are more satisfactory (pp. 192–193).

The drift water and some of the water from near the top of the Pennsylvanian is only moderately rich in calcium, magnesium, and the carbonates and does not generally contain large amounts of sulphates, but the water from the lower part of the Pennsylvanian, here as elsewhere in the State, is rich in sodium and the sulphates.

Water may be found below the coal measures in the Mississippian limestones, but in no large amount and perhaps of poor quality, although with good head.

As Dallas County lies in the trough of the Paleozoic strata the depth to the Ordovician and Cambrian water beds is probably too deep for profitable drilling. At Adel the St. Peter sandstone need not be expected at less than 2,000 feet below the surface (1,100 feet below sea level) and the yield from it will hardly be enough for city supply. The water horizons below the St. Peter are uncertain, but within 500 or 600 feet below the St. Peter the supply should be largely augmented.

A drill hole made at Redfield, in search for oil or gas, is of special interest, as it shows the position of several water beds. The water, which is highly chalybeate, runs unused into Middle Raccoon River. The elevation of the curb is about 900 feet above sea level.

Record of strata in prospect hole at Redfield.

[Based on driller's log.]

	Thickness.	Depth.
Quaternary:	*Feet.*	*Feet.*
Surface material	18	18
Sand and pebbles	15	33
Pennsylvanian:		
Sandstone	37	70
Soapstone or fire clay; red between 85 and 105 feet	75	145
Cave rock	20	165
Slate, dark, caving	3	168
Coal, 18 inches; also 27 feet of sandstone, limestone, and cave rock	28	196
Mississippian, Devonian, and Silurian:		
Glass rock	7	203
Mixed rock	3	206
Mixed limestone	28	234
Sand and lime streaks, bearing mineral water	19	253
Sand rock; bearing water, which comes to the surface	40	293
Limestone	40	333
No record	9	342
Limestone, dark	20	363
Limestone	10	373
Sticky cave rock	15	388
Sand; bearing water	10	398
Peculiar limestone	27	425
Rock, hard; traces of sand	13	438
Sand, hard; bearing water	12	450
Sand, hard; changing to limestone	13	463
No record	25	488
Sand; bearing heavy pressure of mineral water	10	498
Limestone, variegated	30	528
Cave rock	30	558
Limestone	50	608
Rock, hard; breaking into sand	8	616
Sandrock; bearing strong water	14	630
No record	25	655
Slate, light	10	665
Limestone	43	708
Cave rock	20	728
Limestone and water sand	40	768
Hard drilling	20	788
Easy limestone	13	801
Brittle limestone	22	823
Traces of oil rock	27	850
Close and hard	10	860
Very hard, gray marble	8	868
Close sand; bears water	15	883
Close lime	22	905
Hard stone	32	937
Hard limestone	23	960
Water sand	48	1,008
Limerock	17	1,025
Dark lime	12	1,037
Light lime	12	1,051
Traces of sand and water	5	1,056
Drilled hard	8	1,064
Limestone	18	1,082
Pronounced asphaltum	11	1,093
Sandrock	7	1,100
Limestone	8	1,108
Lime, dark	20	1,128
Lime, white	23	1,151
Lime, dark	17	1,168
Lime, soft, variegated	65	1,233
Radical change in lime	10	1,243
—— (?) water	15	1,258
Limestone	19	1,277
Water sand	13	1,290
No record	12	1,302
Very fine water sand	11	1,313
Sandstone	7	1,320
Sandstone	12	1,332
Sandstone	9	1,341
Stone, hard	9	1,350
Traces of lime and sand; water broke in	5	1,355
Rock, red	14	1,369
Rock, red, softer; at 1,376 feet water broke in	15	1,384

CITY AND VILLAGE SUPPLIES.

Perry.—The public supply for Perry (population, 4,630) is drawn from seven wells, of which three are reported to be 4 inches in diameter and 110 feet deep, one 7 inches in diameter and 117 feet deep, and three 10 inches in diameter and 117 feet deep. They pass through 11 feet of sand and gravel and then through blue clay to a total depth of 84 feet, below which they penetrate a 45-foot bed of gravel that rests upon sandstone.

In making the wells, rocks as large as 4 inches in diameter were brought up—some glaciated, others consisting of soft brown sandstone obviously of local origin. All the wells are finished with screens except one which ends with perforated casing. At first they overflowed, but now the water level is said to be 34 feet below the surface. By the application of an air lift they together discharge 2,000 gallons a minute into an underground reservoir, from which the water is lifted into a standpipe by means of duplex pumps. The system includes about 11 miles of mains, 80 fire hydrants, and 835 taps. The analyses given in the table (p. 164) show that the water is only moderately hard and is not otherwise heavily mineralized. It is used for domestic purposes by nearly the entire population, and is also utilized extensively in locomotive and stationary boilers. It is estimated that altogether an average of about 750,000 gallons is consumed daily.

The Chicago, Milwaukee & St. Paul Railway has five 6-inch wells similar to those that furnish the public supply, and the Van Camp Milk Condensing Co. has two wells of the same type, one 6 inches and one 10 inches in diameter. In all these wells air lifts are used.

GREENE COUNTY.

By W. J. Miller and W. H. Norton.

TOPOGRAPHY AND GEOLOGY.

The general flatness of surface so characteristic of all areas covered by the Wisconsin drift is in Greene County considerably modified by the broad valleys, with long gentle slopes to the stream bottoms, cut and occupied by North Raccoon River and its few branches, which flow in a general southeasterly direction across the county.

Earlier drift than the Wisconsin is found over the entire county, but the combined thickness of these deposits is in most places less than 200 feet.

In the western part of the county rocks of Cretaceous age, here very thin, immediately underlie the drift; in the eastern part the underlying rocks belong to the Des Moines group of the Pennsylvanian series. From Jefferson a tongue of the Des Moines, without

Cretaceous above it, extends some distance up North Raccoon River. (See Pl. XI, p. 382.) So far as known none of the formations show any great departure from horizontality.

UNDERGROUND WATER.

SOURCE.

Nearly all of the water used in Greene County is derived from wells in the drift. Most of these wells strike the important water-bearing sandstone or gravel stratum beneath the Wisconsin drift. The thickness of the Wisconsin, and therefore the depth to this aquifer varies a good deal over the county, well records showing differences of 20 to 150 feet or more. The greatest depths, as a rule, are found in the western part of the county. Water from this bed is very satisfactory and is practically unaffected by the weather.

Another important aquifer lies beneath the blue clay of the Kansan drift at depths ranging from 72 to 270 feet, the greatest depth being in the western part of the county. Although this is the most important and persistent water bed in the drift, comparatively few wells are deep enough to reach it. As the Wisconsin and Kansan drift sheets are not always clearly separable in a single section, it is sometimes difficult to tell with which one is dealing.

Sand or gravel beds of considerable thickness are found locally within the Wisconsin or Kansan drift sheets, and a good many wells undoubtedly get their water supply from such deposits.

ARTESIAN BASINS.

In several places in the county wells in the drift yield flowing water. One of these local artesian basins is in the southwestern part along the Willow Creek bottom, where flows are easily obtained by wells ranging in depth from 26 to 100 feet or more. The water probably comes from gravel beneath the Wisconsin drift.

Another basin is in the vicinity of Jefferson, where a number of wells along North Raccoon River and Hardin Creek bottoms yield flowing water. The aquifer from which the water comes has not been definitely determined, but it is probably the gravel beneath the Wisconsin drift at depths of 100 to 125 feet; west of Jefferson at least one well, 270 feet deep, derives flowing water from gravel beneath the Kansan drift.

A third important basin lies along the principal stream bottoms in the northeastern part of the county. Good well records are not available to show the source of the water, but in some places, as in the vicinity of Grand Junction, the water seems to come from the base of the Kansan drift. In other places the wells are much shallower, and the water horizon appears to be at the base of the Wisconsin drift.

A number of deeper wells have penetrated the drift and have gone into the Des Moines group, obtaining water chiefly in sandstones. The deepest well (2,026 feet) in this county, that at Jefferson, derives its supply from Cambrian sandstone.

SPRINGS.

Springs of small size drawing water from the drift deposits are rather common along the main stream courses.

CITY AND VILLAGE SUPPLIES.

Jefferson.—The city well (Pl. XI, p. 382) at Jefferson (population, 2,477) has a depth of 2,026 feet and a diameter of 8 inches; cased to 1,400 feet. The curb is 1,110 feet above sea level, and the head 40 feet below curb. The capacity is 200 gallons a minute, the water coming from 1,400 feet. The well was completed in 1886 by J. P. Miller & Co., of Chicago. The water is pumped by compressed air to a reservoir, from which it is forced to an elevated tank. It is distributed by gravity pressure of 60 pounds through 3½ miles of main to 22 fire hydrants and about 200 taps. About 1,200 persons use the supply, and the daily consumption is 50,000 gallons. The water is hard but is otherwise good.

The strata penetrated by this well are shown in the following record:

Record of strata in city well at Jefferson (Pl. XI, p. 382).

	Depth in feet.
Carboniferous:	
Pennsylvanian:	
Sandstone, dark buff; moderately fine grains, imperfectly rounded	260
Shale, dark, unctuous, noncalcareous	270
Mississippian:	
Sandstone, argillaceous, slightly calcareous; grains of pure quartz, from fine to coarse and but little rounded by attrition	340
Chert, gray; large to small grains of limpid quartz, probably from above, and a little white limestone	350
Limestone, white, nonmagnesian; highly arenaceous, with minute quartzose particles and some rounded grains	355
Limestone, dark and light drab; hard	525
Shale, green-gray, pyritiferous, calcareous (Kinderhook)	700
Devonian(?):	
Limestone, light buff, crystalline, pure	800
Silurian and Galena (Ordovician):	
Limestone, magnesian; in white powder; pure	1,000
Limestone, magnesian, or dolomite; some shale in brown powder; residue cherty	1,100
Limestone, magnesian, brown; in fine sand; effervescence rather rapid	1,200, 1,300
Limestone, magnesian, light blue-gray; luster earthy	1,350
Dolomite, light buff; in fine sand; highly cherty	1,450
Dolomite or magnesian limestone, brown, cherty; slow effervescence	1,500

	Depth in feet.
Ordovician:	
Platteville limestone:	
Shale, green, slightly calcareous	1,670
St. Peter sandstone:	
Sandstone, fine, white, clean; rolled grains, 50 feet thick.	1,700
Prairie du Chien group:	
Dolomite; in fine sand, deep brown; some chert	1,745
Sandstone; in yellow powder and sand of angular particles of quartz with a few round grains	1,800, 1,880

Scranton.—The water supply of Scranton (population, 845) is derived from a well somewhat over 200 feet deep. The water is pumped to an elevated tank from which it is distributed by gravity through about a mile of mains to 5 fire hydrants and 45 taps. The domestic pressure is 50 pounds and the fire pressure 100 pounds. About 250 people use the supply, the daily consumption averaging 15,000 gallons.

WELL DATA.

Information concerning typical wells in Greene County is presented in the following table:

Typical wells of Greene County.

Owner.	Location.	Depth.	Source of supply.	Head above or below curb.	Remarks (logs given in feet).
		Feet.		*Feet.*	
D. Fitz	8 miles west of Churdan.	190	Sand	−60	
Minneapolis & St. Louis Ry.	Grand Junction	325	Sandstone	−13	Engine supply. Black soil, yellow clay, blue clay, fire clay (white), shale (white), iron pyrites layer, 120; shale (dark) and blackjack, 30; coal, 1½; fire clay, 64; sandstone and water, at bottom shale, 110.
Dr. Arthur	6 miles south of Ralston.	26	Sand	+ 2	Flowing well.
William Anderson	6 miles southeast of Jefferson.	192	Gravel	−80	
Electric-light plant.	Jefferson	134	Sand	−60	
Albert Head	1 mile west of Jefferson.	270?	do	+ 3	Boiler use. Black soil, 10; yellow clay, 15; sand and water, 15; clay (dark brown and tough), 16; potter's clay (white), 12; blue clay, 100; sand (hardened) and water, 50; sand, 52.
Mr. Weant	2 miles west of Paton.	159	Sand and gravel.	−30	
R. Townsend	5 miles east 2 miles north of Churdan.	146	do	−13	
R. Adamson	2 miles north of Bayard.	127	Sand	−30	Black soil, 16; sand, 80; blue clay, black "muck" and fossil wood, 16; sand and water, 15.
John McCarthy	2 miles north of Jefferson.	105	Gravel and sand.	+20	Hard, iron bearing.
Town of Grand Junction.	Grand Junction	75	do	+25	Public well.
William Diamond farm.	7 miles northwest of Jefferson.	103	Sand	+ 4	
Ed. Jones	4 miles northeast of Grand Junction.	390	Sandstone	−40	
Chas. Reidel	1 mile south of Rippey.	160	Sand	−60	

GRUNDY COUNTY.

By W. J. Miller and W. H. Norton.

TOPOGRAPHY AND GEOLOGY.

Grundy County comprises an area of low, broad hills which give its surface a slightly undulating appearance. As a rule the hills are just high enough to cause the land to be fairly well drained. There are no large streams to produce noteworthy topographic irregularity.

Iowan drift deposits underlain by Kansan drift extend over the whole county. In some small areas loess may be present. Beneath the drift are sedimentary formations—limestones and shales—belonging to the Mississippian series (lower Carboniferous). These extend over the whole county except in the extreme northeast corner, where the drift rests on Devonian rocks (Pl. VI, p. 258), and in the middle western portion, where it lies above shale and limestone of the Des Moines group of the Pennsylvanian series (upper Carboniferous).

The drift deposits are practically parallel to each other except for local thickening or thinning and there appears to be a general slight eastward dip of all. The underlying rock formations dip slightly westward.

UNDERGROUND WATER.

SOURCE.

The most important aquifer in the drift is the sand or gravel bed at the bottom, which nearly everywhere yields a good supply of water. The depth to this aquifer ranges from 125 to 230 feet, according to the thickness of the drift sheets in different parts of the county. This aquifer is rarely lacking in Grundy County. Higher up and within the blue clay there are some local water-bearing sandy layers. In many localities, however, the water supply from these is small and may fail altogether after a time. Surface wells in the drift fluctuate with the seasons and very few farmers depend on them.

In the rock formations below the drift water is obtained by the deeper wells, many of which have been sunk in recent years.

SPRINGS.

Springs of any considerable size are not known in the county. Those that do exist are merely seepage flows from the drift deposits.

CITY AND VILLAGE SUPPLIES.

Grundy Center.—The water supply of Grundy Center (population, 1,354) is obtained from a well 469 feet deep, drilled in 1897(?) by P. Pfiffner, of Traer. The well is 8 to 4 inches in diameter and is cased to the bottom. The water level is 80 feet below the curb, The strata penetrated are indicated by the following log:

Driller's log of city well at Grundy Center.

	Thickness.	Depth.
Pleistocene:	*Feet.*	*Feet.*
Clay, yellow	10	10
Clay, blue, and some water-bearing sand	180	190
Carboniferous (Mississippian):		
Limestone	5	195
Shale, some water	4	199
Limestone	6	205
Shale, some water	80	285
Devonian:		
Limestone	184	469

The water is distributed by gravity, under a pressure of 56 pounds, through 0.26 mile of mains, to 21 fire hydrants and 120 taps. About 600 people use the supply. It is reported that about 5,000 gallons are used daily. A larger supply might be obtained by sinking wells through the Devonian and Silurian limestones to the Maquoketa shale (Ordovician), which here lies 675 to 725 feet below the surface. The Galena and Platteville limestones would also probably yield some water. The St. Peter sandstone should be reached at 270 to 350 feet below sea level or at a depth at most of 1,325 feet below the surface. Probably these formations would give sufficient water for the needs of the town for many years, but a very large supply may be had from the Prairie du Chien group and the Jordan sandstone, which would be reached by a well a little more than 1,800 feet deep. The water should be of good quality.

Reinbeck.—The town well at Reinbeck (population, 1,205), 339 feet deep, yields a good supply of hard water.

The section reported by the driller is as follows:

Driller's log of Reinbeck town well.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, yellow	4	4
Clay, blue, and sandy beds; water	225	229
Shale	20	249
Limestone; water	90	339

The water is pumped by steam pump and is distributed under gravity pressure of 43 pounds through 3 miles of mains to 13 fire hydrants and 140 taps. About 700 persons are supplied; the daily consumption is estimated at 24,000 gallons.

WELL DATA.

Information concerning typical wells in this county is presented in the following table:

Typical wells of Grundy County.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head below curb.	Remarks (logs given in feet).
		Feet.	*Feet.*		*Feet.*	
Geo. Findlayson.	7 miles north of Morrison.	242	202	Limestone..	60	Pumped by windmill Yellow clay, 12; sand (some water), 190; shale, 20; limestone and water, 20.
Henry Muller..	5 miles southeast of Grundy Center.	580	200	.....do......	60	Yellow clay, 8; blue clay, full of pebbles in sand layers, 192; limestone, some sandy, 377; shale, ½; limestone and heavy flow of water, 2. Pumped by windmill.
John Gange....	3 miles east of Reinbeck.	273	140	.....do......	100	Black soil, yellow clay, and blue shale with some sand beds and water, 140; shale, dark hard rock, and iron pyrites, 60; limestone and water, 18 to 20.
L. G. Benken..	3½ miles northeast of Grundy Center.	344	277	Sandstone...	140±	Yellow clay, 37; blue clay and some sand, 220; sand and much water, 20; shale, 60; sandstone, red, 7.
Mickley Bros...	6 miles southeast of Ackley.	152	146	Gravel......	70	Enters limestone 6 feet.
S. Sinneng.....	4 miles southeast of Ackley.	393	215	No water....	......	Abandoned. Yellow clay and sand, 32; yellow clay, 58; blue clay, 70; hardpan, 10; yellow clay, 20; blue clay, 18; black clay, 7; sandrock (yellow), 2; soapstone or hard shale, 35; soapstone or soft shale, 6; soft soapstone or shale, 85; very hard blue shale, 60.

GUTHRIE COUNTY.

By O. E. Meinzer and W. H. Norton.

TOPOGRAPHY.

The topography of Guthrie County is of two strikingly different types. South and west of Middle Raccoon River the old loess-mantled Kansan till lies at the surface and is thoroughly dissected and perfectly drained; northeast of that stream the much younger Wisconsin till overlaps the Kansan and presents a typical gently undulating drift plain, almost untouched by stream erosion and hence poorly drained, marked with abundant ponds, swamps, and sloughs.

GEOLOGY.

Several formations differing widely in age and character overlap in Guthrie County, making the geology peculiarly interesting and the ground-water conditions more varied than in most of the other counties of the State. The oldest rocks exposed are of Carboniferous age and belong to the Des Moines group of the Pennsylvanian series, which underlies the entire county, with a thickness of several hundred feet, consisting of shale alternating with numerous thin beds of limestone, sandstone, and coal. Near the south margin of the county the Des Moines is capped by the basal limestone of the Missouri group, also of the Pennsylvanian series. Upon the eroded surface of these old formations lie Cretaceous sandstones and shales, well developed and nearly continuous in the western half of the county, but thin or entirely absent in the eastern half. Finally, Cretaceous and Carboniferous alike are in general deeply buried beneath the glacial drift.

UNDERGROUND WATER.

SOURCE.

The Pennsylvanian series includes some sandstone strata that yield moderate amounts of mineralized water under sufficient head to rise nearly or quite to the level of the deepest valleys, but these sandstone strata are so scarce and so readily give place laterally to impervious beds that attempts to tap them are very liable to failure.

In the western half of the county the Cretaceous is a fairly reliable aquifer, but in the eastern half it is commonly too thin and irregularly distributed to be of consequence. In the former section it is found with considerable regularity about 250 feet below the upland surface, and its less cemented beds supply water freely, though the water is not under much pressure and does not rise many feet in the wells. Wells of 4 or 6 inch diameter with independent pumps are more successful than 2-inch "tubulars."

The upper part of the Kansan drift is sufficiently porous to allow a slow seepage of scanty water to wells of large circumference. Associated with this drift are also beds of sand and gravel whose value as water bearers is entirely different where the Wisconsin drift is present from that where it is absent. Where it is absent, they are either drained or contain water under slight pressure only, and hence do not generally supply drilled wells; where it is present, they are charged with water under sufficient pressure to flow freely into a drilled well and to fill it nearly to the top or even to rise above the surface. The village well at Stuart (p. 697) is supplied from a bed of sand beneath Kansan till. Its head is low and its yield not great, but if this same bed of sand occurred in the area of Wisconsin drift the water would be under much greater pressure, would rise much higher in the well, and could be recovered at a much more rapid rate.

PROVINCES.

In respect to ground water the county is divisible into three provinces—one in which the Wisconsin drift is at the surface, one in which the older loess-covered Kansan drift is at the surface and is underlain by water-bearing Cretaceous beds, and one in which the older drift is at the surface and is not underlain by water-bearing Cretaceous beds. Very roughly, the first province may be said to comprise the area northeast of Middle Raccoon River, the second the western part of the area southwest of that stream, and the third the eastern part of this last area.

The first province has the most favorable ground-water conditions. The porous parts of the drift are saturated almost to the surface and flowing wells are frequently obtained, as, for example, in the village of Bagley and in Richland Township between Yale and Herndon. Water-bearing beds are likely to be encountered at any level in the drift, and many of the flows come from wells less than 100 feet deep.

In the second province seepage from the drift is largely relied on, but the drilled wells go to the Cretaceous and obtain supplies that are not influenced by drought. In the third province the Cretaceous is lacking, shallow drift wells are everywhere in use, and successful drilled wells are scarce.

CITY AND VILLAGE SUPPLIES.

Bagley.—In Bagley (population, 488) there are 12 or more flowing drift wells. A public system of waterworks has recently been installed.

Guthrie Center.—The public supply of Guthrie Center (population, 1,337) is derived from seven wells located in the valley 12 feet apart. The wells consist of 3½-foot holes dug through sand and other loose materials to the Cretaceous bedrock at a depth of 28 feet, below which they are drilled to a gravelly stratum at about 50 feet. The water rises within 18 feet of the surface and the pumps are placed about 8 feet below the surface and draw by suction from all the wells simultaneously. Pumping at the rate of 200 gallons a minute for several hours produces no noticeable effect except temporarily to lower the water level somewhat. The wells are finished with open ends and no difficulty with sand has been experienced. The water is only moderately hard and is preferred to the shallow well water. There are two standpipes situated on high ground, and about a mile of mains connect with an extensive system of smaller pipes leading to about 300 points of consumption. The water is used by nearly the entire population and also by the railway company for locomotive supplies. According to the records, the average daily consumption in 1908 was only a little less than 60,000 gallons.

The Mississippian limestones would probably yield a small supply of highly mineralized water under a head sufficient to bring it within easy pumping distance of the surface. Other and presumably better supplies can be had in the heavy beds of limestone which intervene between the Mississippian and the St. Peter sandstone, but, as in all limestone beds, the water will occur in crevices and solution passages whose depth can not be predicted and which may not be struck by the drill. The St. Peter sandstone probably lies about 1,000 or 1,100 feet below sea level, or about 2,100 to 2,200 feet below the surface. Apparently the subjacent sandstones are less well defined than in eastern Iowa, but a well sunk 2,750 feet below the surface should test their capacity.

Herndon.—Little except the depth is known concerning the Chicago, Milwaukee & St. Paul Railway well at Herndon. It was drilled by W. H. Gray & Bro., of Chicago, to a depth of 1,700 feet (?) from a curb elevation of 1,062 feet above sea level. The well does not appear to have found water. The record of the strata, as made out from drillings furnished to the United States Geological Survey, is as follows:

Record of strata in Chicago, Milwaukee & St. Paul Railway well at Herndon.

	Thickness.	Depth.
	Feet.	*Feet.*
No samples	534	534
Shale, drab, calcareous; a few chips of limestone and a little white chert	20	554
Shale, drab	20	574
Shale, greenish; 2 samples	40	614
Shale, blue	20	634
Shale, green, slightly calcareous	20	654
Limestone, blue-gray; in small chips; effervescence slow; some shale from above	20	674
Limestone, light blue-gray; crystalline; in large flaky chips; moderately rapid effervescence; 2 samples	40	714
Limestone, blue-gray; effervescence slow; 5 samples	100	814
Limestone, blue-gray; slow effervescence; some chert	20	834
Limestone and shale; limestone, light blue-gray, with slow effervescence; shale, hard, dark blue	20	854
Limestone, blue-gray and buff; slow effervescence	20	874
Limestone, light buff; slow effervescence; in chips; 6 samples	126	1,000
Limestone, drab; slow effervescence; 2 samples	50	1,050
Limestone, buff; slow effervescence; drillings contain an unchipped fishtooth (of Mississippian age) apparently from some higher horizon	25	1,075
Limestone, buff, crystalline; slow effervescence, 2 samples	50	1,125
Limestone, blue-gray and buff; slow effervescence	25	1,150
Limestone, drab; slow effervescence	25	1,175
Shale or marl; highly calcareous; much anhydrite; in concreted powder	25	1,200
Limestone, hard, drab; slow effervescence; 2 samples	50	1,250
Shale, drab; facies of Maquoketa shale; 3 samples	75	1,325
Shale, light yellow, highly calcareous; in concreted powder; 3 samples	75	1,400
Limestone, white; but drillings stained with ferruginous films so as to be buff in mass; in fine sand; slow effervescence; with considerable chert and crystalline quartz in irregular grains and with some secondary enlargements	25	1,425
Limestone, white, crystalline; slow effervescence; drillings stained deep ocher yellow; in fine sand	25	1,450
Chert, in small chips; white and gray	25	1,475
Chert and shale, blue; in large concreted mass	25	1,500
Limestone and chert, in fine sand; buff in mass; effervescence slow	25	1,525
Limestone and chert; as above; some microscopic quartz particles and some imperfectly rounded small quartz grains	25	1,550
Limestone, argillaceous, or shale, calcareous; white; in concreted masses; gritty with lime particles; residue argillaceous and siliceous with microscopic crystalline quartz	25	1,575
Limestone, gray; in fine chips; slow effervescence; much gray chert	25	1,600
Limestone, buff in mass, in fine sand; much chert; residue of microscopic crystalline quartz; 2 samples	40	1,640
Limestone and shale; limestone, dark drab, argillaceous, crystalline to earthy, slow effervescence; shale, in chips, hard, green, fissile	20	1,660
Limestone and shale; limestone light buff or gray, crystalline to earthy; rapid effervescence; in flaky chips; shale as above	20	1,680
Limestone, gray and buff; rapid effervescence; in sand; some drab flint and minute imperfectly rounded grains of quartz	20	1,700

Analysis of rock from depth of 794 to 814 feet in railway well at Herndon.[1]

$CaCO_3$	48.10
$MgCO_3$	35.51
SiO_2	13.55
Al_2O_3	1.74
Fe_2O_3	.59
	99.49

The National Refining & Manufacturing Co. well at Herndon has a depth of 895 feet and a diameter of 13 to 8 inches. The curb is 1,052 feet above sea level and the head 60 feet below curb. The water comes from 20 feet, 165 feet, and between 720 and 895 feet, in rock reported as "honeycombed limestone." Date of completion, 1908. The water is heavily charged with sodium and foams so much as to prevent its use in locomotive boilers.

Record of strata in National Refining & Manufacturing Co. well at Herndon.

	Thickness.	Depth.
	Feet.	*Feet.*
Unknown	20	20
Till, blue, clayey	115	135
Sand, gray; grains angular, almost loessial in fineness, with some coarser; this is the "gas sand" of the region and blows out with the gas by the wagonload when not drowned with water	10	145
Sand, yellow, coarse, and gravel, glacial	15	160
Sand, orange, coarse	10	170
Shale, blackish, fissile	90	260
Shale, red	10	270
Limestone, argillaceous and finely arenaceous, dark buff or drab; rapid effervescence; and chert, dark drab, with much chalcedonic silica in large chips and a little drusy quartz; chalcedony reported as "water granite"	10	280
Limestone, drab, highly argillaceous, microscopically quartzose; with chert and chalcedony; shale of same color, calcareous	25	305
Chert, dark drab and blackish; highly conchoidal fracture; a little milky white translucent chalcedony	55	360
Limestone, gray, highly argillaceous; milky white chalcedony and white chert	30	390
Limestone, blue-gray; rapid effervescence; argillaceous; crystalline-granular; much white chalcedony	30	420
Limestone, almost white, coarse, crystalline-granular; and limestone, light cream-colored, soft, in flaky chips; effervescence rapid, considerable blue-gray flint	10	430
Limestone, dark buff and drab, finely crystalline; effervescence moderately rapid; with embedded, irregular, minute masses of blue flint; residue contains minute grains of quartz	10	440
Limestone, whitish, macrocrystalline, soft; rapid effervescence; some joints of crinoid stems and oolites or perhaps tests of foraminifers almost too minute to be seen with naked eye	160	600
Shale, green, plastic, fissile, noncalcareous	20	620
Dolomite or magnesian limestone, blue-gray, hard, subcrystalline; effervescence slow	20	640
Shale, pinkish gray, slightly calcareous	15	655
Limestone, magnesian, blue-gray, subcrystalline; effervescence rather slow; 2 samples	40	695
Limestone, yellow-gray, hard, fine grained; some lithographic, subconchoidal fracture; rapid effervescence	25	720
No samples	175	895

The sets of drillings from the two wells at Herndon are, fortunately, complementary and afford a fairly complete section. It will be noted that the Chicago, Milwaukee & St. Paul Railway well stopped near the summit of the St. Peter sandstone in shale resembling much the Decorah shale. Had drilling been carried a few hundred feet farther into the dolomite of the Prairie du Chien group, an abundant water supply would probably have been obtained.

[1] Made in chemical laboratory of Cornell College, Mount Vernon, Iowa.

Geologic section at Herndon.

Well of National Refining & Manufacturing Co.

Geologic division.	Thickness.	Elevation above sea level.
	Feet.	*Feet.*
Pleistocene series	180	882
Des Moines group	100	782
"St. Louis limestone" and Osage group	254	528

Well of Chicago, Milwaukee & St. Paul Railway Co.

Kinderhook shale	120	408
Devonian (?) and Silurian	590	−182
Maquoketa shale	75	−257
Galena and Platteville limestones	381	−638

Panora.—The public well at Panora (population, 1,080) is 16 feet in diameter and 40 feet deep and ends in sand. At present it furnishes about 9,000 gallons a day, but its maximum capacity is much more than this amount. The water is pumped by means of water power transmitted through an electric current. It is lifted into an elevated tank and is thence distributed by gravity through about 2 miles of mains to 10 fire hydrants and 75 taps. It is used by perhaps one-third of the people.

Stuart.—The well that furnishes the public supply of Stuart (population, 1,826) is 6 inches in diameter and 92 feet deep. It is on the upland, extends through clay, and is finished with an open end in a bed of sand or gravel from which the water rises to a level 76 feet below the surface, or 1,130 feet above sea level. With the cylinder placed 3 feet above the bottom, the well has been pumped continuously for three weeks at 16 to 20 gallons a minute; this rate of pumping lowers the water to the bottom of the cylinder and the well can by no device be made to yield more. Wells ending with screens in the same bed of sand were at first used, but the screens became clogged and the wells were lost. The water from this source is of good quality, though it contains considerable calcium carbonate, which gives it a temporary hardness. (See analysis, p. 164.)

The waterworks include a small tank set on a low tower and connected with about one-fourth mile of mains. In spite of the small service, the consumption at present approaches the maximum capacity of the well. As the system in pressure, reserve of water, and extension of mains is inadequate for fire protection, a number of large wells have been dug in different parts of the town and a portable fire engine is kept in readiness.

HAMILTON COUNTY.

By W. J. Miller and W. H. Norton.

TOPOGRAPHY AND GEOLOGY.

The surface of Hamilton County shows the topography characteristic of the Wisconsin drift areas and is for the most part so flat and poorly drained that ponds and lakes are numerous. In the northeastern part of the county this topographic monotony is somewhat relieved by the valley of Boone River. South Skunk River, which rises in the east-central part and flows southward, is the only other stream of any importance.

The drift sheets, Wisconsin and Kansan, which extend over the whole county, rest on Carboniferous rocks belonging to the Des Moines group of the Pennsylvanian series except in the small area along Boone River from Webster City northward, where they are underlain by the Mississippian.

As a rule the drift deposits lie flat except along Boone River, where they follow the slopes toward the stream bottom. The deep rock formations show little or no variation from the horizontal. (See Pl. VI, p. 258.)

UNDERGROUND WATER.

SOURCE.

By far the greater number of the wells in Hamilton County obtain water from the Pleistocene deposits, which here contain two principal water beds of about equal importance—one in sand and gravel beneath the Wisconsin drift, and the other in sand or gravel beneath the blue clay of the Kansan drift. Well data indicate that the depth to the gravels beneath the Wisconsin drift ranges from 90 to 120 feet below the ground surface. Many wells, however, fail to find water at this horizon and must be sunk deeper. The sands and gravels beneath the Kansan drift are reached at depths of 150 to 200 feet. They are lacking in but few places and form the most satisfactory aquifer in the Pleistocene deposits. In some wells, however, the water is not good because charged with organic matter. Some wells appear to derive their supply from local sand or gravel pockets within the drift sheets, but such supplies often fluctuate or even fail. Little dependence is placed on very shallow surface (dug) wells. A few wells obtain water in the older rock formations—limestones or sandstones—the water coming from different depths.

Along the bottoms of the principal streams the water is under sufficient head to overflow at the surface. A number of flowing wells are located along Boone River, as, for example, the 13 wells owned by Webster City. Other flowing wells are found along South Skunk River in the southeastern part of the county. As far as could be learned the water in these wells comes from the sands and gravels beneath the blue clay of the Kansan drift, the Wisconsin drift sheet in the localities named being thin or absent.

SPRINGS.

In the high level parts of Hamilton County springs are almost entirely lacking, but a few emerge from drift deposits along Boone River.

CITY AND VILLAGE SUPPLIES.

Jewell.—The public water system of Jewell (population, 941) is used only for fire protection and by business houses. The water is pumped by steam and is distributed under direct air pressure of 50 pounds through three-fourths of a mile of mains to 12 fire hydrants and 18 taps. The water is hard.

Webster City.—The water supply of Webster City (population, 5,208) is obtained from 13 wells, ranging in depth from 90 to 110 feet, ending in gravel beneath the blue clay of the Kansan drift. (See Pl. VI, p. 258.)

The water is distributed under pressure of 55 pounds through 6 miles of mains to about 350 taps. For fire protection pressure can be increased to 150 pounds. About 1,600 people use the supply, which is ordinarily sufficient.

The gas company well has a depth of 1,250 feet and a diameter of 8 to 6 inches; casing to or near to bottom. The curb is 1,048 feet above sea level, and the head 16 feet above the curb. The water comes from 675 feet and 1,200 feet, and the original flow was 70 gallons a minute. The well was completed in 1888. The water has both the odor and taste of sulphur and so rapidly corrodes iron that the best galvanized pipe withstands it for only about two years. For these reasons the well has never been used except to supply a public watering trough.

Record of strata in well at Webster City (Pl. VI, p. 258).

	Thickness.	Depth.
	Feet.	*Feet.*
Soil, clay, sand, thin layers of rock, etc	180	180
Limestone, light yellow; earthy luster; much quartz sand, yellow, pink, and black, grains imperfectly rounded	20	200
Limestone, light gray, soft, earthy, in flaky chips; fossiliferous	150	350
Shale, blue	10	360
Limestone, dark drab; mottled with white calcite; crystalline	100	460
Limestone, magnesian, hard, brown, crystalline	40	500
Shale, calcareous, dark gray, siliceous; microscopic particles of quartz	20	520
Dolomite or magnesian limestone, dark brown, compact crystalline	30	550
Limestone, dark blue-gray, crystalline; effervescence slow	45	595
Limestone, light yellow-gray, soft, crystalline; effervescence slow	55	650
Dolomite or magnesian limestone	30	680
Limestone, light gray, saccharoidal	95	775
Limestone, close-grained, blue-gray	45	820
Limestone, brown, crystalline	60	880
Limestone or shale, highly argillaceous, blue-gray; white concreted masses of anhydrite powder	120	1,000
Shale, drab, calcareous	75	1,075
Limestone, magnesian, brown, crystalline	15	1,090
Limestone, in pure, white, crystalline sand	40	1,130
"Limestone (?), pure white;" no sample	120	1,250
Limestone, light buff; in fine sand	....	1,250

The record is based on but 20 samples and entries, and is difficult to interpret. The Mississippian probably extends to the base of the shale at 520 feet (528 feet above sea level). No line can be drawn between the Devonian and the Silurian, and the latter seems to include the anhydrite-bearing limestone and shale, stated to extend from 880 to 1,000 feet, the 75 feet of subjacent shale falling in with the Maquoketa shale. From 1,075 feet to the bottom of the well the drill seems to have been working in the Galena and Platteville limestones. Had the drilling been continued 150 feet deeper the St. Peter sandstone would probably have been struck, and 400 to 600 feet deeper the creviced limestones and the sandstones which yield the chief supply for the Iowa wells would have been tapped. A well about 1,850 feet deep would have given a largely increased yield of much better water, the sulphate content being greatly lessened. Hence the failure of the well to get a good water need not deter other enterprises.

WELL DATA.

Information in regard to typical wells in Hamilton County is presented in the following table:

Typical wells of Hamilton County.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head above or below curb.	Remarks (logs given in feet).
		Feet.	*Feet.*		*Feet.*	
Peter Nelson	Jewell	105	None.	Sand or gravel	−30	
Peter House	3½ miles northeast of Jewell.	183	116?	Limestone	−40	
Ole Litre	6 miles southwest of Jewell.	328	107		−50	
E. Challey	2 miles south of Jewell.	95	None.	Sand and gravel.	+15	Flowing well. Black soil, 5; yellow clay, 15; blue clay, 30; blue clay, putty-like, 15; sand and gravel, 30.
A. Bloom	7 miles northeast of Jewell.	295	105	Limestone	−35	
O. Brudos	6 miles southeast of Stanhope.	155	None.	Gravel	−25	
J. E. Olmstead.	¾ mile west of Webster City.	181	181	do	−50	Black soil, 4; yellow clay, 14; blue clay, 83; yellow clay, 40; black muck with leaves, etc., 40; gravel; limestone.
M. Mahoney	2 miles northeast of Duncombe.	176	None.	do	−34	
Jos. Welch	2 miles north of Homer.	181	None.	do	−30	Black soil, 4; yellow clay, 10; blue clay, 16; sand and some water, 3; "hardpan" (hard blue clay), 17; sand and some water, 50; tough black clay, 75; sand and gravel and water, 6.
G. Robinson	2 miles west of Blairsburg.	167	(?)	Sand	−40	Water bed at 156 feet.
S. Bateman	2 miles south of Webster City.	68	None.	Gravel	+25	Flows 10 gallons per minute; pumped by steam. Yellow sand, 8; blue clay, 27; sand and water (flow 30 gallons per minute, but too much sand), 3; blue clay, 28; gravel and water (flow, 10 gallons per minute).
M. H. Brinton.	Ellsworth	91	None.	Sand and gravel.	+14	Flows 10 to 15 gallons a minute.
Lars Severson.	6 miles northwest of Radcliffe.	240	162		−45	
N. E. Waugh	3½ miles north of Roland.	108	30	Limestone	+25	Flows 13 gallons a minute.

HARDIN COUNTY.

By W. J. Miller and W. H. Norton.

TOPOGRAPHY AND GEOLOGY.

An area of loess-covered Kansan drift in the southeastern part, a smaller area of Iowan drift in the northeastern, and a much larger area of Wisconsin drift in the western parts are the controlling factors in the topography of Hardin County.

The surface of the Kansan drift area is well drained. The larger streams have deposited some alluvium, and their tributaries have cut well back toward the divides. The Iowan area is part of the great Iowan drift plain and is comparatively flat. The Wisconsin drift area comprises more than four-fifths of the entire county. Its eastern margin is marked by a chain of hills and knobs that rise 30 to 60 feet above the adjoining uplands. Back of this ridge the general surface is characteristically a plain, marked by many saucer-like depressions and knob-like eminences. Drainage lines are few and broad areas are almost wholly undrained.

The most striking feature of the eastern part is Iowa River channel, which has been cut down well below the general level. In the vicinity of Iowa Falls, Iowa River cuts through ledges of solid limestone. Except very locally along Iowa River, where it has been eroded away, the Kansan drift sheet is probably present throughout the region, extending beneath the Iowan sheet in the northeastern part and beneath the Wisconsin in the western.

From the northern part of the county to a little south of Iowa River, and probably also in the extreme southeast corner of the county, the drift rests on limestone belonging to the Mississippian series of the Carboniferous. (See Pl. VI, p. 258.) Throughout the remaining and larger part of the county the underlying rock is the shale or limestone of the Des Moines group of the Pennsylvanian series.

The drift formations lie in general nearly horizontal; the underlying rocks show a slight westward dip.

UNDERGROUND WATER.

SOURCE.

The most important and persistent aquifer in the drift deposits of the county appears to be the sand or gravel beneath the blue clay of the Kansan drift. As the drift formations vary in thickness from a few feet to a maximum of 300 feet, this aquifer may be found at any depth up to 300 feet; nearly everywhere, however, it lies between 100 and 200 feet.

The next most important aquifer in the drift is the sand or gravel beneath the Wisconsin drift. Well data indicate that this aquifer, where present, lies at a depth of less than 100 feet. In many places, however, the sands or gravels are absent or they do not yield sufficient water.

Some wells obtain water from local sand or gravel pockets in one or the other of the blue clays, but such supplies are rarely satisfactory. Nearly all the very shallow surface (dug) wells show seasonal fluctuations.

Some wells have passed through the drift into the shales, sandstones, and limestones below, obtaining water from the limestones and calcareous sandstones.

Many wells sunk in the depressions obtain water under sufficient head to flow at the surface. All such are comparatively shallow, ranging in depth from 25 to 75 feet; their water comes from sands or gravels, thought to be at the base of the Kansan drift, below a blue clay, which acts as a retaining layer. Such local basins are found in the western portion of the county along the more important streams between Iowa Falls and Hubbard. A number of wells along Rock Run near Iowa Falls and others southwest of Iowa Falls in the vicinity of Buckeye and Cottage yield flowing water.

Several wells obtain flows from the underlying rock formations, for example, the city well of Iowa Falls and a well 3½ miles west of Hubbard.

SPRINGS.

Many springs emerge from both the drift and the underlying formations along the course of Iowa River. The water of the springs north of Eldora comes from the coal measures and carries iron and sulphur. Small springs are common along other streams, especially in the local artesian well basins.

The Siloam mineral springs, owned by Mr. E. E. Cannon, of Iowa Falls, are on Maplehurst farm, 1½ miles northwest of Iowa Falls. The springs emerge near the stream bottoms along a small branch of Iowa River, and the water apparently comes from limestone, which is here near the surface. The water is used both for drinking and as a medicine. About 50 families in Iowa Falls are supplied.

CITY AND VILLAGE SUPPLIES.

Ackley.—Two wells are owned by the city of Ackley (population 1,244), one 2,032 feet deep, the other 119 feet deep. The deep well, which was put down some time prior to 1894, was abandoned because it did not yield sufficient water. The curb of this well is 1,110 feet above sea level; the head is reported to have been 82 feet below the curb, or 1,028 feet above sea level; another report gives the head as

25 feet below the curb. Water was recorded as occurring 50 feet from the top; other veins were not recorded. The strata penetrated are indicated by the following section:

Record of strata in city well at Ackley (Pl. VI, p. 258).

	Thickness.	Depth.
Quaternary (100 feet thick; top, 1,110 feet above sea level):	*Feet.*	*Feet.*
Alluvium, or drift	100	100
Carboniferous (Mississippian):		
Kinderhook group (207 feet thick; top, 1,015 feet above sea level):		
Shale, fine, blue, somewhat calcareous; 2 samples	35	135
Limestone, coarse, buff, vesicular	5	140
Shale, blue, fine, slightly calcareous; 2 samples	23	163
Sandstone, fine, bluish white, friable		163
No samples	62	225
Shale, fine, blue, slightly calcareous; 3 samples	35	260
Sandstone, fine, bluish white, friable	5	265
Shale, blue-gray; with black ferruginous concretions; calcareous	25	290
Shale, fine, blue, somewhat calcareous	17	307
Devonian (328 feet thick; top, 803 feet above sea level):		
Limestone, magnesian, light buff, highly pyritiferous; contains a little chert	13	320
Shale and limestone; shale, blue, calcareous, with a few particles of black carbonaceous shale; limestone, blue, argillaceous, some gray and purer, fossiliferous	15	335
Limestone, dark gray, magnesian, at		335
No samples	65	400
Limestone, argillaceous, nonmagnesian; small fragment of brachiopod resembling *Atrypa reticularis* Linn	10	410
Limestone, light gray; some green shale, at		410
No samples	50	460
Limestone, light gray	13	473
Limestone, light yellow-gray, argillaceous and slightly siliceous, at		473
No samples	27	500
Limestone, blue, argillaceous; 2 samples	70	570
Limestone, brown, slightly magnesian; 3 samples	65	635
Silurian (180 feet thick; top, 475 feet above sea level):		
Limestone, magnesian, light brown; 30.74 per cent $MgCO_3$, at		635
No samples	95	730
Dolomite, brown and buff; much white chert; 5 samples	27	757
Dolomite, light gray; some chert	2	759
Dolomite, cherty; 5 samples	38	797
Dolomite; with green shale and chert; 3 samples	18	815
Ordovician:		
Maquoketa shale (160 feet thick; top, 295 feet above sea level):		
Shale, green	60	875
Dolomite, brown, hard, crystalline, cherty; 2 samples	29	904
Dolomite and shale, dark drab; much green shale in drillings	11	915
Dolomite and shale; chiefly shale, at		915
No samples	25	940
Shale, green and buff; in cuttings, as if washed; 2 samples	35	975
Galena and Platteville limestones (385 feet thick; top, 135 feet above sea level):		
Limestone, light gray, cherty; 2 samples	40	1,015
Limestone, light gray, soft; fossiliferous at 1,205, 1,230, and 1,238 feet; 10 samples	235	1,250
Limestone, light buff, dark gray, and light gray; 3 samples	50	1,300
Limestone, highly argillaceous; fine blue-black calcareous sand, highly pyritiferous, with much clayey matter and minute particles of quartz	25	1,325
Shale, green and bright green, indurated, slaty, highly pyritiferous; 3 samples	35	1,360
St. Peter sandstone (85 feet thick; top, 250 feet below sea level):		
Sandstone; grains white, well rounded, somewhat uniform in size; 3 samples	85	1,445
Prairie du Chien group—		
Shakopee dolomite (120 feet thick; top, 335 feet below sea level):		
Dolomite, white subcrystalline, oolitic; much quartz sand, at		1,445
No samples	35	1,480
Dolomite; in fine light-yellow meal	10	1,490
Dolomite; considerable light-green shale; much quartz sand	10	1,500
Dolomite, buff; quartz sand and shale	5	1,505
Dolomite, white; some chert, quartz grains, and green shale; 2 samples	25	1,530
Dolomite, light yellow; a little quartz sand	10	1,540
Dolomite, hard, gray, subcrystalline; some sand grains	8	1,548
Dolomite, white	2	1,550
Dolomite, hard, rough, light buff	15	1,565
New Richmond sandstone (80 feet thick; top, 455 feet below sea level):		
Sandstone, calciferous; white rounded grains; numerous minute chips of dolomite	15	1,580
Sandstone; as above, but with much less dolomite	15	1,595
Sandstone, light colored, friable; grains rounded and varying widely in size, the largest reaching 1 millimeter in diameter	15	1,610
Sandstone, light gray, hard, moderately fine grained; much green shale (probably from above) and considerable dolomite	25	1,635
Sandstone, white; grains rounded and resembling St. Peter in general uniformity of size; many from 0.7 to 0.9 millimeters in diameter, largest grain over 1 millimeter	10	1,645

Record of strata in city well at Ackley (Pl. VI, p. 258)—Continued.

	Thickness.	Depth.
Ordovician—Continued.		
Prairie du Chien group—Continued.		
Oneota dolomite (175 feet thick; top, 535 feet below sea level):	*Feet.*	*Feet.*
Dolomite, buff; drillings chiefly quartz sand	15	1,660
Dolomite; much quartz sand	15	1,675
Dolomite; drillings chiefly quartz sand. If sand is native in this and the two samples above, the rock should be called calciferous sandstone	10	1,685
Dolomite, hard, gray, subcrystalline, pyritiferous	35	1,720
Dolomite, light gray, at		1,720
No samples	100	1,820
Cambrian:		
Jordan sandstone (210 feet penetrated; top, 710 feet below sea level)—		
Sandstone, white; fine-rolled grains with some dolomite sand and chert, at		1,820
Sandstone, calciferous; mostly quartz sand, well rounded, rather coarse; some dolomite and grains of chert-oolite; some quartz grains seen in dolomitic matrix, at		1,950
Sandstone; as above; grains reach 1 millimeter in diameter; detached grains and chips of sandstone with dolomitic matrix and minute cuttings of dolomite, some arenaceous, at		2,000

Chemical analyses of well drillings.[a]

	Sample from depth of—		
	835 feet.	787 feet.[b]	1,540 feet.
$CaCO_3$	60.45	60.97	50.96
$MgCO_3$	30.74	34.85	43.82
$CaSO_4$	.58	.62	1.06
SiO_2	4.99		2.47
Al_2O_3	2.56	2.07	.59
Fe_2O_3	.58	1.11	.33
H_2O	.37	.37	.79
Total	100.27	99.99	100.02

[a] Chemical laboratory, Cornell College, Mount Vernon, Iowa.
[b] Silica, which formed about one-third of sample in the form of chert, discarded from analysis.

The section of the shallower well, which furnishes the present abundant supply of medium hard water, is reported by the driller as follows:

Driller's log of Ackley city well.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, yellow	10	10
Sand, yellow	2	12
Clay, blue	23	35
Sand	2	37
Clay, blue	8	45
Gravel and sand	19	64
Sandstone and water	55	119

The water is pumped by an electric motor and distributed by gravity under pressure of 40 pounds through four-fifths of a mile of mains to 59 taps and 11 fire hydrants. About 300 people use the supply. The daily consumption is estimated at 10,500 gallons.

Eldora.—The public water supply of Eldora (population, 1,995) is obtained from two wells—one 200 feet, the other 250 feet deep—that end in limestone. The water stands 135 feet below the curb and is pumped by steam to an elevated tank, from which it is distributed under gravity pressure of 35 pounds. A fire protection pressure of 105 pounds is available. The distribution system comprises 3½ miles of mains, 30 fire hydrants, and 193 taps. Practically everybody uses the city water, the consumption of which is estimated at 6,000 gallons daily. Long pumping is required to keep up the supply. The water is medium hard.

The strata penetrated by the shallower well are indicated by the following log:

Driller's log of Eldora town well.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, yellow	30	30
Clay, blue	10	40
Black "muck," with logs 1 foot in diameter	20	60
Sand, yellow, and water	8	68
Clay, blue	40	108
Shale, black	17	125
Fire clay	10	135
Limestone and water	65	200

Eldora is 1,060 feet above sea level, and a deep well will reach the base of the Kinderhook group about 400 feet below the surface. The drill will then pass through Devonian and Silurian limestones in which some water may be found. A heavy dry shale, the Maquoketa, possibly exceeding 100 feet in thickness, will be encountered at about 970 feet from the surface. Below the Maquoketa the Galena and Platteville limestones may be found to contain water, especially toward the base of the Platteville. The St. Peter sandstone, the first reliable water bed, should be reached at about 1,500 feet from the surface, but to obtain a large supply drilling should be carried 500 or 600 feet deeper still through creviced limestones and porous sandstones, which will yield an ample supply.

If a thoroughly water-tight casing is carried down somewhat below the base of the Kinderhook group, the waters from the lower aquifers should make a very fair drinking water. The quality of all inflows above the St. Peter should be tested.

Hubbard.—The town of Hubbard (population, 568) obtains a good supply of medium-hard water from a well 325 feet deep. The water is pumped by gasoline engine and distributed under gravity pressure of 30 pounds through one-half mile of mains to 11 taps and 7 fire hydrants. About 100 people use the water. The daily consumption is estimated at 3,000 gallons.

The strata penetrated by this well are indicated by the following log:

Driller's log of Hubbard well.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, yellow, and sand	75	75
Clay, blue	150	225
Clay, yellow, hard; with sand layers	25	250
Limestone	25	275
Sandstone	25	300
Limestone, white	25	325

Iowa Falls.—The water supply of Iowa Falls (population, 2,797) is derived from two flowing wells, one 276 feet, the other 240 feet deep. (See Pl. VI, p. 258.) The water is pumped by two steam pumps and distributed under gravity pressure of 55 pounds through 4 miles of mains to 300 taps and 31 fire hydrants. About 1,700 people use the supply; the daily consumption is estimated at 70,000 gallons. The water is hard. The city wells end near or at the base of the Kinderhook group (Mississippian). If a well is sunk below these shales, the drill will first penetrate heavy limestones of Devonian and Silurian age, which probably continue with little interruption to a depth of about 850 feet below the surface, where they give place to the Maquoketa shale (Ordovician), here about 150 feet thick. The Devonian and Silurian limestones will probably yield some water. Near their base thin beds containing more or less of gypsum or anhydrite may be encountered, the water from which should be cased out. The Maquoketa shale will of course be dry. Below the Maquoketa shale will be found the Galena and Platteville limestones, which extend to about 1,475 feet from the surface and should contain considerable water under a head which should bring it within easy pumping distance of the surface. The water so far encountered will considerably increase the present supply, but will not improve its quality, and the well should be sunk to the St. Peter sandstone or to about 300 feet below that formation in order to obtain the large supplies which are to be found in the deep formations. To obtain the largest amounts of the best waters, therefore, the well should be sunk to a depth ranging from 1,900 to 2,100 feet. Analyses of the different waters will show which ones should be cased out because of their poor quality.

Radcliffe.—The public water system of Radcliffe (population, 660) is obtained from two wells, the older 130 feet, the newer 95½ feet deep, which yield a good supply of hard water.

The system is equipped with two steam pumps and the water is distributed by gravity under pressure of 35 pounds through two-thirds of a mile of mains to 40 taps and 11 fire plugs. About half the population use the town water. The daily consumption is estimated at 8,000 gallons.

WELL DATA.

Information in regard to typical wells in Hardin County is presented in the following table:

Typical wells of Hardin County.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head above or below curb.	Remarks. (Logs given in feet.)
		Feet.	*Feet.*		*Feet.*	
Mr. Lake	3 miles east-southeast of Buckeye.	58	56	Sand at 53 feet.	+ 2	Flows good stream. Yellow clay, 15; blue clay, 38; sand and water, 3; limestone (?), 2.
M. Thompson	2 miles north of New Providence.	250	250	Drift sand	−100	Limestone under water-bearing stratum.
Mr. Bump	5½ miles south of Iowa Falls.	172	160	Sandstone	− 80	Yellow clay, 20; blue clay, 97; sand, gravel, and water, 3; blue clay, 25; sand, 5; "hardpan" (tough yellow clay), 10; sandstone (soft) or sand and much water, 2; shale, 6; limestone, 4.
J. B. Parmelee	T. 89 N., R. 20 W.	56	No rock.	Sand and gravel.	+ 16	Temperature, 47°; flows 80 gallons per minute. Black soil, 3½; sand, 2; blue clay, 5½; fine sand, 3½; blue clay, sand, gravel, and water, 41½.
Fred Silas	3 miles southeast of Ackley.	236	236	Limestone	− 96	Yellow clay, gravel, bowlders, and sand at top; blue clay and 1 foot hardpan at depth of 90; sand at 194; clay at 197; rock (probably a bowlder) at 198; blue clay at 234; limestone and water at 236.
State Industrial School.	1 mile west of Eldora.	250	92	Limestone (?).	− 40	Steam pump. Black soil, 6; yellow clay, 15; blue clay, 40; very soft coal (?), 7; sand, 20; white clay, 4; sandstone, 1; black shale, 5; sandstone and water, 5; white clay, 2; black shale, 15; gray limestone and sandstone and water alternating, 130.
D. M. Leach	2 miles southwest of Abbott.	245	(?)	Limestone	−170	Water-bearing stratum at 239. Yellow clay (sandstone and water, 10 feet), 15; blue clay, 35; yellow clay, 40; blue clay, 107; bard rock (bowlder), 1; blue clay, 36; hard sandstone (bowlder), 4; soft clay, 1; rock (bowlder), 1½; sandstone and much water, 5.
William Haynes	Steamboat Rock	265	225	do	−110	Limestone, 40. Pumped by windmill.
J. Smuck	3 miles north of Hubbard.	70	70		+ 16	Water in sand over rock.
Mr. Ledge	3½ miles west of Hubbard.	350	298	Limestone	+ 1	Flowing well. Yellow clay, 15; blue clay and pebbles, 240; sand and gravel, 43; limestone and water, 52.

JASPER COUNTY.

By Howard E. Simpson.

TOPOGRAPHY.

Jasper County exhibits two distinct phases of erosional topography. By far its greater part shows the well-drained, maturely dissected surface of the Kansan drift sheet; the remainder, comprising a small area in the northwest corner of the county, including most of Clear Creek Township, the west half of Poweshiek Township, and the northwest quarter of Washington Township, shows the imperfect drainage and level surface of the latest drift sheet, the Wisconsin.

The area is drained chiefly through South Skunk River and its tributaries, the larger streams flowing in a general southeasterly course. A small area in the southwest corner, however, is drained southward through the tributaries of the Des Moines.

All the larger streams meander through broad, deep valleys floored with alluvial deposits. The divides are also rather broad and flat topped, showing less complete dissection than is characteristic of the Kansan plain farther south and nearer the larger rivers. The upland plain slopes gently southward from a maximum of about 1,050 feet above sea level in the north and about 950 feet in the south to 750 feet in the bottoms of the greater valleys.

GEOLOGY.

The entire area of Kansan drift is covered by several feet of loess, a pebbleless gray clay easily distinguished from the drift clay, the latter being in places 100 to 200 feet thick and containing much sand, gravel, and even bowlders, locally stratified but generally unstratified. In the Wisconsin area the bowlder clay overlies the loess, which in turn rests on the older Kansan.

All the larger stream valleys contain alluvial deposits of interbedded silt, gravel, and sand, those in the valley of the Skunk being especially deep and from 1 to 3 miles wide.

So far as known, the unconsolidated surface deposits of the county everywhere rest on Carboniferous rocks belonging to the Des Moines group of the Pennsylvanian series. (See Pl. XV.) Sandstones are more common in the shales of this group than in counties farther south. These coal measures are underlain in the northeastern part of the county by the Kinderhook group and in the southwestern by the "St. Louis limestone," both of which belong to the Mississippian series.

UNDERGROUND WATER.

SOURCE.

The water supply of Jasper County is derived from alluvial deposits, loess, drift, sandstones of the Des Moines group, sandstones in the "St. Louis limestone," and from deeper formations.

Alluvial sands and gravels are important aquifers only along South Skunk River and its two chief tributaries in this county, Indian Creek and North Skunk River, where they have accumulated to considerable depths and are sufficiently loose and porous to permit a very strong underflow. Most of the wells in the alluvial deposits are shallow, as a rule less than 40 feet in depth.

Over large parts of the loess-Kansan area the loess mantle is several feet thick and the basal portion is so sandy that it furnishes a water supply that is utilized by shallow wells to an extent greater than in any other county. The loess on the uplands produces conditions favorable to shallow water supplies such as are used for the public supply of the town of Eddyville, on Des Moines River.

In the region of the Wisconsin drift the underlying loess becomes an important aquifer, for owing to the imperfect surface drainage the ground-water level is high, the younger bowlder clay forms an excellent protecting covering, and the sandy loess is a suitable reservoir. The seepage springs favored by such conditions are unusually common in the valleys crossing the margin of the Wisconsin drift area and are not uncommon from the base of the sandy loess overlying the Kansan, but those from the latter horizon are unsatisfactory as a supply for stock owing to the certainty that they will dry up just when they are most needed. Few loess wells exceed 25 feet in depth.

The Wisconsin drift in this county is thin, yet, because of the undrained character of its surface, it yields a supply of water to many shallow wells. The water is chiefly from small seeps and veins and is closely akin to surface water in quality.

Seeps from sand pockets and small veins in the Kansan clay supply many wells, and an abundant supply of good water is found in beds of sand and gravel beneath the Kansan drift and above the underlying shales. The great thickness of the drift in this region makes it expensive to reach these sands, as in some places they lie 200 to 300 feet below the surface. Flowing wells from these sands are not uncommon in the valleys.

The coal measures as a rule furnish unsatisfactory water. Water is everywhere found in the seams and beds of coal, and is locally so abundant as to interfere seriously with mining operations, but this water is never potable. The shales which compose the greater part of the coal measures are comparatively dry and unimportant as water bearers. Limestone lenses are common. The only available water of importance is found in the thick lenses of sandstone, which are more common in this county than in the coal region farther south; but this water, like most water of the coal measures, is frequently so strongly impregnated with iron as to be unfit for use. One of the most striking exceptions to this rule is afforded by the Red

Rock sandstone, a channel deposit consisting of coarse, friable gray to purplish-red ferruginous rock, which has been found in an area 2 to 4 miles wide extending from the southern boundary of the county east of Monroe to a point some distance northeast of Kellogg. Its precise area and extent are, however, very uncertain. Wells in this sandstone furnish an abundant supply of excellent water and good springs from it are found in several places.

Regarding the coal measures as a source of springs, I. A. Williams[1] says:

> Springs issuing from the coal measures strata are not uncommon. The water is, however, often so charged with sulphuric acid as to make it valueless, where it comes from beds associated with coal seams. Two instances may be cited of springs which come from coal measures strata and furnish never-failing supplies of good water. In the NE. ¼ NW. ¼ sec. 9, Rock Creek Township, is such a spring, flowing from near the base of the Red Rock formation. A spring on the farm of Mr. P. W. Mowry in sec. 34, Des Moines Township, furnishes an abundant supply of excellent water.

The "St. Louis limestone" is an important aquifer in Jasper County as elsewhere, supplying the most famous wells in the State, the Colfax artesian wells known as the Colfax Mineral Springs. From observations elsewhere the "St. Louis limestone" is believed to wedge out in the northeast part of Jasper County; elsewhere other hard limestones, known as the Kinderhook group, directly underlie the Pennsylvanian or the drift.

SOUTH SKUNK RIVER ARTESIAN BASIN.

The lower portion of the valley of South Skunk River and its more important tributaries, including practically all of the present flood plain, the terrace known as the "second bottom," and in places the lower slopes of the valley sides, forms an irregular artesian basin, ranging in width from 1 to 4 miles and extending from the middle of the west county line to the middle of the south county line. Nearly all the wells in this basin range in depth from 250 to 350 feet and are supplied by the same aquifer, the "St. Louis limestone." Two of the wells however, are shallower. One on the farm of Bert Furch, 6 miles west of Newton, in sec. 34, T. 80 N., R. 20 W., is but 150 feet in depth, is reported to end in "a crevice in rock," probably limestone, and has a natural flow of three-fourths of a gallon a minute and a head of 20 feet above the valley floor; the water is not reported as mineral, but simply as "hard," and is in general use for domestic and farm purposes. The other well, 163 feet deep, is on the farm of John Raitchner, 2½ miles southwest of Metz; the flow comes from sandstone at a depth of 150 feet, and the well yields 1¼ gallons a minute under a head more than 10 feet above the valley floor; the water is reported as only slightly mineral.

[1] Ann. Rept. Iowa Geol. Survey, vol. 15, 1905, p. 360.

The deeper wells are generally less strongly mineral than the Colfax wells (pp. 713–714), but none are cased through the Des Moines group, and all probably receive a mixed supply of water. Detailed data of several of these wells are presented in the table of typical wells (pp. 718–719).

Near North Skunk River in the southeast corner of Malaka Township is a small area in which several wells yield small flows under low head. Two of these wells are on the Riverside stock farm in sec. 35.

COLFAX MINERAL WATERS.

The Colfax mineral water was discovered in 1875 by parties prospecting for coal. The drill, located on the south bank of South Skunk River about a mile east of town, had reached a depth of 315 feet when water began to flow from the top of the hole. Drilling was discontinued, and this coal prospect hole became the first of the "mineral springs" which furnish the water now so widely known as Colfax Mineral Water. Since the original well, known as the "Old M. C. spring" or the Colfax Hotel well, was put down, at least 14 other wells have been sunk to depths differing but slightly from this one and all obtain a very moderate flow from the same aquifer—the "St. Louis limestone," of the Mississippian. Some of the wells are 4 inches and others 6 inches in diameter; the diameter of some is reduced to 2 or 3 inches at the bottom.

Until the fourteenth well was drilled, in 1905, no record was kept. The driller's log of this well, as recorded by the owner, C. W. Mills, is as follows:

Record of artesian well at Mills House at Colfax.

[Drilled by M. Neff.]

	Thickness.	Depth.
	Feet.	*Feet.*
Surface and yellow clay	33	33
Sand and gravel (heavily water bearing)	28	61
Sand rock	1	62
Slate, black (shale)	30	92
Coal	1½	93½
Clay, fine	8½	102
Sandstone	4	106
Soapstone (shale)	6	112
Sandstone (water bearing)	40	152
Soapstone, hard (shale)	10	162
Sandstone	40	202
Rock, white, porous (water bearing)	4	206
Flint rock	1	207
Sandstone	20	227
Soapstone, hard (shale)	10	237
Sandstone	15	252
Iron band rock	1	253
Sandstone (water bearing)	30	283
Magnetic rock (?)	7	290
Chert, white	12	302

To a depth of 61 feet the formations are Pleistocene; from 61 to 283 feet they belong to the Pennsylvanian series (Des Moines group); the lowest formation is probably Mississippian ("St. Louis limestone").

The natural yield of the wells has decreased as the number of wells has increased, the maximum now being about 3 gallons a minute. The intimate relation of the wells is shown by the fact that when the Colfax Bottling Works well was flowing at the rate of 8 gallons a minute, before casing was inserted, the Mason House well, near by and up the slope from it, practically ceased to flow and all other flows were somewhat weakened.

The log of the Mills House well harmonizes with the various reports given from memory by those who had most to do with the earlier wells, all placing the mineral-water aquifer at between 285 and 315 feet below the surface. The samples preserved by Dr. Tanner of the water-bearing rock of the fifteenth and latest well—that of the Turner Sanitarium—are of hard magnesian limestone. All of these facts indicate the upper limestone beds of the "St. Louis limestone" as the mineral water horizon.

Several other aquifers are reported in each of these wells, including the sand and gravel bed at the base of the drift, and one to four of the sandstone layers of the Des Moines group (Pennsylvanian). Not only must the water from these upper formations be cased out, but the well must be carefully sealed by means of a seed bag or rubber packing about the base of an inner and smaller tube put down to the aquifer itself in order to obtain the proper mineral flow. Although the sympathetic variation of many of the wells indicates a uniform source a fairly decided difference in the taste and color, especially in those of a sulphurous character, suggest that some of the wells may draw a portion of their supply from the Pennsylvanian rocks, the lowest of which is reported as causing an artesian flow in at least one well.

The rise of the water above the surface varies with the elevation of the well site. The highest level reported, 17 feet, has been since reduced by the drilling of new wells. Probably the water of none of the wells will rise more than 8 or 10 feet above the surface, and some of the wells on the hillside have ceased to flow except as piped out below the surface to a lower level.

It is an interesting fact that the surface relations are so delicately adjusted that changes both of flow and pressure are affected by the changes of the weather. The decrease of barometric pressure before a storm brings an increase of flow and pressure from the wells, which is easily noticed in certain wells carefully controlled by bottling machinery. Especially hard storms produce a milky or oily color, such as water ordinarily carries after standing in the open air, and the water tends to "sour" more quickly than usual; both facts indicate loss of the natural supply of CO_2 with the lessening of the atmospheric pressure.

A complete list of the mineral wells in the town of Colfax, together with the fullest data obtainable, is presented in the following table.[1] The results of chemical and sanitary studies of the water are discussed on page 160.

Statistics of the Colfax mineral wells.

Owner.	Location.	Year completed.	Depth.	Depth to rock.	Head above or below curb.	Discharge.	Remarks.
			Feet.	*Feet.*	*Feet.*	*Gallons a minute.*	
Hotel Colfax	1 mile east of Colfax.	1875	325	......	......	......	Old "M. C. Spring." Former discharge, 3 gallons a minute. Diameter, 3 inches. Curb 12 feet above level of Chicago, Rock Island & Pacific Ry. Temperature, 54°. Water bed at 306.
Colfax Bottling Works.	Second bottom, 1½ blocks southeast of plant.	About 1880	300±	35	+ 6	2+	Diameter, 3 inches. Former flow, 3 gallons a minute. Curb 10 feet above level of Chicago, Rock Island & Pacific Ry. "First water at 140 feet, head 25 feet below curb; second water at 225 feet, head at surface; third water at 245 feet flow; all cased out." Bottled and sold.
Grand Hotel Sanitarium.	....	About 1880	312−	......	− 1	2	No flow. Former head of 6 feet has fallen to 1 foot below curb, and well is now pumped by hand. Curb 36 feet above level of Chicago, Rock Island & Pacific Ry. Diameter, 4 inches and 3 inches. Used for medicinal and table purposes.
Mason House	....	1881	357	......	+ 3	4	Diameter, 4 inches. Temperature, 54½°. Curb 2 feet above level of Chicago, Rock Island & Pacific Ry. Used for baths, table, and medicinal purposes.
D. C. Frye & Co. (Inc.).	....	1882	315	......	+ 8	2	Diameter, 3 inches. Curb 3 feet above level of Chicago, Rock Island & Pacific Ry. Temperature, 51°. Pumped by rotary pump, 5 gallons a minute. Bottled and sold for medicinal and table purposes. Water bed at 310.
Purox-Colfax Co	....	1890	350−	......	+10	1½	Flow decreased from 3½ to 1½ gallons a minute, and head from 12 to 10 feet. Diameter, 4 inches. Odor more sulphurous than others. Bottled and sold for medicinal and table purposes.
Town of Colfax city park.	....	....	300	200+	......	3	Decrease of flow from 4 to 3 gallons. Diameter, 4 inches. Temperature, 52°. Level with Chicago, Rock Island & Pacific Ry.
The Centropolis	....	....	......	......	+ 4	......	Used for medicinal purposes and for bathing. Sold to patrons.
Thos. E. Jordan	....	....	350	47	......	1½	Decreased from 2 to 1½ gallons a minute. Bottled and sold for medicinal and table purposes.

[1] See also Norton, W. H., Artesian wells of Iowa: Ann. Rept. Iowa Geol. Survey, vol. 6, 1897, pp. 293–294; also Williams, I. A., Geology of Jasper County: Ann. Rept. Iowa Geol. Survey, vol. 15, 1905 pp. 307, 363–366.

Statistics of the Colfax mineral wells—Continued.

Owner.	Location.	Year completed.	Depth.	Depth to rock.	Head above or below curb.	Discharge.	Remarks.
			Feet.	*Feet.*	*Feet.*	*Gallons a minute.*	
....	Corner Montgomery Street and Broadway.	....	......	......	+18	3	Diameter, 3 inches. Flows without control. Used only for watering stock.
Colfax Bottling Works No. 2.	At plant..........	1901	300	100	+20	5	Decrease of head from 20 to 18 feet. Diameter, 4 and 2 inches. Other water at 150 feet and 225 feet. Curb 3 feet below level of Chicago, Rock Island & Pacific Ry. Flow increases after being shut off for a time. Bottled and sold for medicinal and table use. Water bed, limestone.
Hotel Colfax No. 2	....	....	294	......	......	1½	"Second M. C. well."
Victoria Sanatorium.	....	1903	391	......	− ½	¼	Flows from pipe through hillside. Used for medicinal purposes and for bathing. Sold to patrons.
Turner Sanitarium.	Side hill..........	1906	365	80	−12	......	Diameter, 4 to 3 inches. Curb about 36 feet above level of Chicago, Rock Island & Pacific Ry. Heavy water at 235 feet. Water lift. Used for medicinal purposes and for bathing. Sold to patrons. Water bed, porous magnesian limestone.
Mills House.......	....	1905	291	95	+ 5	½	Curb about 22 feet above level of Chicago, Rock Island & Pacific Ry. Temperature, 53½°. Curb sunk into 5-foot pit for better flow. Pumping Turner well while drilling decreased this flow. Used for medicinal purposes and for bathing. Sold in bulk to patrons. Water bed, limestone.

CITY AND VILLAGE SUPPLIES.

Colfax.—The public supply of Colfax (population, 2,524) is drawn from the coarse gravels underlying the flood plain of Skunk River, by means of a series of Cook well points, 6 inches in diameter and 36 feet long. The sands and gravels are reached at a depth of 23 feet and are overlain by a heavy black clay. The water stands between 5 and 17 feet below the surface in these points, and is pumped by steam into a steel standpipe, 13 by 80 feet (capacity about 92,000 gallons). This standpipe is so situated on the bluff that the base is about 160 feet above the source and the main portion of the town. From it the water is distributed by gravity through about 2 miles of mains. The pumping capacity is about 750 gallons a minute, and about 60,000 gallons are used daily. The domestic pressure of about 80 to 104 pounds is sufficient for fire protection, except in the residential section in the bluffs, where direct pressure may be used if necessary. Owing to the fact that this water forms a rather solid scale in boilers, the railroads and the boilers at the pumping station use river water for making steam.

Kellogg.—The public water supply of Kellogg (population, 610) is from two drilled wells 120 and 160 feet deep, drawing their supply from the shales of the Des Moines group and the underlying limestone, respectively.

The water of the 120-foot well is pumped by windmill, and though the head is but 30 feet below the surface the supply is scanty, a characteristic common to all shale wells. This well is used only as a reserve supply.

The 160-foot well is much stronger, but the water is somewhat turbid, probably because of improper casing in the shaly beds. The well is pumped by gasoline engine, the water being forced to a cistern on the hill about 50 feet above the level of the town. This cistern is 10 feet in diameter and 20 feet deep and is walled with brick and cemented. From this reservoir the water is distributed through a 4-inch main about one-fourth mile in length to four fire hydrants and 20 private taps.

Most of the private wells in the town are either open or driven and range in depth from 25 to 35 feet. The gravels at this depth are open but grade into fine sand above, overlain by yellow clayey alluvium and deep soil. The supply is abundant and the water exceptionally good for use in boilers. No treatment is required before it enters the boilers, only a slight flaky scale or soft white precipitate being formed. The Gould Balance Valve Co. and the Patten Grain Co. use the water from driven-point wells.

Newburg.—Practically all wells in Newburg (population, 200) and the extreme northeastern corner of the county are dug or bored in the drift at various depths.

The railroad supply comes from four 26-foot wells in a ravine below the town. The best supply comes from gravels in the lower part of the Kansan drift.

Newton.—The water supply for the city of Newton (population, 4,616) is taken from eight gravel wells on Skunk River bottom, 6 miles southwest of the city, in the NE. ¼ sec. 13, T. 79 N., R. 20 W., 170 feet below the level of the Chicago, Rock Island & Pacific Railway station (elevation, 944 feet above sea level). These wells were put down in 1904 by drilling to depths ranging from 43 to 56 feet, and then inserting in each hole an 8-inch strainer, 8 to 10 feet long, attached to the lower end of the casing. The wells are distributed over an area of about 130 feet radius, and so connected that any number or all may be pumped at the same time.

A pumping station, located at the wells, is equipped with a low-service suction pump, capacity 700 gallons a minute, which pumps into an 11,000-gallon reservoir, walled with brick, cemented, and arched over. From the reservoir two high-pressure duplex pumps, capacity 250 gallons a minute each, lift the water 190 feet into the supply tank on a stone tower in the city. The tank has a capacity of 90,000 gallons and the tower is 56 feet high, giving a domestic pressure from gravity of about 25 pounds. The fire pressure is, however, direct and may be raised to 115 pounds. An 8-inch main leads from the wells into the city, and the 75 fire hydrants are supplied through 6-inch and 4-inch mains. Probably more than one-third of the population is supplied through over 400 taps from this source. The daily consumption is estimated to be 70,000 or 80,000 gallons. The meter system is in general use.

The water is clear, abundant, and excellent, and is used for all public and domestic purposes and very extensively by the manufacturing plants of the city and the railroads. Slight scale forms in the boilers, and the supply has proved in all respects satisfactory.

The city supply was formerly taken from two deep wells, described as city wells Nos. 1 and 2.

City well No. 1, completed in 1890, is 1,400 feet deep and 5 inches in diameter, and the water stood 90 feet below the curb. Rock was entered at 90 feet and water was obtained at depths of 550 feet and 1,300(?) feet. (See Pl. XV, p. 670.)

The water of this well is described as a poor potable water and bad in its effect on boilers. It is apparently derived from the Osage group (Mississippian) a short distance above the summit of the Kinderhook (Mississippian), and is augmented by water coming in above the Maquoketa shale (Ordovician), which caved badly and caused the loss of a drill. As the drill could not be extricated, the hole was abandoned and a second was sunk a few feet distant. In this well also a drill was lost at about the same depth, and the attempt to carry the boring deeper was abandoned. In 1895 the supply was said to be abundant, continued pumping failing to lower the level of the water; but some years later the well was given up and another sunk.

City well No. 2, 705 feet deep and 10 to 8 inches in diameter, has also been abandoned. The water in this well stood 50 feet below curb, coming from a depth of 500 feet.

Driller's log of city well No. 2 at Newton.

	Depth in feet.
Gravel	70
Gravel and clay	150
Rock and shale	172
Shale	202
Rock, white, hard	214
Limestone	240
Through limestone	470
Shale	500
Limestone	575
Well completed	705

It should be noted that the very scanty data for these wells seem to indicate that they stopped a good deal short of the main artesian supplies of Iowa, going little if any below the Maquoketa shale. If any other deep wells are sunk they should be carried not only to a depth of 1,750 feet from the surface, where the St. Peter sandstone should be reached, but to as great a depth as 2,050 feet in order to tap the still larger supply of the formations underlying that well-known sandstone.

Prairie City.—The water supply of Prairie City (population, 764) was originally taken from a well 85 feet deep ending in sands and gravels at the base of the drift. The supply was ample, but so much trouble was caused by quicksand that it was found necessary to drill deeper and case the well throughout. During 1904 and 1905 the well was deepened to 390 feet; the approximate record is given by I. A. Williams as follows:

Log of well at Prairie City.

	Thickness.	Depth.
	Feet.	*Feet.*
Loess and drift	85	85
Coal measures shales and sandstones	140	225
Limestone	65	290
Sandstone, coarse, white	2	292
Shale, compact	63	355
Limestone, dense, gray, magnesian	35	390

The limestone from 225 to 290 feet probably belongs to the "St. Louis limestone" (Mississippian). This well was not used, as it was said to be impossible to shut out sand and mud in the Pennsylvanian (coal measures) at depths of 180 to 190 feet, though water was abundant below this level.

The well in present use was drilled in 1905 to a depth of 390 feet. The "St. Louis limestone" was entered at a depth of 220 feet, and the water-bearing sandstone from which the chief supply of water comes at about 65 feet lower. The well is cased to the limestone with 8-inch casing; below this a 6-inch bit was used and at the bottom a 4-inch bit.

The well is pumped by steam, and the head varies from 80 feet below the surface to about 140 under the pump.

The water is distributed by gravity from a 2,200-barrel tank elevated on an 80-foot steel tower, through about 2½ miles of mains. The water used is chiefly for fire protection, a few private taps taking only a few barrels per day in addition to that used by the 12 fire hydrants. The water is unsatisfactory for drinking on account of its mineral taste, and it is too hard for use in boilers.

Reasnor.—Reasnor (population, 250) is located on the bottom lands of Skunk River, where sand point wells may be had at depths of 30 to 40 feet. Small flowing wells may be had in this vicinity on the bottom of the river with depths of about 250 feet in sandstone in the "St. Louis limestone," and good wells may be obtained at about half that depth in the Red Rock sandstone. The town well, sunk only 30 feet on the flood plain of the river, flows slightly, the water probably being derived from the Red Rock sandstone.

WELL DATA.

Information concerning typical wells in Jasper County is presented in the following table:

Typical wells of Jasper County.[a]

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head above or below curve.	Remarks (logs given in feet).
T. 80 N., R. 18 W. (KELLOGG).		*Feet.*	*Feet.*		*Feet.*	
Town of Kellogg		120	85	Shale (Des Moines)	− 30	A weak well.
Do		160	110	Carboniferous limestone.		Water somewhat roily.
Geo. B. Kelton	1 mile southeast of Kellogg.	104	15	Red Rock sandstone.	− 60	On "bottoms." Good.
Ed. Craven	1 mile north of Kellogg.	245	200	Limestone below shale.	− 80	Good farm well.
Gifford Rogers	3 miles north of Kellogg.	174		do		
A. B. Craven	5 miles north of Kellogg.	265		do		
Joe Pierce	3 miles north and 1¼ miles east of Kellogg.	175	175	Over limestone		Good. Plenty.
Ed. Mershon	NE. ¼ sec. 6	325	317	Limestone	−100	High hill.
Albert Harrab	SW. ¼ sec. 36	135		Sand		Bottom. Flows. No rock.
T. 80 N., R. 17 W. (ROCK CREEK).						
A. J. Simpson	SE. ¼ sec. 31	172		Sandstone	−130	
T. 81 N., R. 19 W. (MALAKA).						
Mrs. Cassie Preston	NE. ¼ sec. 2	300		Sand		Sand interferes. No rock.
Christ Wehrman	SW. ¼ sec. 14	200	160	Limestone	−100	Hard and mineral.
T. 81 N., R. 18 W. (MARIPOSA).						
S. Morrison	NE. ¼ sec. 34	254	120	Limestone	− 30	Strong well.
Henry Korf	Sec. 11	400				No water.
Do	do	175	75	Limestone	− 60	
T. 80 N., R. 19 W. (NEWTON).						
L. M. Baker	NW. ¼ sec. 20	140	100	Limestone	− 60	Strongly mineralized.
T. 79 N., R. 20 W. (MOUND PRAIRIE).						
L. A. Greenleaf	SE. ¼ sec. 15	360	100	Sandstone	− 56	Hard water.
G. W. Miller	½ mile east of Metz.	300	22		+ 9	Flows ¼ gallon a minute. Slightly mineralized.
John Kartchner	2½ miles southwest of Metz.	163	50	Sandstone (Des Moines).	+ 10	Flows 1¼ gallons a minute. Slightly mineralized.
Mrs. M. L. Slaughter.	Sec. 8	337	100	"Gravel"(?)	+ 17	

[a] For Colfax mineral wells see table on pp. 713-714.

Typical wells of Jasper County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head above or below curve.	Remarks (logs given in feet).
T. 80 N., R. 20 W. (SHERMAN).						
		Feet.	*Feet.*		*Feet.*	
W. J. Leeper	NE. ¼ sec. 2	159	30	Gravel	+(?)	Slight flow. Mineral.
Lawson Walt	SW. ¼ sec. 16	204	......	......	− 80	Mineral.
Bert Turck	Sec. 34	150	50	"Solid rock"	+ 20	Flows ¾ gallon a minute. Hard.
E. W. Bodley	NE. ¼ sec. 26	90	40	Sandstone	− 30	
T. 78 N., R. 21 W. (PART OF DES MOINES).						
R. W. Brubaker	NE. ¼ sec. 36	376	140	Limestone	−150	Abandoned. Very weak well.
T. 78 N., R. 20 W. (PARTS OF DES MOINES AND FAIRVIEW).						
Sam. Scharf	NE. ¼ sec. 36	268	95	Sandstone	−137	Strong well.
S. F. Oldham	SE. ¼ sec. 22	376	160	......do	−125	Strong well. Fine water.
Jas. Fouche	SE. ¼ sec. 9	240	......	Sandstone	......	Good well.
T. 78 N., R. 19 W. (PARTS OF FAIRVIEW, ELK CREEK, AND PALO ALTO).						
Robt. Marshall	6 miles east of Monroe.	209	......	......do	−100	
J. A. Oldham	Sec. 16	260	60	Sandstone	+ 10	Flow 1 gallon a minute; water slightly mineralized.
Lester Vaugh	Sec. 28	312	140	......do	−160	Mineral.
Town of Reasnor	......	130	......	......do	+ 2½	Bottom land. Flows into tank at present, 1 gallon a minute.
J. H. Loar	Sec. 27	250	......	......do	− 25	
Chicago, Rock Island & Pacific Ry.	Monroe	300	......	......do	......	Scales boilers some.
Oscar Efnor	1½ miles west of Reasnor.	167	100	Red Rock sandstone.	− 67	Good well.
T. 79 N., R. 19 W. (PARTS OF PALO ALTO AND FAIRVIEW).						
George Lisle	Sec. 32	252	117	White sandstone	+ 22	Bottom land. Temperature 52°. Mineral.
George Lisle	SW. ¼ sec. 32	252	54	"White sand"	+ 22	Flows 1½ gallons a minute. Mineral.
Jas. A. Oldham	Sec. 16	260	60	Sandstone	+ 10	Flows 1 gallon a minute. "Hard and salty."
J. M. Woodrow	NE. ¼ sec. 29	233	100±	......do	+ 8	Mineral, similar to Colfax.
F. H. Griggs	NE. ¼ sec. 20	......	......	......	......	Flowing well.
Ed. Ross	5 miles south of Newton.	280	100	Limestone	+ 16	Flows 1 gallon a minute.

MARSHALL COUNTY.

By HOWARD E. SIMPSON and W. H. NORTON.

TOPOGRAPHY.

Marshall County lies immediately east of Story, the central county of the State. Though its prairie plain does not, to the casual observer, differ materially from that in other portions of central Iowa, the careful student will recognize in the topography as many as three distinct types of plain, the distinctions being chiefly the result of different periods of time during which running water has worked upon the till.

The youngest drift, the Wisconsin, overlaps a narrow strip on the western edge of the county, varying in width from practically nothing on the southern border to 3½ miles on the northern border. Here is found the knob and kettle topography characteristic of terminal moraines, though in rather subdued form. Small ponds and sloughs are common and the region is generally one of poor and undeveloped drainage. The area does not exceed 50 square miles.

Almost filling the triangle in the northeast, separated from the remainder of the county by Iowa River, is an area of drift of Iowan age. The slight sag and swell topography and the lack of marked stream dissection away from the master streams indicate the topographic youth of the area, though the lack of ponds and undrained tracts suggests a later stage of dissection than the Wisconsin. This area contains approximately 100 square miles.

Except for the Iowa River valley, the remainder of the county, nearly 400 square miles, possesses a more undulating topography in which stream valleys are broad, divides much more clearly marked, and drainage complete. This area covered by the Kansan drift is, therefore, in topographic maturity.

The broad, flat flood plain of Iowa River is the most striking topographic feature of the county. On the valley floor the river meanders widely and from it many smaller flat-bottomed valleys extend to every part of the county save the southwest corner, which is drained to the south by tributaries of North Skunk River.

GEOLOGY.

All the country rock of Marshall County is of Carboniferous age. Underlying the entire county is a thickness of about 150 feet of the Kinderhook group, consisting chiefly of a heavy limestone overlain by thin shales and underlain by thin sandstones and shales. Overlapping this in the western two-thirds of the county lies the Des Moines group, consisting here chiefly of shales with some sandstones. (See Pl. XI, p. 382.)

The general surface relations of the drift sheets have already been indicated. The depth is variable, but in the uplands 100 to 200 feet is common and 400 feet has been reported. This latter thickness is so great as to indicate a preglacial channel. The Kansan drift, everywhere present, is the most important of the superficial deposits, but distinct evidence of the earlier Nebraskan drift is found in the presence of a dark blue-black till in places beneath heavy beds of sub-Kansan sands and gravels which are evidently of Aftonian age. These gravels are reported in beds locally 30 feet thick.

In many places between the later deposits and the Kansan are found other sand and gravel beds of Buchanan age. These, however, are thinner and less important than the Aftonian except in the stream valleys, where, as valley trains, they underlie and are interstratified with alluvium. The Iowan till in the northeast and the Wisconsin till in the west overlie the Kansan. The Iowan is very thin and relatively unimportant, but the Wisconsin, because of its morainal character and undeveloped drainage, has a marked effect on ground-water conditions. Throughout the Kansan area and in places underlying the Wisconsin is a mantle of yellow loess passing below into sand. As this reaches thicknesses of 15 to 20 feet over some portions of the uplands it is of importance in shallow wells.

The alluvium which fills the Iowa Valley and the narrower valleys of all the larger creeks of the county includes extensive valley-train deposits, chiefly of Buchanan age.

UNDERGROUND WATER.

SOURCE.

The gravels of valley trains of Buchanan age and those beneath the drift and interstratified with it form the chief sources of the abundant waters of the alluvium. Though not so pure as those of the deeper drift and the rock, these waters are not often seriously contaminated, and their abundance and softness render them especially valuable. The public supply for the city of Marshalltown is drawn from the alluvium.

The drift beds are so numerous and in general so prolific of good water that they form the chief source of supply for Marshall County. Dug, bored, and drilled wells reach all the subhorizons at such different depths and with such different results that it is usually impossible to identify the age of the water bed. Depths of 30 to 40 feet are most common and, in general, the greater the depth the greater the supply. For domestic purposes very shallow wells suffice and are satisfactory if not contaminated from the surface, but for stock many of 100 to 250 feet are drilled with good results. In many of the deeper wells the Aftonian gravel is the water bed.

Owing to the lack of drainage shallow wells on the western margin of the county may find water closely akin to surface water in the Wisconsin till.

The Iowan till is too thin to afford any important source of water for even the shallowest wells, but the loess attains depths of 15 to

20 feet in many places on uplands, and its sandy base forms storage for shallow ground waters. Formerly this base was more important, but drainage and cultivation have generally reduced the ground-water level far below it, and it can now be used only by the shallowest wells and is very susceptible to drought.

Where the Buchanan gravel underlies the loess and the later till sheets on the upland in scattered patches, it is unimportant, but where associated with the alluvium it forms an important source of water.

The Kansan till is very thick; open wells sunk into it expose so much surface to seepage and small veins and afford so large a reservoir that it is one of the most important sources of water. A few gravel and sand layers furnish bountiful supplies, but, in general, wells to it are easily pumped out and are liable to fail in extreme drought.

Wells reaching the Aftonian gravel are abundantly supplied with pure and wholesome water. Depths of 100 to 150 feet are not uncommon.

The Nebraskan drift is too vague and indefinite to be of importance. Sands and gravels below the Kansan or at the base of a pre-Kansan till suggest the Nebraskan, and are generally water bearing just above bedrock, as is any drift in such a position.

The shales of the Des Moines group are so dry and the water they bear is so mineralized that the rock is valueless except for a few sandstone lenses from which excellent water may be obtained. Wells deriving water from these sandstones are common in some parts of Marion and Jasper counties, but rare in Marshall County. Wells penetrating the rock in the western portion of the county are liable to find 30 to 50 feet or more of dry shale.

Practically all rock wells in Marshall County draw their supply from the Kinderhook group, in sandy layers that generally underlie a heavy bed of limestone, which in turn may underlie a few feet of shale. Some excellent deep wells are had in these layers, though in many the water is not abundant. The flow is, however, very constant and not subject to drought. The water is generally hard, though pure and wholesome and excellent for stock. Depths of 150 to 200 feet are common.

DISTRIBUTION.

Two ground-water provinces may be distinguished in this county—(1) the Iowa valley floor, including the lower valleys of several of the larger creeks, in which the alluvium only is used; (2) the remainder of the county, in which the drift and Kinderhook are used.

Water in abundance may be had near Le Grande and Quarry. In the river valley the alluvial gravels supply it to driven wells, and on the adjacent uplands the shallowness of the drift, especially to the north, brings gravel and sand beds near the surface, from which a good supply may be had at 30 or 40 feet or less. To the south, in Le Grande Township, extreme depths of drift are found; 100 to 200 feet to limestone is common and 300 feet or more in drift wells is not unusual. The sand well of O. Beyngelson is 355 feet in depth.

Rock wells 80 to 120 feet deep are common, but 200 to 300 feet is not an unusual depth south of the river, where excellent water is obtainable. Near the edge of the river bluffs the upper limestones give rise to some fine springs.

Near Green Mountain the greater depths of the drift make sand and gravel wells somewhat expensive and uncertain. Drift wells 100 feet or more deep are not uncommon, but the chief dependence for larger stock supplies is in the limestone, where water is obtained at depths of 125 to 300 feet. The flow is scant in a few places for large stock supplies, but the quality is good.

The alluvial gravels yield abundantly along the river bottoms at Liscomb, Albion, Marietta, and vicinity, in some places giving rise to flowing wells. A well on the farm of C. E. Asney, located on the Iowa River bottom, in sec. 35, Iowa Township, was dug as an outlet for drain tile, but proved a flowing well. On uplands near the river drift wells are most common at depths of 30 to 50 feet, and the limestone supplies are unfailing, generally from depths of 80 to 200 feet. None of these villages are provided with waterworks. West of the river in Marietta Township most of the deep wells are in drift and have depths of 200 to 300 feet. Some reach limestone at similar or greater depths.

In the Wisconsin drift area near St. Anthony and Clemons shallow drift wells are generally relied upon. Driven wells are found all along the broad bottoms of Minerva Creek and its southern tributary, which flows through Clemons. Excellent water for stock wells is found in limestone at reasonable depths, 100 to 200 feet being common.

Near State Center wells 20 feet deep were formerly abundantly supplied with water; at present drift wells are more commonly 50 feet and a few are 100 feet deep. Reports generally indicate the presence of the Nebraskan till below the Kansan here, but good beds of Aftonian gravel are few and, except in very deep drift wells, do not afford strong supplies. Not uncommonly quicksand and mud are found above shales of the Des Moines group, making drilling difficult. These shales are 10 to 40 feet thick and overlie limestones; in only a very few wells is water found in thin sandstone beds at this horizon. Whenever a considerable quantity is desired drilled wells drawing from the limestone at depths of 100 to 250 feet are put down. These are not very strong, but are constant in supply, 3 to 15 gallons a minute being common.

At Rhodes and Melbourne shallow wells generally furnish abundant water from drift and alluvium. On all the creek bottoms, however, good flows may be had. Three aquifers are reported at approximately 150, 200, and 250 feet. From the last, which underlies the Des Moines group, a head of 27 feet above the surface is sometimes obtained. The water is mineral, closely resembling the Colfax water, and may come from the same aquifer, the "St. Louis limestone," though this bed has not been positively identified in this county.

At Melbourne the brick-factory well draws its supply from a lens of sandstone in the Des Moines group at a depth of 230 feet. Other deep wells are in limestone of the Kinderhook group at similar depths.

The well of H. Knoll, sr., 4 miles north of Haverhill, is reported to draw water from a sandstone of the Des Moines group at a depth of 170 feet. Near Van Cleve, Haverhill, and Laurel limestone wells in the Kinderhook group are common at depths of 200 to 300 feet. Drift waters are commonly used for small supplies, but these do not hold out in dry weather, as the location on the upland divide between Iowa and Skunk rivers is not favorable for shallow wells.

Near Gilman and Ferguson bored wells to depths of 100 feet are common, and drilled rock wells are rare. A few stock wells on uplands draw from the limestone at about 300 feet.

CITY AND VILLAGE SUPPLIES.

Gilman.—Gilman (population, 430) has a small waterworks system supplied by springs. The plant is owned by a canning company. An elevated tank supplies water to one or two fire hydrants at low pressure. The water is reported to be soft and of excellent quality.

Marshalltown.—The water supply of the city of Marshalltown (population, 13,374) is drawn from the gravel beds underlying the flood plain of the Iowa River valley opposite the city near the junction of Asher Creek (SE. ¼ sec. 22, T. 84 N., R. 18 W.). The water is collected by 40 wells, averaging 32 feet in depth, arranged in a straight north-south line 50 feet apart. Twelve-foot Cook strainers are used on the bottom of a 6-inch casing. The gravel immediately overlies the limestone in at least one well. The general section is reported to be as follows:

General section of Marshalltown shallow wells.

	Thickness.	Depth.
	Feet.	*Feet.*
Loamy soil	4	4
Gumbo	1½	5½
Gravel, fine, and sand	3½	9
Gravel, coarse	4	13
Sand, fine, white	14	27
Limestone	5	32

All wells feed by a closed pipe into a 2-foot main which leads across the river to the pumping plant on the south side, where a storage reservoir holding 1,000,000 gallons receives all of the water for aeration. At present rate of consumption this is replaced once each day. A low-service triplex Worthington pump draws the water from the reservoir for a distance of 4,720 feet, discharging it by gravity into the pump well.

At times the ground-water level in the field is reduced below the top of the strainers and, in order to avoid breaking the vacuum, suction is had through inner pipes inserted to the middle of the strainers. Even with this precaution, the vacuum is sometimes broken in case of drought, and then the consumption is limited or water must be drawn direct from the river through the intake provided for emergency. Such an emergency should be nothing short of a conflagration, on account of the foulness of this water. Means are provided for cleaning the well strainers by flushing backwater through them under high pressure, this being done once each month to insure the best flow.

Two Gordon duplex pumps, with an easy working capacity of 5,000,000 gallons daily, supply the mains directly at an ordinary pressure of 65 pounds, which may be increased to 135 pounds in case of fire. This pressure at the plant is decreased about 40 per cent in the business portion of the city. Twenty-eight miles of mains supply 200 fire hydrants besides may private consumers.

The large number of rock wells in the city are supplied by the waters from the limestone of the Kinderhook group at depths ranging from 75 to 200 feet, and when properly cased and protected from surface contamination these deep-seated waters are of excellent quality and many are of almost ideal purity. They are superior even to the city water for domestic purposes and should be used wherever convenient to do so. The hardness of the water renders it unsuitable for boilers and many manufacturing purposes, except after artificial softening.

Excellent examples of the wells reaching this horizon are the two wells of the Iowa Artificial Ice & Refrigeration Co. The water is very hard but of almost ideal purity. The mineral present in all other waters of this vicinity found above bedrock is absent in this, and the ice manufactured from it is clear and brilliant. The two wells have furnished 75,000 gallons in 48 hours without any apparent depletion. During the season 30 tons of ice are made daily from this water, and large amounts are used in the refrigeration process and also, after softening, in the boilers.

Supplies from private wells in the sands and gravels of the drift underlying the city may be pure and wholesome, but they should be looked upon with suspicion because of the ease of surface and sewer contamination and should be used only after bacteriologic examination by competent authority. Such wells in rural regions are generally wholesome if properly guarded at the surface.

All of the water obtained above the rock contains some carbonate of iron, which, on standing, oxidizes to the brown hydrated oxide of iron, and the water becomes milky and precipitates a brownish sediment. In all large supplies this may be removed by aeration, and for domestic use on a small scale it is not objectionable except to the esthetic sense.

A prospect hole for coal and gas, drilled on the bank of Iowa River near Marshalltown (W. ½ NW. ¼ sec. 25), has a depth of 1,020 feet. Its curb is about 885 feet above sea level.

Record of strata in prospect hole at Marshalltown (Pl. XI, p. 382).

	Thickness.	Depth.
Carboniferous (Mississippian):		
Kinderhook group (320 feet thick; top, 885 feet above sea level)—		
Limestone, light gray; in fine sand; many angular fragments of limpid quartz at 68 feet	*Feet.* 70	*Feet.* 70
Limestone, light yellow, compact, earthy luster; 3 samples	45	115
Limestone, brown, crystalline, cherty at 115 feet	30	145
Shale, soft, light-green, calcareous	175	320
Devonian (300 feet thick; top, 565 feet above sea level):		
Limestone (?); no samples	145	465
Limestone, hard, brown-gray, and brown; crystalline; rapid effervescence; samples at 465 and 560 feet	155	620
Silurian (305 feet thick; top, 265 feet above sea level):		
Dolomite, yellow, gypseous and cherty	55	675
Limestone, magnesian, brown, three samples; cherty at 675 feet	95	770
Dolomite, cherty, gypseous; mostly of white and translucent chert	30	800
Chert, white and translucent, at	....	800
No samples	75	875
Limestone; rapid effervescence; drillings almost wholly chert; some gypsum; 2 samples	40	915
Dolomite, white, in powder; some chert and gypsum	10	925
Ordovician:		
Maquoketa shale (95 feet penetrated; top, 40 feet below sea level)—		
Shale, blue and green-gray; noncalcareous in sample at 925 feet	95	1,020

Marshalltown is 890 feet above sea level, and, according to the boring just given, the top of the Maquoketa shale was found at 925 feet below the surface, or 40 feet below sea level. Had the boring been continued the drill would have entered the Galena limestone within about 80 feet of the bottom of the drill hole, and considerable water might have been found in its cracked and porous layers. The St. Peter sandstone may be expected at about 550 feet below sea level, or 1,440 feet below the surface. The drill should encounter below the sandstone dolomites, more or less sandy, with interbedded sandstone layers, and below the dolomites well-marked water-bearing sandstones. A very generous supply should be obtainable from these horizons by a well carried to a depth of 2,000 or 2,200 feet.

The water at each water horizon above the St. Peter should be analyzed, and it may be found advisable to drive water-tight casing to the Galena to shut out deleterious veins.

By drilling several 8-inch or 10-inch wells and by the use of compressed air to increase the discharge it may be possible to obtain a supply sufficient for a city as large as Marshalltown. The water will hardly be good boiler water, a matter of importance in a manufacturing town. A forecast, essentially the same as this, was made for the city on the request of the council in 1899.

State Center.—The town of State Center (population, 898) is provided with a waterworks system, used chiefly for fire protection. The water is pumped from wells into an elevated tank, capacity 60,000 gallons, whence it is distributed by gravity and direct pressure through a mile of mains to 16 fire hydrants. Only 12 private consumers use the water, and not more than a thousand gallons is pumped daily.

WELL DATA.

The following table gives data of typical wells in Marshall County:

Typical wells of Marshall County.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head above or below curb.	Remarks (logs given in feet).
T. 84 N., R. 18 W. (Linn; parts of Taylor and Iowa).						
		Feet.	*Feet.*		*Feet.*	
Iowa Artificial Ice Co.	Marshalltown....	188	34	Limestone ..	− 57	Strong well, hard water, but no iron. Water at 38, easily exhausted. Principal water bed 131 feet. Pumped by steam and used in manufacture of artificial ice. Softened for boiler. Heavy precipitate, indicating very hard water; curb 20 feet above Chicago & North Western Railway. Diameter, 6 inches; temperature, 52°. Surface and yellow clay, 22; blue clay, 12; soft limestone, 60; harder limestone, 94.
Brittain & Co........	.....do.....	162	71	Oolite limestone.	− 24	Principal water bed, 138; minor bed at 76. Pumped with steam suction pump without lowering. Hard. Used for general packing purposes; curb 25 to 30 feet above Chicago Great Western Railway. Yellow clay, 24; sand, 4; blue clay, 40; sand, 3; limestone (blue above, white below streaked with hard layers), 79; shale, 12. Diameter, 6 inches; cased, 71 feet. A second well duplicates this, except 10 feet shallower.

Typical wells of Marshall County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head above or below curb.	Remarks (logs given in feet).
T. 84 N., R. 18 W. (Linn; parts of Taylor and Iowa)—Contd.		*Feet.*	*Feet.*		*Feet.*	
Merritt Green	Marshalltown	169	71	Shaly limestone.	− 80	On slope 30 feet above Iowa Central Railway; water bed in shaly limestone at 98. Pumps 15 gallons per minute with little lowering. Diameter 4½ inches; cased, 71 feet. Yellow clay, 20; sand, 10; blue clay, 41; limestone, 29; shaly limestone, 69.
Lennox Machine Co.	do	119	43	Hard blue limestone.	− 9	Curb 10 feet below Chicago Great Western Railway, on Linn Creek bottom. Water bed 100 feet. Minor bed at 25, in sand. Pumped by steam, lowers to −23 feet. Clay, 20; sand and blue clay, 23; blue and gray limestone, 76. Diameter, 6 inches; cased 43 feet.
	do	70	20	Limestone		Water bed at 67 feet.
Diesing Bros	do	82	35	do		Water bed at 50 feet.
Fourth Ward School	do	145	45	do		
Second Ward School	do	98	60	do		
Arnold School	do	86	62	do		
Third Ward School	do	79	33	do		
Woodbury School	do	156	80	do		
Anson School	do	106	33	do		
Glucose Manufacturing Co.	do	300	19	do	− 19	10 other wells similar, except average 200 feet deep. Curb 6 feet above Chicago & North Western Railway. Second bottom. Open wells all through limestone. 3,000,000 gallons have been pumped in 24 hours. Used in manufacturing glucose. Diameter, 4 inches; cased, 20 feet. Soil, 4; yellow clay, 14; sand and gravel, 1; limestone, 180; shale, blue and buff, 101.
Frank Graham	1½ miles east of Albion.	154	120	do	−100	Very strong flow.
B. H. Kokel	2 miles northeast of Marshalltown.	110	70	do		30-gallon test lowered 10 feet.
W. B. Beeson	3 miles north of Marshalltown.	128	88	Gray limestone.	− 90	Good and strong. Not lowered. Yellow clay, 45; blue clay, 43; limestone, 40.
T. 84 N., R. 17 W. (Marion).						
L. Mickley	4½ miles east of Marshalltown.	246		Sand		No rock.
L. H. Wallace	North Green Mountain.	190	170	Limestone		Water bed in sand with wood at 100.
W. M. Stewart	3 miles northeast of Marshalltown.	198	190	Blue sand	− 80	Chief water in 30-foot bed of sand.
L. Mickley	4 miles east of Marshalltown.	303	300	Oolite limestone.	−140	Strong well. Water, hard. Yellow clay, 90; blue clay and muddy sand, 210; oolitic limestone, 3.
D. Yetley	1 mile northeast of Marshalltown.	162	150	Limestone	−100	Very strong. Yellow clay and sand, 60; blue clay and sand, 90; limestone, 12

Typical wells of Marshall County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head above or below curb.	Remarks (logs given in feet).
T. 83 N., R. 17 W. (LE GRANDE).		*Feet.*	*Feet.*		*Feet.*	
Col. Dougherty	2 miles north of Le Grande.	92	9	Limestone	− 80	Hard rock exposed in Le Grande quarry, near by. Strong well. Water very hard. Yellow clay, 9; limestone, 83.
D. Holken	SE. ¼ sec. 21	306	300	Soft limestone.	−140	Lowers 100 feet on pumping. Yields 5 gallons per minute. Yellow clay, 60; blue clay, 190; quicksand, 56.
Chas. Lodge	6 miles southeast of Marshalltown.	260	......	Gravel and sand.	−120	No rock.
F. B. Brenecke	2 miles north of Ferguson.	562	408	Shale and sandstone.	−180	Test of 5 gallons lowers water 20 feet. Yellow clay, 35; blue clay, 85; sand and clay, 70; blue clay, 110; soft shale, 108; slate and limestone, 40; shale and sandstone, 114.
O. Bryngelson	Le Grande	355	......	Sand	−135	No rock.
E. Harem	do	337	......	do	−137	Do.
J. Hanks	do	232	225	Limestone	−132	
D. Wolken	do	306	300	do	−156	
S. R. Piper	do	325	......	Sand	−150	Do.
J. J. Mote	do	280	120	Limestone and shale.	− 40	
T. 83 N., R. 18 W. (TIMBER CREEK).						
John Goshon	3½ miles south of Marshalltown.	281	120	Shaly limestone.	−100	Not a strong well.
H. Knoll, sr	4 miles northwest of Haverhill.	170	130	Sandstone (DesMoines)	......	
J. F. Cooper	Northeast Haverhill.	183	120	Shaly limestone.	−120	Pumping 5 gallons a minute lowers water 50 feet.
H. Mesinesse	2 miles east of Luray.	236	140	do	−140	
T. 82 N., R. 18 W. (JEFFERSON).						
T. Breekweg	½ mile south of Haverhill.	180	140	Limestone	−110	First water bed at 140.
T. 82 N., R. 17 W. (GREEN CASTLE).						
Chas. Coulbrom	N. ½ sec. 32	308	207	Oolitic limestone.	−140	Strong well.
T. 83 N., R. 19 W. (WASHINGTON).						
J. H. Harff	3 miles southeast of Lamoille.	210	132	Limestone and shale.	......	
T. 82 N., R. 19 W. (LOGAN).						
Poffamburger & Walker.	NE. ¼ sec. 5	231	190	Sand in shale (Des Moines).	−130	Used in manufacture of brick and tile.
William Fort	NE. ¼ sec. 1	258	205	Shaly limestone.	−150	Capacity 10 gallons a minute without lowering.
T. 83 N., R. 20 W. (STATE CENTER).						
Mrs. Bishop	6 miles southwest of State Center.	232	190	Limestone	−140	
Louis Ricker	W. ½ sec. 15	255	192	do	......	3-inch vein; no sand or sediment.
C. H. Lehman	NW. ¼ sec. 15	109	......	Sand and gravel.	− 18	Good gravel well. No rock.
....	State Center	346	......	do	......	Pumps dry 1½ hours by steam.

Typical wells of Marshall County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head above or below curb.	Remarks (logs given in feet).
T. 84 N., R. 19 W. (MARIETTA).						
		Feet.	*Feet.*		*Feet.*	
W. E. Tomlins	S. ½ sec. 22	225				No rock.
H. Monniger	5 miles southwest of Albion.	320		Gravels and sand.		Strong water in sand at 300. No rock.
T. 85 N., R. 20 W. (LIBERTY).						
Thos. Andrews	SE. ¼ sec. 22	223	180	Limestone	− 80	Yellow clay (seep water), 30; blue clay (streaks of sand with little water), 143; soapstone, 30; shaly limestone, 5; limestone, blue and hard, 20.
C. M. Smith	SW. ¼ sec. 4	235		do		
W. E. Elliott	NE. ¼ sec. 14	132	129	do		No shales.
T. 85 N., R. 19 W. (BANGOR; PARTS OF IOWA AND LISCOMB).						
Susan J. Brown	SE. ¼ sec. 9	130	100	Limestone		Very strong vein in crevice in limestone. Yellow clay, 35; blue clay, 55; sand and gravel (seep water), 10; blue clay, 100; sand, 20; blue clay, 105; shaly, light-colored rock, 25; hard limestone, 10; quicksand (?), 3; limestone, 2.
Carrie E. Arney	NW. ¼ sec. 35	208	204	do	− 40	Yellow clay, 30; sand and clay, 10; blue clay, 35; sand, 10; blue clay, 65; sand, 6; blue clay, 99; soapstone, 35; coal, 1; white clay, 2; limestone, 10.
T. 84 N., R. 20 W. (MINERVA).						
Henry Busse	SW. ¼ sec. 13	365	325	Limestone	−150	
Joe Goodman	SW. ¼ sec. 34	303	225	do		Yellow clay, 20; sand and clay, 5; blue clay, 75; sand, 10; blne clay, 72; gravel and sand (heavy water), 10; shaly rock, 10; hard limestone, 53.

POLK COUNTY.

By HOWARD E. SIMPSON and W. H. NORTON.

TOPOGRAPHY.

Polk County is located immediately south of the geographic center of Iowa, and the location of Des Moines, the capital and chief city of the State, within its borders, has made it the political and commercial center. The surface is that of the gently rolling prairie plain characteristic of northern and central Iowa, modified only by its stream-carved valleys. The general elevation of this plain is approximately 1,000 feet above sea level.

Two distinct phases of the drift plain are present, differing chiefly in maturity of dissection and topographic age. The line separating the younger Wisconsin plain on the north from the older Kansan on the south passes just south of Mitchellville, Rising Sun, Des Moines, and Valley Junction. About five-sixths of the county is therefore within the area covered by the latest glacial invasion, the Wisconsin, and this line marks its southernmost extension in the United States. The Wisconsin area is remarkably level, only slight sags and swells being noticeable. The former are frequently saucer-shaped and hold sloughs and shallow ponds. The latter are but gentle rises of land between the sags. The stream valleys are narrow and shallow, and the whole area has the appearance of extreme topographic youth. The Kansan area, on the other hand presents narrower, flat-topped divides and broader, deeper stream valleys, the whole showing the well-drained, maturely dissected topography of a much older type.

Polk, like the counties of southeastern Iowa, is crossed by master streams flowing southeastward through broad preglacial valleys. The most important is the Des Moines, meandering in its broad valley from the northwest to the southeast corner, 150 to 200 feet below the upland, and dominating almost the entire drainage. Of less importance is South Skunk River, paralleling the Des Moines to the northeast, in a valley only slightly less broad and deep. Raccoon River furnishes a marked exception to the general trend of master streams and enters Des Moines River at Des Moines from a direction somewhat south of west.

GEOLOGY.

Alluvial deposits are found on the broad flood plains of Des Moines, Raccoon, and South Skunk rivers and on some of their leading tributaries. These deposits are especially thick south of the line marking the limit of the Wisconsin ice, comprising heavy deposits of gravel in the form of valley trains in valleys leading southward. These are so covered with alluvium that they can not be distinguished and will therefore be classed with the alluvial deposits.

The limits of the Wisconsin drift have been outlined in discussing its topography. The loess forms a thin veneer over the uplands lying outside of the Wisconsin limits and underlies the Wisconsin in places. The Kansan drift underlies the Wisconsin drift and the loess and controls the topography of the latter. It is the most important superficial deposit in this area. Beneath the Kansan extensive gravel deposits and buried soil beds and an older drift have been noted in places. The gravels are believed to belong to the interglacial Aftonian stage and the drift to the Nebraskan stage.

The country rock beneath the drift of Polk County everywhere belongs to the Des Moines group of the Pennsylvanian series. Shales and sandstones, with a few limestones and here and there a coal seam, constitute the chief rocks. The Des Moines group rests unconformably upon a very uneven surface of "St. Louis limestone." (See Pls. XIII, XV, XVI.)

UNDERGROUND WATER.

SOURCE.

The aquifers utilized in Polk County are the alluvium and valley train gravels, the loess, the drift, and the sandstones of the Des Moines group.

Polk County is well supplied with shallow drift waters. Country-rock water, however, is very variable and is generally of poor quality, owing to the large amount of mineral matter it holds in solution.

A valuable water horizon is that of the gravels and sands interstratified with alluvium and underlying the flood plains of Des Moines, Raccoon, and South Skunk rivers and other smaller streams of lesser importance, such as Beaver, Big, Fourmile, Mud, and Camp creeks, tributaries of the Des Moines; Walnut Creek, a tributary of the Raccoon; and Indian Creek, a tributary of the Skunk.

Drive points and open wells find an abundance of good water at very shallow depths in these valleys. The deposits are especially valuable in the southern part of the county, owing to the large amount of gravel spread out upon these valley floors as valley trains by streams from the melting Wisconsin ice. The public supply for Des Moines is secured from these beds by a series of infiltration galleries built into the gravels of the Raccoon River valley. Valley Junction also derives a small public supply from the same source by means of an open well.

In the area south of the Wisconsin ice front the thick deposit of fine porous clay, known as the loess, is an important source for shallow wells from which but a small supply is needed. The chief importance of the loess lies in the fact that it grades downward into a fine sand, becoming coarser and overlying the relatively impermeable till sheet of Kansan age. The common depth of loess wells is 10 to 20 feet; one well, that of J. G. Berryhill, in sec. 19, T. 78 N., R. 25 W., has a depth of 70 feet, but this is exceptional. This loess in the Kansan area is a very uncertain source for water—except in the certainty with which its wells go dry during droughts.

Within the area occupied by the Wisconsin drift many wells penetrate the loess and draw excellent water from it, but owing to the difficulty of distinguishing it from the drift, the two are better classed together. The water is plentiful because this porous deposit, lying between the two till sheets, forms a good storage reservoir and does not dry out so readily as it does where it is exposed, as in the surface overlying the Kansan. This is a condition usually favorable for seepage springs, and such springs are common in the valleys cutting the margin of the Wisconsin drift.

The drift furnishes water for the great majority of wells in Polk County. The wells are so variable in depth and the drift sheets so variable in thickness that it is difficult to distinguish the different water beds, though several are worthy of mention.

The Wisconsin drift is thin, yet owing to the undrained character of the surface, it yields much water to shallow wells which may be obtained almost anywhere by means of a spade or an auger. The water comes from small seeps and veins associated with sand pockets or from thin layers of sand and gravel. With the usual depression of the ground-water level in dry summer seasons many of these fail and the wells have to be dug deeper.

A better supply may be found in the sandy lower portion of the loess wherever this is present between the Wisconsin and the Kansan. Even in the absence of the loess this horizon is frequently marked by a gravel or sandy layer which is a strong water bearer and source of springs.

The Kansan is the most commonly used of all the drift horizons, the water being found, as in the Wisconsin, in small seeps and veins.

The Aftonian gravel, underlying the Kansan drift, forms a most valuable source of well water where it occurs, but in this region it can not often be found unless the gravels immediately overlying the country rock are of this age.

The Nebraskan is not clearly distinguished, but where found it generally consists of a thin layer of gravel and sand lying on the bedrock beneath the Aftonian gravel, thus adding another possible source of water.

The drift is present everywhere throughout the county, except where replaced in river valleys by the alluvium, which is in itself an even better aquifer. It is therefore rarely necessary to enter country rock except for a larger supply than the drift affords.

Although water can be found in the sandstones and coal seams in the Des Moines group, it is rarely potable on account of its impregnation with many minerals. The only available sources in this group are the thick lenses of sandstone, some of which usually carry excellent water. Unfortunately such thick and persistent lenses are relatively uncommon in this area. Some beds exist in the southeast corner and to the north of Ankeny, but nowhere are they more than local as compared with the Red Rock sandstone of Marion and Jasper counties.

FLOWING WELLS.

Of the several deep wells the deepest and best known is the Greenwood Park well in Des Moines, with a depth of 3,000 feet; water now stands 45 feet below curb, though at first there was a small flow from the St. Peter sandstone. Others are the courthouse well in Des Moines, 381 feet deep, flowing from the Des Moines group, and the well on the river bank in front of the Des Moines public library, 461 feet deep, flowing from a sandstone bed at 360 feet. A flow on the farm of M. R. Sadler, near Mitchellville, from a coal prospect hole 100 feet in depth, is an example of another class of shallower wells, some in the drift and some in the coal measures.

GAS WELLS.

Gas has been reported in several of the drift wells near Saylorville and in the northern part of the county; one opening owned by Louis Brendel furnishes it in sufficient quantity to operate a gas burner.

CITY AND VILLAGE SUPPLIES.

Ankeny.—On the uplands about Ankeny (population, 445) drift wells 40 to 60 feet deep are common, though some go down 150 feet. These are supplied from layers of sand and gravel and are variable. Not uncommonly the drift supply is insufficient, and rock wells are drilled. As the highest rock (the shales of the Des Moines group) is in many places 150 to 230 feet deep, it may be necessary to sink to depths ranging from 200 to 400 feet, the last hundred feet being in the "St. Louis limestone." An excellent sandstone water is not infrequently found among the coal shales of this vicinity, but no well-defined sandstone layer occurs in the "St. Louis limestone," as it does in the counties to the south and east.

Des Moines.—The public water supply of Des Moines (population, 86,368) is owned by the Des Moines Waterworks Co. The supply is derived from the gravel beds of the Raccoon River valley on the inside of the great bend opposite the intersection of Nineteenth and Walnut streets, in the southwestern part of the city. The water is collected in infiltration galleries built 25 or 30 feet below the surface in such a way that the water flows from the bottom only. A section consisting of loam, river-washed sand and gravel, silt, sand, and gravel, potter's clay, and sandstone is reported. More than half a mile of galleries are constructed in a layer of coarse, clean sand and gravel fine and free from silts. They lead by gravity through a 36-inch cast-iron main into a large pump well, 48 feet in diameter and 34 feet deep, located on the station grounds northeast of the river. This is bricked and cemented and arched like a great cistern.

An old gallery 1,450 feet long extends from a small pump well in the station yard westward along the railroad tracks, and at its west end a short branch leads directly to Raccoon River. In times of great emergency water may be taken directly from the river, but this has been done only a few times. The estimated capacity of the present system of collecting galleries is 10,000,000 gallons a day at the lowest stage of water. At an ordinary stage it is inexhaustible with the present pumping plant. The actual consumption for the year 1911 was 5,258,770 gallons daily.

Within the pumping station three pumps—an 8,000,000-gallon Holly, a 7,000,000-gallon Gaskill, and a 6,000,000-gallon Worthington—give a daily capacity several times that yet required. The Worthington pump is held in reserve and with one of the others may be connected direct to the river intake in case of conflagration. The three are supplied with steam from a battery of five boilers of 110 horsepower each, by which a head of 100 feet is constantly maintained, a pressure ample for any fire. A direct pressure of 100 pounds for the business portion and 140 pounds for the higher northwest portion of the city is maintained. The lower pressure may be increased to 140 pounds in case of fire, though this is rarely necessary. About 130 miles of mains supply 1,303 fire hydrants and 12,315 taps, the latter through meters. Probably 80 per cent of the population depend on the public water supply.

The Des Moines Linseed Oil Co. and the Des Moines Manufacturing & Supply Co. have abandoned drive wells as unsatisfactory for steam purposes on account of boiler pitting and use the public supply. Both of these companies, together with the Des Moines Gas Co., treat the water with 2 or 3 pounds of soda ash for 1,000 gallons and find the results very satisfactory. The Edison Electric Light Co. and the Des Moines Incubator Works, as well as many other manufacturing plants near Des Moines River, take their supply direct from the river. The Des Moines Ice Co. secures its supply from four 26-foot point wells, drawing 40 gallons a minute at a temperature of 64°, for use in the manufacture of ice and for the condensers. River water is used for the boilers. The Des Moines Hosiery Mills uses a supply from eight points varying in depth from 12 to 34 feet, in alluvium and gravel. The water stands 8 to 10 feet below the surface. The longer points furnish water carrying increasing amounts of iron salts in solution. The water is hard and requires the use of a compound to prevent boiler scale. Points are generally renewed every year or two, on account of ferruginous and calcareous cement collecting on the screen. A storage reservoir having a capacity of 10,000 gallons is used. At the plant of the National Starch Works Co., 1½ miles south of the fair grounds, a supply of 300,000 gallons daily was obtained from 50-foot collecting galleries. The plant is now abandoned, so the water system is not in use.

A large private water-supply system is that of the Agar Packing Co. This company uses the public water supply for washing and cooking, but does not find it economical for all purposes. Two sources are used. The first consists of a battery of seven 4-inch Cook points, with 5-foot screens, driven 40 feet into alluvium and gravel. The general section is as follows:

General section at factory of Agar Packing Co.

	Feet.
Filling	6
Clay, yellow	10
Gravel and sand	24
	40
Clay, hard, blue.	

Water stands 15 feet below the surface, and the wells average 16 pounds vacuum while pumping. The water yields some scale and rust. This water is used first as a condenser of ammonia in the refrigeration plant and afterward for washing and scrubbing. About 500 gallons a minute is constantly pumped, except in freezing weather. The second source is a well 18 feet in diameter by 16 feet deep, connecting directly with the river by means of a 12-inch pipe opening with screen in the channel. About 900 gallons a minute may be thus obtained and is used for boilers, the other waters being too hard, and for spraying hog pens and similar work. The river water scales but slightly, and this tendency is easily removed by the use of a small amount of boiler compound. Fire protection for the plant is had by the use of all the pumps and of water from the city system.

The courthouse well has a depth of 381 feet. Its curb is 805 feet above sea level. It flows at the surface from a depth of 370 feet. It was completed by George Garver in 1888.

Driller's log of well at courthouse at Des Moines.

	Thickness.	Depth.
	Feet.	*Feet.*
Sand and gravel	63	63
Slate, black	18	81
Coal	3	84
Fire clay	5	89
Slate	24	113
Sandstone	10	123
Slate	10	133
Iron pyrites	1½	134½
Slate	4	138½
Coal blossom	½	139
Sandstone and granite	101	240
Shale with pyrites; shale layers 2 to 4 feet thick	60	300
Sandstone	39	339
Slate	6	345
Sandstone, with two bands of flint, 18 inches and 9 inches thick, respectively	17	362
Sandstone	19	381

The Greenwood Park well (Pl. XVI) has a depth of 3,000 feet and a diameter of 10 to 3 inches. Its curb is 872 feet above sea level, and its head 45 feet below the curb. The tested capacity is 400 gallons per minute. Sulphureted water from depths of 498 and 668 feet

(Mississippian) rises within 30 feet of the surface. Water beds were indicated by changes of level of water in the tube at several depths between 1,011 and 1,208 feet (Silurian); water from depth of 1,425 feet (Niagara) rose above surface; water was found at 2,025 feet (St. Peter); at 2,208 feet (New Richmond); and at 2,330 feet (Oneota). Date of completion, 1896. Drillers, J. P. Miller & Co., of Chicago. T. Van Hyning, who supervised the drilling of the well, reported that when the drill entered the St. Peter the flow of water increased until it amounted to 1½ gallons a minute; pumping 52 gallons a minute for 18 hours lowered the water level 125 feet; when the pump was stopped the water rose within 6 feet of the top but did not flow again. When the drill entered the New Richmond the water level fell to 50 feet below the surface; in the Oneota it fell to 80 feet below the surface. Probably other water beds were struck, for on the completion of the well the water stood 45 feet below the curb. It still maintained this level when, in 1902, the city water mains were extended to the park and the well was closed.

Record of strata in Greenwood Park well at Des Moines (Pl. XIII, p. 526; Pl. XV, p. 670; Pl. XVI, p. 672).

	Thickness.	Depth.
Pleistocene (14 feet thick; top, 872 feet above sea level):	*Feet.*	*Feet.*
Till, buff, sandy, with a few pebbles; noncalcareous	14	14
Carboniferous:		
Pennsylvanian:		
Des Moines group (484 feet thick; top, 858 feet above sea level):		
Shale, black, brittle, carbonaceous	1	15
Shale, gray, "fossiliferous"	1	16
Shale, black, carbonaceous, calcareous, highly pyritiferous	3	19
Shale, gray	4	23
Shale and limestone, bluish gray, highly fossiliferous	15	38
Shale, varicolored	67	105
Shale, bluish gray, highly and finely arenaceous, hard	10	115
Shale, bluish gray, slightly calcareous	60	175
Shale, dark drab and black, carbonaceous	11	186
Shales, gray, drab, and purplish; practically noncalcareous; 1 foot of gray chert at 284 feet	312	498
Mississippian:		
"St. Louis limestone" and Osage group (200 feet thick; top, 374 feet above sea level):		
Chert and shale; heavy bed, very hard to drill; most of the sample is an argillo-calcareous powder; the shale is reported as caving in from above, but its calcareous nature indicates that it is in part interstratified with chert and limestone	170	668
Limestone and chert, brownish gray	30	698
Kinderhook group (160 feet thick; top, 174 feet above sea level):		
Shale, light blue and gray	40	738
Shale, terra cotta red, highly calcareous	10	748
Shale, light blue-gray	25	773
Shale, light gray, highly calcareous; fine cherty residue	85	858
Devonian (80 feet thick; top, 14 feet above sea level):		
Limestone, light buff; much gray chert	80	938
Silurian (507 feet thick; top, 66 feet below sea level):		
Limestone, light blue-gray, crystalline, saccharoidal; effervescence slow; considerable white gypsum	2	958
Limestone, cherty, crystalline, blue-gray; effervescence moderately rapid	53	1,011
Limestone, cherty, crystalline, saccharoidal, dark blue-gray and buff; effervescence indicates magnesian limestone, but not dolomite	97	1,208
Gypsum and shale; gypsum gray and white, in flakes; shale green, perhaps from above	15	1,223
Limestone, light blue-gray, highly seleniferous; some flakes of gypsum	145	1,368
Limestone, cherty, arenaceous; grains of sand, minute rounded; much shale in rounded fragments, perhaps from above	22	1,390
Dolomite, buff, crystalline, granular with much chert and some chalcedonic silica; 3 samples	55	1,445

Record of strata in Greenwood Park well at Des Moines (Pl. XVI)—Continued.

	Thickness.	Depth.
Ordovician:		
Maquoketa shale (33 feet thick; top, 573 feet below sea level):		
Shales; in large fragments; purplish yellow and green; noncalcareous; finely laminated	*Feet.* 33	*Feet.* 1,478
Galena dolomite and Platteville limestone (508 feet thick; top, 606 feet below sea level):		
Dolomite; in yellow-gray powder; cherty	260	1,738
Dolomites, yellow, buff and brown; mostly cherty; residue finely quartzose; 5 samples	200	1,938
Shale, green, very slightly calcareous	8	1,946
Dolomite, brown, arenaceous	30	1,976
Shale, dark green, hard, "fossiliferous"; practically noncalcareous	10	1,986
St. Peter sandstone (39 feet thick; top, 1,114 feet below sea level):		
Sandstone, fine, white; grains moderately well rounded	39	2,025
Prairie du Chien group:		
Shakopee dolomite (124 feet thick; top, 1,153 feet below sea level):		
Shale; greenish powder of dolomite, chert, fine quartz sand, green shale, and pyrite	7	2,032
Dolomite, arenaceous, cherty	30	2,062
Shale, drab, calcareous; in finest powder; grains of buff, cherty dolomite	23	2,085
Dolomite, gray	5	2,090
Dolomite, gray; minute rounded vesicles resembling matrix of oolite from which grains have been dissolved	5	2,095
Dolomite	5	2,100
Shale; as at 2,085 feet; "exceedingly hard to drill"	40	2,140
New Richmond sandstone (94 feet thick; top, 1,277 feet below sea level):		
Dolomite, arenaceous, gray; 2 samples	9	2,149
Shale, drab, calcareous	5	2,154
Sandstone, white, fine, calciferous	10	2,164
Dolomite, buff	8	2,172
Sandstone, clean white quartz sand; grains rounded	10	2,182
Dolomite, buff	15	2,197
Sandstone, buff; grains broken, much dolomite	11	2,208
Sandstone, friable, white, fine	2	2,210
Shale, drab, slightly calcareous	4	2,214
Sandstone, white	5	2,219
Dolomite, buff, white; much quartz sand	3	2,222
Shale	2	2,224
Sandstone, gray and buff, calciferous; most of grains broken	14	2,238
Shale, light blue	5	2,243
Oneota dolomite, (175 feet thick; top, 1,371 feet below sea level):		
Dolomites of various tints, many cherty; argillaceous at 2,250, 2,272, 2,333, 2,340 feet; arenaceous at 2,270 and 2,333 feet; at 2,305 feet there is 17 feet of white, blue, and green chert; 32 samples	175	2,418
Cambrian (582 feet penetrated; top, 1,546 feet below sea level):		
Sandstone, white; fine grains, mostly rough surfaced; some dolomite	12	2,430
Dolomite, brown; in chips	2	2,432
Sandstone	4	2,436
Dolomite, rough, gray, and brown	4	2,440
Sandstone, fine, white and reddish; 3 samples	12	2,452
Shale, light blue-gray	2	2,454
Sandstone, calciferous, buff	4	2,458
Dolomite, arenaceous, gray, buff, and brown; 6 samples	30	2,488
Shale, light blue-gray	10	2,498
Dolomite, gray and buff, siliceous	9	2,507
Sandstone, gray, fine, calciferous	27	2,534
Marl, highly quartzose, dolomitic, argillaceous; yellowish powder; 2 samples	19	2,553
Sandstone, calciferous, gray and white; 3 samples	12	2,565
Sandstone; in sand and small chips superficially resembling dolomite; calciferous, glauconitic, close grained; grains white, gray and buff; 10 samples	145	2,710
Shale and dolomite; shale hard, bright green, slaty; dolomite white, highly siliceous, with much greenish, translucent amorphous silica, 2 samples; over one-half of the second sample soluble in acid	20	2,730
Sandstone, buff; in powder, glauconiferous; rock is termed sandstone although composed chiefly of light-colored particles which effervesce freely in acid; fragments of crystalline quartz form but a small proportion of the drillings	20	2,750
Sandstone, saccharoidal; dark with purplish tinge, dark color due to numerous grains of glauconite, purplish tinge to ferruginous stains on quartz sand; sand grains of crystalline silica, rough surfaced, imperfectly rounded, many fractured	130	2,880
Dolomite, dark gray, greenish, macrocrystalline, glauconiferous; sparingly arenaceous	5	2,885
Sandstone, greenish; grains microscopic	5	2,890
Shale, dull gray, fine grained, and exceedingly finely laminated	5	2,895
Sandstone, glauconiferous, calciferous; grains imperfectly rounded, with hard, dark-green slaty shale	15	2,910
Marl; in buff flour; microscopically arenaceous; calciferous; glauconiferous	50	2,960
Marl, pink; calciferous; arenaceous; one-third of drillings by weight insoluble in acid; to bottom of well	40	3,000

Mitchellville.—The State Industrial School for Girls at Mitchellville is supplied with water from several wells. (See Pl. XV, p. 670.)

Water is forced into a tank of 1,600 barrels capacity, elevated on a 90-foot tower, from which 10 fire hydrants and taps in each building are supplied at a pressure of 45 pounds. The school consumes about 8,000 gallons of water a day, less than one-fifth the capacity of the plant.

Well No. 1 has a depth of 865 feet. The water is strongly saline and is not potable and the well was abandoned. Driller, F. J. McCarthy, Minneapolis.

Well No. 2 has a depth of 470 feet and a diameter of 8 inches to 103 feet, 6 inches to 350 feet, 4½ inches to 370 feet, 3½ inches to the bottom; 6-inch casing to 103 feet, and 4½-inch from 348 to 360 feet to shut out a foot of soapstone. The curb is 987 feet above sea level, and the head 102 feet below curb. Water came in at 100 feet but was cased out; also from 320 to 350 feet, heading 50 feet below curb, but the supply was small and easily reduced by pumping; also from 440 to 452 feet in porous rock; tested capacity 20 gallons a minute. Date of completion 1901.

By August, 1904, this well had filled with sediment to 340 feet above its base, or nearly 200 feet above the working barrel of the pump.

Well No. 3 has a depth of 625 feet and a diameter of 10 inches to 107 feet, 8 inches to 317 feet, and 6 inches to the bottom; casing, 4½ inch, from 477 feet to bottom. The curb is 987 feet above sea level and the head 63 feet below curb. Tested capacity 15 gallons a minute at completion of well; present capacity 45 gallons a minute; water at depth of 550 and 563 feet. Temperature, 60° F. The well was drilled by J. H. Shaw, of Sioux City, and was completed in January, 1907.

Driller's log of well No. 1 of the State Industrial School, Mitchellville.

	Thickness.	Depth.
	Feet.	*Feet.*
No samples	296	296
Shale	269	565
Rock	45	610
Shale, green	75	685
Limestone and shale	180	865

Record of strata in well No. 2 of the State Industrial School, Mitchellville.[a]

	Thickness.	Depth.
	Feet.	*Feet.*
Soil, black	4	4
Clay, yellow	10	14
Sand	3	17
Clay, blue	35	52
Clay, gravel, and small stones	2	54
Clay, yellow	30	84

[a] Driller's log to 352 feet; from 352 to 470 feet description of samples.

Record of strata in well No. 2 of the State Industrial School, Mitchellville—Contd.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, cobblestones, and gravel	3	87
Clay, yellow	5	92
Clay and sand mixed	10	102
Sandstone	3	105
Soapstone	7	112
Rock, red	10	122
Rock, hard, with layers of flint	2½	124½
Soapstone and slate	12	136½
Rock, blue	2½	139
Slate and soapstone	10	149
Rock, hard, gray	6	155
Soapstone with hard layers of slate (dark)	18	173
Rock, hard, gray	8	181
Soapstone	2	183
Rock, hard	12	195
Soapstone, hard	5	200
Rock, hard, gray	10	210
Soapstone	2	212
Rock, hard, with 1 foot of iron pyrites	12	224
Slate	5	229
Rock, hard, with bands of flint	7	236
Soapstone, hard	5	241
Slate, hard, gray	10	251
Sandstone	15	266
Iron pyrites	2	268
Sandstone, hard	4	272
Slate	2	274
Sandstone	15	289
Slate, gray	5	294
Sandstone, hard, with crushy layers	24	318
Slate, gray	2	320
Sandstone, hard	7	327
Iron pyrites	2	329
Sandstone, very hard	5	334
Limestone	10	344
Sandstone, hard	5	349
Soapstone	1	350
Limestone	2	352
Limestone, brown, crystalline, vesicular; with large masses of blue-gray chert	4	356
Limestone, brown; with irregular blue shaly masses	2	358
Shale, blue, calcareous, nearly gritless	2	360
Shale, blue-gray; with disseminated siliceous nodular masses	1	361
Limestone, brown, vesicular; effervescence moderately slow; crystalline; fossiliferous	5	366
Shale, blue-gray and buff mottled, massive, calcareous; highly siliceous, with minute quartzose particles		380
Limestone, blue, crystalline, somewhat vesicular; effervescence rather slow		400
Limestone, blue, crystalline, porous; fossiliferous, with casts and molds; minutely arenaceous, argillaceous		410
Limestone, mottled gray; much disseminated chert in grains and with geodic cavities with chalcedonic and crystalline quartz		420
Limestone, yellow and dark gray; mottled like diorite; rather slow effervescence; argillaceous, minutely arenaceous		430
Limestone, blue-gray, argillaceous, and green-gray, saccharoidal; macrocrystalline		445
Limestone, light brownish gray, saccharoidal, macrocrystalline; rapid effervescence		450
Limestone, mottled dark and light gray, vesicular; effervescence rather slow; macrocrystalline-earthy, siliceous, with green disseminated particles of clay		460
Limestone, blue-gray, vesicular, with cavities lined with chalcedonic and crystalline drusy quartz; with disseminated green clay as above		470

Record of strata in well No. 3, State Industrial School, Mitchellville.[a]

	Thickness.	Depth.
	Feet.	*Feet.*
Sandstone, fine, gray; some effervescence in hot hydrochloric acid, indicating magnesian cement; some carbonaceous shale in coarse grains	8	120
Sandstone, similar to the above; brisk effervescence in hot hydrochloric acid, none in cold acid; a few crystals of pyrite	11	174
Shale, blue-gray, fine, rather hard, no grit	12	186
Limestone, subcrystalline, gray, fine grained; some dark carbonaceous shale, also some similar to that at 174 feet	5	191
Shale, dark, fissile, fine textured	16	207
Shale, light to dark gray; light colored is hard and fine textured; dark gray is gritty and crumbles more easily; some calcareous content is indicated by effervescence in cold hydrochloric acid; a little sandstone	4	211
Shale, gray, fine textured	29	240

[a] Description of drillings by James H. Lees, assistant State geologist of Iowa.

Record of strata in well No. 3, State Industrial School, Mitchellville—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Shale, variegated, gray, red, green; sample shows some crystal grains which probably come from magnesian limestone; slight effervescence in hot hydrochloric acid	6	240
Limestone, blue-gray, fine grained, subcrystalline; some fragments of gray fine-textured shale like that at 211 feet	10	250
Shale, dark gray, fine	10	260
Clay shale, dark gray, no laminæ evident; darker than the above; slightly gritty, hard, clay concretions	57	317
Limestone, light gray, fine grained, pyritiferous, crystalline; brisk effervescence in cold hydrochloric acid	10	327
Clay shale, gray, fine textured; effervesces slightly in cold hydrochloric acid	3	330
Limestone, light to dark gray, subcrystalline; grains of vesicular pyrite present; brisk effervescence in hydrochloric acid	10	340
Limestone, as above, containing water	7	357
Chert and limestone; chert gray, fine grained, one fragment being part of a quartz geode; limestone, gray calcite and dark-gray granular limestone; effervescence brisk with cold hydrochloric acid	10	370
Limestone, magnesian, light to dark gray; finely granular; some grains of quartz	24	419
Shale, blue-gray, fine	1	420
Limestone, white and crystalline to dark gray; brisk effervescence in cold hydrochloric acid; considerable dark sand and some quartz crystals; water	14	434
Limestone and chert; chert, milk-white, with numerous well-formed quartz crystals; limestone, gray, granular	6	440
No record	125½	565½
Chert and limestone; chert predominates in sample, in small, angular, blue-gray chips; limestone in light yellowish-gray powder and fine sand; abundance indicated chiefly by brisk effervescence in cold hydrochloric acid. Large residue of clay and chert, with a few sand grains, after thorough digestion. Sample contains some blue-gray shale which may have come from above	9	574½
Chert and limestone, in about equal amounts; chert similar to that in sample above; limestone subtranslucent, crystalline-granular, somewhat iron stained. Residue after digestion in acid chiefly chert with some quartz grains and ferruginous granules; at	....	575
Limestone with some chert; limestone in crystalline granules and yellowish powder; chert as above. Residue almost entirely chert, some fine, light-gray silica, a few pyrite grains. Sample lighter gray than preceding; at	....	579
Limestone in fine, clear, granular sand, brownish gray from coating of calcareous powder; some chert and a little shale, the latter possibly from above. Effervesces readily, residue small, chiefly chert, with some small grains of translucent quartz; at	....	595
Limestone, similar to above, but less chert, pyritiferous, effervescence more rapid than that of higher strata. Residue small, chiefly quartz; at	....	610
Limestone, similar to above, little chert, cleavage faces of calcite give sparkling appearance. Residue small, chert and quartz grains, with some clay, as in previous samples; at	....	615
Limestone, in fine gray and subtranslucent sand; digestion in acid reveals presence of much quartz in fine grains, also a little blue-gray chert. Some shale and numerous small masses of limestone fragments held by ferruginous cement; at	....	620

A combination of the data of wells 2 and 3 gives the following section:

Combined section of wells 2 and 3 (*Pl. XV, p. 670*).

	Thickness.	Depth.
	Feet.	*Feet.*
Quaternary (987 to 885 feet above sea level)	102	102
Carboniferous:		
Pennsylvanian:		
Des Moines group (885 to 670 feet above sea level)	215	317
Mississippian:		
"St. Louis limestone" and Osage group (670 to 517 feet above sea level)	153	470
Probably same as last (517 to 377 feet above sea level)	140	610
Kinderhook group (377 to 302 feet above sea level)	75	685

Below the green shale from 610 to 685 feet "the limerock and shale," extending, according to the log of well No. 1, to 865 feet (122 feet above sea level) may be in part Kinderhook, but in all probability it includes also some upper Devonian. If the saline water of this well is considered as native to the lower sources, it is possible that the drill penetrated to the Salina (?) formation of the Silurian.

Another well at Mitchellville, 95 feet deep, draws from a gravel layer at 80 feet. The water is excellent and is used for all purposes. The supply may, however, be readily exhausted by hard pumping.

Saylor.—A boring 1,800 feet deep is reported from the vicinity of Saylor, in sec. 12, T. 79 N., R. 24 W., but no reliable data regarding it are available.

Saylorville.—A flowing mineral well, less than 400 feet deep, near Saylorville, in sec. 3, T. 79 N., R. 24 W., is said to discharge about 5,000 gallons an hour. The source of the water is probably in or immediately above the Mississippian.

Valley Junction.—The public supply of Valley Junction (population, 2,573) is owned by the Valley Junction Water & Light Co., which owns two wells that furnish the supply. One is a flowing well 278 feet in depth which receives its water from a sandstone bed near the bottom and has a head 16 feet above the curb. The water is strongly mineral and is permitted to flow into a cistern, whence it is pumped for fire and in emergency.

The common supply is taken from a large open well 24 feet in depth, which draws its waters from the alluvial gravels found at depths of 12 to 24 feet anywhere in the town. Water stands within 12 feet of the surface, but it may be pumped out. Water is pumped from the second well into a tank 22 feet in diameter and 16 feet high, elevated on a 75-foot tower from which it is distributed by gravity through 2 miles of mains to 17 fire hydrants and 30 taps; 90 pounds pressure is generally maintained.

Driven wells may be had almost anywhere in the lower part of town at depths of 12 to 25 feet. The water stands so near the surface that in case of flood in Raccoon River the cellars are filled and water occasionally breaks up through the streets. The open sands and gravels lie immediately under the surface soils, except where they are covered with a layer of gumbo, and the ground water rises and falls with the river. Thus water is easy to get but liable to be contaminated. On the hill bored wells 40 to 50 feet in depth are the rule.

WELL DATA.

The following table gives data of typical wells in Polk County:

Typical wells of Polk County.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head above or below curb.	Remarks (logs given in feet).
		Feet.	*Feet.*		*Feet.*	
Mrs. Jennie E. Day.	3 miles south of Ankeny.	......	......	Des Moines.	+ 20	Coal prospect. Water bed, 250 (?).
Fort Dodge, Des Moines & Southern R. R.	Ankeny	150	......	Sand and gravel.	− 20	No rock. Other water beds, 75 to 125.
W. M. Donnaghy	6 miles north of Ankeny.	274	290	.....do......	− 70	Filled to 274; other water beds 150 to 200, in fine sand.
F. H. Hunter	2 miles northeast of Ankeny.	265	140	Sandstone (Des Moines).	− 80	Other water beds, 150 to 200.
Henry Wagner	½-mile from Ankeny.	380	240	Sandstone...	− 60	
City of Des Moines.	City Library	461	44	Gray sandstone.	+ 7	Till (alluvium), 44; soapstone, 10; sandstone, 7; fine clay, 111; slate, 17; coal, 4; sandstone, 80; sandstone, striped, some water, 30; sandstone, 120; sandstone, hard, striped, water bearing, 38. Principal water bed at 360; another at 225; flows freely as a park well.
Girls Industrial School.	Mitchellville	470	102	Sand and gravel.	−102	Other water beds in rock.
Do	.....do	865	......	At 350 feet..	− 60	Very hard water.
Do	.....do	95	......	Gravel	......	No rock.
T. S. Sayre	NW. ¼ sec. 20, T. 79 N., R. 22 W.	220	......	Sand	− 80	No rock. Slight sulphur taste.
J. O. Lee	SW. ¼ sec. 16, T. 78 N., R. 22 W.	175	......	.....do......	− 25	No rock. Hard water. Drift 25; blue clay, 25; yellow clay, 20; hard black clay, 100; yellow clay, with gravel, 5; gravel and water.
Beaver Township	NE. ¼ sec. 25, T. 79 N., R. 22 W.	65	......	.....do......	......	No rock. Hard water. Drift or soil, 21; blue clay, 44; soft blue sand rock (drift conglomerate); sand and water.
Valley Junction Water & Light Co.	Valley Junction...	24	......	Gravel and quicksand.	− 12	10 feet in diameter. No rock.
Do	.....do	278	......	Sandstone...	+ 16	Flows ½-inch stream; mineral.

STORY COUNTY.

By Howard E. Simpson and W. H. Norton.

TOPOGRAPHY.

Story County is at the geographic center of Iowa. Its surface, as a whole, is so nearly level, compared with the southern and eastern parts of the State, that it appears nearly flat—a condition due to the drift deposited over it by the last great ice sheet. Since this deposition too little time has elapsed to permit much modification of the gently rolling surface, and the area remains one of physiographic or topographic youth. Swales and shallow saucer-shaped basins are very common, but only the largest streams have developed well-marked valleys. The hills are inconspicuous low swells, save in a few places where kames and morainal ridges are well developed. Local relief is slight, and the maximum difference in elevation, between the highest point on the moraine hills near Summit, with an altitude of 1,075 feet, and the point where South Skunk River leaves the county, is less than 250 feet.

South Skunk River, which drains the western half of the county, and Indian Creek, which drains the eastern half, both flow southward through fairly well developed preglacial valleys. Their tributaries, however, are few and poorly developed, and ponds, small sloughs, and undrained areas are common. Many smaller tributaries and most ponds are intermittent, disappearing in dry seasons.

GEOLOGY.

The glacial drift is thickly spread over the surface of the entire county except in the valley floors of South Skunk River and its chief tributaries, Squaw and Indian creeks, where it has been eroded away or covered with alluvium. In the South Skunk River bottoms below Ames and along Indian Creek at Maxwell these deposits have been found to be from 50 to 100 feet thick, showing the preglacial character of the lower portions of the valleys.

Two drift sheets at least are present, the Wisconsin and the Kansan. They are separated by the loess and in many places by sands and gravels (the Buchanan), beneath the loess. Beneath the Kansan another gravel bed (the Aftonian) is locally present. The bedrock is everywhere the coal measures (Des Moines group), except in the west-central portion about Ames, where South Skunk River and Squaw Creek have cut through them into the "St. Louis limestone," the cutting being made possible by a decided arching of the strata. Surface exposures of the bedrock are comparatively rare.

Aside from the low anticline which elevates the "St. Louis limestone" along South Skunk River about Ames and the minor irregularity of the surface, Story County shows no structural features worthy of mention. The Des Moines group has a maximum thickness of about 200 feet, is of varying character, and dips slightly southeast. (See Pl. XI, p. 382.) The thickness of the drift layers is extremely variable.

UNDERGROUND WATER.

SOURCE.

In Story County water is drawn from the alluvium, the Wisconsin drift, the loess, the underlying interglacial sands and gravels (Buchanan), the Kansan drift, the sands and gravels (Aftonian) beneath the Kansan, the Des Moines group, the "St. Louis limestone," and deeper beds.

Alluvium in quantity sufficient to form a water bed is limited to the valleys of South Skunk River and Squaw and Indian creeks. Here, not only beneath the flood plain but under the well-marked terraces which lie from 20 to 30 feet above it, coarse gravels and sands of glacial and fluvial origin alternate with clay and silt for depths of 50 to 100 feet and form a fairly distinct water province, whose importance is enhanced by the fact that several towns, including Ames and Cambridge on South Skunk River, and Maxwell and Iowa Center on Indian Creek, are situated within it. All these towns draw their supplies from these deposits, which yield a satisfactory quantity of good water.

The creamery well at Cambridge[1] shows the nature of the strata.

Record of creamery well at Cambridge.

	Thickness.	Depth.
	Feet.	*Feet.*
Loam and yellow clay	10	10
Sand and gravel	10	20
Clay, blue	25	45
Sand, fine	10	55
Gravel, coarse	10	65

The alluvial area is about half a mile wide on each stream, except on South Skunk River south of Ames, where it is about 2 miles.

As in all the other areas covered by the Wisconsin drift sheet, the drainage of the Wisconsin area in this county is immature and the ground-water level so near the surface that the chief source of underground water for all purposes has been shallow bored and dug wells. The depth of the Wisconsin till, 20 to 80 feet over the general upland, is so great that in the earlier days comparatively few wells penetrated it even to the loess. Cultivation and artificial drainage have, however, lowered the ground-water level and this, together with the increased demand for water for stock, has necessitated the deepening of old wells or the sinking of new ones, and the latter as a general rule have been bored or drilled. Most of them draw their supplies from the sand and gravels between the two great drift sheets, which still remain the source most commonly utilized in the county. These beds give rise to many springs where they are exposed in the stream valleys; many are perennial and form an excellent supply for stock pastures.

Deeper drift wells reach a fairly persistent and satisfactory bed beneath the Kansan, in the sands and gravels immediately overlying the bedrock, though many good wells are obtained in local sand layers higher up. The depth is variable owing to the great variations in thickness not only of the Kansan but of the overlying Wisconsin; 100 to 130 feet is common in the western portion of the county, and 150 to 300 feet is not uncommon in its eastern portion.

The general relations are shown in a well section given by S. W. Beyer[2] and interpreted by Norton.

[1] Beyer, S. W., Geology of Story County: Iowa Geol. Survey, vol. 9, 1899, p. 206.
[2] Idem, p. 197.

Log of Larson well in the NE. ¼ sec. 5, Lafayette Township.

	Thickness.	Depth.
	Feet.	*Feet.*
Wisconsin drift:		
Soil and yellow clay	10	10
Clay, blue	5	15
Loess:		
Quicksand	5	20
Kansan drift:		
Clay, blue and yellow mixed	5	25
Quicksand	1	26
Clay, blue	77	103
Aftonian gravel:		
Sandstone, gravel, water bearing	50	153
Des Moines group:		
Sandstone	6	159
Chert	2	161
Shale, blue and black; coal; fine clay; and shale, black	15	176

The heavy deposit of sand and water-bearing gravel is somewhat anomalous and may signify a preglacial channel. In some portions the Kansan is so thin that it is difficult to distinguish its upper beds.

The record kept in the sinking of the Iowa State College well is of value in showing the relations of the drift horizons.

Record of Iowa State College well, at Ames.

	Depth in feet.
Till, yellow and gravelly; upper portion modified into soil	1–16
Till, blue, sandy	16–32
Till, blue; some yellow clay	32–35
Sand, yellow	35–40
Till, bluish green, contains an abundance of gravel	40–50
Silt, ash-brown; with greenish tinge, loesslike, but finer	62–97
Silt, slightly arenaceous, at	102
Sand, very fine, light yellow, at	105
Sand; with coarse gravel; water bearing	110–120
Shale, light bluish gray, calcareous, and cherty, at	126

A gravel layer about 16 feet below the surface is the probable source of a spring which furnished the earlier water supply of the college. A sand and gravel bed 10 feet in thickness at a depth of 40 feet and the coarse sand and gravel near the base of the well all indicate excellent supplies sufficient for ordinary use, though they have in late years proved insufficient to meet the demands of the college.

A few wells penetrate the entire drift and, entering the bedrock, find a satisfactory supply in sandstone lenses in the coal measures (Des Moines group). These layers are so local and variable that no general prediction can be made concerning them, and their water is in places too highly impregnated with sulphur salts to be valuable for domestic use. As a rule, this group is here chiefly composed of shales and therefore practically dry. These beds are absent in the small area about Ames & Soper's mill, but reach a maximum thickness of 200 feet in the southwestern portion of the county. A driller's log indicates the type of well.

Log of Tilden well, in the NE. ¼ sec. 12, Franklin Township.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and yellow clay (Wisconsin)	45	45
Sand and clay (loess)	10	55
Clay, blue (Kansan)	63	118
Slate	12	130
Sand; with coal and water	8	138

The "St. Louis limestone" lies so deep over most of the county as to be beyond the reach of ordinary wells, and its shaly character makes it less certain as a water bearer than it is farther south. However, sandy layers mingling with the shaly beds beneath the heavy upper limestone supply a number of wells ranging from 130 to 400 feet in depth.

At the Iowa State College, at Ames, and at Nevada, the deeper beds have been drawn upon.

DISTRIBUTION.

In the eastern part of the county the stock wells are generally deeper than in the western part. Depths of 200 to 300 feet are not uncommon, the water being drawn mostly from sandstone beds of the Des Moines group. Bored wells in drift are sufficient for ordinary household purposes and small farms.

Throughout the southwestern portion of the county farm wells 200 to 400 feet in depth are most common, but few of them enter bedrock, abundant water being supplied by heavy gravel layers in the base of the drift. Cambridge, Maxwell, and Iowa Center, in the southern portion of the county, draw their supplies from the alluvial sands interstratified with the silts of South Skunk River and Indian Creek. Wells 200 to 300 feet deep are common in the southeastern section. One of these is utilized for a small town supply at Collins.

Several small and well-defined flowing-well basins are found in the northern part of Story County, in the bottoms of valleys, and have their origin in the drift. Beyer [1] describes these basins as follows:

Of these, Keigleys Branch, Zearing, and Dyes Branch constitute the most noteworthy artesian basins in the order of their importance. Watkin's well is the strongest well in the Keigleys Branch basin and may be considered typical of the area. The sequence of strata passed through is as follows:

Soil, 3 feet; clay, yellow, 17 feet; clay, blue, 35 feet; gravel and sand, water bearing, 7 feet; blue clay penetrated.

It is reported that the drill dropped 9 feet on reaching the gravel and that water carrying gravel with it spouted out with great violence. Bowlders of several pounds weight were thrown out. The water contains much suspended sediment. Temperature, 48° F.; rate of flow, 28,000 gallons per hour.

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[1] Geology of Story County: Iowa Geol. Survey, vol. 9, 1899, pp. 230-232.

There are numerous other flowing wells in this vicinity, but all of small flow. In the majority of instances the temperature is 2° or 3° higher than in the case of Watkin's well and about 5° higher than in ordinary shallow wells in the same locality, which show a temperature of about 45° to 46° F.

In the Zearing basin all of the wells are located on the bottom land along Minerva Creek, within a radius of a mile from the town of Zearing. All are of small capacity and vary from 60 to 90 feet in depth.

Along Dyes Branch several flowing wells have been developed. The water-bearing stratum is reached at from 80 to 120 feet below the surface, the depth depending upon the position of the mouth of the well. The water is of good quality, but, as in the case of the preceding basins, it carries considerable ferruginous matter, as evidenced by the taste and by the brownish rust which coats all vessels in which the water has been allowed to stand.

Several other flowing wells are known at widely separated points in the county, but in every case they are of small capacity and possess little of general interest.

The Skunk Valley at Story City and the Bear Creek Valley at Roland are also noteworthy artesian basins. In the former is located the city well of Story City.

CITY AND VILLAGE SUPPLIES.

Ames.—The location of Ames (population, 4,223) on the terraces of South Skunk River and Squaw Creek insures an abundant supply in the alluvial sands at no great depth. The city supply is drawn from a well 10 inches in diameter, drilled within the casing, which was driven as fast as the well was drilled to a depth of 99 feet, and finished with a 10-foot screen. The water is thus drawn from coarse sands and gravels at a depth beyond danger of surface contamination. The head is usually about 48 feet below the surface.

The Chicago & North Western Railway uses a similar well in which a Cook strainer was sunk to a depth of 104 feet, the water standing 30 feet below the surface. The log is of interest in this connection.

Record of Chicago & North Western Railway well at Ames.

	Thickness.	Depth.
	Feet.	*Feet.*
Loam, sandy	20	20
Sand, blue, and clay	35	55
Gravel, coarse	10	65
Sand, water bearing	39	104

One of the most important wells in this vicinity is that of the Iowa State College of Agriculture and Mechanic Arts. (See Pl. XI, p. 382.) Formerly an abundant and excellent supply had been obtained from the gravels underlying the Wisconsin till, but this source failed entirely in the dry summers of 1894 and 1895. The well has a depth of 2,215 feet and a diameter of 12 inches for 120 feet, 10 inches for 300 feet, 8 inches for 648 feet, 6⅝ inches for 362 feet, 5⅜ inches for 505 feet, and 5 inches for 280 feet, to the bottom. It is cased within 280 feet of the bottom; no repairs made. The curb is 1,000 feet above sea level, and the present head is 20 feet below the curb. The original pumping capacity was 100 gallons a minute; present yield, 100 gallons a minute; yield can be materially increased by speeding the pumps. The well was completed in 1897 by Gray Bros., of Chicago.

The water beds are stated by Beyer to be the Jordan, the New Richmond, and the St. Peter. Pumping tests indicate that the water-yielding ratio of these formations is 15 to 4 to 1, respectively.[1]

The temperature observations made of this well by Beyer [2] are of especial value. When the tests were made the well was practically full of water and had not been disturbed for more than a month. No corrections were made for convection currents nor for conduction. A Miller-Casella self-registering maximum-minimum thermometer was used. The instrument was lowered and the depth measured by a steel wire which passed around a calibrated drum. Readings were taken every 100 feet. The mean annual temperature at Ames is 47.2° F.; the temperature at 2,100 feet below the surface is 63.4° F.; and the average gradient is 1° F. for every 129.6 feet of depth.

Record of strata in deep well at Ames (Pl. XI, p. 382).[3]

	Depth in feet.
Pleistocene (120 feet thick; top, 1,000 feet above sea level):	
Till, yellow, sandy to gravelly; upper portion modified into soil	1–16
Till, blue, sandy	16–32
Till, blue; some yellow clay	32–35
Sand, yellow	35–40
Till, greenish blue; abundance of gravel and cherty limestone pebbles; matrix effervesces freely with dilute hydrochloric acid	40–50
Silt, ash-brown; with greenish tinge, calcareous and absorbent, loesslike but finer	62–97
Silt, slightly arenaceous	102
Sand, very fine, light yellow	105
Sand; with coarse gravel, water bearing; quartz pebbles abundant; limestone fragments present	110–120
Carboniferous (Mississippian) (300 feet thick; top, 880 feet above sea level):	
Shale, light bluish gray, calcareous, cherty	126
Limestone, blue-gray, argillaceous, pyritiferous	151
Limestone, gray, argillaceous; some quartz	160–170
Limestone, light gray, soft, even textured, cherty; effervesces very freely with weak hydrochloric acid	185
Limestone, slightly argillaceous	200
Limestone and shale	210

[1] Beyer, S. W., Iowa Agricultural College water supply, Ames, 1897, p. 11.
[2] Idem, pp. 13–14.
[3] Idem, pp. 6–9.

	Depth in feet.
Carboniferous (Mississippian) (300 feet thick; top, 880 feet above sea level)—Continued.	
Shale and limestone	240
Shale, blue, noncalcareous, pyritiferous	310
Limestone, argillaceous; tending toward an oolitic facies; effervesces strongly with dilute hydrochloric acid	315
Shale, with fragments of white limestone; fossiliferous and pyritiferous	320
Shale, earthy blue, arenaceous	325
Shale, light reddish brown; some green shale, slightly calcareous	330
Limestone, blue-gray; some green shale and brown limestone	375
Limestone, brown, pyritiferous	385
Limestone, brown; fragments of white cherty limestone and angular quartz grains	395
Limestone, brown, argillaceous	400
Shale, light gray, highly calcareous	415
Shale, gray-blue, calcareous	416–420
Devonian (310 feet thick; top, 580 feet above sea level):	
Limestone, yellowish gray; some carbonaceous matter	420
Limestone, white, compact	440–456
Shale, light bluish gray	460–475
Shale and limestone	495
Shale and limestone	540
Limestone, white, and shale, greenish blue, noncalcareous	550
Shale, ash-blue, calcareous	560
Limestone, gray-blue; fragments of brown limestone and green shale	570
Limestone, gray-blue	580
Limestone, gray, and shale, blue and green	590
Limestone, fossiliferous	600–610
Limestone, gray-brown, subcrystalline	615–640
Limestone, gray-brown, and shale	645–660
Limestone, buff, subcrystalline	660–680
Silurian (150 feet thick; top, 270 feet above sea level):	
Limestone, buff; earthy luster; soft; effervesces moderately with hydrochloric acid	690
Limestone, blue and buff; the latter in part vesicular and magnesian	700
Limestone, drab, highly argillaceous	710
Limestones; several kinds; one a buff earthy limestone, finely laminated, effervescing slowly, the laminæ marked by dark-gray bands	720
Dolomite, light gray	730
Dolomite, brown and gray, subcrystalline; varying in hardness and color	740
Limestone, buff	750
Shale, olive-green	755
Limestone, buff	775, 815–830
Shale and limestone	840–850
Dolomite, ash-gray	860
Dolomite, white	870

	Depth in feet.
Ordovician:	
Maquoketa shale (160 feet thick; top, 120 feet above sea level):	
Shale, green, plastic, noncalcareous	880
Shale, brown; slightly or not at all calcareous; 2 samples	890, 900
Shale, blue and green, noncalcareous	930
Shale, brownish, slightly calcareous	940
Shale, brownish; white fragments	950
Shale, blue, noncalcareous	960
Shale, earthy brown, calcareous	970
Shale, blue, calcareous	980–1, 030
Galena and Platteville limestones (380 feet thick; top, 40 feet below sea level):	
Limestone; sharp drillings in an argillaceous powder	1, 040
Limestone, white	1, 050–1, 060
Limestone, white; much argillaceous material	1, 080–1, 090
Limestone, gray-blue, with blue shale and white chert	1, 100
Limestone, gray-blue, compact; white chert in abundance; drillings sharply angular	1, 110–1, 130
Limestone; as above, but less chert	1, 140–1, 170
Limestone, slightly earthy, gray-blue	1, 180–1, 190
Limestone, gray-blue, marly	1, 200
Limestone, buff, magnesian, marly	1, 210–1, 230
Limestone, ash-gray	1, 240–1, 260
Limestone, ash-gray; fragments of noncalcareous black and green shale	1, 270
Limestone, brown, soft	1, 280
Limestone, gray and brown, cherty	1, 290
Limestone, gray; considerable reddish brown residual material	1, 300
Limestone, cherty	1, 310
Limestone gray, with green shale	1, 320
Limestone, gray, siliceous	1, 330–1, 380
Shale, green, fissile, noncalcareous, fossiliferous and pyritiferous; fossils identified, *Dalmanites pygidia* and *Isotelus* (*Asaphus*) *pygidia* resembling some forms of *I. gigas* DeKay; *Rafinesquina alternata*, *Orthis subequata*, *O. fissicosta*, and other Orthidæ	1, 385–1, 410
St. Peter sandstone (70 feet thick; top, 420 feet below sea level):	
Sandstone, fine textured, white; grains even and well waterworn	1, 420–1, 460
Sandstone, calciferous	1, 470–1, 480
Prairie du Chien group (610 feet thick; top, 490 feet below sea level):	
Dolomite	1, 490–1, 500
Dolomite and sandstone; some doubly terminated quartz crystals	1, 510
Sandstone	1, 520
Dolomite	1, 530

	Depth in feet.
Ordovician—Continued.	
Prairie du Chien group (610 feet thick; top, 490 feet below sea level)—Continued.	
Dolomite, coarse sand, and green shale	1,540
Sandstone and dolomite; sandstone varying in size of grain	1,550
Sandstone; grains angular	1,560
Dolomite	1,570
Dolomite, arenaceous	1,580
Dolomite, arenaceous and cherty	1,590–1,600
Sandstone, fine grained, angular, calcareous cement	1,610
Sandstone, yellow; much siliceous dolomite	1,620
Dolomite, highly arenaceous	1,630–1,640
Dolomite, white, finely quartzose	1,650
Dolomite, arenaceous	1,660–1,680
Marl, yellow; in argillo-calcareous powder, cherty, quartzose	1,690
Dolomite	1,700–1,710
Dolomite, highly arenaceous	1,720–1,730
Dolomite	1,740–1,750
Dolomite; chert and sand	1,760
Sandstone	1,770–1,790
Dolomite	1,800–1,830
Dolomite, arenaceous	1,840
Dolomite, argillaceous and arenaceous	1,850
Dolomite	1,860–1,880
Dolomite and sand	1,890–1,910
Dolomite, highly arenaceous	1,920
Sandstone	1,930
Dolomite	1,950–1,960
Dolomite, arenaceous; grains well waterworn	1,970–1,990
Dolomite, arenaceous; some green shale	2,000–2,010
Dolomite	2,020–2,040
Dolomite, highly arenaceous	2,050
Dolomite	2,060–2,070
Dolomite, argillaceous	2,080
Shale, blue, noncalcareous	2,090
Cambrian:	
Jordan sandstone (115 feet penetrated; top, 1,100 feet below sea level):	
Sandstone; with dolomite and a little blue shale	2,100
Sandstone, white and waterworn; a small percentage of the grains contained iron	2,110
Sandstone, white; grains fine, sharp	2,120
Sandstone; as above, with coarser well-rounded grains	2,130
Sandstone, white; grains fine, even, well worn	2,140–2,175
Sandstone, white; texture variable	2,185
Sandstone; grains stained red with iron oxide; red and green shale; grains larger than above and more angular; iron pyrites and a black metallic mineral present	2,195
Shale, brownish red, arenaceous	2,205
Shale, green	2,215

Nevada.—The city of Nevada (population, 2,138) has two distinct sources of supply, a shallow open well 25 feet in depth, drawing its water from a coarse gravel bed, presumably at the base of the Wisconsin, and a drilled well 980 feet in depth, reaching the Silurian aquifers. Water is pumped chiefly from the shallow well and the deeper one is held in reserve, because of the expense of pumping the latter from a depth of 300 feet and because its water is strongly mineral.

The shallow well yields only about 500 barrels a day and is easily pumped out in dry summers. The water is distributed by gravity from a tank, capacity 35,000 gallons, elevated on a 90-foot tower, and a pressure of 50 pounds is maintained on the main streets. Mains 5½ miles long supply 35 fire hydrants and about 140 taps. About one-fourth of the population use the city supply, and all others are provided with shallow wells from the same aquifer.

The drilled well (Pl. XI, p. 382) has a depth of 980 feet and a diameter of 11, 8, and 6 inches; casing to 810 feet. The curb is 1,005 feet above sea level and the original head 103 feet below curb. The water bed is at 940 feet (Silurian), and the tested capacity 200 gallons a minute. Date of completion, 1895. Drillers, Palmer & Sandbo, of Caledonia, Minn.

Driller's log of city well at Nevada (Pl. XI, p. 382).

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, yellow	30	30
Clay, blue	6	36
Clay, yellow	10	46
Sand	55	101
Clay, till	20	121
Shale	50	171
Clay, black	75	246
Slate	3	249
Coal and slate	3	252
Clay, light gray	15	267
Shell limerock	15	282
Limerock, white, mixed with flint	50	432
Granite, blue	50	482
Limestone, blue	93	575
Shale, red	8	583
Limestone, blue	80	663
Soapstone	8	671
Limestone, white	98	769
Limestone, blue	32	801
Clay, blue	3	804
Limestone, blue	55	859
Limestone, white	40	899
Sandstone, dark	35	934
Sandstone, white	10	944
Sandstone, red	12	956
Sandstone, white	8	964
Sandstone, red	4	968
Limestone, white	12	980

The clay shales and coal from 101 to 267 feet may be interpreted as the Des Moines group. The Mississippian includes the "limestone mixed with flint" and the so-called "granite," and the Kinderhook may be represented in at least the upper part of the blue limestone from 482 to 663 feet. Under this interpretation the limestones from 671 to 899 feet may be Devonian, and the sandstone beneath them may be dolomites of the Silurian. Certainly no sandstone is to be looked for at this horizon.

Nevada is 1,005 feet above sea level. The artesian water used for city supply is so highly mineralized that it is important to know whether a better water could not be had by drilling deeper. This question may be answered in the affirmative. The records of the present city well are regrettably incomplete and inconclusive, but the very scant data seem to show that the supply is drawn from the Silurian and higher strata. Had the well been drilled deeper it would have found a much better water and the supply would also have been increased. Should the present well be deepened or another drilled, the Maquoketa shale may be expected within 50 or 100 feet below the bottom of this well, and this dry shale may reach a thickness of 150 feet. The Galena and Platteville limestones, underlying the Maquoketa, should yield some water, especially above the green shale at or near the base of the Platteville, but the drill may fail to find water by failing to strike a crevice. The St. Peter sandstone, the first reliable water bed, would normally be encountered at about 600 feet below sea level, or about 1,600 feet below the surface, but the presence of an upwarp of the strata in this vicinity, as shown by the deep well at Ames, may bring this sandstone 100 or even 200 feet higher. Below the St. Peter abundant stores of water will be found in the Prairie du Chien group and the Jordan sandstone, and the well may be sunk with advantage to 2,300 or 2,400 feet, although a supply sufficient for present needs may be found within 2,000 feet. The well should be cased water-tight to the Maquoketa or to the Galena.

Story City.—The public supply of Story City (population, 1,387) comes from a flowing well which just reaches rock at 100 feet, the aquifer being the Aftonian gravel at the base of the Pleistocene. This overflows at the surface at the rate of about 50 gallons a minute into a cistern from which it is pumped into an elevated tank which furnishes a pressure of about 40 pounds on the mains. The flow has slightly decreased.

The same aquifer is generally drawn upon by the deeper wells in this vicinity. In many wells on lowlands the water flows and in all it rises nearly to the surface. The supply from these wells is abundant and good. Where but a moderate quantity is needed, it is obtained at depths of 25 to 30 feet.

Minor supplies.—Though shallow bored wells are common near Gilbert (population, 235) for household purposes, drilled wells 100 to 200 feet in depth are generally necessary for stock, and both the lower drift gravels and the country rock furnish the water. Maxwell (population, 754) has two wells 80 and 100 feet in depth; a tank with a capacity of 1,300 barrels, elevated 60 feet from the ground, receives the water from the pumps, and from this it is distributed by gravity to the few fire hydrants and taps necessary for the village. Direct pressure is available in case of fire.

WELL DATA.

The following table gives data of typical wells in Story County:

Typical wells of Story County.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head above or below curb.	Remarks (logs given in feet).
		Feet.	*Feet.*		*Feet.*	
H. C. Wickham	SW. ¼ sec. 10, T. 85 N., R. 21 W.	365	120	Rock (Des Moines).	− 60	
R. D. Tresseler	2 miles southwest of Gilbert.	98	90		+4+	Flow 16 gallons a minute.
J. Weigle	7½ miles north of Gilbert.	386	150	Rock ("St. Louis"?).	− 40	Pleistocene: Yellow clay, 18; sand, 12; blue clay, 120. Des Moines: Slate, 50. "St. Louis:" Fine clay mingled with streaks of hard rock, 186.
City	Ames	108		Sand and gravel.	− 48	10 inches diameter 9½-foot screen.
Henry Byal	5½ miles south of Collins.	420	200	Sandstone ("St. Louis"?).	−180	Soil, 2; yellow clay, 25; blue clay, 53; sand, 2; blue clay, 118; slate, 10; sandrock, 8; slate, 2; sandrock, 12; slate, 1; sandrock, 20; slate, 1; rock, various changes, 176. No water above 418.
Jos. Olinger	2½ miles northeast of Maxwell.	288	125	do	−138	"In alternating hard rock and sandrock."
Sam Miller	2½ miles northwest of Maxwell.	118	100	do	− 6	
Frank Fish	Collins	298	180	Brown sandstone.	− 90	
G. Elliott	3 miles east of Collins.	60		Aftonian(?) sand.	− 20	Soil and yellow clay (Wisconsin), 12; Sand (loess?), 6; sand, coarse (Buchanan), 8; clay, yellow (Kansan), 8; clay, blue (Kansan), 23; sand and water (Aftonian?), 3.
B. Olson	3½ miles north of Slater.	100			− 60	Bored. Cased with 12-inch tiling. Soil and yellow clay, 16; blue clay, 50; yellow clay, sand and water, hard dark clay, 34. Good supply of hard water.
Chicago & North Western Railway Co.	Ames	104		Sand and gravel.	− 30	Cook well strainer.
City	Nevada	25		Coarse gravel.	− 10	12 foot diameter; capacity, 500 barrels a day.
Do	do	980	100	Silurian sandrock.	−150	Mineral. Poor boiler water. Sand water beds at 25 and 100 feet.

WEBSTER COUNTY.

By W. J. Miller and W. H. Norton.

TOPOGRAPHY.

Webster County is situated in the middle of the Wisconsin drift and in most parts shows the almost perfectly flat surface configuration so common to all the counties covered by that drift sheet. One very marked deviation from the generally flat country is the deep valley cut out by Des Moines River, which enters the north-central portion of the county and passes out at the southeast corner. Several tributaries of the Des Moines in the northwest have also considerably modified the flat country.

GEOLOGY.

The drift is represented by both the Kansan and the Wisconsin sheets, each of which extends over practically the whole county. The rock formations under the drift are represented by the Mississippian, Pennsylvanian (Des Moines group), and Permian (?). The Des Moines group extends over all except the northern part of the county, which is underlain by the Mississippian. The Permian (?), which carries gypsum, occurs in isolated areas on either side of Des Moines River in the vicinity of Fort Dodge.

The drift deposits have been for the most part laid down horizontally, although abrupt thickening and thinning of the beds are shown. Along Des Moines River they appear to follow the slopes of the river bottom. Little is known regarding the structure of the older rocks, but they are probably nearly horizontal. (See Pls. VI, p. 258; XVI.)

As is generally the case in counties of central Iowa that are covered by the Wisconsin drift, Webster County has two important drift-water horizons, one beneath the Kansan and the other beneath the Wisconsin. Some wells have gone through the drift and into the underlying rocks, where they have obtained water from limestone or sandstone.

In Webster County comparatively shallow drift wells are numerous and yield good supplies of water. Rock wells are scarce. Nearly all water is rather hard.

UNDERGROUND WATER.

SOURCE.

So far as the existing supply of water is concerned, the most important aquifer in this county is the sand or gravel beneath the Wisconsin drift, which in most places lies within 100 feet and in some places within 35 to 50 feet of the surface. Except along the stream bottoms the sand or gravel beneath the Kansan drift is reached at not less than 100 feet and in places at not less than 200 or 230 feet. Locally the Wisconsin has been completely removed by erosion along the main waterways and the first important aquifer to be reached is that beneath the Kansan instead of that beneath the Wisconsin. This is particularly true in the vicinity of Fort Dodge. Locally water-bearing sand beds may occur within either the Wisconsin or the Kansan drift.

Some wells have gone into the rock formations below the drift, as along the river north of Fort Dodge, where the "St. Louis limestone" is reached, and farther south along the river near Lehigh, where the coal measures (Des Moines group) have been reached. A few deeper wells in the high-level country have also gone through the whole drift and into the coal measures, where water is obtained either from limestone or sandstone.

DISTRIBUTION.

No distinct water provinces exist in Webster County. Conditions are very similar over the entire county, except along the principal drainage lines where some flowing wells occur, as along Des Moines River near Fort Dodge and along the tributaries of the Des Moines near Lehigh and Dayton. It is thought that the source of water in these flowing wells is at the base of the Kansan, the Wisconsin having generally been stripped along the streams.

SPRINGS.

Springs are uncommon in Webster County, except along drainage lines—the Des Moines and its branches. Several large springs occur along Lizard Creek near Fort Dodge. A mineral spring is utilized at Kalo and many small springs may be found along the larger streams.

CITY AND VILLAGE SUPPLIES.

Dayton.—Dayton (population, 717) pumps its water by gasoline engine from a well about 688 feet deep and distributes it by gravity with a pressure of 45 pounds. There are $1\frac{1}{8}$ miles of mains and 16 fire hydrants; 400 persons use 10,000 gallons daily. The water is hard. The well (Pl. XVI) has a diameter of 10 to 6 inches. The curb is 1,089 feet above sea level and the head 111 feet below the curb. The water, which comes from 570 to 688 feet, is lowered 100 feet by pumping. The well was completed in 1895 by J. H. Shaw, of Sioux City.

Driller's log of well at Dayton.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and yellow clay	25	25
Clay, blue	50	75
Sand, white, and bowlder	5	80
Clay, blue, or shale	25	105
Clay, yellow, or shale	20	125
Clay, blue, or shale	83	208
Coal	3	211
Clay, blue, or shale	24	235
Clay, black, or shale	25	260
Clay, blue, or shale	110	370
Limestone, brown	48	418
Limestone, white	247	665
Limestone, blue	15	680
Limestone, white	8	688

Record of strata in well at Dayton (Pl. XVI, p. 672).

	Thickness.	Depth.
	Feet.	*Feet.*
Quaternary (163 feet thick; top, 1,089 feet above sea level):		
Soil	4	4
Clay, stiff, light gray, calcareous	21	25
Till, blue; 3 samples	50	75
Sand, coarse	8	83
Till, blue	22	105
Till, yellow, and fine gravel	20	125
Till, blue; 3 samples	38	163
Carboniferous:		
Pennsylvanian:		
Des Moines group (207 feet thick; top, 926 feet above sea level):		
Shale, drab, calcareous; 4 samples	45	208
Coal and coaly shale	3	211
Shale, hard, drab	24	235
Shale, dark reddish-brown, nearly black	25	260
Shale, drab	40	300
Shale, black; 4 samples (from 300 to 350 feet)	70	370
Mississippian:		
"St. Louis limestone" and Osage group (155 feet thick; top, 719 feet above sea level):		
Sandstone, light gray, fine grained; in chips	20	390
Limestone, brown, and chert, drab; some chips of black shale from above	28	418
Limestone, light yellow-gray; brisk effervescence; in part oolitic, in part encrinital; 5 samples	107	525
Kinderhook group (163 feet penetrated; top, 564 feet above sea level):		
Dolomite, hard, light brown, crystalline, porous; in sand; 2 samples	30	555
Limestone, magnesian, drab, crystalline; moderately slow effervescence; in thin chips; 3 samples	45	600
Chert, light gray; siliceous oolite, drab; some brown limestone; 3 samples	65	665
Chert, light gray, and brown limestone	15	680
Limestone, gray, cherty; slow effervescence; some fine quartz sand; fine sand	8	688

Fort Dodge.—The water supply of Fort Dodge (population, 15,543) is obtained from a deep well and is distributed by direct pressure and by gravity. The domestic pressure is 100 pounds and the fire pressure 125. There are 20½ miles of mains, 122 fire hydrants, and 1,359 taps. The daily consumption in summer is 1,600,000 gallons and in winter 900,000 to 1,200,000 gallons.

The city well at Fort Dodge (Pls. VI, XVI) has a depth of 1,827½ feet and a diameter of 15 inches to 278 feet, 13½ inches to 328 feet, 12 inches to 499 feet, 10½ inches to 1,056 feet, 8½ inches to 1,390 feet, 6 inches to 1,421 feet, and 5 inches to the bottom of the well. It is cased between 1,036½ and 1,056 feet, 1,332 and 1,390 feet, and 1,375 and 1,438¾ feet. The curb is about 1,011 feet above sea level. A flow from "gravel" at 328 feet was 144 gallons a minute; at 1,497 feet it had increased to 316 gallons a minute; at 1,535 feet it measured 314 gallons a minute; at 1,578 feet it had risen to 484 gallons a minute; and at the completion of the well supplies from still lower beds raised the total amount to 571 gallons a minute. Temperature, about 55° F. The well was completed in 1907, at a cost of $8,000, by the Miller Artesian Well Co., of Chicago.[1]

[1] Since 1908 two additional wells have been drilled for city supply. Well No. 2 has a depth of 670 feet and a diameter of 20 inches at the top and of 13½ inches at the bottom. It is a flowing well and discharges 150 gallons a minute. Well No. 3 is located 1,000 feet from the other wells. It is 215 feet deep, 8 inches in diameter, and flows 600 gallons a minute. The combined flow of the three wells in March, 1912, was reported at more than 1,500,000 gallons in 24 hours.

Record of strata in city well No. 1 at Fort Dodge (Pl. VI, p. 258; Pl. XVI, p. 672).

	Thickness.	Depth.
	Feet.	*Feet.*
No samples		98
Carboniferous (Mississippian) (450 feet thick; top, 913 feet above sea level):		
Limestone, buff; slow effervescence; in sand		98
Sandstone, yellow-gray, calciferous, and argillaceous	10	108
Shale, tough, greenish	20	128
No record	10	138
Limestone, light yellow-gray, in finest meal, residue argillaceous and siliceous; and shale, greenish gray, minutely sandy and limy	10	148
Shale, tough, greenish; 3 samples	30	178
Limestone and shale	10	188
Shale, bluish	10	198
Shale and limestone	10	208
Shale; two samples	20	228
Limestone, oolitic, white or light-yellow, soft; rapid effervescence; 2 samples	20	248
Limestone, minutely arenaceous and pyritiferous	10	258
Limestone; rapid effervescence	10	268
Shale	10	278
Limestone; rapid effervescence; light colored; 3 samples	30	308
Limestone, magnesian	10	318
Limestone, white, crystalline	10	328
Limestone, buff; slow effervescence	10	338
Limestone, yellow, crystalline; rapid effervescence	10	348
Limestone, buff, moderately slow effervescence	10	358
No samples	30	388
Limestone, cherty	10	398
Limestone, buff; moderately slow effervescence	10	408
Limestone, buff, hard, vesicular; considerable calcite; slow effervescence	10	418
Limestone, as above; drab, cherty	10	428
Limestone; rapid effervescence; in large chips	10	438
Limestone, as above; cherty	10	448
Limestone; slow effervescence; cherty	10	458
Limestone; drab; rapid effervescence	10	468
Shale; in concreted powder; light blue-gray; calcareous	10	478
Shale and limestone; shale, green, noncalcareous; limestone, yellow; rapid effervescence	10	488
Dolomite, dark blue-gray; in fine sand	10	498
Dolomite, dark-drab, porous, subcrystalline; in chips	10	508
Limestone, in fine drab sand; slow effervescence; residue pyritiferous, argillaceous, and minutely quartzose	10	518
Shale, greenish-gray; in concreted calcareous powder	10	528
Limestone, blue-gray; slow effervescence; some yellow limestone of rapid effervescence; some chips of calcareous greenish shale	10	538
Shale, hard, green, finely laminated; somewhat calcareous	10	548
Devonian and Silurian (310 feet thick; top, 463 feet above sea level):		
Limestone, buff and light yellow, soft; rapid effervescence; some shale from above	10	558
Limestone; in fine white meal; rapid effervescence	10	568
Limestone, light buff and drab; moderately slow effervescence	10	578
Dolomite, light blue or light yellow gray; in fine sand; at 598 macrocrystalline; highly vesicular; in large chips; 5 samples	50	628
Limestone, blue-gray; rapid effervescence	10	638
Dolomite, hard, compact, subcrystalline, yellow and blue gray; 2 samples; some greenish shale at 648 feet	20	658
Limestone, yellow and gray; rapid effervescence; some greenish shale	10	668
Limestone, buff, compact; slow effervescence; some shale	10	678
Dolomite, blue-gray, compact, subcrystalline; in large chips; some shale	10	688
Dolomite, light and darker blue-gray; 2 samples; in fine sand	20	708
Shale, highly calcareous, in light gray loosely concreted powder; some dolomite	10	718
Shale, as above; light blue	10	728
Dolomite; buff	10	738
Dolomite and shale; dolomite drab, rough; shale, blackish, bituminous, burns with flame	10	748
Dolomite; drab, earthy	10	758
Dolomite; light buff, dense	10	768
Dolomite; drab; considerable blackish shale; 2 samples	20	788
Shale, blue, clayey, and buff dolomite; chips of both rusted on surface to ocher yellow	10	798
Limestone, magnesian, or dolomite; drab, earthy	10	808
Dolomite; drab or buff; mostly in crystalline sand; 5 samples	50	858
Ordovician:		
Maquoketa shale (250 feet thick; top, 153 feet above sea level):		
Shale, blue; in calcareous, concreted powder; 4 samples	40	898
Limestone; rapid effervescence; buff and gray, soft	10	908
Shale and limestone; shale, green, pyritiferous; limestone, light buff, fine crystalline, granular; slow effervescence	10	918
Shale; in highly calcareous, blue-gray concreted powder	10	928
Limestone or dolomite, buff, hard; in sand, some greenish shale, probably from above	10	938
Limestone and shale; limestone, light gray, rather soft, moderately slow effervescence, fine crystalline granular; in sand; shale, in blue powder	10	948

Record of strata in city well No. 1 at Fort Dodge (Pl. XVI)—Continued.

	Thickness.	Depth.
Ordovician—Continued		
Maquoketa shale (250 feet thick; top, 153 feet above sea level—)Continued.		
Shale; in light blue-gray, highly calcareous powder, concreted; 15 samples; some white chert at 958 feet, much white chert at 968 and 988 feet; limestone, gray magnesian at 988 feet, cherty from 1,058 to 1,098 feet	*Feet.* 150	*Feet.* 1,098
Shale, bright green; in chips; chips of white nonmagnesian limestone and white chert	10	1,108
Galena dolomite (170 feet thick; top, 97 feet below sea level)		
Dolomite and chert, light gray	10	1,118
Shale, in gray concreted powder, calcareous	10	1,128
Dolomite, gray; in fine sand, mingled with powder of shale; 2 samples	30	1,158
Shale or marl, in light-yellow concreted powder; highly calcareous; residue cherty and argillaceous	10	1,168
Limestone, gray; in sand; much chert	10	1,178
Dolomite, crystalline, vesicular, yellow-gray and blue-gray; 4 samples	40	1,218
Dolomite, light buff; much white chert	10	1,228
Dolomite, light buff and drab; 2 samples	20	1,248
Dolomite, gray and buff, subcrystalline; much chert; effervescence slow; 3 samples	30	1,278
Platteville limestone (130 feet thick; top, 267 feet below sea level)		
Shale, highly calcareous; in greenish-gray, loosely concreted powder; residue cherty and minutely arenaceous; 5 samples	50	1,328
Dolomite or magnesian limestone; buff; like that at 1,258 feet	10	1,338
Shale, green-gray, calcareous; chips of argillaceous limestone at 1,338 feet; 4 samples	40	1,378
Shale, bright-green, hard, fissile	10	1,388
Shale, dark brown, fissile, bituminous; burning with flame; with limestone of rapid effervescence	10	1,398
Shale, as at 1,378 feet, a few fragments of brown, bituminous shale	10	1,408
St. Peter sandstone (50 feet thick; top, 397 feet below sea level)		
Sandstone, light gray; largest grains 0.8 millimeter diameter	10	1,418
Sandstone, white and light yellow, clean; 4 samples	40	1,458
Prairie du Chien group (310 feet thick; top, 447 feet below sea level)		
Dolomite, gray, hard; some quartz sand; 3 samples	30	1,488
Sandstone, clean, white; grains rounded; 5 samples	50	1,538
Dolomite and oolitic chert and quartz sand	10	1,548
Dolomite and quartz sand; 5 samples	50	1,598
Sandstone	10	1,608
Dolomite, gray, crystalline; arenaceous in chips	10	1,618
Sandstone and dolomite; white fine-grained sandstone; a very little admixture of dolomite; 3 samples	60	1,678
No samples	40	1,718
Dolomite, gray, hard, crystalline; in fine clean sand; 2 samples	20	1,738
Sandstone, white, and dolomite; chiefly quartz sand with a few grains of dolomite	10	1,748
Dolomite, in small chips; with much white quartz sand	10	1,758
Sandstone and dolomite; as at 1,738 feet	10	1,768
Cambrian:		
Jordan sandstone (59 feet penetrated; top, 757 feet below sea level)		
Sandstone, clean, white; 2 samples	20	1,788
Dolomite and chert with sandstone; mostly sand	10	1,798
Sandstone, clean, white; 2 samples	20	1,818
Dolomite and sandstone; dolomite, gray; sandstone, white; drillings chiefly sand	9	1,827

Analyses of drillings from city well at Fort Dodge.[a]

	Depth of samples, in feet.				
	308	628	808	938	1,228
$CaCO_3$	56.35	49.24	47.09	45.48	47.05
$MgCO_3$	39.49	40.01	40.63	31.25	41.26
$CaSO_4$	.11	.92	1.00	....	.67
SiO_2	2.16	1.65	2.01	17.60	7.69
Al_2O_3	.39	7.37	8.54	.96	2.42
Fe_2O_3	.25	.37	.33	1.50	.30
H_2O	.94	.48	.61	3.21	.65
	99.69	100.04	100.21	100.00	100.04

[a] Made in chemical laboratory of Cornell College, Mount Vernon, Iowa.

A flowing well at Fort Dodge has a depth of 127 feet.

Driller's log of Fort Dodge flowing well.

	Thickness.	Depth.
	Feet.	*Feet.*
Black soil, yellow clay, and blue clay	31	31
Limestone	6	37
Shale, blue	27	64
Limestone	6	70
Sandstone, white, and water	2	72
Sandstone, white	40	112
Limestone (no water)	15	127

Gowrie.—Gowrie (population, 829) pumps its public supply from a well 620 feet deep, and distributes it by gravity with a pressure of 40 pounds through one-half mile of mains to 10 fire hydrants and 10 taps. Sixty persons use the water, consuming 15,000 gallons daily. The water is hard.

The well has a diameter of 8 inches to 200 feet and 6 inches to bottom; casing to about 350 feet. The head is 50 feet below the curb and the temperature 45° F. The well was completed in 1902, at a cost of $1,150, by Mattock & Louke, of Jefferson, Iowa.

According to the driller's log, soil, yellow clay, blue clay, and shale prevail to a depth of about 155 feet, limestone from 155 to 315 feet, and water-bearing sandstone from 315 to 620 feet; according to another report, the well is mostly clay and shale to the depth of 200 feet.

WELL DATA.

The following table gives data of typical wells in Webster County:

Typical wells of Webster County.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head above or below curb.	Remarks (logs given in feet).
		Feet.	*Feet.*		*Feet.*	
Charles Daniels	3 miles east-northeast of Lehigh.	235	187	Sandstone	− 55	Black soil, 2; yellow clay, 15; blue clay, 170; blackjack or shale, 30; sandstone, 15; very white sandstone and water, 3.
W. H. Goodrich	4 miles east of Lehigh.	120	112	Sand	+ 15	Flow from drift sand. Black soil, 2; yellow clay, 28; blue clay, 36; sand, 40; blue clay, 3; fine sand and water (flow), 3; limestone, 8.
....	Fort Dodge	127	31	Sandstone	+ 3	Pressure, 12 pounds; water-bed, 72.
County farm	4 miles west-southwest of Fort Dodge.	366	85	Limestone	− 75 to −100	Pumped by gasoline engine. Black soil, 5; yellow clay, 15; blue clay, 65; gypsum, 10; light-colored shale, 11; coal, 4; limestone, 5; shale and limestone alternations, 91; limestone, 59; potter's clay, 2; limestone and water, 99.

Typical wells of Webster County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head above or below curb.	Remarks (logs given in feet.)
		Feet.	*Feet.*		*Feet.*	
A. W. Hawley	2½ miles east-southeast of Pioneer.	227	112	Sandstone	− 40	First water in drift sand at 100 feet. Black soil, yellow clay, blue clay, 100; sand and water, 12; black jack or shale, 114; sandstone and water, 1.
Peter Nelson	3 miles northeast of Vincent.	125	....	Sand	− 50	No rock.
Z. W. Thomas	5 miles southwest-south of Barnum.	219	....	....do	− 40	Do.
J. Mann	8 miles east-northeast of Fort Dodge.	68	....	....do	− 8	Bored well, 12-inch tiling. No rock.
Plymouth Gypsum Co.	1½ miles southeast of Fort Dodge.	54	54	....do	− 12	Bored well to gypsum.
Minneapolis & St. Louis R. R.	Gowrie	625	41	Sandstone	− 60	Steam pump for locomotive. Black soil, 3; yellow clay, 8; blue clay, 30; shale, 70; harder shale, 45; limestone, 160; sandstone and water at bottom, 309.
Town of Dayton	Dayton	688	208	Limestone	−111	Gasoline engine pump (see p. 757).
Chicago & North Western Ry.	....do	68	....	"Soft muck" (?).	+ 2	Flows, used for locomotive. No rock. Yellow clay, blue clay, sand, gravel, 60; clay or soft shale, 7; soft mucky clay or shale and water, 1.

CHAPTER XIII.

SOUTH-CENTRAL DISTRICT.

INTRODUCTION.

By W. H. Norton.

The south-central district embraces the 12 counties of Adair, Appanoose, Clarke, Decatur, Lucas, Madison, Marion, Monroe, Ringgold, Union, Warren, and Wayne. The entire area is underlain by the Pennsylvanian series, the Des Moines group forming the country rock over the eastern counties and the Missouri group that over the larger part of the six western counties.

Deep wells have been drilled at but six points—Centerville (Pl. XVI), Pella (Pl. VIII, p. 352), Flagler, No. 10 Junction, Corydon, and Osceola. Of the first five wells drillings, or at least the drillers' logs, have been preserved; but four of the five are situated along the eastern border of the area, and of the Osceola well nothing is known except the depth. Both geologic structure and artesian conditions are thus left largely to inference. The deeper strata of southern Iowa form a trough whose axis extends from Des Moines to the southwestern counties of the State. In south-central Iowa the water-bearing beds of the early Paleozoic terranes dipping toward this axis reach their maximum depth in the southwestern counties of the district. The surface, moreover, rises toward the west. For these reasons the St. Peter sandstone lies more than 2,000 feet beneath the surface, except along the eastern border. (See Pl. XVI, p. 672.)

The sandstone at the base of the Pennsylvanian series is not persistent in the eastern part of the district, but the meager facts at hand indicate that it thickens to the west. It yields water at Glenwood and at Bedford, in the southwest district of the State.

In the eastern counties, where the cover of the Pennsylvanian is thin and is cut by the major river valleys, the base of the Pennsylvanian is found to vary widely in elevation. This is due not only to local upwarps and downwarps of the strata but also to the strong unconformity that parts the Mississippian series from the Pennsylvanian. The map (fig. 6, p. 898) exhibits the conjectural elevation above sea level of the base of the Pennsylvanian in south-central and southwestern Iowa. The data on which the map is constructed consist of a few drill holes, sunk in search of coal, and deep wells at several points in Iowa and northern Missouri. From Polk County southwest to Bedford the Mississippian descends about 650 feet; from Polk County due south to Chillicothe, Mo., it falls in the aggregate but 250 feet. From Centerville west to Bedford it falls 733 feet; from Bedford west-northwest to Glenwood it rises 140 feet (Pl. XVIII, p. 898); and west to Nebraska City it rises 150 feet. From the map it will be seen that the Mississippian floor forms a shallow trough extending from near Des Moines to the southwest corner of the State. The line of the maximum depth may not coincide with the Des Moines to Bedford axis, although it is necessarily so drawn, as these two points are those of maximum known depth. The sag may also be narrower than represented and be bounded on each side by more level surfaces. In the eastern counties the contours bend somewhat sharply southward, and as shown by the depth to the Mississippian at Chillicothe, Mo., they must bend to the southwest before reaching that town. To the west the contours also extend southward, as shown by the gentle dip of the floor from Lincoln, Nebr., to Glenwood, a dip averaging some 3 feet to the mile. In using the map (fig. 6, p. 898) it should be remembered that the known points are far apart and between them may intervene minor sags and swells entirely unknown. Erosion valleys cut into the Mississippian before the Pennsylvanian was deposited may lower the floor in places 100 or 200 feet below the estimate.

In southeastern Iowa the Mississippian series, especially the white limestone of the Burlington and the sandstones in the "St. Louis limestone," are aquifers of local value, but although these beds continue under this area they yield small and uncertain supplies. A sandstone of Silurian age is known to occur at Pella and at Centerville, and sandstones apparently too high for the St. Peter and probably to be placed in the Silurian are reported at Ottumwa, Bloomfield, and No. 10 Junction in Monroe County. How far west these sandstones may extend is altogether problematic; but the Silurian continues to be a water bearer by means of its limestones beyond the western limits of the district. The heavy magnesian limestones assigned, because of their anhydrite beds, to the Salina(?) formation of the Silurian yield water at both Bedford and Glenwood, and will probably also yield water in this area at depths nowhere exceeding 1,000 to 1,100 feet below sea level. The water at Bedford, however, is so highly mineralized that it is worthless.

Soon after well No. 3 at Centerville was drilled in 1904 its water contained 1,228 parts of solids, but the solids regularly increased to 2,545 parts in 1908, probably due to the deterioration of the casing and the entrance of the upper harder waters. Well No. 2 reaches only into the Silurian and, according to the analysis by Dr. J. B.

Weems, contains a very much larger amount of mineral matter than the other Centerville well.

The Maquoketa shale may not extend far into the south-central district, and probably to the south and west the Silurian and Galena merge into an unbroken series of magnesian limestones. These limestones should be water bearing, but at what particular levels can not be predicted, nor is it certain that any given well will find a water-bearing crevice. Moreover, the quality of the water is unknown, but very probably, in the western part of the area at least, it is too highly mineralized for an acceptable city supply.

In the eastern counties the St. Peter and the water beds subjacent are to be reckoned as dependable artesian assets, and here artesian wells can be recommended, though the water is as a rule highly mineralized. The failure of the deep city well at Pella (Pl. XIII, p. 526) to secure potable water has had a discouraging effect in its own and adjacent counties—an effect not wholly counteracted by the successful wells at Bloomfield and Centerville (Pl. XVI, p. 672). The Pella well was sunk only about 60 feet below the St. Peter. The mineralized waters of the higher formations were first cased out, but as the supply from the St. Peter proved insufficient, the casing was pulled and all waters allowed to mingle. No analysis was made of the St. Peter water while it alone was admitted to the well. Had the casing been retained and the well drilled a few hundred feet deeper, an abundant supply of good water would probably have been obtained, as at Ottumwa (Pl. X, p. 374).

Except in the eastern tier of counties the depth to the St. Peter and the water beds below it is so great that the sinking of deep wells to these deeper formations is not recommended. Nowhere south and west of Des Moines have these deep terranes been reached by the drill.[1] At Chillicothe, Mo., almost due south of Des Moines and a little more than 50 miles beyond the State line, a deep well found at 250 feet below sea level a sandstone referred by Shepard to the St. Peter,[2] the overlying Ordovician and the Silurian being supposedly absent. If this reference is correct—and it is corroborated by the rise of the sandstone southward from Chillicothe to outcrops near Missouri River—there may be a gentle rise of the St. Peter from Polk and Warren counties due south as well as southeast. As the Chillicothe section is made up from a driller's log, it is possible that the sandstone in question is the Silurian sandstone found at Centerville and elsewhere in southeastern Iowa. In this case there is still a rise of the strata southward from Des Moines, but one much more gentle. To the west the first accurate data obtainable as to the St. Peter are

[1] A deep boring at Nebraska City, Nebr., reached the St. Peter sandstone in 1912 at a depth of 2,783 feet below the surface, or of 1,853 feet below sea level.

[2] Underground waters of Missouri: Water-Supply Paper U. S. Geol. Survey No. 195, 1907, p. 67.

from the deep well at Lincoln, Nebr., where the St. Peter was reached at 127 feet below sea level. The wells at Council Bluffs, Glenwood, and Bedford, as well as those of Forest City and Burlington Junction, Mo., all fail of reaching this terrane. The drill hole at Nebraska City, Nebr., reached the summit of the Decorah shale at 1,824 feet below sea level and the St. Peter was reached at a depth of 1,853 feet below that level. These facts point to a wide trough in the older Paleozoic rocks, whose axis extends southwest from Des Moines to the southwestern counties of the State. The descent of the axis is probably very gentle, being much less than the southwestern dip of the strata of northeastern Iowa, unless the strata below the Pennsylvanian thicken toward the southwest. From the axis the rise of the strata to the east is exceedingly gentle; to the west and north it seems considerably steeper. The hypothetical elevation of the St. Peter is seen in the map (Pl. III), which is based on several assumptions—that the St. Peter descends from Des Moines to the southwest as other terranes are known to do as far as Forest City, Mo.; that it descends from Glenwood eastward, as other terranes are found to do as far as Bedford (Pl. XVIII, p. 898); that the upwarp of the strata seen at Chillicothe, Mo., deflects the contours somewhat to the southwest in the southern counties of the district; that along the axis of the trough the strata between the base of the Mississippian and the St. Peter maintain and somewhat increase the thickness which they show at Des Moines.

The table below shows the elevation above sea level of the chief towns of the district, and the estimated depths to the base of the Pennsylvanian and that to the top of the St. Peter. These estimates are not so accurate as those made for the eastern and northern parts of Iowa, but even if they are as much as 300 feet in error, they will serve to indicate in a general way the depth to which wells must be sunk to reach these horizons. Another unfavorable condition is the high altitude of towns along the divide between the Missouri and the Mississippi, on account of which the water will stand low in the wells.

Artesian estimates for towns in the south-central district of Iowa.

Town.	Elevation above sea level.	Hypothetical depth—	
		To base of Pennsylvanian.	To top of St. Peter.
	Feet.	*Feet.*	*Feet.*
Albia	959	....	1,700
Chariton	1,042	575	2,100
Corydon	1,105	750	2,050
Creston	1,312	1,225	2,900
Greenfield	1,368	1,150	2,650
Indianola	976	450	2,175
Knoxville	909	....	1,850
Leon	1,019	820	2,325
Osceola	1,137	875	2,550

ADAIR COUNTY.

By Howard E. Simpson.

TOPOGRAPHY.

Adair County is in the south-central district of the State. Its surface is a high, slightly rolling drift plain, across which runs the "great divide." The crest of the divide passes southeastward through Adair. North of Greenfield it divides and a secondary branch goes southward beyond the State line. West of this branch the drainage is southward to the Missouri through tributaries of the Nodaway. The drainage of the small triangle between the two branches passes southeastward to Grand River, another tributary of the Missouri. The northeast third of the county is drained into the Mississippi through Middle and North rivers, tributaries of the Des Moines. The county contains no ponds or undrained areas.

GEOLOGY.

Loess mantles the uplands of the entire county, in the eastern part with the fine, light, clayey type typical of southern Iowa, and in the western part with the darker, less clayey kind, characteristic of the Missouri Valley. The Kansan drift thickly covers the area, and well sections in many parts of the county indicate that heavy beds of Nebraskan drift are general. The drift is very thick, especially in the western half of the county.

The Dakota sandstone underlies the drift in the western third of the county, and is in turn underlain by Carboniferous rocks (Missouri group). The Missouri group, which lies beneath the drift in the eastern two-thirds of the county, comprises heavy limestones, interbedded with thin, light shales.

UNDERGROUND WATER.

SOURCE AND DISTRIBUTION.

Few wells in the county fail to obtain water from the drift. In many places sandy beds are found beneath the loess, beneath the Kansan, and beneath the lowest drift sheet, and as a rule all of these are water bearing. Many shallow wells rely entirely on seepage from the loess, but such wells are likely to fail in dry seasons. On the uplands the entire drift yields so scantily that many stock farms resort to ponded rain water.

All wells passing through the drift into the soft, porous Dakota sandstone find, at depths ranging from 150 to 300 feet, an abundant supply of good water that rises within 100 to 230 feet of the surface. Neither dry holes nor undesirable water have been reported. In the area underlain by the limestones of the Missouri group the drift is a little thinner. The wells in that part of the county range in depths from 100 to 250 feet, and the water is invariably hard. No deep wells have been bored in this county.

The southeastern portion of the county is the most favored in the matter of ground water. Bored wells, ranging from 20 to 50 feet, are common, and a few are much deeper. Drilled wells obtain excellent water from the Dakota sandstone at depths ranging from 200 to 300 feet.

SPRINGS.

The sandy layers of the drift supply water to seepage springs, but few such springs yield sufficient water for a stock farm. A few stronger springs, whose waters may come from the Dakota sandstone on the adjacent divide, are reported in the southwestern part of the county along the valley sides of the East Nodaway and its tributaries.

CITY AND VILLAGE SUPPLIES.

Adair.—Adair (population, 900) is situated on the crest of the Mississippi-Missouri divide, a region where the drift is so thick that it is difficult to obtain a satisfactory supply of water. An unsuccessful well was sunk by the city to a depth of several hundred feet, but unfortunately no complete record exists.

Most of the residents are supplied with water by wells dug or bored into the loess or by cisterns. Five cisterns, with a capacity of 200 to 350 barrels each, a gasoline fire engine, and 900 feet of hose furnish the fire protection for the city.

Greenfield.—In Greenfield (population, 1,379) drift wells 30 to 60 feet in depth afford the general supply. A public supply used for drinking and for fire protection is obtained from 30 dug wells 8 feet in diameter. A city well drilled some years ago into limestone of the Missouri group to obtain boiler water for the electric-light plant was abandoned because the water contained so much sulphate of lime and magnesia that it was unfit for the purpose. The well was 221 feet deep and was sunk 13 feet into the limestone. The water rose within 75 feet of the surface. The strength of this well suggests a supply from the lower drift rather than from the limestone. Since abandoning this well the lighting plant has used storm water collected in an artificial surface reservoir.

A well on the farm of W. W. Whittams, 1½ miles west of Greenfield, was abandoned at a depth of 274 feet, the last 34 feet of which was in limestone of the Missouri group; the well was quickly pumped dry.

WELL DATA.

The following table gives data of typical wells in Adair County:

Typical wells in Adair County.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head below curb.	Remarks.
T. 74 N., R. 33 W. (WASHINGTON).		*Feet.*	*Feet.*		*Feet.*	
J. A. Hulbert	4½ miles southeast of Bridgewater.	286	276	Sandstone (Dakota).	100	Strong; slightly mineral.
T. 76 N., R. 32 W. (PRUSSIA).						
John Montgomery	1¾ miles southwest of Canby.	187	180	....do	127	Hard; roily before storms.
T. 77 N., R. 33 W. (SUMMIT).						
William Turner	1½ miles west of Adair	345	307	Fine sandstone.	230	
T. 75 N., R. 32 W. (SUMMERSET).						
W. W. Whittams	1½ miles west of Greenfield.	274	240	Limestone (Missouri).	137	Scanty supply; abandoned.
Henry Hida	3 miles south of Fontanelle.	316	300	Sandstone (Dakota).	146	Slightly mineral.
John Mangle	2 miles west of Fontanelle.	315	299	....do	125	
H. W. Adams	NW. ¼ sec. 21	254	240	Limestone (Missouri).	75	Hard water; strong well.
T. 76 N., R. 33 W. (EUREKA).						
Frank H. Seers	6 miles northwest of Fontanelle.	282	260	Sandstone (Dakota).	......	Strong well.
T. 75 N., R. 33 W. (JACKSON).						
Truman Lewis	5 miles north of Bridgewater.	317	300	....do	120	Strong well.
Henry Rose	2 miles north of Bridgewater.	286	270	Limestone	176	Fine hard.
Al. Bowers	3 miles north of Bridgewater.	270	260	Sandstone	160	
T. 75 N., R. 31 W. (GREENFIELD).						
City of Greenfield	Electric-light plant	221	208	Drift and limestone (Missouri).	75	Strong well.
T. 77 N., R. 30 W. (LINCOLN).						
G. D. Whittams	Sec. 19	148	136	Sandstone (Dakota).	108	Soft water; strong well; 20 gallons per minute.
W. H. Barnett	SE. ¼ sec. 23	78	......	Drift sand	......	Plenty; good.
T. 76 N., R. 30 W. (HARRISON).						
William Wallace	SE. ¼ sec. 23	135	56	Limestone (Missouri).	......	No water.
David Johnson	NE. ¼ sec. 19	82	36	....do	78	Good hard water.
T. 76 N., R. 31 W. (GROVE).						
Harriet Guthiel	NE. ¼ sec. 14	134	122	....do	......	Abundant from black shale; bad taste.
Nate Brinton	SE. ¼ sec. 12	200	......	Gravel	......	Insufficient; abandoned.

APPANOOSE COUNTY.

By O. E. Meinzer and W. H. Norton.

TOPOGRAPHY.

The surface of Appanoose County consists essentially of a much-eroded drift plain sloping very gently toward the east. Chariton River, the principal stream, enters at the northwest corner and flows southeastward diagonally across the county in a flat-bottomed valley approximately 150 feet deep and several miles in maximum width. From the west it receives a number of relatively long tributaries, all of which, with their branches, have cut into the upland plain, but from the east it is fed by very short streams, the divide that separates its drainage system from that of Soap Creek and Fox River being only a few miles east of the Chariton. Apparently the minor streams tend to flow in the direction of the general upland slope.

GEOLOGY.

The following formations are exposed within the county: (1) Alluvium, which is confined to the principal valleys; (2) loess, which is only a few feet thick, but which lies at the surface over much of the region; (3) glacial drift, which is generally found at the surface or immediately below the loess; and (4) Carboniferous rocks belonging to the Des Moines group of the Pennsylvanian series, which crop out at many points along the principal streams.

In a large part of the county the drift sheet is thin, but in places, especially near the east margin, it is more than 100 feet thick. The irregularities of the rock surface produce many corresponding local irregularities in the thickness of the overlying drift. The glacial material is reported to contain a large amount of wood, leaves, and shells. The Pennsylvanian is several hundred feet thick and consists of shale with minor amounts of limestone, sandstone, and coal. Below it lie the rocks of the Mississippian series, which consist chiefly of limestone. (See Pls. X, p. 374; XVI, p. 672.)

UNDERGROUND WATER.

SOURCE.

The rocks of the Pennsylvanian series furnish water to a few wells, but in general they are unsatisfactory as a source of water. They consist chiefly of impervious shale with porous beds few and far apart, and therefore yield meagerly; also their water is undesirable for many purposes, because of its high mineralization. Below the Pennsylvanian are formations that yield more freely, but the cost of drilling to these is so great that it can be undertaken only by municipalities or by railway companies or other large industrial concerns, and as far as exploration has gone the water is so high in different dissolved solids that it is ill adapted for use in boilers and is not desirable for public supplies. Moreover, its head is so low that in many places it would have to be lifted several hundred feet to bring it to the upland surface.

In some of the largest valleys the alluvial materials yield abundant and reliable supplies of only moderately hard water to shallow and inexpensive dug or driven wells, but many of the settlements and a vast majority of the farms are remote from valleys, and their principal underground source of supply consists of irregularly distributed sandy and gravelly deposits associated with the bowlder clay. Whether these yield a sufficient amount is very much a matter of hit and miss. In some localities gravel beds occur that will furnish enough for waterworks and locomotive supplies; in others it proves difficult to extract enough water from the drift to meet the consumption on an ordinary stock farm, and in years of severe drought the lack of water for household and stock purposes may become an acute problem. The shallow water is rich in calcium and the bicarbonate radicle, but is usually superior to the water from the Pennsylvanian or deeper formations for both domestic and boiler use.

One of the largest supplies secured from glacial material is that of the Chicago, Rock Island & Pacific Railway Co. at Centerville. The well is situated on the upland, which is trenched, at no great distance from the well, by deep ravines that lead to tributaries of Chariton River a few miles away and at a level 150 feet lower. The well was dug to a depth of about 37 feet and ends in a bed of sand, from which about 3,500 gallons of water an hour are obtained.

Because of the unsatisfactory status of underground sources, Appanoose County has come to depend to a great extent on surface water for household, stock, and boiler supplies. For the household, rain water is stored in cisterns; for stock, the wash from rains is collected by constructing dams across ravines; and for boiler feed, different plans are employed, as, for example, the reservoir of the Chicago, Milwaukee & St. Paul Railway Co. at Mystic, into which surface and spring waters are gathered. In resorting to surface supplies, quality is the chief consideration for the household, soft water being desired; quantity is the chief consideration for live-stock supplies; and both quality and quantity are factors in railway and other industrial enterprises.

In the many villages of Appanoose County the water for drinking is drawn mainly from shallow private wells in close proximity to a variety of contaminating agencies. The situation is especially bad in valley towns, where shallow wells on the bottom lands at the foot of populated slopes are peculiarly exposed to pollution. It is not easy, however, to find a feasible means of improving the conditions.

Something would be gained if each householder would protect his own well, but a really adequate remedy requires a system of waterworks drawing from a source safe from pollution. In spite of difficulties it is probable that systematic search will discover a sufficient sanitary and otherwise satisfactory source of public supplies for most of the villages.

CITY AND VILLAGE SUPPLIES.

Centerville.—Information concerning the three deep wells that have been sunk in Centerville (population, 6,936) is presented in the following paragraphs:

City well No. 1 is 2,495 feet deep. Its diameter is 12 inches to 55 feet, 10 inches to 95 feet, 9 inches to 155 feet, 8 inches to 335 feet, 7 inches to 492 feet, 6 inches to 616 feet, 5 inches to 2,335 feet, and 4 inches to bottom of well. It is cased to 804 feet. Its curb is 1,017 feet above sea level, and its head 260 feet below the curb. It obtains water at 1,200 and 2,450 feet. Tested capacity at completion, 200 gallons a minute. It was completed earlier than 1893 by J. P. Miller & Co., Chicago.

The strata penetrated are indicated in the following table:

Record of strata in deep well No. 1 at Centerville (Pl. X, p. 374; Pl. XVI, p. 672).

	Thickness.	Depth.
	Feet.	*Feet.*
Quaternary (top, 1,017 feet above sea level)	90	90
Carboniferous:		
Pennsylvanian (436 feet thick; top, 927 feet above sea level):		
Shales	67	157
Coal and coaly shale	1	158
Shale, with a few thin seams of limestone, none more than 5 feet thick; sample of calcareous shale at 500	368	526
Mississippian:		
"St. Louis limestone" and Osage group (515 feet thick; top, 491 feet above sea level):		
"Rock;" probably limestone	34	560
Shales, variegated, arenaceous toward bottom	50	610
Limestone, rough, gray, siliceous; 2 samples	30	640
Shales, seleniferous, with some limestone and chalcedony; 7 samples	65	705
Limestone, nonmagnesian, blue gray, highly cherty; shale, arenaceous; in concreted powder; 4 samples	55	760
Shales, cherty; limestone; 4 samples	55	815
Limestone, white; rapid effervescence; much white flint and chalcedony; 3 samples	40	855
Limestone and shale; limestone, brisk effervescence, soft, white, dark, brown, blue gray, in places clayey, siliceous, and pyritiferous; shales, in places arenaceous; shale marked at 855, 895, and 915; 18 samples, in concreted powder	186	1,041
Kinderhook group (59 feet thick; top, 24 feet below sea level):		
Shale, blue and green gray; 6 samples	59	1,100
Devonian (260 feet thick; top, 83 feet below sea level):		
Shale, with white and gray nonmagnesian, soft, limestone; 6 samples	60	1,160
Limestone, gray, rather soft; rapid effervescence	8	1,168
Shale, arenaceous	21	1,189
Limestone, gray, rapid effervescence; siliceous; water bearing	11	1,200
Shale; arenaceous at 1,210 feet	20	1,220
Limestone, argillaceous	10	1,230
Limestone, light gray, argillaceous; brisk effervescence	10	1,240
Limestone, compact, fine grained, light blue gray	20	1,260
Shale, calcareous; or limestone, argillaceous, light yellow	10	1,270
Limestone, hard, somewhat argillaceous, light yellow	10	1,280
Limestone, white (some gray), compact, moderately hard, nonmagnesian; much shale in flakes	20	1,300
Limestone and shale, in gray concreted powder; limestone, yellow and gray, crystalline, soft, in fine meal; nonmagnesian; cherty residue; at 1,350 residue of fine, rounded quartz grains; 6 samples	60	1,360

Record of strata in deep well No. 1 at Centerville—Continued.

	Thickness.	Depth.
Silurian (180 feet thick; top, 343 feet below sea level):	*Feet.*	*Feet.*
Limestone, buff, magnesian; argillaceous at 1.360 feet; 2 samples	20	1,380
Shale, blue, and limestone; in concreted powder	10	1,390
Limestone, soft, blue, nonmagnesian, with some white chert and much shale	10	1,400
Limestone, blue gray, hard, compact, fine grained, nonmagnesian	10	1,410
Limestone and shale, blue, calcareous, in light gray powder and meal	20	1,430
Sandstone; grains fine and only fairly well rounded; many pointed with secondary enlargements; in fine powder containing also particles of light-colored limestone	10	1,440
Sandstone, light gray, calciferous; as above	10	1,450
Sandstone, buff, calciferous	10	1,460
Sandstone, white, fine; grains fairly uniform in size and well rounded, mostly smooth, but many show crystalline secondary enlargements, giving the sand a sparkling appearance	10	1,470
Sandstone, calciferous, with some fragments of blue shale in drillings	10	1,480
Limestone, in gray meal; moderate effervescence; highly siliceous with rounded quartz grains and chips of chert; 4 samples	60	1,540
Ordovician:		
Galena dolomite and Platteville limestone, 200 feet thick; top, 523 feet below sea level:		
Dolomite or magnesian limestone, buff and gray; many drillings have cherty and arenaceous residues	160	1,700
Limestone, dark and light gray; moderate effervescence; much green shale in drillings	20	1,720
Limestone, buff; moderate effervescence	10	1,730
Shale, blue, soft, unctuous, noncalcareous	10	1,740
St. Peter sandstone, 40 feet thick; top, 723 feet below sea level:		
Sandstone; white, clean, quartz sand; rounded grains, moderately fine; 4 samples	40	1,780
Prairie du Chien group (715 feet penetrated; top, 763 feet below sea level):		
Shakopee dolomite:		
Dolomite, buff and gray; arenaceous at 1,820 feet; 6 samples	110	1,890
New Richmond sandstone:		
Sandstone and dolomite, light gray and white; drillings consist of rounded grains of quartz and angular chips of dolomite; 8 samples	105	1,995
Sandstone, light yellow gray, in fine angular grains; a little white dolomite and green shale in drillings	65	2,060
No samples	65	2,125
Oneota dolomite:		
Dolomite, light gray and white, highly cherty from 2,140 to 2,185 feet; somewhat arenaceous at 2,125 and 2,240 feet; 9 samples	135	2,260
No samples	92	2,352
Sandstone, calciferous, or dolomite; arenaceous; grains rounded, smooth, of moderate size; chips of hard gray dolomite	....	2,352
No samples	68	2,420
Dolomite, gray; buff at 2,455 feet; somewhat arenaceous from 2,440 to 2,465 feet	75	2,495

This well was drilled in the public square of the town long before waterworks were installed, and was never pumped except at the driller's test. When waterworks were built it was thought best to drill another well in a convenient location rather than to erect the pumping station in the public square.

City well No. 2 is 1,540 feet deep. Its diameter is 10 inches to 368 feet, 8⅝ inches to 480 feet, 7¼ inches to 630 feet, 6¼ inches to 826 feet, 5 inches to 1,160 feet. Uncased from 1,160 feet to bottom of well. The curb is 1,017 feet above sea level; and the head is 280 feet below the curb. Water is obtained from 1,439 feet to bottom; tested capacity, 350 gallons a minute. The well was drilled in 1895 by J. P. Miller & Co., of Chicago.

The driller reported a sand rock extending from 1,470 to 1,510 feet and yielding water that rose within 60 feet of the surface; beneath the sand rock the drill passed into a fissured rock, and the water sank to 280 feet below the curb, and the drillings were washed away.

City well No. 3 is 2,054 feet deep. Its diameter is 16 inches to 73.25 feet; 12 inches to 180 feet, 10 inches to 500 feet, 8 inches to 733.25 feet, 6-inches to 118.15 feet, $4\frac{7}{8}$ inches (uncased) to bottom. The curb is 1,017 feet above sea level, and the head 286 feet below curb. The tested capacity is 200 gallons a minute. The well was drilled by L. Wilson & Co. of Chicago and was completed in 1904, at a cost of $10,000.

The casing of this well is admirably designed to keep out the upper waters. The 10-inch pipe extends to the curb, and it and all other piping of smaller diameters are sealed at bottom with lead.

Driller's log of well No. 3 at Centerville.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, yellow	50	50
Clay, blue	10	60
Gravel	10	70
Cap rock	4	74
Soapstone and shale	51	125
Shale of different colors	25	150
Shale streaked with rock	9	159
No record	6	165
Coal blossom	5	170
Shale, at		185
Soapstone, at		200
No record	60	260
Soapstone with some sand	20	280
No record	13	293
Soapstone and shale	47	340
No record	21	361
Shale, at 361, 380, 425, 450, 475, 500, and		585
Sand, white	15	600
Shale	30	630
Rock and shale, shale caving badly	20	650
Shale, blue, hard	30	745
Limestone and shale, at		790
Limestone, at		830
Limestone and shale, at 860, 900, 925, 950, 980, 1,015, and		1,127
Solid limestone; traces of natural gas in black rock at 1,190 feet	213	1,340
Shale, blue	100	1,440
Limestone	10	1,450
Sandstone	46	1,496
Limestone	256	1,752
Sandstone	40	1,792
Limestone	108	1,900
Streaks of sand and limestone	50	1,950
Sand	100	2,050

The water is lifted from this well into a surface reservoir and thence pumped into a standpipe from which it is distributed, by gravity pressure, through $8\frac{1}{4}$ miles of mains to 74 fire hydrants and 352 service pipes. It is estimated that about one-fifth of the homes are connected with the waterworks and that an average of 63,000 gallons of water is consumed daily.

The chief disadvantage of the water of well No. 3 is its heavy mineralization. The water, as shown by analysis (p. 174), is so hard that it is undesirable for toilet, laundry, or boiler uses; its iron content discolors vessels in which it is used; and it is so salty that it is somewhat unpalatable. If, as seems not improbable, enough water can in years of normal rainfall be obtained from a system of wells or infiltration galleries in the drift gravels known to exist in the vicinity of the city, this source would be preferable to a deep well, as the water is better and would probably be much more extensively used by the people. The pumping lift would also be much less. The deep well could be held in reserve to furnish a supplemental supply when needed. A third possible source of water for Centerville is filtered water from Chariton River.

Moulton.—The Electric Light Co. well at Moulton has a depth of 538 feet and a diameter of 6 to 3½ inches. It is cased to 498 feet. The curb is 987 feet above sea level, and the head is 230 feet below the curb. It yields 16 gallons of highly mineralized water a minute from 40 feet of hard white sandstone at 530 feet depth. It was completed in 1905 by F. D. Tuttle, of Cedar Rapids.

Driller's log of well at Moulton.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay	100	100
Sand, fine, at	....	100
No record	300	400
Shale, dark, sticky	63	463
Limestone	24	487
Sand, white, fine	43	530
Limestone	2	532

CLARKE COUNTY.

By Howard E. Simpson.

TOPOGRAPHY AND GEOLOGY.

Clarke County is in the south-central portion of the State, on the divide between Mississippi and Missouri rivers. The crest of the divide has here an easterly trend and pitch, so that though the drainage of the northern slope is toward Des Moines River and that of the southern slope toward the Missouri, the drainage of the main eastern slope is divided between the two. The area is primarily a drift plain into which the stream valleys have been carved, and all parts of it are well drained by open valleys separated by broad flat-topped uplands.

The entire surface is mantled with loess and Kansan drift which, in many places, is 100 to 150 feet thick.

Throughout the county the drift rests on Carboniferous rocks, for the most part belonging to the Missouri group and consisting of limestone, shales, and some thin coal seams. The Missouri group thins eastward and is absent in the valleys of some of the larger creeks on the eastern and northern borders of the county, thus bringing the rocks of the Des Moines group directly beneath the drift. The Des Moines group consists chiefly of shales and sandstones with some limestone and beds of coal and is the productive coal formation in the State. Though well-marked local dips occur, the strata are in general practically horizontal.

UNDERGROUND WATER.

SOURCE.

The water supply of Clarke County is obtained chiefly from shallow wells in the drift, which are in general satisfactory for domestic and stock use but are inadequate for public supplies.

Two important water horizons occur in the drift, one in the sand immediately underlying the loess, locally known as first sheet water, and the other in the sand and gravel beneath the Kansan, locally known as second sheet water. In some localities other water-bearing sands and gravels are found higher within the drift, but the water is likely to be so polluted with decaying vegetable matter as to have a disagreeable taste and odor.

On the lower ground in the county water is obtained as a rule from shallow wells dug and bored to the first horizon, though many of the stock-farm wells reach the second. On upland divides the water from the first horizon, though fairly satisfactory in quality, often fails in dry seasons, owing to the general lowering of the ground-water level. The depth at which it is reached ranges from 10 to 40 feet, depending on the thickness of the loess. Where sufficient water is not obtained from the subloessial sand, wells are bored or drilled to the sand and gravel just beneath the drift, which horizon may be within 50 feet of the surface or may not be within 250 feet; the supply, however, seldom fails.

Water from this deeper sand and gravel is obtained on the farm of Adam C. Rarick (SE. ¼ sec. 18, T. 72 N., R. 26 W.) from a well 163 feet deep, in which the water level is but 16 feet below the surface. The water is hard and slightly mineral.

Local failures to find water in the drift have resulted in the sinking of a few wells into the bedrock. Those reported range in depth from 250 to 300 feet, and probably draw supplies from the limestone of the Missouri group. The water is said to be very satisfactory for stock, but the data are insufficient to warrant very definite conclusions as to the general value of this limestone as an aquifer. From evidence obtained in the surrounding counties, however, it is known to be generally unsatisfactory on account of hardness of the water and its meager quantity. One of the deepest and best wells of this type is that of Louis A. Brown, 3 miles northeast of Murray (SE. ¼ sec. 35, T. 73 N., R. 27 W.). This well is 298 feet deep, enters rock at a depth of 189 feet, and draws its chief supply from the limestone of the Missouri group at a depth of 260 feet. The water is hard and stands 80 feet from the surface. R. Arnold, 7 miles southwest of Murray, failing to find a satisfactory supply of water by digging 90 feet, drilled 340 feet to water; and John Diehl, 4½ miles northeast of Osceola, drilled 320 feet to find water. Drilled wells are more common in the west-central part of the county.

SPRINGS.

In the more hilly portions of the county many good stock springs are found on steeper slopes, where the sand and gravel layers of the drift outcrop. Shallow wells dug on hillsides tap similar strata and are made to flow into cattle troughs by means of pipes let into the lower side a few feet below the surface. For a fuller discussion see Lucas County (pp 786–787).

CITY AND VILLAGE SUPPLIES.

Murray.—Murray (population, 796) has no public system of water supply. Fire protection is afforded by a half dozen open wells 30 feet deep, pumped by hand.

Osceola.—The public supply of Osceola (population, 2,416) is secured from an artificial reservoir, 2.72 acres in area, which collects the surface drainage of 280 acres of pasture land. A triplex pump (capacity 250 gallons a minute) raises the water from the intake well to a 60,000-gallon tank elevated on a 90-foot tower. The water is distributed by gravity through about 4 miles of mains to 27 fire hydrants and 50 taps. In case of fire direct pressure of 120 pounds may be applied by pumping. The average consumption is 10,000 gallons daily, sold at rates ranging from 35 to 20 cents a thousand gallons, according to the amount used. The Osceola Light, Heat & Power Co., which pumps the water, finds it satisfactory for use in boilers. It is customary to treat it with a small quantity of kerosene. The city system is connected with the Chicago, Burlington & Quincy Railroad tank, so that in case of emergency either system may supply the other.

Sediment is removed from the water by a mechanical filter. The supply is sufficient to meet all demands and is fairly satisfactory.

Unfortunately information regarding the underground-water supply of this county is exceedingly meager. A well is said to have been sunk at Osceola to a depth of 1,953 feet, diameter 8 to 4 inches; but no further information was obtainable.

WELL DATA.

The following table gives data of typical wells in Clarke County:

Typical wells in Clarke County.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head below curb.	Remarks.
		Feet.	*Feet.*		*Feet.*	
A. C. Rarick	SE. ¼ sec. 18, T. 72 N., R. 26 W.	163	....	Drift sand	16	Hard and slightly mineral.
William Beebe	SE. ¼ sec. 29, T. 71 N., R. 27 W.	250	250	Sand above bed rock.	100	
L. A. Brown	SE. ¼ sec. 35, T. 73 N., R. 27 W.	298	189	Limestone	80	Water bed at 260 feet.

DECATUR COUNTY.

By O. E. Meinzer and W. H. Norton.

TOPOGRAPHY.

The upland level in Decatur County lies 1,100 to 1,200 feet above sea level, and is cut by numerous southward-trending stream valleys into parallel ridges and trenches that must be crossed by east-west railways and wagon roads. The principal stream, Grand River, occupies a broad flat-bottomed valley 200 feet below the flat-topped ridges and plateaus.

GEOLOGY.

Beneath the uplands and, to some extent, beneath the valley sides, is a thin but widespread deposit consisting of loess and a related gray-blue plastic clay, in some places partly oxidized to yellow. This plastic clay is nearly free from grit but includes locally some tiny pebbles, as can be seen in the railway cut at Lamoni. In fineness of grain and imperviousness to water it differs sufficiently from the typical loess to influence profoundly the agricultural value of the land. Over the wide flood plains of the principal streams the surface formation consists of alluvium.

Next below the loess and clay, or in many localities lying at the surface, is an accumulation of bowlder clay with minor amounts of sand and gravel. The bowlder clay is weathered and yellow at the top, but is darker, more compact, and quite unweathered at some distance below the surface. The upper part is Kansan in age, but there is reason to believe [1] that the basal deposits belong to an older drift

[1] Bain, H. F., Geology of Decatur County: Ann. Rept. Iowa Geol. Survey, vol. 8, 1898, pp. 283–292.

sheet. Beneath the uplands the average thickness of the drift and associated material is probably not far from 200 feet, but in many places the streams have cut through to the bedrock.

The rocks upon which the drift rests belong to the Pennsylvanian series of the Carboniferous. Throughout most of the area the upper rock is predominantly limestone, well exposed in a quarry 1½ miles southwest of Davis City; it marks the base of the Missouri group of the Pennsylvanian and overlies the Des Moines group of the same series. The latter consists of several hundred feet of strata that are predominantly shale, though they include numerous thin beds of sandstone, limestone, and coal, with heavy beds of sandstone near the bottom. Shales belonging to the Des Moines group outcrop in the valleys in the southern part of the county. The sandstone near the bottom of the Des Moines group is shown in the lower part of the section of the Biggs or Hazelett well (p. 783). Its occurrence is noteworthy, as no sandstone corresponding to it has been reported in the counties directly east. A higher bed was penetrated in the Sharp boring at Leon.

Section of Sharp prospect hole at Leon, in the NW. ¼ NE. ¼ sec. 32 T. 69 N., R. 25 W.[a]

[Altitude of surface, about 1,050 feet.]

	Thickness.	Depth.
	Feet.	*Feet.*
Bowlder clay	23	23
Sand (dry)	3	26
Glacial drift	274	300
Sand (with water)	5	305
Shale	34	339
Limestone or calcareous shale	2	341
Shale	41	382
Sandstone, fine grained	7	389
Shale	19	408
Limestone	½	408½
Coal	1 7/12	410
Shale	20½	430½
Coal	1 1/12	431½
Shale	14	445½
Limestone	¾	446
Shale	2	448
Coal	2	450
Shale	22⅔	473
Coal	1½	474½
Shale	2½	477
Limestone	⅔	478
Shale	4½	482½
Coal	2¾	485
Shale	8 11/12	494
Limestone	¾	494½
Shale	6	500½
Coal	1 7/12	502
Shale	7½	509½
Sandstone	4¼	514
Shale	4	518
Coal	1½	519½
Shale	2	521½
Coal	1⅓	523
Shale	3½	526½
Limestone	2	528½
Shale	2	530½
Sandstone, entered	23⅔	554

[a] A complete description of the drill core of the Sharp boring has been prepared by James H. Lees, assistant State geologist of Iowa, and is published in Iowa Geol. Survey, vol. 19, 1909, pp. 247-251.

UNDERGROUND WATER.

SOURCE.

In Decatur County water is obtained from (1) the alluvium, (2) the upper layer of the glacial drift, and (3) sand beds at the base of the drift or incorporated between deposits of bowlder clay. Reliance is placed chiefly on shallow dug or bored wells which end near the contact of the loesslike clay with the oxidized bowlder clay or which penetrate the latter, ending if possible in a gravelly zone. The extent to which the surficial water table follows the irregularities of the surface is remarkable. Thus, for instance, in ascending a hillside at Leon one may find a succession of shallow wells, each with water near the surface and with the water level differing notably within the space of a few rods. This condition is also illustrated by the fact that in some places artificial springs are made by projecting an iron pipe horizontally from the bottom of a hillside well to the surface farther down the slope. It is obvious that the steep gradients of the water table are correlated with imperfect porosity of the water-bearing material and small yields of the wells. The shallow water is moderately hard but otherwise good, except that in many places it is obviously exposed to pollution, some hillside wells, especially in villages, being so located that they must receive the direct seepage from privies on higher ground and not many yards distant.

Altogether a number of wells have been drilled to the lower part of the drift and beds of sand have generally been encountered, but it seems that the water from these is likely to be meager in quantity and poor in quality, though further prospecting might develop more favorable results.

The water-bearing strata in the Pennsylvanian series are for the most part so thin and imperfectly porous that their yield is small. The water is rich in sulphates, which give it a certain medicinal value as a laxative, but make it undesirable for general household use and also cause foaming in boilers, especially in locomotives. In hardness and scale-forming properties it differs widely, the water from some wells being relatively soft.

In the valley of Pot Hole Branch (sec. 29, T. 68 N., R. 26 W.), where Pennsylvanian strata are at the surface, a 6-inch well was drilled through limestone, shale, and a little sandstone, etc., to a depth of 118 feet, where a porous seam was pierced, from which mineralized water with a laxative effect issued and rose to a level 30 or 40 feet below the surface.

Two miles south of the State line, near the southeast corner of the county (NW. ¼ sec. 1, T. 66 N., R. 24 W.), in a valley bottom whose altitude is about 672 feet above the sea, a feeble flow was obtained by drilling into Pennsylvanian strata to a bed of quicksand at the depth of 153 feet. The water is rich in sodium sulphate and is used for medicinal purposes. Several other wells in this locality are of the same character except that they have never overflowed.[1]

It is evident from these data that the water from different seams does not rise to an accordant level and that there is a possibility of striking a flow in any deep valley. However, such flows are invariably weak and of very little, if any, practical value.

By expensive drilling, deeply buried water-bearing formations can be tapped, but the water is likely to have a low head and to be of bad mineral quality.

With present prospects, deep drilling can hardly be recommended, yet, on the other hand, run-off waters stored in surface reservoirs must be regarded as far from satisfactory and the condition of the private wells is most insanitary. Preliminary to installing waterworks, every municipality can afford to explore the resources of the drift and other unconsolidated deposits above the bedrock, and it seems probable that if right methods are pursued enough water can in most places be secured from such a source. If no bed of sand that will furnish enough water of reasonably good mineral quality is found in the deeper parts of the drift, then it may be possible to develop a sufficient supply from the shallower parts of the drift. It is seldom advisable to dig a single well of great diameter. If instead smaller holes are bored at proper distances apart, the excavation of a given amount of earth will result in a much larger infiltrating surface, and the expenditure of a given amount of money ought to result in a larger supply. Moreover, such a system is elastic, for the number of bored wells can be increased indefinitely and the contributing area can thus be enlarged until the requisite amount of water is secured. It is not generally understood that any number of bored wells can, without difficulty or great expense, be connected at the bottom by horizontal iron pipes so that one pump can draw from all of the wells simultaneously. (See p. 910.) This method of connecting a series of wells could also be employed to much advantage on stock farms.

CITY AND VILLAGE SUPPLIES.

Lamoni.—At Lamoni (population, 541) a system of waterworks has recently been installed. The water is obtained from a reservoir which holds the run-off from a ravine west of the town and has a capacity of 3,500,000 gallons. The water is pumped into a tank elevated on a steel tower and is distributed by gravity through about

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[1] Shepard, E. M., Underground waters of Missouri: Water-Supply Paper U. S. Geol. Survey No. 195, 1907, p. 68.

3¼ miles of mains, tapped by 29 fire hydrants and about 20 service pipes.

In the town two holes have been drilled into Pennsylvanian strata. The well of C. Brown was sunk near the railway bridge, where the surface is about 1,110 feet above the sea. It is 5½ inches in diameter and 300 feet deep. The drill passed through yellow and blue clay to about 150 feet, where a 2-foot bed of sand was found that contained some water; it then penetrated light-colored limestone and dark shale and sandstone, with 3 feet of red shale at a depth of about 200 feet. The well ends in limestone from which a small amount of water rises to the surface and trickles over the rim of the casing. The other drill hole was a coal prospect and is located on higher ground. It was carried to a depth of 425 feet and revealed a similar stratigraphic section.

Leon.—At Leon (population 1,991) the electric light plant obtains one of the best water supplies in the county from three open wells located in a small valley at the east margin of the town. Two of the wells are 6 feet and the other is 10 feet in diameter; all are cased with brick and go to a depth of about 40 feet. The water is reported to stand 12 to 25 feet below the surface, according to the season. In an ordinary day the pump is operated for about 2½ hours, in which time approximately 7,000 gallons are drawn from the wells and the water level is thereby temporarily lowered less than 10 feet. The wells have been in use for a number of years and are reported never to have failed. The water is tolerably satisfactory for boiler feed, though it forms some scale.

One well and several coal prospects at Leon have been sunk into the Pennsylvanian strata.

The well was drilled for William Biggs in 1902 at a point a few rods west of the city square. It is 803 feet deep and is cased with 350 feet of 4½-inch, 152 feet of 3½-inch, and 210 feet of 2¾-inch pipe. The curb is 1,120 feet above sea level. Water was found in sandstone at a depth of 700 feet. No other water was reported. The normal water level is 340 feet below the surface or approximately 780 feet above sea level. With the suction pipe extending 36 feet below water level the yield is not sufficient to supply the pump, somewhat less than 40 gallons a minute having been reported. In 1906 Mr. Biggs reported the yield to be 15 gallons per minute. The analysis (p. 174) shows that the water is only moderately hard but that it contains sufficient sodium and the sulphates to render it mildly laxative and give it some reputation as a medicinal water. The water is said to be more or less turbid at all times.

Driller's log of Biggs or Hazlett well at Leon.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, yellow	55	55
Clay, blue, and stone	80	135
Limestone	5	140
Clay, yellow	23	163
Clay, blue	22	185
Sand	1	186
Clay, blue	40	226
Gravel	14	240
Clay, blue	25	265
Limestone, blue	2	267
Clay, blue	20	287
Clay and gravel	6	293
Clay, blue	40	333
Limestone	2	335
Coal	2	337
Soapstone	7	344
Blue stone	10	354
Blue soapstone	23	377
Coal	1	378
White soapstone	62	440
Limestone	4	444
Slate, black	6	450
Hard soapstone	20	470
Slate, black	1	471
Coal	4	475
Soapstone, blue	33	508
Limestone, white	7	515
Soapstone, white	6	521
Soapstone, hard, white	44	565
Coal	4	569
Soapstone, blue	66	635
Sandstone, white	158	793
Unknown	10	803

LUCAS COUNTY.

By Howard E. Simpson.

TOPOGRAPHY.

Lucas County lies on the eastern slope of the high plain which forms the divide between Mississippi and Missouri rivers. The area as a whole slopes gently eastward, but there is a slight slope both northward and southward from Chariton, the highest point on the divide in Lucas County. From this vicinity Whitebreast and Cedar creeks flow northward through Marion County into the Des Moines, and Chariton River, approaching from the southwest, bends away southeastward and thence toward the Missouri.

The entire area is part of a drift plain whose flat and almost level surface has been cut by a few broad stream valleys and an innumerable network of smaller ones until every portion of the region is well drained. The divides are broad and flat-topped, and pass gradually into the gently rolling hills which border the valleys.

GEOLOGY.

In the broad bottom lands along Chariton River and Whitebreast and Cedar creeks the alluvial deposits of sand and gravel alternating with silt and mud are many feet in depth.

Over the uplands and extending well down into the valleys lies a mantle of the fine yellow clay called loess. Beneath this and covering the entire county lies the Kansan drift, a bowlder clay containing pebbles of all sizes and shapes, many of which are granite or dark-red quartzite and therefore do not resemble the underlying bedrock. The maximum depth encountered in any of the coal prospect drillings of the Inland Coal Co., near the center of sec. 1, Lincoln Township (T. 72 N., R. 21 W.) was at an elevation of 1,017 feet above sea level. The section here is not only remarkable for depth but for the amount of sand contained.

Log of coal-prospect hole in sec. 1, Lincoln Township.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and loess	18	18
Till (Kansan)	42	60
Sand	74	134
Sand, with bands of blue clay	14	148

The bedrock immediately underlying the drift of the entire county belongs to the Pennsylvanian series of the Carboniferous (Pl. XVI, p. 672) and, with the exception of an irregular strip averaging less than a mile in width along the western border, to the Des Moines group. The Des Moines group consists chiefly of shales, sandstones, and a few limestones and coal seams. This narrow western margin is slightly overlapped by the rocks belonging to Missouri group, in which limestone and shale predominate.

The sandstone of the "St. Louis limestone," which constitutes so important an aquifer in the counties to the east as to be known as the "white water sandrock," is not utilized in Lucas County. The top of the upper limestone of the "St. Louis," which immediately overlies the sandstone of that terrane, is reported to be about 350 feet beneath the surface. In the NW. ¼ sec. 15, Liberty Township (T. 73 N., R. 22 W.) the Inland Coal Co. gives the following section, the surface being 832 feet above sea level:

Log of coal prospect hole in Liberty Township.

	Thickness.	Depth.
	Feet.	*Feet.*
Drift	20	20
Des Moines group	198	218
Limestone	46	264
Sandstone	42	306

SURFACE WATER.

The large streams of Lucas County afford a permanent supply of running water which is not only economical but good for stock. The springs along the margin of the "bottoms" and in the broken lands in the vicinity of the larger streams are greatly valued by the stock farmers.

On many stock farms where running water is not available a dam is built across a small ravine, behind which storm water collects and usually remains throughout the summer, as the drift forms a very impervious bottom and prevents rapid drainage. The water thus impounded is, however, very unsatisfactory, and the condition of such stock ponds toward the close of a warm, dry summer may be imagined better than described. Such water is suitable for use only in boilers, and for this purpose it is probably the least objectionable that can be obtained in this region.

UNDERGROUND WATER.

SOURCE.

Alluvial bottoms of Chariton River and Whitebreast and Cedar creeks afford frequent shallow wells for many stock pastures. The newer public supply at Chariton is derived from this source.

Most of the wells of the county are shallow and draw their water from sandy lenses irregularly distributed through the drift or from the sand and gravel deposit commonly found at the base of the drift. The remarkable sand layer noted in the section given on page 784 seems fairly persistent between the Kansan till and the blue clay below (possibly the Nebraskan drift); at other points in the eastern part of the county it is said to be 40 feet thick and to supply some large and permanent springs.

Except on the upland divides wells in the drift yield water that is satisfactory both in quantity and quality for ordinary demands for stock and domestic uses.

Few wells in the county enter bedrock and none are known to pass through the coal measures, but the many coal prospect holes afford sufficient evidence of the quantity and quality of the contained waters. Beds of sandstone and sandy shale occur irregularly in the shales of the Des Moines group, and though many of these sandstone beds are reported dry, some are so heavily water bearing as to interfere seriously with mining operations.

Concerning mine waters in the western part of the county Mr. Verner, formerly State mine inspector, says:

Mine waters in this part of the State come from the surface or from sandstone lying over a shale roof covering coal. This shale runs from nothing to 70 feet in thickness, and when it is thick it permits little water to percolate through. When this roof shale is thin, the mines are, as a rule, very wet and it is difficult to keep the roof from falling, and it may be necessary to abandon the mine.

Some mine waters are so strongly charged with hydrogen sulphide as to be unfit for general use. Shaft waters are not good for steam making, for they pit and corrode the boilers rapidly, and as the waters of the drift wells are generally too hard, the boilers of many of the mining plants are supplied with impounded storm waters.

The sandstone of the "St. Louis limestone," which in this county may be reached at depths of 400 to 600 feet, would probably produce moderate quantities of pure and wholesome hard water provided the water from the overlying Des Moines group were thoroughly cased out.

The depth and arrangement of the drift and the sandstone layers of the Des Moines group that might be water bearing are indicated by the driller's log of a coal prospect hole drilled by the Inland Coal Co. The hole is located on Chariton River bottoms a little northeast of the southwest corner of sec. 30, T. 72 N., R. 21 W.

Log of coal prospect hole near Chariton.

[Elevation of mouth above sea level, 971.95 feet.]

	Thickness.	Depth.
	Ft. in.	*Ft. in.*
Soil	7	7
Clay, yellow	7	14
Clay, dark	6	20
Sand	2	22
Clay, black	18	40
Sand	5	45
Clay, black	30	75
Sand	3	78
Shale, soft dark blue	9	87
Shale, gray	17	104
Shale, green	4	108
Shale, dark	3	111
Coal	0 11	111 11
Clay, fine	3 1	115
Shale, light	2	117
Limestone, red	1 8	118 8
Shale, light	4 4	123
Limestone	1	124
Sandstone	20	144
Sandstone, soft	27	171
Bowlder	2	173
Coal	1	173 1
Shale, black	7	180 1
Shale, soft, light	3 10	183 11
		183 11

SPRINGS.

Many excellent springs emerge from heavy beds of sand and gravel of the drift outcropping on the sides of the valleys in Lucas County. They are as a rule very constant in flow and are of great value on stock farms, as they yield streams of pure water, cool in summer and warm in winter, sufficient for 500 to 1,000 head of cattle, without expense of time, labor, or money except the initial cost of walling up and piping to a suitable tank. A spring on the farm owned by Hanna

Kent, 3 miles west of Lucas, is typical. This spring flows in a good, strong stream from an outcropping layer of sand at the bottom of a hill. On the J. M. Taylor farm, 3¼ miles north of Derby, a spring of excellent water is located on the "old Mormon trace" road, so called because the locality was used by the Mormons in their western migration as a camping ground on account of the "plenteous water." The "Black Spring," owned by George Johnson, 5 miles northeast of Russell, flows a perennial stream of clear, hard water.

CITY AND VILLAGE SUPPLIES.

Chariton.—The public water supply of Chariton (population, 3,794) is drawn from shallow wells in the alluvial gravels and sands underneath the bottom lands along Chariton River about 2 miles south of the city and about 89 feet below the level uplands. The water is pumped into an elevated tank in the city and supplies 7 miles of mains leading to 60 fire hydrants with water under about 50 pounds pressure. This normal pressure is supplemented by a steamer service for fire protection.

The Chicago, Burlington & Quincy Railroad formerly obtained water for engines, roundhouses, and shops by a dam across a branch of Chariton River immediately west of the city, supplemented by two wells 12 feet in diameter and 30 feet deep. The better well yielded 35,000 gallons of water daily. The water was a good boiler water for this region, but the reservoir was unsatisfactory on account of the tendency of the river to flood in spring and to go dry in summer.

Recently the company constructed a new reservoir a short distance farther west of the city, by damming a small stream fed by permanent springs. The dam is 30 feet high in the middle and the resulting pond is 1¼ miles long. Abundant supply of satisfactory boiler water is secured.

The deepest well reported at Chariton, that at the electric-light company plant, is 70 feet deep; little water is obtained below 33 feet, and that little is very hard.

Derby.—At Derby (population, 326) bored wells 10 to 60 feet deep, averaging 33 feet, are commonly used, as they furnish a good supply of water which rises within a few feet of the surface. There are several fine springs in the neighborhood.

Lucas.—At Lucas (population, 666) water is obtained from drift wells ranging in depth from 15 to 50 feet.

Russell.—Wells at and about Russell (population, 612) are shallow, averaging about 30 feet. The city well, 6 feet in diameter and 30 feet deep, is used by the public for drinking and for teams. A well 9 feet in diameter and 31 feet deep, and two cisterns 10 by 12 feet, constitute the supply for fire protection. The water is pumped directly by a gasoline fire engine. The city well yielded 120 gallons per hour when dug.

A composite well section in and about Russell, showing fairly persistent gravel layers, is as follows:

Composite well section near Russell.

	Thickness in feet.
Soil and loess	8 to 20
Subloessial sand; scanty water.	
Yellow till (Kansan)	9 to 30
Gravel at base of Kansan till; water-bearing.	
Clay, blue	10 to 60
Coarse sand and gravel; much water.	
Coal shales.	

WELL DATA.

The following table gives data of typical wells in Lucas County:

Typical wells of Lucas County.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Remarks (logs given in feet).
T. 72 N., R. 21 W. (LINCOLN).		*Feet.*	*Feet.*		
A. Culbertson	NE. ¼ sec. 18	342	94	Drift sand; sandstone (Des Moines).	Clay, 10; sand and gravel, 84; coal measures, 248
D. G. Bennett	SE. ¼ sec. 24	304	70	Drift sand	Loess, 10; drift, 60; coal measures, 234.
J. A. Slattengren	SW. ¼ sec. 23	324	65	do	Clay, 50; sand, 15; coal measures, 259.
L. C. Whitten	NE. ¼ sec. 13	131	17	Sandstone (Des Moines).	Drift, 17; coal measures, 114.
J. M. Cowan	NW. ¼ sec. 8	174	22	Drift sand	Clay, 11; sand, 11; coal measures, 152.
C. G. Erickson	NE. ¼ sec. 2	148	21	Sandstone (Des Moines).	Clay, 18; sand, 3; coal measures (with 45 feet of sandstone at base), 127.

MADISON COUNTY.

By Howard E. Simpson.

TOPOGRAPHY.

Madison County is on the eastern slope of the divide between Mississippi and Missouri rivers. On the whole the area is a maturely dissected drift plain sloping gently to the northeast, in which direction the principal streams, North River, Middle River, Clanton Creek, and South River, flow toward Des Moines River. The southwest corner of the county is drained by Grand River, which flows southward toward the Missouri.

In the western and southern parts of the county the relief is very slight; in the northeastern part the flat-topped uplands are trenched 100 to 300 feet by deep broad valleys with abrupt sides.

GEOLOGY.

The loess, a whitish-buff clay, free from gravel, covers all uplands in Madison County and extends well down the slopes into all the larger valleys. This deposit is not so thick as it is in the counties to the south and east. The Kansan drift underlies the entire county except where eroded away from some of the steeper valley sides. In its upper parts much woody and vegetable matter is found and in some places gas has been reported. These facts suggest that the deeper sand is an interglacial gravel of Aftonian age.

The drift in the western and southern portions of the county rests directly upon the Missouri group, here represented by some heavy beds of limestone with shale. The limestone of the Missouri group is much altered above and the well sections frequently show a few feet of geest, or residual soil, between the drift and the unaltered limestone. In the northeastern portion the drift rests upon the Des Moines group, which consists chiefly of shales and sandstones with some limestones and coal seams. All the formations are nearly horizontal except for slight local dips.

UNDERGROUND WATER.

SOURCE AND DISTRIBUTION.

Sandy layers within and at the base of the loess yield small quantities of water to wells, few of which exceed 30 feet in depth. The loess is extensively used except on the uplands where it has been found very unsatisfactory owing to the serious diminution and frequent failure of its water supply in dry seasons. The upper sand bed and loess is dry in "ridgy" ground except in the middle of ridges.

The water-bearing sands and gravels beneath the Kansan drift form the chief source of water supply for the county and are tapped at depths ranging from 20 to 200 feet. Locally, water may be obtained by sandy layers within the Kansan drift.

In the uplands about St. Charles water is found in the Kansan by wells about 30 feet deep, and in deeper drift sands overlying blue clay practically free from pebbles at depths ranging from 50 to 60 feet.

In view of the importance of the drift waters in Madison County a composite section on the uplands about Winterset is of interest.

Composite section on upland near Winterset.

	Thickness in feet.
Soil and yellow loess, dry	10–17
Loess, blue gray, water bearing	3–10
Sand, water bearing	2
Till, yellow; some sand beds and pockets, the latter usually water bearing	10–30
Till, blue, variable and often wanting; water very scarce	40
Clay, light blue; much sand and gravel and many bowlders; generally much water immediately over bedrock	1–3

The surface of the uplands underlain by limestone of the Missouri group is so nearly level that, though the drift is but a few feet thick, few wells penetrate to rock. An abundance of good water is found in the limestone or in sandy layers at the base of the loess. Ground-water level is so high that water stands near the surface in the shallow dug wells or overflows as in the 13-foot well on R. A. Lenscher's farm (SE. ¼ sec. 19, T. 77 N., R. 29 W.). An excellent type of the deeper drift well in this vicinity is that of J. M. Hochstetter (SE. ¼ sec. 29, T. 77 N., R. 29 W.), a 50-foot well to sub-Kansan sands, which yields an abundance of fine water, with head 15 feet from the surface. An interesting result of the ease with which water is obtained in this region is noted in the absence of windmills over the farm wells. Such conditions are found in the vicinity of Earlham and the region southwest.

On the higher divides about Macksburg the loess is generally dry and the wells are bored to depths of 20 to 60 feet, many of them drawing their supply from the gravels beneath the Kansan. Not uncommonly the higher farms find serious difficulty in obtaining a full supply.

In the broad belt of broken ground lying east of Earlham, Winterset, and Barney, the stream valleys are cut through to the soft shales and the uplands between are capped with the limestone. Here the loess and upper sands are well drained except in the middle of the broad divides, and wells are sunk to the sands at the base of the drift. The many outcrops of limestone in the sides of the valleys suggest why even these are dry in some localities. On the farm of G. W. Bowles (SW. ¼ sec. 20, T. 74 N., R. 27 W.) 5 dry holes, ranging in depth from 75 to 170 feet, were sunk; and on that of Jesse Roberts, 1½ miles northeast of St. Charles (SE. ¼ sec. 12, T. 75 N., R. 26 W.), 14 dry holes were dug before water was obtained from a valley well 35 feet deep. The aquifer in this well is a sandy layer at the base of the drift and above the shale, as shown by the following section:

Section of Roberts well near St. Charles.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, yellow	25	25
Sand	3	28
Shale	7	35

The drift sands overlying limestone in the broken region are thoroughly drained, but the water in those over shale is retained.

Few wells in the county completely penetrate the drift. Some of those in the western and southern portions of the county find a good hard water in the second or third heavy limestone beds of the Missouri group, since these are interbedded with thin layers of clay or shale. In the northeastern portion of the county, where the drift overlies the Des Moines group, the rock wells are even more uncertain. A few obtain good supplies from sandstone beds, but the water is frequently highly mineralized. One well, that of Finley McDonald (see p. 792), penetrates the entire coal measures and draws a fair supply from the "St. Louis limestone" at a depth of 799 feet.

SPRINGS.

Strong flowing springs are common along margins and outcrops of the limestone of the Missouri group, and seepage springs are more or less frequent where drift sands outcrop in broken lands. The former afford valuable supplies of stock water on the margin of the deeper valleys.

CITY AND VILLAGE SUPPLIES.

None of the towns of the county except Winterset have public supplies other than that furnished by shallow dug wells on the main streets, the water being drawn by hand pumps.

Winterset.—At Winterset (population, 2,818) water is obtained chiefly from drift wells ranging in depth from 10 to 100 feet, the supply varying greatly with the season. One of the four wells which supply the Electric Light Co. plant may be considered typical. The section is as follows:

Log of Electric Light Co. well at Winterset.

	Thickness.	Depth.
	Feet.	*Feet.*
Loam	3	3
Loess, yellow	10	13
Clay, blue	22	35
Sand and gravel	1	36
Till, blue	16	52
Limestone	....	....

Water is found chiefly just over the limestone and is very hard and requires considerable treatment to render it fit for use in boilers. The wells are 4 feet in diameter and the four yield about 200 barrels daily in the drier seasons.

The prospect of obtaining water from the deeper formations at Winterset is indicated by the record of the Finley McDonald well (NE. ¼ NE. ¼ sec. 1, T. 75 N., R. 28 W.), which has a depth of 799 feet and a diameter of 3¼ inches. The curb is approximately 1,100 feet above sea level and the head 190 feet below curb. Water was found at 248, 433, 538 (2½ gallons a minute), 630 to 648 (2¾ gallons heading 2 feet below curb, strong flow in sandstone), and 758 to 770 (strong flow in crevice at 797 feet). The capacity of the well is 300 gallons per hour, lowering 21 feet under a 10-hour test.

Driller's log of McDonald well at Winterset.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay (Pleistocene)	28	28
Limestone (Missouri)	22	50
Shale (Des Moinès) of various colors; fire clay, sandstone, limestone, and some coal	562	612
Sandstone	36	648
Shale, white	12	660
Shale, black, bituminous	60	720
Sandstone, hard, flinty	26	746
Sandstone, dark-colored	12	758
Sandstone, white (base of Des Moines)	12	770
Limestone, white, hard, cherty (Mississippian)	29	799

WELL DATA.

The following table gives data of typical wells in Madison County:

Typical wells of Madison County.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head below curb.	Remarks (logs given in feet).
T. 76 N., R. 26 W. (CRAWFORD).						
		Feet.	*Feet.*		*Feet.*	
Peter Cunningham.	2 miles north of Patterson.	103	64	Sand, at base of drift.	......	Abandoned; insufficient.
T. 75 N., R. 29 W. (WEBSTER).						
T. D. Peterman	NW. ¼ sec. 5	301	115	Sandstone (Des Moines); limestone (Missouri).	......	Drift, 115; Missouri, 148; Des Moines, 38. All waters only 1¼ gallons per minute. Mineral.
T. 75 N., R. 28 W. (LINCOLN).						
Dave McCleary	5 miles southwest of Winterset.	577	100	Sandstone (Des Moines).	260	Drift, 100; Missouri, 56; Des Moines, 421. A weak well. Mineral.
T. 76 N., R. 28 W. (DOUGLAS).						
Finley McDonald	NE. ¼ sec. 1	799	28	Sandstone ("St. Louis").	190	Mineral. Test 300 gallons per hour for 21 hours. Drift, 28; Missouri, 22; Des Moines, 720; "St. Louis," 29.
T. 76 N., R. 29 W. (JACKSON).						
Dave Ford	NE. ¼ sec. 25	133	21	Missouri	40	Good hard water. Drift, 21; Missouri, 20; Des Moines, 92.
Rush Tate	SW. ¼ sec. 13	95	....	do	50	2¾ gallons per minute.
T. 76 N., R. 27 W. (UNION).						
S. A. Foley	3½ miles east of Winterset.	485	27	Des Moines	90	20 barrels per day; insufficient. Drift, 27; Missouri, 27; Des Moines, 431. Abandoned.

Typical wells of Madison County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head below curb.	Remarks (logs given in feet).
T. 74 N., R. 27 W. (Walnut).						
		Feet.	*Feet.*		*Feet.*	
H. W. Tate	SE. ¼ sec. 18	113	8	Limestone (Missouri).	75	Excellent well.
H. Hatterbuhr	SW. ¼ sec. 20	315		do		Scant; abandoned.
T. 75 N., R. 26 W. (South).						
Jesse Roberts	SE. ¼ sec. 12	185	70	Coal (Des Moines).		Unsatisfactory; abandoned.
Flouring mill	St. Charles	114	99	Drift and sandstone (Des Moines).	16	
T. 77 N., R. 27 W. (Jefferson).						
A. D. Fletcher	SE. ¼ sec. 36	268	100	Sandstone (Des Moines).	160	Soft water.
T. 77 N., R. 29 W. (Penn).						
J. M. Hochstetter	SE. ¼ sec. 29	50		Drift sand	15	Abundant and fine.

MARION COUNTY.

By Howard E. Simpson and W. H. Norton.

TOPOGRAPHY.

Marion County lies slightly southeast of the center of Iowa. The surface is a fair type of the Kansan till plain, approaching a mature stage of dissection. Des Moines and South Skunk rivers, conforming to the general trend of the master streams of the eastern portion of the State, flow southeastward across the northern part of the county, the former draining the major portion of the county through the Whitebreast, English, and Cedar creeks, which flow parallel to each other from the southwest and enter the Des Moines almost at right angles. This attitude is probably due to a slope of the plain to the northeast.

The broad upland divides are gently rolling and vary but slightly from 900 feet above sea level; near the main streams the land is somewhat rough and broken. Des Moines and South Skunk rivers and Whitebreast Creek have completely developed flood plains with meanders and cut-offs in valleys largely preglacial. All other drainage is probably postglacial, though English and Cedar creeks are also well graded. No morainal depressions or ridges remain to impede the drainage.

GEOLOGY.

The entire county is covered with loess, Kansan drift, and possibly Nebraskan drift, save where the streams have cut through to bedrock or have deposited alluvium on their flood plains.

The bedrock underlying the drift consists chiefly of Carboniferous shale with some beds of sandstone and coal, all of which have been assigned to the Des Moines group of the Pennsylvanian series. (See Pl. XIII, p. 526.) In the deeper valleys of the eastern portion of the county the drift rests on limestone or, more rarely, on the underlying sandstone of the "St. Louis" division of the Mississippian series. Formations below the Carboniferous are not exposed in the county and are only known through deep wells put down at Pella and Flagler.

The "St. Louis" strata have a slight southwestern dip and are somewhat irregular, owing to the presence of numerous anticlines and synclines of small extent.

The Des Moines group rests unconformably upon the "St. Louis limestone" and contains many minor unconformities, due probably to contemporaneous erosion between its beds, which dip slightly and thicken toward the southwest. The usual great unconformity exists between the Des Moines group and the drift.

UNDERGROUND WATER.

SOURCE.

Each of three series, the Pleistocene, the Pennsylvanian, and the Mississippian, furnishes an important source of water supply in Marion County, though all are variable both in quantity and quality.

The chief supply of water in the county is obtained from shallow wells dug in the drift, which is a fairly homogeneous bowlder clay ranging in thickness from 10 to 80 feet, though in few places exceeding 60 feet, and which is found throughout the county. Water is within 15 to 40 feet of the surface, generally in small sand pockets, veins, or seeps, and almost invariably at the base of the drift where it rests on shale. The drift water, where uncontaminated, is of good quality and is very generally used for household purposes, since it is easily accessible and comparatively free from mineral matter. It is, however, subject to pollution in the larger towns and near coal mines. Its quantity is generally insufficient except for household use and for small farm supplies. Stock farmers find it inadequate and either dig large open wells into the shale to form reservoirs or drill into the bedrock.

The coal measure rocks consist of coal, shale, and sandstone with occasional beds of limestone and conglomerate. Water is usually found in the seams and beds of coal, but this water is never potable owing to the abundance of iron and sulphur compounds in solution. The shales which compose the greater part of the group are comparatively dry and where water is found in them it is so strongly impregnated with mineral matter as to be unfit for use. This is characteristic of almost all waters of the Des Moines group. Exceptions occur, however, in the case of thick local lenses of sandstone several of which are found in the county. The best known of these is the channel deposit known as the Red Rock sandstone, which occupies an area of less than 30 square miles in the north-central portion of the county and has a maximum thickness of about 100 feet. Since it lies near the surface and furnishes an abundance of good water no wells go through it, but, owing probably to contemporaneous erosion, it is lacking in many wells where it might reasonably be expected.

Another important water horizon is in many places found at depths of 100 to 200 feet in sandstone lenses some distance above the base of the Des Moines and usually above the coal seams. The rock varies in color from light blue to nearly white and in thickness from 10 to 40 feet, and contains pyrite and ironstone concretions, coal, fossils, and shale bands. The water is usually of good quality for stock, though occasionally mineralized. The quantity is satisfactory; no well drawing water from this horizon has been known to fail under ordinary windmill or horsepower pumping, and no severer tests have been reported. Beds at this horizon are on the whole the most satisfactory source of supply for stock farms, quality and quantity both considered.

The third water-bearing bed of the county, known among drillers as the "white water sandrock," is a sandstone immediately underlying a heavy-bedded limestone (the upper bed of the "St. Louis limestone" of the Mississippian). It is a white, compact, granular sandstone with numerous flinty layers of cherty limestone from 1 to 3 inches in thickness. At many points it is dry above, but at depths of 300 to 350 feet it contains an abundant supply of water for all stock wells. All wells to this sandstone stand windmill and horsepower tests, and several have been pumped with a steam pump with no apparent exhaustion. The water is generally hard and in some places mineralized, but is usually considered good for stock and for domestic uses. The "St. Louis" will probably prove the most satisfactory source in the county, but it is not yet much used except in the eastern part, on account of the expense of drilling to the depth at which it lies. Wells to the "St. Louis" are reasonably sure of finding good wholesome hard water, which may be utilized in many kinds of manufactures but is unsuitable for boiler purposes on account of the lime carbonate and other minerals it carries in solution.

Only two wells in the county, those at Pella and Flagler, go below the "St. Louis" water rock.

DISTRIBUTION.

A few small areas of sand-veneered upland are found in Marion County in which the water supply is so interesting and unusual as to deserve mention. They lie in secs. 1, 11, and 12, T. 77 N., R. 18 W.; secs. 11 and 12, T. 76 N., R. 20 W.; and secs. 10, 15, and 16, T. 75 N., R. 20 W. In all the sand is mixed with loess and has been wind borne to the northeast from the flood plain of a stream near a point where the erosion of thick beds of soft sandstone has been in progress.

A supply of good water may be obtained in shallow wells near the base of the sand stratum, but some difficulty has been experienced on account of clogging of screens. Several permanent hillside springs rise from the same source. Though the quantity is scant and variable the possibilities of obtaining a supply from this source have been demonstrated in the private plant which furnishes water to the town of Eddyville in Wapello County.

Along the bottom lands of Des Moines River and its tributaries are a number of small flowing wells, most of which are prospect holes sunk for coal. Most interesting of these is the 752-foot well drilled by the Whitebreast Fuel Co. at Flagler, in the valley of English Creek. A flow was obtained at 320 feet, and a stronger one at 626 feet, probably in the Devonian; the water has been used locally for medicinal purposes.

Three artesian wells for stock have been sunk with good success on the Des Moines bottoms south of the river from Dunreath, and about 2 miles west of Red Rock. One of these, owned by James Worthington, on the line between secs. 3 and 4, T. 76 N., R. 20 W., is about 215 feet deep and is believed to penetrate the "St. Louis," though a slight flow was found in the coal measures, which increased to 2½ gallons. The Robinson and Coffin wells are believed to be not so deep. All are slightly mineral, but are good stock wells. Several coal-prospect holes about Swan produced flowing wells, which have now disappeared and become only boggy places, owing to the pulling or rusting out of the casings. All are believed to be 200 to 300 feet deep.

Across the river in Morgan Valley and down toward Dunreath other flowing coal holes have been utilized for stock wells. Another is in sec. 8, T. 77 N., R. 18 W., in South Skunk Valley.

Most of the water of Knoxville and vicinity is drawn from shallow wells bored or dug into the drift, where a sufficient quantity for domestic use is found within 15 to 30 feet of the surface. When uncontaminated this is a good source, since it is usually free from the minerals which give an unpleasant taste to most of the waters from the coal measures. The water comes chiefly from the sand pockets and small veins characteristic of the drift. The supply is, of course, limited, and is decreasing, requiring the digging of more and deeper wells.

Probably the best source of water in this vicinity, quality and quantity both considered, is the layer or layers of Pennsylvanian sandstone which outcrop extensively in the Competine Creek valley on the east side of town and also in Whitebreast Creek on the west side. This sandstone is the source of good wells on all sides of Knoxville but it seems to die out about 3 miles west of town; at least it is missed from several wells in that direction.

This sandstone is from 10 to 40 feet thick, light blue to white in color, and bears some concretions or bands of iron sulphide. It is frequently dry above, but near the base at depths of 170 to 210 feet contains water, which rises to within 90 to 120 feet of the surface. It is a very good stock water, and many wells drilled for this purpose are also used for domestic purposes and are as a rule very satisfactory. The water is rather hard, but in only a few places is reported mineralized. Wells drawing their supply from this bed are not exhausted by the windmill and horsepower pumps in ordinary use on the stock farms.

Where the sandstone is not found or where its waters are unsatisfactory on account of excess of minerals, the Mississippian "white water sand rock" may be found at depths of 250 to 350 feet, underlying a bed of heavy limestone. This granular white sandstone may also be found dry above, but it contains an abundant supply of water toward the base. Though hard and frequently of strong mineral taste, it is a good stock water.

In coal-prospect holes about Dallas a heavy lens of sandstone is found below coal seams 180 to 220 feet below the upland and 80 to 100 feet below the Whitebreast Creek bottoms. This will probably prove a helpful source of supply for farm wells where the shallow wells prove unsatisfactory. As yet, 20 to 40 foot wells in drift are in general use. Near Gosport and Attica coal-prospect holes to a depth of 150 to 200 feet show little sandstone and slight water. A dry well 210 feet deep has been drilled in the northern edge of Attica, but at depths of 250 to 350 feet the sandstone immediately below the upper limestone of the "St. Louis" produces some excellent wells. Bored wells, 10 to 40 feet deep, are common about Marysville, Bussey, Tracy, and Hamilton, and in the latter place some are flowing. At Harvey 10 to 15 foot sand points are common along the Des Moines River and English Creek bottoms.

SPRINGS.

Springs, though fairly common in outcrops of coal measures along the borders of the chief valleys, are generally so slight in flow as to be of no importance. The cover of the drift forms boggy places rather than springs. Among the best known in the county is one known as the Mineral Spring, located 1½ miles northwest of Hamilton on land owned by M. D. Flanders (sec. 27, T. 74 N., R. 18 W.).

CITY AND VILLAGE SUPPLIES.

Flagler.—The Johnston well has a depth of 752 feet and a diameter (at top) of 4 inches; casing of iron, cement, and tile to 51 feet. The curb is 745 feet above sea level. Water comes from depths of 320 and 626 feet, discharging at the rate of 1½ gallons per minute.

Record of strata in deep well at Flagler.

	Thickness.	Depth.
Pleistocene:	*Feet.*	*Feet.*
Clay	5	5
Sand	12	17
Carboniferous (Mississippian):		
Undifferentiated:		
Limestone	28	45
Shale, sandy	6	51
Sandstone	72	123
Limestone	7	130
Magnesian limestone	13	143
Limestone	10	153
Shale, sandy	7	160
Limestone	25	185
Shale, sandy	6	191
Limestone	3	194
Shale, sandy	4	198
Limestone	93	291
Rock, hard, white	1	292
Limestone	162	454
Kinderhook group:		
Shale, sandy	72	526
Devonian:		
Limestone	64	590
Shale, sandy	31½	621½
Limestone	65½	687
Do	65	752

Knoxville.—The public supply of Knoxville (population, 3,190) is owned by the city and is drawn from Whitebreast Creek and its underflow at a point about 2½ miles west from the city. The intake, which drains into a large well 22 feet deep, is a timbered tunnel cut through shale under the creek bed for a distance of 85 feet and filled in with broken brick. A Knowles steam pump, capacity 500,000 gallons a day, forces the water through an 8-inch pipe into an open reservoir, the capacity of which is 10,000,000 gallons. An electrically driven Gould triplex pump with a capacity of 1,000,000 gallons pumps the water for general use from the reservoir into a 100-foot standpipe with a capacity of 96,000 gallons. For fire purposes direct pressure is resorted to, a reserve steam pump of 1,000,000 gallons capacity being brought into use. The supply secured in this way is ample for fire protection, but the impurity of the water at the source is such as to render it generally unsatisfactory for domestic use.

Pella.—Near Pella (population, 3,021) the drift is the chief source of supply for domestic purposes, though a number of wells go 200 to 300 feet to the coal measures sandstones and a few probably to the lower sandstone, which, however, affords only a scanty supply of highly mineralized water. On the bottoms of both Des Moines and Skunk rivers and their larger tributaries sand points driven a few feet frequently produce quite satisfactory wells.

In 1895–6 the city of Pella drilled an 1,800-foot well. (See Pl. XIII, p. 526.) Water was first found in the drift at a depth of 150 feet and rose to within 100 feet of the surface, close to which it has remained ever since, as in other good wells in the vicinity. Other water-bearing beds were found from 1,300 feet to the bottom in the Galena, Platteville, St. Peter, and Oneota formations. The supply from the latter formations was found to be insufficient. Tubing has been put down to a depth of 1,200 feet, but the amount of mineral matter present makes it probable that the water is at least partly from the coal measures. Analysis shows that it contains 9,116 parts per million of solids and is so highly mineralized that it is totally unfit for domestic or manufacturing or boiler uses. The only uses to which it is put are sprinkling the streets and fire protection, for which purposes it is raised by a direct pump operated by a 10-horse-power gasoline engine (capacity 120,000 gallons) to an elevated tank with a capacity of 63,000 gallons. The original pumping capacity was 250 gallons a minute; present capacity, 50 gallons. Date of completion, 1896. Drillers, J. P. Miller & Co., of Chicago.

The capacity of the lower water beds was tested by inserting a 3-inch pipe with rubber packing at base 126 feet above the bottom of the well; through this pipe but one-half as much water could be drawn as on previous tests. Unfortunately no test of quality seems to have been made of the lower waters when thus separated.

Record of strata in city well at Pella (Pl. VIII, p. 352; Pl. XIII, p. 526; Pl. XIV, p. 548).

	Thickness.	Depth.
Quaternary (135 feet thick; top, 868 feet above sea level):	*Feet.*	*Feet.*
Humus	6	6
Till, yellow, mottled with gray; clay predominant ingredient; ocherous nodules; calcareous	54	60
Till, blue, dense, tough, calcareous	50	110
Sand and gravel; pebbles mostly buff, impure limestone and greenish and black siliceous clay stone; a fragment of coal and one of fossil wood	25	135
Carboniferous:		
Pennsylvanian:		
Des Moines group (195 feet thick; top, 733 feet above sea level):		
Clay, dark, yellow-gray, sandy; a few small pebbles and fragments of gray unctuous shale	55	190
Sand, very coarse; fragments of gray and black shale	2	192
Gravel, coarse; up to 5 centimeters in diameter; surfaces stained with ferric oxides; in a matrix of black ferruginous clay or shale. Pebbles: Greenish-black argillo-siliceous, 22; clay ironstone, 13; flint, 6; limestone, 6; jasper and quartz, 6; sandstone, 2	3	195
Shale, black; gravelly at 235 to 245 feet; fissile and gravelly at 272 feet. Pebbles at 272: Limestone, 9; green argillo-siliceous, 6; flint, 12; red and yellow jasper, 3; 5 samples	90	285
Shale, dark gray	2	287
Shale, hard, black, finely laminated, pebbly; 2 samples	43	330
Mississippian:		
"St. Louis limestone" and Osage group (270 feet thick; top, 538 feet above sea level):		
Limestone and shale; in bluish-gray concreted argillo-calcareous powder; a few minute fragments of light-gray limestone, some chalcedony, drusy quartz, and quartz crystals	15	345
Limestone; in fine cream-colored powder	30	375
Limestone and shale; in concreted powder; washing discloses gray limestone sand, disks of crinoid stems, chalcedony, white chert, and particles of hard blue-green shale	25	400
Shale, blue, highly calcareous	5	405

Record of strata in city well at Pella (Pl. VIII, p. 352; Pl. XIII, p. 526; Pl. XIV, p. 548)—Continued.

	Thickness.	Depth.
Carboniferous—Continued.		
Mississippian—Continued.		
"St. Louis limestone" and Osage group (270 feet thick; top, 538 feet above sea level—Continued.	*Feet.*	*Feet.*
Shale, blue-gray, slightly calcareous	15	420
Shale and limestone; in light blue-gray argillo-calcareous powder; some limestone and chert	30	450
Limestone and shale; in light blue-gray, argillo-calcareous powder; some limestone and chert	10	460
Shale and limestone; in powder as above; some fragments of dark-gray flint and a few of limestone	20	480
Limestone (?); highly argillaceous calcareous powder; many chips of blue and gray flint, a few of light yellow-gray limestone, and some of shale	30	510
Limestone; chips of blue and gray flint, drusy quartz, chalcedony, blue shale, and many chips of earthy buff limestone	5	515
Limestone, light yellow-gray; in sand, with argillaceous powder; some chalcedony	85	600
Kinderhook group (125 feet thick; top, 268 feet above sea level):		
Shale, green, fissile; some drab	100	700
Shale, green, somewhat calcareous; in molded masses	25	725
Devonian and Silurian (420 feet thick; top, 143 feet above sea level):		
Limestone, nearly white, soft; earthy luster; rapid effervescence	10	735
Limestone; as above, with sand of hard brownish-gray magnesian limestone or dolomite	10	745
Limestone, magnesian, light brown, coarsely crystalline, close textured; effervescence slow; a few fragments of selenite noted; residue dark brown, argillaceous; 4 samples	55	800
Limestone, soft; in part chalky; effervescence rapid	20	820
Limestone, light gray-brown, magnesian; some "clod" shale of same color; 2 samples	20	840
Limestone, light gray, crystalline, highly cherty; drillings rusted so as to appear buff in mass	10	850
Limestone, blue-gray; in large flakes	10	860
Limestone, light brown-gray and gray; at 860 a few crystals of selenite; 4 samples.	30	890
Marl, gypseous; in gray-white, concreted powder largely of gypsum; some limestone, argillaceous matter, and microscopic crystals of quartz; 2 samples	35	925
Limestone, light gray, mottled with dark drab; in large flaky chips; numerous crystals of selenite	10	935
Dolomite, hard, gray; in chips; 2 samples	20	955
Marl, gypseous, or gypsum; in light-yellow, nearly white powder, concreted into tough masses; breaking with smooth, slightly conchoidal fracture; friable with difficulty; in acid does not disaggregate, though slightly calcareous; under the microscope anhydrite is seen to be an important constituent and some pyramidal crystals of quartz are observed	15	970
Shale, blue-gray, strongly calcareous; 2 samples	45	1,015
Limestone, magnesian, light brown, crystalline	11	1,026
Limestone and shale; limestone gray, earthy, pyritiferous; shale, light green, fossiliferous	19	1,045
Limestone, magnesian, light brown, crystalline	5	1,050
Limestone, mottled gray, crystalline, highly gypseous	5	1,055
Marl, gypseous; some light-gray impure limestone and shale	25	1,080
Marl, gypseous; 4 samples; at 1,110 feet a few thin flakes of limestone	50	1,130
Limestone, magnesian, buff, gypseous	5	1,135
Limestone, earthy, soft, gypseous, light gray, in flaky chips	3	1,138
Dolomite, light blue-gray, hard; irregular fracture, microcrystalline; 2 samples	7	1,145
Ordovician:		
Maquoketa shale (190 feet thick; top, 277 feet below sea level):		
Shale; green, green gray, drab, and slightly purplish; slightly calcareous or noncalcareous; hard and fissile; 4 samples	115	1,260
Shale in molded masses, drab, somewhat calcareous; fine dolomitic sand	75	1,335
Galena and Platteville limestones (350 feet thick; top, 467 feet below sea level):		
Dolomite; gray, crystalline, cherty; in fine sand; 4 samples	90	1,425
Limestone, rather soft; much gray flint and a little brown bituminous shale	10	1,435
Limestone, magnesian; in light buff sand; 2 samples	20	1,455
Limestone, soft, white; effervescence rapid	5	1,460
Limestone, magnesian, yellow gray	5	1,465
Limestone, light brown, crystalline; effervescence rapid; 2 samples	10	1,475
Limestone, magnesian, buff, crystalline	5	1,480
Dolomite, cream yellow, buff, and brown, mostly cherty; residue after digestion in acid microscopically arenaceous or quartzose in several samples; chert usually pyritiferous with embedded crystals; 11 samples	113	1,593
Limestone, brown, cherty; some small chips of dark-brown bituminous shale; 2 samples	22	1,615
Limestone, magnesian, gray, crystalline, with hard, slaty, blue-green shale	20	1,635
Limestone, magnesian, light buff	15	1,650
Limestone, gray, earthy, crystalline; rapid effervescence; 2 samples	35	1,685
St. Peter sandstone (15 feet thick; top, 817 feet below sea level)—		
Sandstone, clean, white; quartz sand; 2 samples	15	1,700
Prairie du Chien group:		
Shakopee dolomite (60 feet penetrated; top, 832 feet below sea level):		
Dolomite; drillings highly arenaceous, cherty, gray, and buff; 3 samples	40	1,740
Dolomite, buff	20	1,760

Pleasantville.—The entire water supply of Pleasantville (population, 691) comes from sheets of sand in the drift at a depth of 20 to 35 feet. Two dug wells on the corners of the public square are used for drinking and afford the only means of fire protection. In the country a few stock wells are drilled 200 to 250 feet to sandstone.

WELL DATA.

The following table gives data of typical wells in Marion County:

Typical wells of Marion County.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head above or below curb.	Remarks (logs given in feet).
T. 75 N., R. 21 W. (FRANKLIN).						
		Feet.	*Feet.*		*Feet.*	
J. Watkins	SE. ¼ sec. 25	87	75	Des Moines		
T. 74 N., R. 19 W. (INDIANA).						
J. Louden	NW. ¼ sec. 23	105	30	Des Moines		
Thos. Craig	SE. ¼ sec. 6	346	260	"St. Louis"		High hill. Highly mineralized and salty. Stock prefer it to stream or pond water.
J. K. Cathcart	NW. ¼ sec. 28	320	260	do		
	NW. ¼ sec. 11	210		Des Moines		Dry.
Frank Caruthers	SW. ¼ NW. ¼ sec. 33.	155	34	Sandstone ("St. Louis").		Strong flow, 60 gallons per minute. Soil and clay, 18; sand and clay, 16; soft dark shale, 2; coal, ½; medium soft dark shale, 28½; soft light shale, 7; limestone, 2; soft dark shale, 2; soft light shale with limestone bands, 12; hard limestone, seamy, 2; soft light sandstone heavily water bearing toward base, 60; hard limestone, seamy, 5.
T. 74 N., R. 18 W. (LIBERTY).						
M. D. Flanders	SE. ¼ sec. 25	84	12	Des Moines		High ridge.
W. B. Spillman	NW. ¼ sec. 29	256	196	"St. Louis"		High ridge. Mineral.
T. 76 N., R. 20 W. (PARTS OF UNION AND KNOXVILLE).						
Jos. Worthington	NE. ¼ sec. 4	215	30	"St. Louis"(?)	+ 18	Just before sandrock occurs a hard, shelly limestone. Flow began in Des Moines and increased in "St. Louis." Slightly mineral.
W. R. Myers	SE. ¼ sec. 33	56		Des Moines		Rapid flow 2½ feet from bottom in fine, compact buff sandstone.
David Horsman	Sec. 5	216		do		Dry hole.
Do	do	191		do		
T. 77 N., R. 20 W. (RED ROCK; PART OF UNION).						
S. D. Robinson	NE. ¼ sec. 34	172			+ 37	River bottoms. Flow from cavity in rock.

Typical wells of Marion County—Continued.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head above or below curb.	Remarks (logs given in feet).
T. 75 N., R. 19 W. (PART OF KNOXVILLE).						
		Feet.	*Feet.*		*Feet.*	
Walter Jenkins	SW. ¼ sec. 8	171	72	Des Moines	−110	Soft water; river bottoms.
P. M. Stentz	SW. ¼ sec. 5	169	16	do	−80	
E. W. De Witt	SE. ¼ sec. 19	173		Sandstone	− 85	
John Smith	W. ½ sec. 33	253	About 100	Des Moines		
Chas. Bender	E. ½ sec. 33	100		do		Good well.
State Inebriate Home.	Knoxville	340	33	Sandstone ("St. Louis").		"Second well."
——— Johnston	SW. ¼ sec. 2	752	17	Devonian limestone.	+ 10	Mineral artesian.
T. 75 N., R. 20 W. (PART OF KNOXVILLE).						
B. M. Long	NE. ¼ sec. 18	125	100	Des Moines		
John Fee	NE. ¼ sec. 2	175		Sandstone	− 60	
John Bruitt	SW. ¼ sec. 29	93		Des Moines		
John Ken	Sec. 14	94		do		Plenty of good water.
T. 76 N., R. 19 W. (POLK; PART OF KNOXVILLE).						
John Bush	SE. ½ sec. 31	277		"St. Louis"	6	Slightly mineral.
T. 75 N., R. 18 W. (CLAY; PART OF LAKE PRAIRIE).						
	2½ miles west of Tracy.	185		do		Soft.
Brick and Tile Co.	Harvey	90	8		− 20	
T. 76 N., R. 21 W. (PLEASANT GROVE).						
Geo. Erb	4 miles southeast of Pleasantville.	283		Sandstone ("St. Louis").	−150	An excellent well.
T. 76 N., R. 18 W. (PARTS OF LAKE PRAIRIE AND CLAY).						
Pella Canning Co.	Pella	250	160			Scant and soft.
Do	do	300	290	Sandstone	−125	Strong, hard and salt.
Light & Power Co.	do	190		Drift gravel	−100	
Central College	do	299		Sandstone	−150	

MONROE COUNTY.

By HOWARD E. SIMPSON and W. H. NORTON.

TOPOGRAPHY.

The topography of Monroe County is of the type characteristic of the mature drift plain in southern Iowa. Being on the upland between Des Moines and Chariton rivers, the most southerly of the many parallel streams of Iowa flowing southeastward to Mississippi and Missouri rivers, the plain is well dissected by streams flowing irregularly out in all directions from the central divide on which the county seat, Albia, is located. The maximum elevation is approximately 1,000 feet above sea level on the divide at the center of the southern border of the county, where the Iowa Central and Wabash railroads enter the county, and the minimum is about 680 feet above sea level where Des Moines River touches the corner of the county at Eddyville. Creeks and smaller streams are sufficiently numerous to give complete drainage, though none are of importance for other purposes. Only the largest, Cedar Creek, which truncates the northwest corner, and its tributary, Coal Creek, which drains the western half of the county, are mature enough to have the broad well-developed flood plains characteristic of similar streams in Marion and Mahaska counties. Des Moines River has a broad flood plain seven-eighths mile in width and a much broader old preglacial valley which slopes very gradually to the upland level. Its immediate tributaries are so steep as to produce a rather rugged topography throughout the northeastern part of the county. A small and unimportant part of the drainage of the southwestern portion of the county flows into Chariton River.

GEOLOGY.

The surface deposit, except where it is removed by erosion, is loess, which overlies a fairly thick mantle of drift. The drift rests upon the Des Moines group of the Pennsylvanian series, except over a very small area in the northeast corner, where Des Moines River and its tributaries, Grays and Mill creeks, have cut through to the "St. Louis limestone" (Mississippian). The thickness of the coal measures (Des Moines group) is probably 300 feet in the central part of the county increasing to 400 feet in the southwestern part. The Carboniferous strata dip gently to the southwest and slight local anticlines and synclines are discovered in working for coal. There is a marked unconformity between the Des Moines group and the "St. Louis limestone."

UNDERGROUND WATER.

SOURCE.

Monroe County draws for water on the alluvium, the Pleistocene drift, the Des Moines group (coal measures), and the "St. Louis limestone." As in other counties underlain almost entirely by the coal measures, the waters from shallow or moderately deep wells are variable in quantity and frequently unsatisfactory on account of an unpleasant mineral taste. There are no distinct underground water provinces in the county.

Along Des Moines River in the extreme northeast corner of the county, lies a belt of alluvium 1 to 2 miles wide, and along Coal, Cedar, and Avery creeks narrow bands of the same deposit are found, in all of which water may be procured in the sandy or gravelly layers by points driven a few feet into the ground.

In the north central part of the county near Buxton some windblown sand occurs (pp. 795–796). It is, however, little utilized, and is of importance as a water bearer over only a very small area.

The fine yellow, clayey silt known as loess veneers all the uplands in depths ranging from a few feet to 30 feet, thinning out along stream valleys. It is so closely associated with the underlying glacial drift that the two are here treated together.

The Kansan drift consists of yellow clay mingled with bowlders, gravel, and sand above, passing into a more compact blue bowlder clay below. The upper portion is stained yellow and red by the oxidized iron compounds which have been leached out, and the blue is the unaltered, unoxidized drift. Few places are known in which the drift is over 80 or 100 feet thick, and 70 feet is perhaps a fair average for the county. The drift is thickest in the southwestern part, where few wells penetrate to the rock.

The water which supplies most of the county for domestic purposes is procured from dug or drilled wells a few feet in depth which open sand pockets and small veins in clay. There is, however, below the Kansan till sheet a heavy sand and gravel layer 5 to 20 feet thick, in places cemented into conglomerate, which rests directly on bedrock. This somewhat resembles the Aftonian gravel and suggests an older drift.

The coal measures (Des Moines group) are composed chiefly of shales with irregularly bedded sandstones, but in the northern part of the county their upper parts contain coal seams of great economic importance. The shales are of no value as water bearers and even the sandstones, which in places grade into limestones, are so variable, so inclosed in shale, and so permeated with iron sulphate as to be of little value. A few local lenses, however, yield very satisfactory water.

The "St. Louis limestone" consists of a compact, even-bedded limestone 20 feet in thickness overlying a coarse heavy-bedded sandstone. The latter, which is known as the "white water sandrock," is seldom used in Monroe County, though it lies only 250 to 350 feet below the surface. No wells in the county go below this. One prospect hole, sunk by the Consolidated Coal Co., is reported to have been driven down to 1,365 feet, but no data concerning it can be secured.

DISTRIBUTION.

Shallow dug and bored wells and drive points penetrating alluvial sands and gravels are common in the valley of Des Moines River and its tributary creeks. On the uplands the sands beneath the loess and the gravels beneath the drift furnish the chief supply. A few wells on the upland south and west of Eddyville penetrate the coal measures and procure water at depths ranging down to 220 feet.

At Lovilia, drift wells 20 to 50 feet in depth furnish an abundant supply of water, and water from some bored wells even flows away over the surface. The 50-foot wells draw their supply from the sands and gravels immediately overlying the bedrock sandstone.

Similar conditions prevail in the valleys of Coal and Cedar creeks. On the upland divide, however, as at Weller, a good supply of water is difficult to get, except with a boring machine in low places or in wet seasons. It is probable that good stock wells may be had by drilling 300 or 400 feet as at the place of M. A. O'Bryan, 4 miles southeast of Weller, where slightly mineralized water is secured from coal measures with a head but 60 feet befow the surface.

Underlying most of Albia (T. 72 N., R. 17 W.) and vicinity, and immediately overlying the first vein of coal, is a bed of sandstone 25 to 60 feet in thickness. This is best known in the mining shafts 3 or 4 miles west about Tower, where it is so abundantly supplied with water as to seriously interfere with the working of the mines and to compel the closing of some of the shafts. A second sandstone, coarse, gray in color, and 25 to 75 feet thick lies between the second and third veins of coal. The water-bearing capacity of these lenses is well illustrated in the abandoned shaft on the farm of D. A. Noble (NW. ¼ sec. 24, T. 72 N., R. 18 W.). The shaft, 113 feet deep and 7 by 12 feet across, was filled by water to a depth of 52 feet in 24 hours on cessation of pumping. It is a matter of regret that this supply was not more carefully investigated by the town of Albia before it resorted to surface waters for its public supply.

At about 300 feet the hard, buff limestone of the "St. Louis" is reached, and this is immediately underlain by "white water sandrock" 20 to 30 feet in thickness. The latter is said to contain, as usual, a plentiful supply for ordinary wells though it would probably be insufficient for public supplies. One of the few wells reaching this horizon, that of H. K. Runkle, 2 miles north of Albia (NW. ¼ sec 10, T. 72 N., R. 17 W.), is situated on a hill and is 456 feet in depth. At 95 feet the water horizon at the base of drift was reached; another vein in the base of the coal measures was tapped at 350 feet; and the "white water sandrock" was found at 440 feet. The water heads about 40 feet below the surface and is not materially lowered by windmill pumping. It is reported to be a good stock water.

On the uplands back of Melrose, in the southwest, many farm stock wells are drilled to depths of 157 to 200 feet. In a 380-foot well on the farm of William Bernard the "St. Louis limestone" was reached at a depth of 340 feet.

At Hocking shallow bored wells a few feet in depth are used; some of them flow. Deeper drift wells on the upland secure water over shale at the base of the drift at depths of 65 to 105 feet. Two miles southwest, on the farm of M. J. McLaughlin, a 250-foot well gives a good flow from coal measures sandstone at a depth of 180 feet.

At Foster the drift wells range from 20 to 65 feet. On the upland to the northeast between Brompton and Avery many drift wells 30 to 100 feet in depth have been sunk, and though much sand is encountered they are frequently dry. Artificial ponds are generally used for stock water.

SPRINGS.

Springs are not uncommon in Monroe County and are generally found along the lower slopes of the valleys of the larger creeks, the water coming from the subloessial sands, the sands and gravel underlying the drift, or the outcropping edges of coal measures sandstone. They are little used except for stock water, for which they are of value to the farmers, who frequently wall them in and pipe the flow out to a small tank.

The waters of many shallow bored wells on hillsides or slopes of bluffs are led out through pipe or tile a few feet below the surface into a tank placed on lower ground. This type of artificial spring or modified flowing well provides good cool pasture water at slight expense.

CITY AND VILLAGE SUPPLIES.

Albia.—The public supply of Albia (population, 4,969) is taken from an artificial reservoir formed by the damming of a small stream. The ponded water is pumped into a supply tank and distributed by gravity pressure through about 6 miles of mains to 45 fire hydrants. A steamer is maintained to supply added pressure as needed. The water is not extensively used for domestic purposes.

Owing to the difficulty of procuring satisfactory ground water, cisterns supply many houses with rain water. Dug and bored wells, the only type used in the town, penetrate the drift 18 to 20 feet on the east side and 20 to 40 feet on the west side of the city square. Bedrock of sandstone or shale is reached at 40 to 70 feet

A type section by Mock Bros., well borers, is as follows:

Section at Albia.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, gray (oxidized loess)	16	16
Joint clay, blue (unoxidized loess); including subloessial sands, water bearing	8	24
Water clay, yellow (commonly with sand layers)	6	30
Clay, blue (Kansan)	25	55

Buxton.—Buxton resorts chiefly to very poor cistern waters. Two wells in the drift 28 to 66 feet deep yield a scant supply. In the dry season of 1901 the people were supplied almost wholly with water brought from Des Moines River in tank cars. An 8-acre rain-water reservoir supplies a poor quality of water for the mining companies, machine shops, and heating plant. At No. 14 shaft, a few miles to the south, the air shaft, 145 feet deep, and the main shaft, 138 feet deep, have no water except a slight amount from drift near the surface. At Hiteman shafts Nos. 3 and 4 are practically dry.

Melrose.—The location of Melrose (population, 459) in the valley of Cedar Creek insures a supply from shallow drift wells 10 to 30 feet in depth. One of 65 feet does not reach bedrock. Springs are quite common, and a few of the wells overflow. The best of this type is perhaps a bored well owned by A. B. Murray, which strikes a strong flow in gravel at a depth of 17 feet and delivers a constant 2-inch stream 3 feet above the surface. This is used by many of the families of the town for domestic supply. The Chicago, Burlington & Quincy Railroad procures a supply from the creek. A system for fire protection is proposed, and this can no doubt be procured at comparatively small cost from springs or shallow wells.

No. 10 Junction.—The track well of the Chicago & North Western Railway (NW. ¼ sec. 8, T. 73 N., R. 17 W.) has a depth of 1,345 feet and a diameter of 10 inches to 340 feet, 8 inches to 586 feet, 6 inches to bottom; casing to 195 feet. The curb is 895 feet above sea level. The tested capacity is 80 gallons a minute. The well was completed in 1901 by S. Swanson, of Minneapolis.

Driller's log of railway well at No. 10 Junction.

	Thickness.	Depth.
	Feet.	*Feet.*
Earth	127	127
Sandstone	7	134
Limestone	87	221
Sandstone	11	232
Limestone	29	261
Shale	14	275
Limestone	312	587
Shale	9	596
Limestone	5	601
Shale	147	748
Limestone	78	826
Shale	52	878
Limestone	93	971
Shale	40	1,011
Limestone	15	1,026
Shale	75	1,301
Sandstone	18	1,319
Shale	11	1,330
Sandstone	15	1,345

The "St. Louis limestone" and Osage group seem to extend to a depth of 587 feet (308 above sea level) and the Kinderhook group thence to 748 feet (147 feet above sea level). The Devonian and

Silurian beneath can not be distinguished in the alternating shales and limestones of the log. The heavy shales from 1,026 to 1,301 feet may be the gypseous marls found in the Silurian of the region; and the sandstones at base, from which the water is probably derived, appear equivalent to the Silurian sandstones of southeastern Iowa.

WELL DATA.

The following table gives data of typical wells in Monroe County:

Typical wells of Monroe County.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head above or below curb.	Remarks (logs given in feet).
T. 72 N., R. 17 W. (Troy).						
		Feet.	*Feet.*		*Feet.*	
Dan O'Hare	SE. ¼ sec. 18	180		Sandstone (Des Moines).		Strong.
H. K. Runkle	NW. ¼ sec. 10	456	95	Sandstone ("St. Louis")	− 40	Slightly mineral. Water bed at 440.
T. B. Dotts	NW. ¼ sec. 16	290				No water.
T. 71 N., R. 19 W. (Jackson).						
Wm. Bernard	SW. ¼ sec. 9	380		Sandstone ("St. Louis").		Abandoned on account of lost drill, closing hole.
T. 72 N., R. 19 W. (Wayne).						
M. A. O'Bryan	NW. ¼ sec. 2	360	80	Sandstone ("St. Louis").	− 60	Slightly mineral. Drift, 80; Des Moines, 225; limestone ("St. Louis"), 45; sandstone ("St. Louis"), 10.
James Smith	NE. ¼ sec. 22	230	125	Sandstone (Des Moines).	+ 5	Flowing well.
James Foley	SE. ¼ sec. 9		125	do		Do.
T. 73 N., R. 17 W. (Bluff Creek).						
James Gray	NE. ¼ sec. 26	220		Sandstone (Des Moines).		Abandoned on account of scant yield.
T. 71 N., R. 17 W. (Monroe).						
N. J. McLaughlin	SE. ¼ sec. 6	250	180	Sandstone (Des Moines).	+ 2½	Fine flow, 1-inch stream.
T. 73 N., R. 16 W. (Pleasant).						
Grant Cowley	NE. ¼ sec. 11	192	188	Sandstone (Des Moines).	+ 15	Strong mineral flow.

RINGGOLD COUNTY.

By O. E. Meinzer.

TOPOGRAPHY AND GEOLOGY.

The streams of Ringgold County flow southward through deep valleys that are separated by dissected ridges and plateaus whose general altitude is slightly more than 1,200 feet above sea level.

The bedrock lies essentially below the valley levels and is mantled with a thick accumulation of glacial and associated materials out of which the valleys have been carved. The glacial drift comprises very dark clay at the bottom (perhaps Nebraskan) and yellow gravelly clay at the top (Kansan), with layers of "hardpan" or beds of sand at intermediate positions (perhaps Aftonian). Widely spread over the yellow gravelly clay is a loesslike deposit, in few places 25 feet thick and averaging much less, which is yellow at the top but ashy blue and plastic at the bottom and which throughout is very nearly free of pebbles and grit. Upon the floors of the valleys a small amount of alluvium has been deposited. The bedrock consists of upper Carboniferous (Pennsylvanian) strata whose character is indicated in the following section condensed from the driller's log of a drill hole on the farm of Al Dunsmoor, about 2 miles west of Tingley, on ground intermediate between the upland and the valley levels:

Section near Tingley.

	Thickness.	Depth.
	Feet.	*Feet.*
Bowlder clay	12	12
Sand	13	25
Clay, blue	20	45
Sand and gravel	2	47
Drift	13	60
Sand	2	62
Clay	7	69
Shale, blue	40	109
Sand	45	154
Shale, sandy	36	190
Sand	5	195
Shale, blue	30	225
Potter's clay	9	234
Limestone (water bearing)	9	243
Shale; with 2-foot bed of limestone	19	262
Limestone; with 2-foot bed of shale	20	282
Shale; with 1-inch seam of coal	12	294
Impure limestone	22	316
Shale; with several thin beds of limestone, sandstone, etc	173	489
Coal	½	489½
Fire clay	3	492½
Shale (black, blue, gray, green, and red)	87	579½
Coal	½	580
Fire clay	4	584
Shale; with thin bed of limestone and sandstone	40½	624½

UNDERGROUND WATER.

SOURCE.

The underground sources of water in Ringgold County can be grouped as (1) alluvium; (2) weathered, gravelly clay underlying the ashy plastic clay; (3) sand beds in the deeper parts of the drift or at its base; (4) thin sandstone and limestone strata interbedded with Pennsylvanian shales; (5) basal sandstone of the Pennsylvanian; and (6) lower sandstones and limestones.

In the valleys the alluvium may furnish moderate amounts of fairly good water. Below the undissected upland the weathered gravelly clay contains a certain amount of good but moderately hard water which it contributes slowly to dug or bored wells, but on the ridges and valley sides this material may be dry. The sand beds that occur in places in the deeper parts of the drift generally yield ample and reliable supplies, but unfortunately these beds are not found in all localities. They seem to be best developed in the area west of West Fork of Grand River, where they are tapped by a number of successful wells. Their water is usually good although rather hard, but some of it is mineralized in much the same way as the subjacent Carboniferous waters. Water-bearing seams of sandstone or limestone are almost invariably found when the drill penetrates the Pennsylvanian strata to any considerable depth, but as a rule they are not an important source of supply, for they yield but little water, and that is full of sulphates and other minerals. Here and there, however, seams are encountered which provide rather large amounts of water of fairly good quality except that it is rich in sodium sulphate and therefore has at least a mild cathartic effect when used for drinking. Very few wells in this county have entered the Pennsylvanian strata. So far as known, the basal sandstone of the Pennsylvanian has nowhere in the county been reached by the drill; something, however, can be inferred as to its occurrence and character as a water-bearing formation from the deep well at Leon, 14 miles east of the Decatur County line, in which it was found between 635 and 793 feet, and from the deep well at Bedford (Taylor County), about an equal distance to the west, in which it was found below 1,180 feet. At Leon the yield is moderate, the head low, and the quality fairly good except for large amounts of sodium sulphate.

CITY AND VILLAGE SUPPLIES.

At present there is no system of public waterworks in the county, a deficiency due no doubt in part to the difficulties of procuring an adequate supply. In view of the results obtained with deep wells in adjacent counties, drilling into the rock formations must be considered of doubtful expediency and should at best be viewed as a last resort, but every village can afford to prospect thoroughly the glacial drift and other unconsolidated deposits above the rock before being content with surface water or seepage from shallow wells. If, however, no satisfactory bed of sand or gravel is found in the drift, it may be possible to develop a sufficient supply by boring a large number of wells into the surficial layer of drift.

SUPPLIES FOR STOCK FARMS.

On most farms plenty of water can be obtained for ordinary purposes, but on some, especially the larger stock farms, the lack of it has been severely felt and much unsuccessful boring and drilling has been done. On farms adjoining the principal valleys supplies can usually be obtained from streams or springs, or from shallow wells in the alluvium. In some upland sections satisfactory supplies are found in deeper parts of the drift, but in others seepage from the upper part of the drift seems to be the only available source of water, and the amount of this seepage is in many places exceedingly small. In the past too much reliance has been placed upon a single shallow well or on isolated wells of this kind. A better method is to bore a series of shallow wells of large diameter close enough together to be connected with pipes at the bottom and thus drawn upon simultaneously by a single pump and windmill. (See p. 910.)

On the farm of B. F. Talley (NW. ¼ sec. 12, T. 69 N., R. 31 W.), about 2 miles southwest of Diagonal, a well was bored to a depth of 147 feet, passing through 125 feet of drift and 10 or 12 feet of loose yellow sand, and ending in black "sand" which contains pieces of wood, twigs, etc. The water, which is corrosive and apparently impregnated with a small amount of gas, rose within 57 feet of the surface. Other wells of this character were reported in the western part of the county. On the farm of G. W. Bentley, in the same section as the Talley well but on a creek bottom perhaps 65 feet lower, water flows from a hole 88 feet deep. Another flow was obtained on the farm of A. Harris, in the creek valley about 2 miles east of Benton. This well is only 30 feet deep, but is said to yield copiously.

WELL DATA.

A number of wells a few hundred feet deep, at least some of which enter bedrock, have been reported. Analyses (p. 174) of the water from the wells of L. Myers and Robert Hall, both south of Kellerton, show a large content of mineral matter, especially of sodium sulphate. Approximately at the west margin of sec. 3, T. 68 N., R. 29 W., 2½ miles east of Mount Ayr, in a valley just south of the railway, a hole was at one time sunk into the Pennsylvanian strata for the purpose of prospecting for coal, and a weak flow of water was obtained.

At the village of Diagonal both railway companies maintain locomotive supplies. The Chicago Great Western well is in the valley about 1,088 feet above sea level. It is 12 feet in diameter and 36 feet deep and is walled with stone. Its water level and yield vary somewhat with the season. The records at the pumping station show that it furnishes an average of about 35,000 gallons a day, and that on certain days it is required to furnish as much as 60,000 gallons, which, however, approaches its maximum capacity, especially in dry seasons.

In Mount Ayr a well was at one time sunk for the municipality to a depth of about 300 feet, where a water-bearing bed of sand was discovered. Because of difficulty with the sand or for some other reason, this well was never finished.

UNION COUNTY.

By Howard E. Simpson.

TOPOGRAPHY.

Union County lies on the branch of the great divide that separates the southeasterly flowing waters of Grand River from the southwestward flowing waters of Platte and Nodaway rivers. The crest of the divide runs southward through Spaulding and Creston. At Creston the Chicago, Burlington & Quincy Railroad attains an elevation of 1,312 feet, a rise of 261 feet from Afton Junction. By a peculiar adjustment of the drainage lines the entire drainage passes into Missouri River—that of the eastern slope through Grand River and that of the narrower western slope through Platte and Nodaway rivers.

The surface is a slightly rolling drift plain. Maturity is shown by the absence of ponds and undrained areas, by the completeness of the drainage, and by the presence of the numberless small intermittent tributary streams. On the east, especially about Afton Junction, the plain is more dissected and broken.

GEOLOGY.

The country rock beneath the surface of the county belongs to the Missouri group of the Pennsylvanian series, and consists chiefly of limestones, shales, and some beds of sandstone and seams of coal. Above these rocks, though separated from them by an unconformity indicating the lapse of a very long period of time, lie the loose, unconsolidated deposits of clay, sand, gravel, and bowlders known as the drift. This averages from 100 to 250 feet in thickness and is chiefly of Kansan age. Beneath the Kansan till, and separated from it by a heavy bed of gravel known as the Aftonian, from its discovery in the railway cuts west of Afton Junction, is an earlier till known as the Nebraskan drift. That this older drift is present throughout the greater portion of the county at least is shown by the presence within the drift sheet of a very persistent gravel bed corresponding to the Aftonian, by the presence of old forest or soil deposits, and by peculiarities of the basal till, showing differences in composition and age.

Above the drift everywhere except on the bottoms of the deeper valleys lies the loess, a light yellow plastic clay, generally free from pebbles, but containing numerous white calcareous concretions. Widely associated with the lower layers of the loess is a sticky, black plastic clay called gumbo.

In all stream valley bottoms a deposit of alluvium has been formed, chiefly from the wash of the loess, gumbo, and drift. The alluvium is thinner and of less importance in Union County than in other counties of southwestern Iowa that are farther from the divide.

UNDERGROUND WATER.

SOURCE.

The chief shallow-water beds of the county are the alluvium, the loess, the Kansan till, the Aftonian gravel, the Nebraskan till, and the limestone of the Missouri group. All of these are frequently unsatisfactory or insufficient except the Aftonian gravel, which is one of the best aquifers in Iowa.

Sufficient quantities of sand interstratified with silt are found in the alluvium of some of the larger tributaries of the Grand, in the southeastern portion of the county, to allow the use of drive-point wells, which, however, are not common.

The seepage at the base of the loess, especially where it overlies gumbo, supplies many shallow wells for domestic use, but the quantity is meager and uncertain.

The upper portion of the Kansan till usually contains much gravel and sand and these frequently supply sufficient water for many shallow wells, so that this horizon, together with the sandy base of the loess, is known as the "first water." A few wells find sand pockets in the Kansan till; the water from these is excellent in quality but is very variable in quantity, frequently failing altogether in dry seasons.

The Aftonian gravel, lying between the two till sheets, forms the best aquifer of this portion of the State, and its water is generally known on the uplands as the "second water." It is usually pure, wholesome, and abundant. In the valleys, owing to the absence of loess, the Aftonian is in many places the first water bed reached. The depth to it ranges from 30 to 200 feet. Wherever the gravel outcrops it forms a horizon of strong springs. A good illustration is found on the farm of John Leininger, 2½ miles north of Afton, where a powerful permanent spring flows from the base of a hill in which the gravel outcrops. In some places water from the Aftonian is rendered disagreeable and impotable by the presence of decaying organic matter of old soil, peat, and forest beds.

A "third-water" horizon is found in beds of sand and gravel in the base of the Nebraskan drift, immediately above the bedrock. This usually lies at depths of 100 to 200 feet, but its occurrence is uncertain;

probably in many places the Aftonian gravel rests immediately on the bedrock.

The country rock, composed as it is of thinly bedded limestones and calcareous shales, is not a good water carrier, its supply being small and its water hard and locally mineralized. The great thickness of the drift also makes it an expensive source of supply, and it is not resorted to when it is possible to obtain water from the upper beds. If the supply is insufficient after deep drilling, it is advisable, before abandoning the well, to try "shooting" with nitroglycerin and puncturing the casings opposite higher beds, in order to combine the supplies.

Because of the scarcity of good ground water at ordinary depths on the higher uplands of the county about Creston and Spaulding, many of the larger stock farms resort to ponded storm waters.

The following composite section, from descriptions given by well men, shows the relations of the several water beds:

Composite well section about Creston.

	Thickness in feet.
Soil, black	1–3
Loess: Light yellow clay containing calcareous concretions	10–20
Kansan till:	
Yellow gravelly clay, containing numerous sand and gravel beds; water bearing (first water)	2–6
Blue bowlder clay, compact and hard	20–100
Aftonian: Sand and gravel, yellow and coarse; heavily water bearing (second water)	2–5
Nebraskan till:	
Yellow, hard and gravelly	10–20
Blue and black, pebbles, and bowlders	20–40
Sand and gravel, water bearing (third water)	2–4
Shaly limestone.	

The upper portion of the Aftonian in many wells shows soil, peat, or forest beds, and the upper portion of the shaly limestone at the base of the section is often broken into a coarse rubble, mingled with residual gravel and soil and characteristic geest. The thickness of the drift at Creston is reported to be 260 feet.

SPRINGS.

Strong springs are numerous along the valley sides in the broken portion of the county. The Aftonian gravel, lying as it does between the till sheets, supplies one of the best spring horizons in Iowa. Little use is made of the springs, however, except as stock water, and even then they are rarely walled up and piped, but are simply permitted to flow, forming more or less of a bog in many cases.

CITY AND VILLAGE SUPPLIES.

Afton.—The public supply of Afton (population, 1,014) consists of five wells on the town square, ranging from 25 to 40 feet in depth. All are likely to fail in summer, except the 40-foot well, which usually contains 20 feet of water and is permanent.

A well at the creamery, in the northwestern portion of the town, is 365 feet in depth and reaches bedrock at 173 feet. It obtained abundant water in a gravel and sand layer in the drift a few feet above bedrock. The water doubtless was too hard for boiler use. Later the well was abandoned on account of clogging by mud and fine sand. The log follows:

Log of creamery well at Afton.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, yellow, and soil	58	58
Clay, blue	115	173
"Sandstone" (probably cemented sand and gravel)	4	177
Sand and gravel, fine	1	178
Mud, blue and black	3	181
Shale and "soapstone"	184	365
Limestone, hard.		

An important deep well is that of C. C. Boys (SE. ¼ sec. 11, T. 72 N., R. 30 W.). This well is 671 feet deep and was originally drilled as a coal-prospect hole. No good section or log can be obtained, but it is known that bedrock was reached at 116 feet and the most important water bed was found in a 10-foot bed of sand and gravel 46 feet above this, probably in the Aftonian. This was cased out until the prospect hole was finished; it was then opened up for a well and has yielded a large and permanent supply.

Creston.—The public supply of Creston (population, 6,924) is drawn from an artificial lake about 2 miles long, about one-half mile wide, and 30 feet deep. Similar though smaller ponds are used by many farmers about Creston to assure a stock supply in summer.

Minor supplies.—Most villages are supplied from shallow wells, 15 to 20 feet deep. About Afton Junction, Talmage, and Thayer the Aftonian gravel lies within comparatively few feet of the surface.

WARREN COUNTY.

By J. L. Tilton.

TOPOGRAPHY.

The upland of Warren County is a well-dissected plain sloping from 1,088 feet above sea level in the southwestern portion to 900 feet in the northeastern portion. It is drained chiefly by three streams, North, Middle, and South rivers, that flow toward the northeast, with tributaries extending back to all portions of the upland.

GEOLOGY.

The Des Moines group with its shale, sandstone, and coal underlying all sections of the county, extends from near the surface to a depth of 250 to 300 feet. (See Pl. XVI, p. 672.) In a few square miles only in the western half of Virginia Township the Missouri group with its limestone and shale overlies the Des Moines. Between these Carboniferous strata and the overlying Pleistocene lies a thin deposit of subglacial sand and old soil, remnants of the old surface prior to the advent of the Nebraskan ice sheet.

The Nebraskan drift is a tough, impervious, bluish-black till containing pebbles of greenstone, white quartzite, and light-colored granite. It is especially thick in the southern and western portions of the county, where the Kansan drift is thin. The sands and gravels (Aftonian) which overlie the Nebraskan drift, were largely derived from the erosion of this older till.

The Kansan drift is bluish black where not weathered and yellowish where weathered, containing here and there fine sand and minute pebbles. Among its numerous pebbles and bowlders red quartzite and greenstone are common, together with dark decomposing granite. In some portions of the county the Kansan drift is but a few feet thick; in other places it measures at least 80 feet.

The post-Kansan deposits consist in part of a yellowish and a grayish loess, between which in some places lies a clayey deposit (gumbo), which appears to be a loess modified by deposition in water.

The different depths of drift make it evident that from the southern and eastern parts of Jackson Township a large buried valley extends southeastward across Squaw Township and northeastward across Jefferson Township, with branches extending eastward to near Indianola and northeastward to the southwest corner of Greenfield Township. Another buried valley underlies the central part of Linn Township, whence it extends east into Greenfield Township and also southwest and northwest. The area covered with thick drift suggests an outlet to the northwest, but deeper preglacial valleys suggest an outlet to the northeast through Greenfield Township.

UNDERGROUND WATER.

SOURCE.

In former years wells on the uplands very commonly ended in a gumbo, or modified loess, which is found almost universally throughout the upland in the central portions of the county, 15 to 20 feet below the surface. During the drought of 1894, however, these wells were sunk beneath this deposit or its yellow equivalent to a sand which is generally found next beneath. Wells that are not over 30 feet deep are so constructed that they receive both the surface ground water and water from the sand below.

At a depth of about 30 feet throughout the uplands and of somewhat less in the bottom lands lie deposits of sand and gravel which are the common source of water supply throughout the county. In the central part of the county this deposit is in part post-Kansan and in part gravel (with bowlders) left after erosion of the Kansan surface. In other portions of the county, especially the southern and western parts, where the Kansan and all above it are thin, the sand is Aftonian. Along the river valleys the thick deposit of sand penetrated by wells 12 to 18 feet deep is Aftonian. In the southern and western parts of the county wells 100 feet deep pass through the Nebraskan drift into preglacial sands and soils. In general these preglacial deposits lie at depths varying from the level of the streams to 60 feet below this level. In the upland bored wells are ordinarily used; in the river valleys driven wells are very satisfactory.

The Simpson College well, which is 112 feet deep, ends in the bottom of deposits of old soil 25 feet deep. In testing this well it was first pumped for 49 hours at the rate of 840 gallons an hour, the pumping lowering the water 81 feet. This continued pumping merely drained away the surface water, for the water rose thereafter to within 30 feet of the surface. In the final test, after 17 hours of continuous pumping with a 4-inch pump worked by a 2½-horsepower gasoline engine, the water was reduced to a level 99 feet below the surface, the water toward the last lowering very slowly. When the pumping ceased the water rose 5 feet 9 inches in the first three minutes and 9½ inches from the thirty-third to the thirty-sixth minute; three days later it had risen within about 34 feet of the surface of the ground. The greatest quantity of the water came through the gravel at the base of the Aftonian. The rest came in slowly from above.

In the eastern half of the county the Carboniferous strata lie so near the surface that they are penetrated by many wells. Some of these extend into the Carboniferous for only a foot or two, just far enough to form a basin to hold water that comes in from the upper aquifers. In some the water enters from the shale. The wells that penetrate the shale more than a foot or two are dug by hand or drilled, the shale being so dense that it is bored by a well auger only with extreme difficulty. The general dryness of the shale makes such a formation one into which it is not advisable to penetrate; the sandy phases are bearers of good water, but the quantity is generally too small to supply a good stock well. Sulphur water, characteristic of all wells that penetrate the coal measures, corrodes metal receptacles and is unacceptable for kitchen and laundry use, and therefore presents a serious difficulty in all deep wells. Such water is not generally harmful, though it is laxative. To some people the taste is unpleasant.

Several wells that are 100 to 200 feet deep extend into the coal measures. Only two are flowing wells, both of them on low ground in the northeastern part of the county near the small anticline which runs northwest and southeast just east of Ford. Throughout most of the county the strata dip very slightly to the west or are horizontal, and the surface is so high that deep flowing wells are not obtainable.

Only two wells in the county reach below the Pennsylvanian; one is said to penetrate 2 feet and the other 38 feet into the "St. Louis." In all near-by counties deep wells have been sunk, but with results too unsatisfactory to be encouraging.

WAYNE COUNTY.

By O. E. Meinzer and W. H. Norton.

TOPOGRAPHY AND GEOLOGY.

The surface of Wayne County consists of a plain which has been carved by postglacial erosion into an intricate system of sharp valleys and ravines. Along the principal divides still exist broad strips of the undissected plain over which the railways have been constructed and upon which, as a consequence, the villages have been built.

The bedrock belongs to the Pennsylvanian series of the Carboniferous and consists of shale and thin strata of sandstone and limestone. On the rock rests a thick accumulation of glacial material, at least the upper part of which belongs to the Kansan drift sheet. Widely spread over the drift is a veneer of loess or grayish-blue clay resembling loess. Below are given several sections, as reported, of the drift and upper part of the Pennsylvanian.

Sections at Corydon.

[Sec. 19, T. 69 N., R. 21 W.]

	Thickness.	Depth.
Shaft No. 1.	*Feet.*	*Feet.*
"Drift"	267	267
Shale, argillaceous	27	294
Sandstone	6	300
Shale, sandy	12	312
Limestone	6	318
Shaft No. 2.		
"Drift and secondary drift"	301	301
Shale, argillaceous	12	313
Sandstone	14	327
Shale, sandy	15	342
Shale, argillaceous	30	372
Limestone with clay partings	20	392
"Crushed limestone with rotten coal"	12	404
Shaft No. 3.		
"Drift"	297	297
"Irregular layer of rotten sandstone"	1	298

Section at Humeston.

[Humphrey creamery well.]

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and clay	50	50
Clay, blue	330	380
Quicksand	20	400
Seam containing coal.		
Shale and soapstone	100	500
Rock entered.		

UNDERGROUND WATER.

SOURCE.

In Wayne County the water is generally obtained from wells dug or bored from 25 to 50 feet into the drift. In years of normal rainfall, most of these wells receive enough seepage for household use and stock farms, but in dry years many of them fail. Ponds made by throwing dams across small ravines serve as an additional supply for live stock on many farms.

The loosely aggregated and somewhat gravelly drift that furnishes the seepage for the shallow open wells gives place downward to a more compact and impervious bowlder clay, below which there is a possibility of obtaining water from (1) beds of sand or gravel at the base of the drift or between two sheets of bowlder clay; (2) strata of sandstone or limestone in the Pennsylvanian series; and (3) different sandstones and limestones at still greater depths. Such prospecting of the deeper parts of the drift as has been done at different times has not been very successful. This is attributed by drillers to the absence of sand or gravel deposits, but it may be due more largely than is realized to the leakage caused by the many deep valleys, whereby porous beds are drained or their head so much reduced that the water will not flow rapidly into the drill holes. Neither is the Pennsylvanian satisfactory as a source of water. In its several hundred feet of thickness certain water-bearing strata are nearly always encountered, but these are usually so thin and imperfectly porous and so completely incased by thick impervious beds of shale that their supply is small. Moreover, the water from these strata is objectionably rich in sulphates and commonly also in hardening constituents and iron.

At the creamery of J. L. Humphrey, jr., at Humeston, a 4-inch well was drilled to a depth of 384 feet, and was finished with a 6-foot strainer in a bed of sand. It appears that the sand eventually entered the well and shut off the water. A second well, 5 inches in diameter at the top and 4 inches at the bottom, was later drilled to the depth of 501 feet, but it seems that no additional supply was found and the same bed of sand was utilized. The water is reported to be hard and ferruginous and to have a laxative effect, which is no doubt due to a large content of sulphates. The section as reported suggests that the sand bed lies at the base of the drift, but the data are too indefinite to allow any positive statement. The water seems to have the chemical character of that found in the Pennsylvanian strata.

One of the deepest wells known in the county is that drilled at Corydon, in 1903, for E. A. Rea. It goes to a depth of 834 feet, ends in rock, and is said to have passed through water-bearing beds at about 75 feet, 300 feet, and 440 feet below the surface and also near the bottom. It is cased with 6¼-inch and 5-inch pipe to a depth of 610 feet, and has 20 feet of 4¼-inch casing at about 700 feet, and 50 feet of 3-inch casing at the bottom. With a pump drawing from a depth of 692 feet (578 feet below the water level) the well was successfully tested, immediately after it was completed, at the rate of 20 gallons a minute for 7½ hours continuously. At the time it was visited, however, it was for some reason not in condition to yield water.

In 1911 the town of Corydon put down a drill hole to 1,240 feet, at which depth the well was abandoned, as its capacity amounted to but 20 gallons a minute. This well has recently been deepened and now supplies the town. The elevation of the curb is about 1,110 feet.

The log of the hole, so far as kept, is as follows:

Driller's log of well at Corydon.

	Thickness.	Depth.
	Feet.	*Feet.*
Unknown	610	610
Shale, sandy	53	663
Sandstone; some water	68	731
Flint	11	742
Sandstone	6	748
Limestone	35	783
Soapstone	22	805
Limestone	2	807
Soapstone	3	810
Limestone	278	1,088
Soapstone	57	1,145
Limestone	15	1,160
Shale, blue	15	1,175
Limestone	65	1,240

The following samples of the drillings were submitted:

Record of strata in well at Corydon.

	Thickness.	Depth.
	Feet.	*Feet.*
Sandstone, fine, grains imperfectly rounded; and limestone, light gray, rapid effervescence	6	748
Chert, white, and limestone, blue gray		770
Limestone, drab, fine granular; moderately rapid effervescence	2	807
Chert, blue gray, and limestone of same color, rapid effervescence		810
Limestone, light gray, soft; rapid effervescence	14	835
Limestone, brown, hard; with brown flint	6	841
Limestone, blue-gray, soft; in flaky chips	4	854
Limestone, gray, soft, cherty		875
Shale, blackish, bituminous	3	898
Limestone, cream-colored, macrocrystalline; much white chert		906
Limestone, light blue-gray; with white chert	7	925
Limestone, light yellow, macrocrystalline; rapid effervescence	3	928

In this section, the base of the Pennsylvanian may be drawn at 731 feet from the surface, 379 feet above sea level. The shales from 1,088 to 1,175 feet are similar in position to shales at Centerville which are referred to the base of the Mississippian and, like them, include an intercalated limestone. The shales at Centerville, however, lie somewhat lower than those at Corydon. Whether the footing of the drill hole is in the Devonian or in the Mississippian, it is certain that it was not carried far enough to reach the Silurian water bed tapped at Centerville, to say nothing of the Ordovician sandstone aquifers. If the shales referred to are the same as those of the basal Mississippian at Centerville the Silurian sandstones would have been encountered within 250 feet of the bottom of the well. The general dip of the strata would indicate a probable depth from the surface to the St. Peter sandstone of about 2,050 feet. But the upwarp of the Ordovician strata in southeastern Iowa and northeastern Missouri may extend farther to the west than is now supposed and the St. Peter may lie 200 feet higher than the estimate.

The 501-foot well at Humeston is reported to have cost $850 and the pump for it $150. The Corydon well is reported by Mr. Rea to have cost $3,000 and the pump $450. All things taken into consideration, the prospects for water below the bowlder clay are not encouraging. The meager yield and poor quality of water that are to be expected, together with the uncertainties involved, would not seem to warrant the necessary expense except perhaps where urgent necessity exists.

HEAD.

The surficial drift layer is so imperfectly pervious that the water level conforms closely to the surface, the water in a shallow upland well commonly standing high above a near-by valley. But the head from the lower aquifers approximates more closely to the valley level. In the deep well at Corydon the water rises to a level 114 feet below the surface or to a point about 990 feet above the sea; and in the deep creamery well at Humeston it rises to a point about 100 feet below the surface, perhaps not far from 1,000 feet above the sea. At Seymour (NW. ¼ NW. ¼ sec. 24, T. 68 N., R. 20 W.) a flowing well 87 feet deep discharges water rich in sulphates at the rate of about a gallon a minute. In a deep valley west of Lineville and south of the State line a well that ends in the Pennsylvanian once overflowed. (See Decatur County).

CITY AND VILLAGE SUPPLIES.

Corydon.—The deep well at Corydon (population, 1,669) is pumped to a 75,000-gallon supply tank and a 50,000-gallon reserve cistern. Connections are now (1912) being made. The water is mineralized and is said to be beneficial.

Minor supplies.—Aside from the plant at Corydon, Wayne County has no system of waterworks, although it contains several villages of considerable size. The problem of procuring a satisfactory public supply is difficult. Shallow wells yield supplies that are too small and unreliable; deep drilling is expensive, involves considerable uncertainty and, at best, will furnish water that is objectionable because of its mineralization; and reservoirs in which the wash from rains is collected are likely in the course of time to receive poor care, so that the water will be unfit for drinking or household use.

Though it is not generally possible to extract much water from a single shallow well, a much larger quantity could be obtained from a series of such wells. A large number of these could be bored at a moderate cost and they could all be connected at the bottom with horizontal pipes, so that a pump operating at one would draw from all. (See p. 910.) It seems probable that adequate supplies for most of the villages could in normal years be obtained in this way, but a shortage might occur in seasons of drought.

CHAPTER XIV.

NORTHWEST DISTRICT.

INTRODUCTION.

By W. H. Norton.

The northwest district includes 19 counties—Buena Vista, Calhoun, Carroll, Cherokee, Clay, Crawford, Dickinson, Emmet, Ida, Lyon, Monona, O'Brien, Osceola, Palo Alto, Plymouth, Pocahontas, Sac, Sioux, and Woodbury. Over this area the heavy mantle of drift has in few places been cut through by stream erosion and rock outcrops are rare. Below the clays and sands of the drift lie the shales and soft sandstones of the Cretaceous, which rest with marked unconformity on older terranes. The Carboniferous strata, on whose beveled edges the Cretaceous formations in most places rest, are prevailingly shaly, and the shales of these two series of rocks can be distinguished with difficulty when they are ground to powder by the drill. Another unconformity probably separates the Carboniferous from the older formations of the Paleozoic. The earlier Paleozoic strata strike northeast and southwest and dip southeast, the younger giving place westward to more ancient rocks.

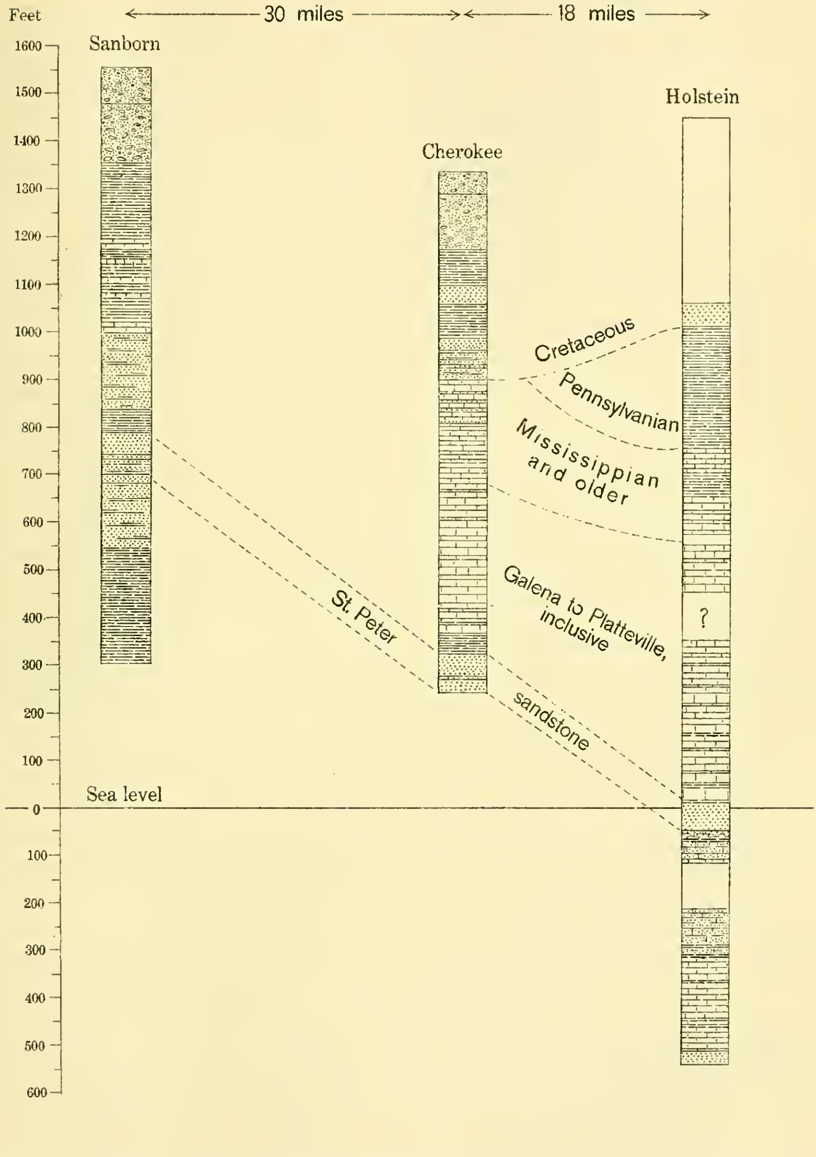
From Emmetsburg to Fort Dodge the St. Peter sandstone descends 874 feet in 48 miles, or at the rate of a little more than 18 feet to the mile. (See Pl. XVI, p. 672.) From Sanborn to Cherokee and Holstein its dip is 16 feet to the mile. (See Pl. XVII.) From Holstein to Dunlap, if the formation is rightly distinguished at Dunlap, its dip is somewhat less than 10 feet to the mile.

In the extreme northwestern sections of Lyon County the Sioux quartzite outcrops. This is the most ancient rock exposed to view in Iowa and is referred to the Algonkian. Its surface sinks rather steeply toward the south and east from its outcrops in Lyon County.

On the whole, conditions appear to be somewhat favorable for artesian wells over a large part of northwestern Iowa. The successful well at Jefferson, just southeast of this area, suggests that deep wells in the southeastern counties of this district might obtain satisfactory supplies. The deep wells at Sanborn, Cherokee, and Holstein (Pl. XVII) carry the favorable forecasts to the counties of the second tier east of Missouri River, where the Ordovician and Cambrian sandstones may be found within drilling distance of the surface and will probably yield sufficient water for municipal supplies. A deep well at Emmetsburg, in the northeastern part of the district, was not successful. For the western tier of counties the forecast is far less favorable (p. 825).

The St. Peter and the subjacent formations enter northwestern Iowa from the east under their normal facies. At Holstein, where the drill hole was sunk about 550 feet below the summit of the St. Peter, the samples preserved from below that formation indicate about 200 feet of the arenaceous dolomites of the Prairie du Chien group, underlain by about 250 feet of the St. Lawrence formation and 35 feet of sandstone referable to the Dresbach, the latter extending to the bottom of the well. At Le Mars (Plymouth County) the deep well affords no evidence of the strata penetrated between the base of the Cretaceous at 810 feet above sea level and the pre-Cambrian gneiss at 215 feet above sea level, except two sandstones reported at about 400 and 300 feet above sea level. (See Pl. VI, p. 258.) If the upper of these sandstones is the St. Peter, the combined thickness of the subjacent terranes to the base of the Cambrian is only about 200 feet. At Sanborn (O'Brien County) a sandstone is reported at 787 feet above sea level, and below this lie nearly 450 feet of "shales, blue and green, mixed with sandstone" and "shales, green and white." This sandstone may be the St. Peter or the Jordan, the shaly nature of the subjacent bed rather favoring the latter reference. At Sioux City (Woodbury County) minute-grained, calciferous sandstones and marls, prevailingly glauconiferous, extend from the fundamental schists upward for about 250 feet. These have the appearance of the St. Lawrence formation. At 155 feet above sea level occurs a white sandstone which, like that at Sanborn, may be either the St. Peter or the Jordan.

Of the formations above the St. Peter, the Decorah shale and the Platteville limestone cross the entire eastern area of northwestern Iowa in full force and continue at least as far west as Cherokee. They are succeeded upward by heavy dolomites, which no doubt include the Galena, and may also include the Maquoketa and the formations of Devonian and Silurian age. These dolomitic beds measure about 300 feet at Cherokee and may exceed 500 feet at Holstein. At Sanborn they are not mentioned in the driller's log, but at Sioux City dolomites, largely cherty, occupy at least 300 and possibly 400 feet of the section above the Ordovician and Cambrian sandstones and glauconiferous shales. Though these dolomites at Sioux City may belong to the Prairie du Chien group, their reference to the higher terranes is more in accordance with the supposed general stratigraphy of the area. At Jefferson all the samples of drillings for 650 feet above the shale of the Platteville and the Decorah shale are of dolomite or magnesian limestone. These limestones carry artesian water in other districts of Iowa, but practically nothing is known of their capacities here.



GEOLOGIC SECTION BETWEEN SANBORN AND HOLSTEIN, IOWA
By W. H. Norton

THE NORRIS PETERS CO., WASHINGTON, D. C.

In the counties bordering on Missouri River, so much difficulty is felt in making artesian forecasts that general statements must suffice. The chief water-bearing strata are hundreds of miles from their nearest outcrops in the State in the eastern counties bordering Mississippi River, and though they have been carefully traced from one deep well to another far to the west the deep wells of western Iowa are so few, and so little is known of them and the line of stepping stones is so broken that little more than general stratigraphic considerations remain for guidance and support. Fortunately artesian water may be found in the Cretaceous sandstones under the drift, so that the question of a deeper supply is not so pressing as it otherwise would be.

In Lyon, Sioux, and Plymouth counties the Sioux quartzite and pre-Cambrian schists underlie the region at depths rapidly increasing southward and eastward. Unquestionably above these pre-Cambrian rocks lie the older Paleozoic rocks, but their lithologic nature is largely a matter of conjecture and it is possible that in these counties they contain few or even no beds so constituted as to carry artesian water in considerable quantities. At Sioux City, for example, the well of the Sioux City Water Co. penetrated the Paleozoic rocks to a depth of at least 700 feet, but failed to find artesian water in paying quantity. The deep well at Hull found water below 700 and 800 feet, and the supply was stated to be unlimited, but Mr. Meinzer was informed that the casing of the well had been cut at about 350 feet from the surface and that most of the water of the well came from this horizon in the country rock, a statement which finds some support in the head of the well as compared with those of other wells in the Cretaceous of the vicinity. The texture of the saccharoidal sandstones found at Hull at 755 feet to 1,263 feet would allow them to yield copiously, but at Hull they are interbedded with impervious sills. Outside the area of these igneous intrusions, an area that is probably small, these sandstones, if not indurated, may yield artesian water. Thus wells drilled below the Dakota sandstone in these three counties may be considered experimental. The geologic conditions are not strongly adverse to such experiments, but the two or three deep wells already sunk do not encourage them.

In Woodbury and Monona counties the Paleozoic rocks are no doubt thicker than they are in the northern counties bordering the Big Sioux and the possibility that they may include water beds is greater. The general geology of the deeper strata, so far as it can be inferred, is somewhat encouraging to deep-well digging in eastern Monona and Woodbury counties, but all artesian wells must be largely experiments and can not be definitely recommended. The lower Paleozoic water beds, if found, should occur at Onawa above 600 feet below sea level or within 1,650 feet of the surface, and a well of this depth should be sufficient to test possibilities at this station.

BUENA VISTA COUNTY.

By O. E. Meinzer.

TOPOGRAPHY AND GEOLOGY.

The surface of Buena Vista County consists essentially of a gently undulating drift plain containing numerous undrained depressions, the largest of which is occupied by Storm Lake. This plain ranges in altitude from less than 1,300 feet above sea level, in the southeast, to more than 1,500 feet in the vicinity of Alta. The only striking break in the topography is caused by Little Sioux River, which enters from the north and flows westward near the county line for some miles, occupying a gorgelike valley over 150 feet deep.

Beneath the thick and continuous mantle of glacial drift lies a stratified series of shales, sandstones, and limestones, supposed to be Cretaceous in age. (See Pl. VI, p. 258.)

UNDERGROUND WATER.

SOURCE.

The water supply of Buena Vista County is drawn chiefly from alluvial deposits, the surficial portions of the glacial drift, sand in the deeper portions of the glacial drift, and Cretaceous sandstone. The alluvial deposits are practically confined to the valley of the Little Sioux in which they supply shallow wells; the surficial portions of the drift are penetrated by several thousand shallow bored wells, most of which yield only small supplies and many of which fail in dry seasons; the sand deposits in the deeper portions of the drift are reached by many drilled wells; and the Cretaceous strata have apparently been entered in a few places. Beneath these formations are other water-bearing formations not yet reached by the drill in this county, but some knowledge as to what is to be expected from these sources can be gained from the deep wells in the surrounding towns of Mallard, Emmetsburg, Sanborn, Cherokee, and Holstein.

The only source of water below the surficial deposits and within reach of ordinary drilling consists of beds of incoherent sand. In times of severe drought the shallow wells on many farms failed and wells were drilled to these beds of sand, but they proved so unsatisfactory that most of them have been abandoned and reliance again placed upon shallow wells. The water is under low head, is highly mineralized, and is separated from the fine-grained and incoherent sand with great difficulty. Screens of fine mesh have been used, but the sand packs around these and becomes firmly cemented by precipitates from the water, and thus effectually closes the inlets, compelling the substitution of new screens or the abandonment of the wells. This incrustation has given so much trouble in so many wells that it has been generally concluded that the deeper sand strata are not practicable sources of water supply. These deeper sources are, however, greatly needed, and much of the failure in the past has been due to improper methods of drilling and finishing the wells. For the most part, 2-inch "tubular" wells have been sunk and the pump valves have been fitted into the casing itself. For several reasons (see pp. 192–193) wells of this type are ill adapted to the conditions found in this region. Six-inch wells should be drilled and fitted with independent pumps. Then if the water is lifted slowly—for example, at the rate at which a windmill operates—the suction will be slight and regular, and in many wells screens can be dispensed with. But even where screens are found necessary, they are likely to last longer, and they can be drawn up with less difficulty through the large casing.

HEAD.

In general the water does not rise so near the surface in the deepest drilled wells as in those that end at higher levels. Owing to the indefinite character of the well data it is impossible to state to what extent the wells having low head are to be correlated with the Cretaceous sandstone and those having a higher head with the drift, but it seems evident that water from the Cretaceous rises to approximately 1,200 feet above sea level and water from most of the moderately deep drift beds rises much higher. In the following table the wells of the first group are believed to have a head of about 1,200 feet and those of the second group a higher head, but the head of the farm wells is uncertain because the surface altitude is not definitely known.

Head of water in and near Buena Vista County.

Location.	Altitude of surface above sea level.	Depth of well.	Height to which the water rises.	
			Above or below surface.	Above sea level.
GROUP 1.	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Fonda (Pocahontas County)	1,234	331	+ 14	1,220
Aurelia (Cherokee County)	1,387	301	−190	1,197
Peterson (Clay County)	1,238	90	− 30	1,208
T. 90 N., R. 35 W. (Newell):				
Newell	1,264	285	− 65	1,199
T. 93 N., R. 36 W. (Lee):				
S. ½ sec. 2	....	417	−160	....
NE. ¼ sec. 5	....	320	− 60	....
T. 92 N., R. 38 W. (Elk):				
SE. ¼ sec. 34	....	338	−285	....
T. 91 N., R. 38 W. (Nokomis):				
SE. ¼ sec. 28	....	330	−270	....
SE. ¼ sec. 35	....	360	−300	....
T. 90 N., R. 38 W. (Maple Valley):				
SW. ¼ sec. 1	....	350	−290	....
SW. ¼ sec. 25	....	360	−280	....
SE. ¼ sec. 29	....	300	−240	....
GROUP 2.				
Rembrandt creamery well	1,335	280	− 65	1,270
T. 93 N., R. 35 W. (Poland):				
Marathon village well	1,394	161	− 74	1,320
T. 91 N., R. 37 W. (Washington):				
SE. ¼ sec. 30	....	216	....	....

CITY AND VILLAGE SUPPLIES.

Alta.—The public water supply of Alta (population, 959) is pumped from two dug wells, 80 feet deep, one 8 feet and the other 3 feet in diameter. It is distributed by gravity from a tank elevated upon a tower. About 9,000 gallons are said to be used daily and this is nearly the maximum yield of the wells. The inhabitants rely chiefly on shallow bored wells, many of which yield small and uncertain supplies.

Marathon.—The following section of the village well at Marathon (population, 532) was furnished by the driller:

Section of village well at Marathon.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and yellow clay; blue clay	70	70
Sand	10	80
Clay, blue	70	150
Sand	11	161

The water is reported to rise within 74 feet of the surface, or 1,321 feet above sea level, and the well has been pumped continuously for 8 hours at the rate of 100 gallons a minute. The waterworks consist of an air-pressure system with 1⅛ miles of mains, 6 fire hydrants, and 17 taps. Only a small portion of the people use the public supply and only about 2,000 gallons are consumed daily.

Newell.—The public supply for Newell (population, 728) is pumped from a drilled well, 285 feet deep, into an elevated tank, from which it is distributed by gravity through approximately 1 mile of mains. There are 14 hydrants. The daily consumption of water is estimated at 12,000 gallons.

Sioux Rapids.—The public supply of Sioux Rapids (population, 868) is obtained from a well 10 feet in diameter and 27 feet deep, sunk into the gravel of the river bottom. The water is pumped to an elevated tank from which it passes to the mains. There are 15 fire hydrants. The average daily consumption is reported to be about 30,000 gallons.

Storm Lake.—The public supply of Storm Lake (population, 2,428) is taken from the lake, from which it is pumped into a standpipe and is thence carried by gravity through about 5 miles of mains to 28 fire hydrants. The water is used extensively in boilers and for various other purposes and is led through private pipe lines to several farms near the city. The culinary supplies are obtained chiefly from shallow private wells.

According to Norton a deep well drilled at Storm Lake would first pass through the drift clays and sands, then through heavy beds of

Cretaceous shales and sandstones, and possibly through still lower shales of the coal measures (Carboniferous), below which it would have a long run through limestones. After penetrating the shales of the Platteville limestone (which may need casing) the drill would enter the St. Peter sandstone at about 120 feet above sea level, or about 1,300 feet below the surface. To obtain the largest yield the well should be sunk to about 1,700 feet below the surface, at which depth it should tap the Jordan sandstone, if that formation preserves its identity so far to the west. On account of the high surface elevation, no flow can be expected, but the water should rise within pumping distance.

CALHOUN COUNTY.

By W. J. Miller and W. H. Norton.

TOPOGRAPHY AND GEOLOGY.

Calhoun County presents a level surface over which many ponds are scattered. The only important stream that modifies this flat topography is North Raccoon River, which cuts across the extreme southwest corner of the county, receiving from the north Camp and Lake creeks, much smaller streams.

Wisconsin drift covers the entire region, resting on the Kansan drift, which presumably also extends throughout the county. Except in a narrow strip on the eastern edge of the county occupied by the Des Moines group (Carboniferous), the drift rests on Cretaceous rocks.

The drift deposits lie horizontally on the rocks, which in turn either lie flat or dip slightly eastward. (See Pl. VI, p. 258.)

UNDERGROUND WATER.

SOURCE.

In Calhoun, as in the neighboring counties, there are two important water beds in the drift, one at the base of the Wisconsin drift and the other at the base of the Kansan drift. A large number of wells obtain good supplies of hard water from the drift and are as a rule so satisfactory that comparatively few wells go into the rock formations below.

The available data show that the sand or gravel at the base of the Wisconsin drift has not been struck at a depth of less than 45 feet and that in all but a few localities it is more than 160 feet below the surface. Though most of the wells of the county derive water from this source, it does not everywhere yield water and in places the supply is not satisfactory.

The sand or gravel lying at the base of the Kansan drift almost invariably affords a good supply of water, seemingly unaffected by the seasons. Well records show that this aquifer has not been struck at a depth of less than 108 feet or more than 280 feet, the most common depth being from 200 to 230 feet. Occasionally a good water supply is obtained from local sandy layers in one of the blue clays. Some deep wells have obtained water from shales, sandstones, and limestones of the Cretaceous and older rocks.

Only two flowing wells have been noted in this county, one near Somers and the other near Lohrville. Both are situated near small streams or slough bottoms. The horizon from which the water comes is not known.

SPRINGS.

Springs of any consequence are very scarce in Calhoun County. A few seep from the drift along the sloughs.

CITY AND VILLAGE SUPPLIES.

Lake City.—The public water supply of Lake City (population, 2,043) is taken from two wells 229 feet deep. The water is pumped to a standpipe and distributed under gravity pressure of 30 pounds to 172 taps. About 35,000 gallons is used daily by 600 people. The water is hard. The driller's log of these wells shows the following section:

Driller's log of Lake City well.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil, black	4	4
Clay, yellow	20	24
Clay, blue	36	60
Sand (water)	6	66
Clay, blue	20	86
"Hardpan"	6	92
Clay, hard	18	110
Clay, yellow; hard blue clay; fine sand (water)	119	229

The chief water beds of the Iowa artesian system lie deep below Lake City, the uppermost, the St. Peter sandstone, hardly less than 300 or 350 feet below sea level, or from 1,550 to 1,600 feet below the surface. As the Paleozoic limestones overlying the St. Peter yield more or less water a well 1,700 feet deep might obtain an adequate supply, but to get the largest supply a well 2,000 feet deep may be necessary and any contract for a deep well should provide for a depth of 2,200 or 2,300 feet.

In sinking such a well below the drift the drill will pierce Cretaceous and Carboniferous shales. The quality of any waters found in accompanying sandstones should be tested, as they may be so heavily impregnated with various mineral substances as to make it desirable to case them out. In the Mississippian limestone and the dolomites which extend thence downward to the shales of the Platteville limestone some water of fair quality should be had under good head; but the main supply is to be looked for in the St. Peter sandstone and the creviced dolomites and porous sandstones underlying it.

Lohrville.—The town well of Lohrville (population, 674), 180 feet deep, furnishes a good supply of hard water. The water is pumped to a tank, from which it is distributed under gravity pressure of 35 pounds through one-fourth mile of mains to 20 taps and 5 fire hydrants. About 3,100 gallons is supplied daily to 100 persons. No log is available.

Manson.—The public supply of Manson (population, 1,236) is obtained from a well 1,250 feet deep, put down in 1905 by J. F. McCarthy, of Minneapolis. (See Pl. VI, p. 258.) The well is cased with 10-inch pipe to 290 feet, 8-inch pipe to 834 feet, and 6-inch pipe to 1,250 feet. The curb is 1,245 feet above sea level and water stands 25 feet below curb. The tested capacity, original and present, is 300 gallons a minute. Water comes from 1,250 feet (according to another report from 1,050 feet) and from other depths unrecorded. The temperature of the water is 56° F. The water is pumped through 3 miles of mains to 25 fire hydrants and 75 taps. Domestic pressure is 50 pounds and fire pressure 80 pounds. About 400 persons are supplied daily. The daily consumption is 30,0C0 gallons. The water is said to be soft.

Driller's log of Manson city well (Pl. VI, p. 258).

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and yellow clay	23	23
Clay, blue	187	210
Gravel and water	3	213
Clay, blue	97	310
Shale or slate; some hard; some soft; some red	740	1,050
Sandstone	170	1,220
Shale, red	30	1,250
Granite-like rock.		

A citizen of the town asserts that no rock of any kind was struck until the drill reached a depth of 1,050 feet, when it entered porous sandrock, from which water flowed in immense volume. Another citizen who had much to do with the well attempts to support the theory that this sandstone is the St. Peter by stating that it was "as hard as flint and as white as snow, and ground up into fine dust or powder." The driller states that he believes "that it was the true quartz rounded white sand rock."

Literally construed this log would revolutionize the current conception of the deep geology of the region. Although but 18 miles distant from Fort Dodge, Manson is reported to find a heavy sandstone 600 feet higher than the first sandstone at Fort Dodge—the St. Peter. The St. Peter undoubtedly rises from Fort Dodge toward Manson, but according to the average dip from Cherokee to Fort Dodge the St. Peter would not be encountered at Manson within 1,500 feet of the surface—450 feet below the summit of the sandrock of the Manson well.

If there are no local sharp deformations of the deep-lying strata in this region the aquifer at Manson is Silurian or Ordovician (Galena). Dolomites from these formations are not infrequently termed sandrock, because of the sparkling crystalline sand to which they are crushed by the drill. The description of the Manson water bed as "a rock hard as flint" in no way fits the St. Peter, which is uniformly one of the softest of rocks, but seems to point to cherty layers that occur in both the Silurian and the Galena.

As to the granite-like rock at the bottom of the well, it is improbable that any deformation exists in this area sufficient to bring the floor of crystalline rocks so near the surface. The sample of this granite submitted for examination was a granitic pebble of glacial drift, about 3 inches in diameter.

The Manson well, with its exceptionally large supply of water of unusual softness and high head and its exceedingly peculiar log, emphasizes the need and value of keeping samples of the cuttings at frequent intervals as the well is drilled. There are few localities where the lack of such information is more severely felt.

If the well should fail and repairs should prove ineffectual, a larger supply may be obtained by sinking the well deeper. Assuming an uninterrupted dip of the terranes from Cherokee to Fort Dodge, the St. Peter sandstone lies about 250 feet below the bottom of the drill hole. Drilling not only to the St. Peter but also to the sandstones of the Prairie du Chien group and the Jordan sandstone should give an inexhaustible supply within 1,900 feet of the surface.

Pomeroy.—The public supply of Pomeroy (population, 815) is obtained from a well 149 feet deep, from which it is pumped by direct pressure (air) through 1½ miles of mains serving 40 taps and 20 fire hydrants. The domestic pressure is 40 pounds and fire pressure 60 pounds. About 300 persons use the city supply. The daily consumption is 9,000 gallons. The water is rather hard. The strata penetrated by this well are indicated by the following log:

Driller's log of Pomeroy town well.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil, black	3	3
Clay, yellow	12	15
Clay, blue	20	35
Sand (some water)	1	36
Clay, blue	45	81
Clay, yellow	15	96
Clay, blue	36	132
Sand and gravel (water)	17	149

Rockwell City.—Rockwell City (population, 1,528) owns two deep wells—one 1,475 and the other 950 feet deep. The water is pumped to a standpipe, from which it is distributed under gravity pressure of 40 pounds domestic and 75 pounds fire through 2.6 miles of mains to 70 taps and 19 fire hydrants.

The 950-foot well, which until lately supplied the town and two railways, is 12 inches to 6¼ inches in diameter and is cased with 10-inch pipe to 264 feet, 8⅝-inch pipe to 355 feet, and 6¼-inch pipe to 490 feet. The water stands 200 feet or more below the curb and has been pumped at rate of 105 gallons a minute. The well was completed in 1904 by J. P. Miller & Co., of Chicago.

Driller's log for city deep well No. 1 at Rockwell City.

	Thickness.	Depth
	Feet.	*Feet.*
Drift	264	264
Shale and streaks of rock, caving	91	355
Lime, hard, and shale, caving	135	490
Lime, hard	160	650
Lime, shaly	200	850
Lime, hard	91	941
Shale, sandy, to bottom of well	9	950

The deeper well was completed in 1910. The geologic section, so far as it can be made out from the samples saved, is as follows:

Record of strata, city deep well No. 2, Rockwell City.

	Thickness.	Depth.
Quaternary (161 feet thick; top, 1,223 feet above sea level):	*Feet.*	*Feet.*
Soil	2	2
Clay, yellow, sandy	20	22
Till, blue	133	155
Till, light yellow	6	161
Carboniferous:		
Pennsylvanian (160 feet thick; top, 1,062 feet above sea level):		
Shale, dark drab	90	251
Sandstone, white; grains very imperfectly rounded; calcareous cement; much pyrite	3	254
Shale, blackish	50	304
Shale, dark drab, pyritiferous	5	309
Shale, light drab	12	321

Record of strata, city deep well No. 2, Rockwell City—Continued.

	Thickness.	Depth.
Carboniferous—Continued.		
Mississippian (499 feet thick; top, 902 feet above sea level):		
Dolomite, dark buff, with finely disseminated white silica in granules; also dolomite, blue-gray, hard, compact, in larger chips	*Feet.* 194	*Feet.* 515
Dolomite, dark, buff, coarse crystalline-granular	85	600
Shale, light blue, calcareous but nonmagnesian, pyritiferous; also much buff and drab dolomite, in chips	220	820
Devonian and Silurian (160 feet thick; top, 403 feet above sea level):		
Limestone or dolomite; rather slow effervescence; light buff, fine crystalline-granular, in small chips	73	893
Dolomite, light yellow-gray; in sand	7	900
Dolomite, buff; in small chips; crystalline granular	80	980
Limestone, dark-blue gray; slow effervescence; rather small argillaceous residue; some hard green shale and well-rounded grains of quartz, at		980
Ordovician (495 feet penetrated; top, 243 feet above sea level):		
Galena dolomite and Platteville limestone:		
Dolomite, brown, crystalline	50	1,030
Dolomite, brown, fine-grained, compact	110	1,140
Dolomite, light blue gray, saccharoidal, cherty	50	1,190
Dolomite, light yellow, in fine crystalline sand	75	1,265
Dolomite, buff, granular crystalline	30	1,295
Dolomite, cream colored, in fine sand	43	1,338
Limestone, whitish, rapid effervescence	75	1,413
Shale, greenish, facies of the Decorah shale	59	1,472
St. Peter sandstone:		
Shale, sand, white, with much brown bituminous shale in drillings	5	1,475

Analyses of drillings from city deep well No. 2, Rockwell City.[a]

	1	2	3
$CaCo_3$	56.583	69.608	57.742
$MgCo_3$	41.189	21.416	32.187
SiO_2	.857	6.987	6.841
Fe_2O_3 and Al_2O_3	.877	1.893	3.140
H_2O	.109		
	99.615	99.904	99.910

[a] Made in chemical laboratory of Cornell College, Iowa.

1, Stratum at depth of 515 to 600 feet; 2, stratum at depth of 1,190 to 1,202 feet; 3, stratum at depth of 1,265 to 1,295 feet.

It had been estimated that the St. Peter sandstone would be found at 300 feet below sea level (1,525 feet below the surface). In May, 1910, the formation was reached at 1,472 feet below the surface.

Somers.—The Chicago Great Western Railway track well at Somers (population, 169) has a depth of 1,483 feet and diameters of 12 inches to 152 feet, 10 inches to 200 feet, 8 inches to 339 feet, and 6 inches to bottom; casing to 660 feet. The curb is 1,157 feet above sea level, and the head 60 feet below the curb. The capacity is 100 gallons a minute, the water coming from 1,000 to 1,200 feet (small amount) and from 1,470 feet (main flow). The well was completed in 1904 by C. A. Stickney, of St. Paul. Two sets of samples of the drillings have been examined, one having been sent to the United States Geological Survey at Washington and one directly to the senior writer by a contractor. The two are conflicting and several of the labels are evidently incorrect.

Record of strata in railway well at Somers.

	Depth in feet.
Till (U. S. Geol. Survey sample): Limestone, yellow; slow effervescence; hard, dark drab, calcareous and siliceous shale, all in fine sand	60
Limestone, gray; slow effervescence	70
Till, blue (U. S. Geol. Survey)	76
Till, blue (U. S. Geol. Survey): Limestone, light buff; slow effervescence; much white chert	106
Shale, dark, carbonaceous (U. S. Geol. Survey); limestone, crystalline, light yellow gray, hard; slow effervescence	155
Shale, blue (U. S. Geol. Survey); limestone, light buff, hard; slow effervescence	210
Shale, dark drab, carbonaceous (U. S. Geol. Survey); shale, blue, noncalcareous, pyritiferous, minutely arenaceous	220
Dolomite, buff, porous, crystalline, in sand at 508, 520, and	566
Limestone, gray, cherty; slow effervescence	680–689
Dolomite, crystalline; gray; much white and gray chert and some rather fine rounded grains of quartz sand	1,315
Dolomite, buff; much white chert	1,320
Dolomite, drab and white; a few grains of quartz sand	1,335
Dolomite, buff; with white chert	1,340
Dolomite, light yellow gray (U. S. Geol. Survey); shale, dark drab, black when wet, apparently from coal measures and evidently misplaced	1,345
Dolomite, white, crystalline; in fine sand	1,350
Dolomite, buff	1,355
Dolomite, white and gray; 1,360 and	1,365
Dolomite, light gray; with white shale	1,370
Dolomite, light yellow	1,375
Dolomite, gray (U. S. Geol. Survey); limestone, light yellow, rapid effervescence, compact, earthy luster; some lithographic with conchoidal fracture, probably misplaced	1,380
Dolomite, light yellow, crystalline	1,385
Dolomite, light gray (U. S. Geol. Survey); drab till, evidently misplaced	1,390
Marl, light pinkish yellow; large residue of cryptocrystalline and crystalline quartz particles	1,395
Dolomite, buff; cherty, at 1,400, 1,410, and	1,415
Dolomite, light and dark gray	1,420
Marl; as at 1,395 feet	1,425
Dolomite, white, gray, and buff; some chert; 6 samples	1,430–1,470

It may be added that the driller who had charge from 660 feet to the completion of the well reports that for this distance the drill appeared to be working in one solid mass of hard "limerock." The dolomites from 1,315 to 1,470 feet evidently belong to the Galena. (See Fort Dodge section, pp. 759–760.)

WELL DATA.

The wells listed in the following table may be considered typical for the county:

Typical wells of Calhoun County.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head below curb.	Remarks (logs given in feet).
		Feet.	*Feet.*		*Feet.*	
Frank Casey	4 miles southwest of Manson.	162	......	Sand	20	Bored well, 12 inch. Black soil, 3; yellow clay, 22; sand (some water), 6; blue clay, 129; sand and water, 2; no rock.
G. Haney	2 miles north of Rockwell City.	125	......	...do	40	Bored well, 22 inch. Black soil, 3; yellow clay, 15; blue clay, 106; sand and much water, 1; no rock.
Sam Ness	3 miles northeast of Somers.	300	230	Sandstone	90	Black soil, 4; yellow clay, 20; blue clay, 106; gravel (no water), 5; blue clay, 93; sand, 2; sandstone (water at bottom), 70.
Henry Arnold	2½ miles east of Manson.	196	......	Sand and gravel.	60	Black soil, 3; yellow clay, 17; blue clay, 60; sand (no water), 3; blue clay, 107; sand and gravel and water, 6; no rock.
Charles Dunnonn.	1½ miles south of Manson.	223	......	Gravel	20	Black soil, 3; yellow clay, 15; blue clay, 60; yellow clay, 25; blue clay, 65; clay (harder), 50; "hardpan"—hard clay, 1; gravel (water), 4; no rock.
J. D. Hunt	½ mile east of Manson	198	......	......	17	Water in rock (?) at base.
Moody & Davey	½ mile south of Jolley	145	129	Shale (?)	22	
R. S. Middleton.	2 miles south of Lohrville.	53	......	Gravel	15	No rock.
George Linvillinger.	5 miles east-northeast of Lake City.	209	......	...do	100	Black soil, 3; yellow clay, 10; blue clay, 62; sand and gravel (dry), 75; yellow clay, 4; sand and gravel (dry), 46; sand and gravel and water, 9; no rock.
—— Workman.	3 miles south-southeast of Lake City.	126	......	...do	60	No rock.

CARROLL COUNTY.

By W. J. Miller and W. H. Norton.

TOPOGRAPHY.

Carroll County comprises two topographic provinces, separated by a line extending from the northwest to the southeast corner. The line of separation is, however, not sharp. The southwestern area is made up of low rounded hills and intervening valleys like those in Crawford County lying to the west, and it is crossed by the high land of the Iowa divide. It is cut by many small streams, of which Brushy Creek, on the east side, is the largest. The northeastern area is primarily a flat country, poorly drained except in the vicinity of the main waterways and showing only very broad, gentle undulations; North Raccoon River crosses its northeastern corner and Middle Raccoon River flows along its western border. Branching streams are few.

GEOLOGY.

The loess covers half of the county, but thins eastward. In the southwestern half of the county it rests everywhere on Kansan drift. Wisconsin drift extends over all of the northeastern half and causes the level land of that region. The Kansan drift, under the loess or under the Wisconsin, is spread over the whole county. The drift is exceedingly thick in the western part along the Iowa divide and gradually becomes thinner toward the east. Rocks of Cretaceous age, lying flat or dipping very gently eastward, everywhere underlie the Kansan drift. (See Pl. XI, p. 382.)

UNDERGROUND WATER.

SOURCE.

At least three well-defined water horizons are found in the drift deposits of Carroll County—one in sand or gravel just below the loess at depths ranging from 10 to 50 feet below the ground surface; one in sand and gravel beneath the Wisconsin drift at depths ranging from 70 to 150 feet; and the third in sand or gravel just below the blue clay of the Kansan at depths ranging from 150 feet to 400 feet. The beds at the last-named horizon are the most widespread, persistent, and satisfactory, almost everywhere yielding water in large supplies, unaffected by seasons. The greatest depths to water are found in the western part of the county along the Iowa divide, where the drift is deepest. In some wells water has been struck in sandy layers within the blue clays of either the Wisconsin or the Kansan drift.

Little is known regarding the sources of water in the rock formations underlying the drift, but a few wells have been drilled through the thin Cretaceous beds, and derive their water from the upper coal measures (Missouri group).

In the loess-covered southwestern half of the county many dug wells obtain water from the sands and gravels below the loess and below the blue clay of the Kansan. In the northeastern half of the county, where Wisconsin drift overlies the Kansan, many drilled wells obtain water at the base of the Wisconsin and at the base of the Kansan.

In the northeastern area, especially toward the east side of the county from Lanesboro southward to Coon Rapids, the drift deposits, like the ground surface, slope gradually downward from the Iowa divide, and low ground along the stream courses affords conditions favorable for flowing wells. A number of such wells are found along North Raccoon River or Middle Raccoon River and its tributaries and on low land near them, where the head of water is great enough to cause overflow. The gathering ground for this water is probably on the higher land farther west. The water in most of these wells is thought to come from gravel under the blue clay of the Wisconsin at depths ranging from 25 to 130 feet according to location. Along Willow Creek, in the extreme southeastern part of the county, flowing wells are easily obtained at depths ranging from 25 to 40 feet.

SPRINGS.

In the eastern part of the county along the principal stream bottoms, such as North Raccoon River and Middle Raccoon River, are many small springs, most of them from the Wisconsin drift.

CITY AND VILLAGE SUPPLIES.

Carroll.—Carroll (population 3,546) is supplied from three wells 113, 116, and 120 feet deep. The water is pumped to a standpipe, whence it is delivered by gravity through 4½ miles of mains to 38 fire hydrants and 300 taps. Three thousand people use 150,000 gallons daily. The domestic pressure is 85 pounds and the fire pressure 100 pounds.

The drilling of a deep well at Carroll (elevation, 1,251 feet) is not discouraged, but it should be definitely understood that the quantity and quality of the water in the deeper rocks are not certain. Some water will be found in the drift, in the sandstone interbedded with the heavy shales of the Cretaceous and the Pennsylvanian, and in the underlying Mississippian limestones. Water should also occur in the dolomites (Galena), hundreds of feet thick, that intervene between the Mississippian and the Decorah shale. If the general attitude of the deep strata assumed for western Iowa prevails here, and there is no local deformation, the St. Peter sandstone lies about 400 feet below sea level, or 1,650 feet beneath the surface.

For a town the size of Carroll a well should be sunk through the St. Peter and the underlying creviced dolomites and porous sandstones, which as a rule yield far more generously. When the drill reaches any considerable thickness of glauconiferous shales or marls, drilling should be stopped. The water may be expected to belong to the sodic sulphated class. If the upper waters from the Cretaceous and Carboniferous are admitted to the well the water will probably be distinctly more highly mineralized.

Minor supplies.—Small village supplies are summarized in the table following:

Minor supplies in Carroll County.

Town.	Nature of supply.	Pumping system.	Distribution.	Pressure. Domestic.	Pressure. Fire.	Mains.	Fire hydrants.	Taps.	Persons supplied.	Daily consumption.
				Pounds.	*Pounds.*	*Miles.*				*Galls.*
Coon Rapids.	Well 90 feet deep.	Steam pump, double acting.	Gravity from tank.	40	(?)	1	15	40	350	12,000
Glidden......	2 wells 122 and 132 feet deep.	Gasoline engine and deep well pump.	Direct (air) pressure.[a]	20–70	70	1½	12	140	700	30,000–40,000
Manning.....	17 driven wells with sand points.[b]	Steam pump, double action.	Gravity from tank.	60–80	80+	1.1	18	161	1,200	30,000

[a] One tank in reserve for fire.

[b] One well dug for fire only.

WELL DATA.

The following table gives data of typical wells in Carroll County:

Typical wells of Carroll County.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head above or below curb.	Remarks (logs given in feet).
		Feet.	*Feet.*		*Feet.*	
J. Shrower.......	2 miles east of Arcadia.	400	360	Sandstone.......	− 75	Drift, 360; sandstone, 40.
Town............	Glidden..........	122	......	Sand............	− 76	Soil and yellow clay, 40; blue clay, 50; sand, 32; no rock.
Mrs. C. J. Brown.	7 miles southeast of Glidden.	175	......	Gravel and sand.	− 80	20-foot bed water-bearing sand at bottom. Gasoline engine pumps 90 gallons a minute. No rock.
O. C. Dutton.....	5 miles south, 2 miles east of Glidden.	426	175	....	......	Unsuccessful well. Black soil, yellow clay, blue clay, gravel (no water), 175; sandstone, 25; shale (hard and black) and sandstone layers, 218; coal, 8.
Chas. Stuteman..	5½ miles north, 2 miles west of Glidden.	316	......	Gravel..........	− 4	Flows through pipe out of side well. No rock.
M. J. Hieres......	1 mile northwest of Carroll.	435	......	Sand and gravel.	−100	8-foot sand bed at bottom. No rock.
W. Anderson.....	5 miles northeast of Arcadia.	400	(?)	Sandstone or cemented sand.	......	
H. Eklers........	6 miles south of Arcadia.	400+	......	Sandstone.......	......	Sandstone or consolidated sand.
Chicago & North Western Ry.	Carroll..........	158	......	Sand............	......	Steam pump for railway. No rock.
Mr. Kelly........	3 miles south of Lanesboro.	70	......	Gravel..........	......	Flows at elevation of several feet. Yellow clay and pebbles, gravel, 20; blue clay, 35; sand, gravel (water), 15; no rock.
Y. Moore.........	2 miles northeast of Lidderdale.	248	......	Gravel and sand.	− 40	No rock.
Mr. Arneal.......	¾ mile west of Lidderdale.	238	......	Sand............	− 40	Do.
G. W. Stout......	Coon Rapids......	250	......	Sand or sandstone.	−190±	Do.

CHEROKEE COUNTY.

By O. E. Meinzer and W. H. Norton.

TOPOGRAPHY AND GEOLOGY.

Cherokee County occupies a gently undulating upland plain, most of which is more than 1,300 feet above sea level and a part more than 1,400 feet. Intrenched in this upland is the valley of Little Sioux River, whose flood plain throughout most of its course is less than 1,200 feet above the sea.

The upland surface is covered by a thick layer of glacial drift, whose upper portion is somewhat yellowish and gravelly, but whose deeper portions consist chiefly of a denser and darker bowlder clay. In the valleys water-laid deposits of gravel, sand, and clay are found at the surface. Below the glacial drift is a stratified series of soft blue shale and poorly cemented sandstone, supposed to be Cretaceous in age, and below this are older sedimentary formations. (See Pls. VI, p. 258; XVII.) The Cretaceous strata have apparently been entered by the drill in a number of wells, and the underlying older formations have been deeply penetrated at the hospital for the insane at Cherokee, in a well sunk from the upland level to a depth of 1,070 feet.

UNDERGROUND WATER.

SOURCE.

The water supplies are derived from the alluvial sand and gravel, glacial drift, Cretaceous sandstones, and pre-Cretaceous sandstone (deep well at the hospital for the insane).

The alluvial sands and gravels are practically restricted to the valley of the Little Sioux, where they yield copious quantities of water, which is of excellent quality where the wells are protected from pollution.

The clay and gravel that constitute the upper layers of glacial drift are tapped by several thousand shallow wells and furnish nearly all of the water used for culinary, stock, or other purposes on the extensive upland tracts. The abundance and permanence of the supply from this source vary with different localities according to the amount of gravelly material and the depth at which it is found and also according to the topographic relations that determine the ease with which the water may be drained from these porous beds. Where conditions are favorable the supply is ample at all seasons, but where they are adverse serious difficulty is experienced during dry years. The wells are generally sunk in low places, the conditions being so local that radical differences are found in different parts of the same farm. The water is hard, but is otherwise generally of good quality.

A small number of drilled wells end in sand and gravel at or near the base of the drift, and most of these wells are giving satisfactory service. In some localities, however, water-bearing deposits have not been found in the deeper portions of the drift.

Only a few wells extend to the Cretaceous. Some of these are successful, but in others there is difficulty in separating the water from the fine incoherent sand. The water from this source rises to about 1,200 feet above sea level. Thus on the uplands it remains 200 feet, more or less, below the surface, but in the Little Sioux Valley in some places it overflows. It should not be supposed that because flows are obtained in the valley they can also be obtained by deep drilling on higher ground.

HEAD.

The following table gives approximate data as to the head of the water in some of the deepest wells in the county:

Table showing head of water in Cherokee County.

Description.	Altitude of surface above sea level.	Depth.	Height to which the water rises.	
			Above or below surface.	Above sea level.
	Feet.	*Feet.*	*Feet.*	*Feet.*
Aurelia village well	1,387	301	−190	1,197
Group of farm wells near Aurelia	1,390±	300–375	−190±	1,200±
Three Cherokee city wells	1,180	165–200	+0	1,180
Two hospital wells at Cherokee	1,350±	343	−150	1,200±
Group of wells between Cherokee and Quimby	1,190–1,200	100	+0 to −10	1,190

CITY AND VILLAGE SUPPLIES.

Aurelia.—The well which furnishes the public supply of Aurelia (population, 625) is 301 feet deep and ends in sand from which water rises within 190 feet of the surface, or very nearly 1,200 feet above the sea. It has been tested at 50 gallons a minute. The water is lifted from the well into a cistern from which it is pumped into two air-tight tanks and thence distributed by air pressure through more than a mile of mains to 14 fire hydrants and 23 taps. A small portion of the people use the water, and it is reported that about 6,000 gallons are consumed daily.

Cherokee.—About half of the people of Cherokee (population, 4,884) are supplied from the city waterworks and the other half from private wells, most of which are shallow. The public supply is obtained from three flowing wells 165 to 200 feet deep, situated in the valley and apparently ending in sandy Cretaceous strata. The artesian head is about 1,180 feet above sea level. The water is allowed to discharge into an underground reservoir from which it is pumped into a standpipe and distributed through the mains by gravity. There are 40 fire hydrants and approximately 400 taps and it is estimated that 115,000 gallons of water are consumed daily.

At some date preceding 1890 a deep well was drilled at Cherokee in the center of the town. The following record is given by Todd:[1]

Old city well at Cherokee.

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene and unknown	300	300
Limestone, light blue	400	700
Shale, blue, or soapstone	260	960

Well No. 1 of the State Hospital for the Insane has a depth of 1,070 feet. The curb is 1,338 feet above sea level and the head 150 feet below curb. The tested capacity is 60 gallons a minute. Water was found at 240, 435, 470, and 725 feet (rising within 180 feet of the curb), and from 1,012 feet to the bottom (rising within 150 feet of the curb). Date of completion, 1902.

Driller's log of State Hospital well No. 1, at Cherokee.

	Thickness.	Depth.
	Feet.	*Feet.*
Loam, black	4	4
Clay, light yellow	36	40
Clay, dark yellow	20	60
Clay, blue-gray; gravel	20	80
Clay, light blue; gravel	40	120
Clay, dark blue	10	130
Clay, blue-gray; gravel	30	160
Clay, dark blue	80	240
Quicksand	15	255
Gravel	5	260
Quicksand	10	270
Clay, gray-blue	10	280
Clay, pink and blue	10	290
Clay, blue-gray	50	340
Clay, dark blue	15	355
Sandrock	20	375
Slate	10	385
Slate, pink	15	400
Gravel	5	405
Slate, gray	5	410
Slate, pink and red	20	430
Limestone, gray	20	450
Slate, gray	20	470
Limestone	10	480
Slate, light	10	490
Limestone	15	505
Sandrock	5	510
Slate	15	525
Sandrock	10	535
Limestone, crevice of 10 feet at 735 feet	430	965
Slate	50	1,015
Sandrock	55	1,070
Shale, soft, crumbling.		

[1] Todd, J. E., Proc. Iowa Acad. Sci., vol. 1, pt. 2, 1892, p. 14.

Record of strata in State Hospital well No. 1, at Cherokee (Pl. VI, p. 258; Pl. XVII, p. 824).

	Thickness.	Depth.
Quaternary (160 feet thick; top, 1,338 feet above sea level):	*Feet.*	*Feet.*
Soil	10	10
Clay, pale yellow, calcareous; with sand and small pebbles; a till, 2 samples	20	30
Clay; as above, with flakes of drab siltlike clay, the dark color disappearing before blowpipe	10	40
Till, yellow; sightly darker than at 10 feet; calcareous	10	50
Till; as at 30 feet	10	60
Till, greenish drab, calcareous	10	70
Till, blue	10	80
Till, drab	10	90
Clay, fine, yellow drab, dense; nodules of lime; limestone pebbles numerous; drillings contain pebbles of northern drift, and soft, lignitic coal; 3 samples	30	120
Clay, drab, dense; reddens before blowpipe; destitute of pebbles; calcareous, gritty	10	130
Clay; as at 90 feet	30	160
Cretaceous (275 feet thick; top, 1,178 feet above sea level):		
Shale, dark drab, gritty; few if any pebbles present; very sightly calcareous; in tough cemented masses; 8 samples	80	240
Sandstone, fine, green-gray	15	255
Sandstone, coarse, yellow	5	260
Sandstone, fine, yellow	10	270
Sandstone, light gray, fine, argillaceous	10	280
Shale, light gray, noncalcareous, gritty	10	290
Shale, drab; in molded masses with no cuttings of fissile shale; gritty, practically noncalcareous; less argillaceous than Maquoketa and Pennsylvanian shales; 10 samples	65	355
Sandstone, light gray, fine; grains but slightly rounded; mostly of clear quartz; 4 samples	20	375
Sandstone; as above, somewhat argillaceous	5	380
Shale, white, highly arenaceous; grains minute; noncalcareous	10	390
Shale, ocher-yellow; as above	5	395
Shale; as at 380 feet	5	400
Sandstone, yellow, coarse, argillaceous	5	405
Shale; as at 380 feet	10	415
Sandstone, fine, brown	10	425
Shale, pink, noncalcareous	5	430
Shale, yellow gray	5	435
Carboniferous (Mississippian) (220 feet thick; top, 903 feet above sea level):		
Chert, white	5	440
Limestone, dark and light drab; granular-crystalline, rather soft; rapid effervescence; in flaky chips	10	450
Limestone, gray, argillaceous; minute fragments in the midst of powder; large quartzose residue with some chert	10	460
Shale, blue, calcareous	10	470
Limestone, dark drab, hard, crystalline; moderately slow effervescence	5	475
Limestone, earthy; light yellow-gray; rapid effervescence; in large flakes	5	480
Sandstone; grains irregular in form, varying widely in size, mostly of clear quartz, but some of reddish cryptocrystalline silica; considerable shale	5	485
Limestone, light gray, nonmagnesian, fine-grained; much sand and shale; 3 samples	15	500
Sandstone, grains subangular	5	505
Limestone, light yellow and drab; nonmagnesian	5	510
Sandstone, gray; grains irregular, mostly of clear quartz, but some green and red	5	515
Shale and limestone; large fragments of green shale; small chips of limestone with quartz sand	10	525
Sandstone, gray; as at 510 feet	10	535
Chert, white, and some light-gray nonmagnesian limestone	5	540
Limestone, light gray; brisk effervescence; soft; with considerable chert; 3 samples	15	555
Limestone, light gray; moderately effervescent	10	565
Limestone, dark drab, argillaceous, soft; in large flakes; brisk effervescence; cherty	10	575
Limestone, dark brown, cherty	10	585
Limestone, dark brown; moderate effervescence; some chert	10	595
Limestone, gray, cherty; moderate effervescence	5	600
Limestone and chert; drillings largely quartz sand, probably from above	10	610
Limestone, drab; effervescence slow; cherty	15	625
Limestone, blue gray, highly argillaceous	5	630
Limestone, brisk effervescence; granular drillings consist largely of fine quartz sand	25	655
Ordovician:		
Galena and Platteville limestones (360 feet thick; top, 683 feet above sea level):		
Limestone, magnesian; in fine powder; 4 samples	20	675
Dolomite, blue-gray; some chert in places; 54 samples	285	960
Dolomite and shale	5	965
Shale, blue; 9 samples	50	1,015
St. Peter sandstone (55 feet thick; top, 323 feet above sea level):		
Sandstone, white; 5 samples	20	1,035
Sandstone; no samples	35	1,070
Prairie du Chien group:		
Shale (Shakopee), soft; no samples.		

Analysis of drilling at 765 feet.[1]

$CaCO_3$	50.29
$MgCO_3$	41.47
SiO_2	4.92
Fe_2O_3	.89
Al_2O_3	.67
H_2O	2.68
	100.92

Well No. 2, at the State Hospital for the Insane, located 80 feet from well No. 1, has a depth of 343 feet and a diameter of 12 inches; 12-inch casing to 335.5 feet. Water enters between 330 feet and the bottom. The maximum daily yield is reported to be 125,000 gallons. The well was drilled a few months after the completion of well No. 1. Its water is said to be much the better, but it contains sediment which varies considerably in quality from time to time. For weeks together the water will remain so clear that it can be used in the pipes and flush tanks of the institution without trouble and for all domestic purposes; it may then suddenly become so filled with silt as to wear the pump leathers and deposit sediment in the flush tanks, and a week or two of pumping may be required to clear it.

Marcus.—The public supply of Marcus (population, 896) is derived from two dug wells, each 10 feet in diameter and 20 feet deep; they seem to furnish an adequate and dependable supply. The waterworks include 1⅓ miles of mains, with which are connected 16 fire hydrants and 67 taps. It is estimated that the water is used by approximately one-third of the population.

CLAY COUNTY.

By O. E. Meinzer.

TOPOGRAPHY.

Clay County is bordered on the east by a belt of high land characterized by irregular morainic topography, with numerous lakes, ponds, swamps, and sloughs. Farther west the surface is more gently undulating and somewhat better drained.

Little Sioux River flows irregularly southward through the central part of the county; after crossing the southern boundary it turns northwestward, reenters the county, and cuts across the southwest corner. Its valley is wide and shallow in the north, but becomes deeper and narrower downstream.

The highest parts of the county are along the east and west margins, where the general altitude is between 1,400 and 1,500 feet above sea level; the lowest point is where the Little Sioux crosses the west boundary, below the village of Peterson, at an altitude of scarcely more than 1,200 feet.

[1] Made in chemical laboratory of Cornell College, Mount Vernon, Iowa.

GEOLOGY.

The surface deposits of Clay County comprise outwash materials and bowlder clay. The outwash materials consist of stratified gravel and other sediments. They occur along Little Sioux River and are well developed in the vicinity of Spencer. The bowlder clay, which has an average thickness of several hundred feet, is yellow and gravelly near the surface but denser and darker at greater depths. Interbedded with it are a few lenses of sand and gravel. Beneath the bowlder clay there is a stratified series of soft shales, limestones, and sandstones of probable Cretaceous age.

The following is the driller's log of the deep well of D. C. White:

Section of deep well of D. C. White at Webb.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, yellow, etc	40	40
Clay, blue	145	185
Sand	3	188
Clay, blue	38	226
Clay, yellow	34	260
Clay, dark blue	90	350
Clay, light blue, and sand	97	447
Quicksand and gravel	4	451
Limestone and sandstone	99	550
Soapstone.		

UNDERGROUND WATER.

SOURCE.

The horizons from which water is taken may be grouped as outwash sands and gravels, surficial portions of the glacial drift, sand and gravel deposits in the deeper portions of the drift, and Cretaceous sand strata.

In the valley of Little Sioux River, and also in a rather extensive low-lying area associated with Little Sioux and Ocheyedan rivers east of Spencer, the outwash deposits furnish an abundant and permanent water supply to very shallow driven wells. Elsewhere most of the supply is obtained from shallow wells bored or dug into the upper part of the unstratified glacial drift, from which they receive seepage.

The drilled wells, which constitute a very small percentage of the total number, are supplied from deeper horizons that probably belong to the drift, although the sections of only a few wells were obtained. In depth they range from less than 100 feet to at least 550 feet. In the Little Sioux Valley, especially in the lower portion, the water in these wells rises nearly to the surface, but on the uplands it remains at considerable depths. Thus in the village well at Peterson, situated in the valley, the water comes within 30 feet of the surface, whereas in the deep well of D. C. White at Webb it stands 180 feet below the surface, though in both wells it rises to approximately the same level, about 1,200 feet above the sea.

The deepest water-bearing formations have not been reached by the drill, but successful deep wells have been sunk at Emmetsburg and Mallard, about 12 miles east of the east boundary. (See pp. 873–874.) In Clay County the head of the water from these deep formations would probably not be higher than in the deepest wells already drilled. At Spencer the surface elevation is 1,315 feet above sea level and the deep water would probably not rise higher than 1,200 feet.

CITY AND VILLAGE SUPPLIES.

Peterson.—The village well at Peterson (population, 480) is 90 feet deep, the last 20 feet being in sand and gravel. It is pumped at 20 gallons a minute and is giving satisfactory service. The water is lifted into a surface reservoir on the top of the valley cliff and thence distributed by gravity. There is a small system of mains with 5 fire hydrants and 20 taps. The average daily consumption probably does not exceed 1,500 gallons.

Spencer.—The public supply of Spencer (population, 3,005) is obtained from three 16-foot wells, one 40 feet, one 16 feet, and one 8 feet in diameter, dug in outwash sand and gravel. The wells will fill within 5 feet of the top and furnish 1,000 gallons of water a minute. The water is pumped to an elevated tank and distributed through 4½ miles of mains to 21 fire hydrants and about 200 taps. Approximately 1,000 people are supplied, and 100,000 gallons is consumed daily.

CRAWFORD COUNTY.

By W. J. Miller.

TOPOGRAPHY AND GEOLOGY.

Crawford County lies just west of the Iowa divide and its principal drainage slope is toward the southwest. The surface is made up of low rounded hills, the rolling contours being somewhat more pronounced in the western portion than in the eastern. The region is thoroughly dissected by many branching streams, the largest of which, Boyer River, flows across the county from northeast to southwest. Soldier River and its branches flow across the northwestern part.

Both the loess and the Kansan drift are well represented, the combined thickness on the Iowa divide being 450 to 550 feet, much above the average for the State. Both the loess and the Kansan are spread over the entire county. Over much of the county the

Kansan drift rests on rocks of Cretaceous age, chiefly sandstones. In places, however, heavy limestones, probably of Missouri age, immediately underlie the glacial deposits. Except for variations in the thickness, the drift deposits are horizontal. The Cretaceous rocks probably dip slightly to the west; the older rocks lie nearly flat or dip slightly to the east. (See Pl. XI, p. 382.)

UNDERGROUND WATER.

SOURCE.

The water supply of Crawford County is largely obtained from shallow dug wells and the supply in general is not altogether satisfactory, because many of the wells are affected by the seasons and fail altogether in times of extreme drought.

There are two important water horizons in the drift deposits. One is found in sand or gravel just below the loess and is reached by wells that range in depth from a few feet to 75 feet, depending on the thickness of the loess; this is the so-called "first water" level. The second horizon is found in sand or gravel just below the blue clay of the Kansan drift. Though much more satisfactory than the first comparatively few wells extend to it, as it lies 140 to 500 feet below the surface, the greater depth being in the eastern portion of the county. Wherever tapped, however, it yields a never-failing supply. A few wells obtain a good water supply from local layers of sand or gravel within the blue clay, but as a rule these layers are either dry or yield little water, and in some of them the water is so heavily charged with decomposing organic matter as to give off a disagreeable odor.

A few wells have passed through drift deposits into the underlying Cretaceous sandstones or limestones of the Missouri group. Most of the deeper rock wells are in the eastern part of the county.

SPRINGS.

Springs are not common in this county. Small springs or seepages from the drift are found along the chief stream courses.

CITY AND VILLAGE SUPPLIES.

Denison.—Denison (population, 3,133) draws its supply from two wells 25 feet deep, which it pumps by steam, delivering the water by gravity from a standpipe with a pressure of 45 to 90 pounds. There are 6½ miles of mains, 42 fire hydrants, and 600 taps. Three thousand people use the water, consuming 98,000 gallons daily. The supply is apt to run short in dry weather.

According to Norton, any deep well forecast for Denison must be based on the supposed general succession of formations deeply buried below the surface and pierced by no wells within scores of miles. Whether the St. Peter sandstone extends this far west is uncertain though probable. The drill may be expected to pass first through heavy Pleistocene deposits of stony clays and sand and gravel beds and through heavy Cretaceous and Pennsylvanian shales with some sandstones; below these beds it will find Mississippian limestones, probably in part cherty. These limestones may be expected to rest on dolomites of uncertain age, accompanied by much argillaceous limestone and considerable shale. It is quite possible that the shale of the Platteville will be found to rest directly on the arenaceous dolomites of the Prairie du Chien group at about 200 feet below sea level; or the latter may be absent and the Ordovician sandstones may not be found higher than about 1,350 feet from the surface. From a level about 1,350 feet below the surface the drill will very probably pass through several hundred feet of sandy dolomites and sandstones which carry water; and a well 1,500 or 2,000 feet in depth is not likely to fail of moderate success. Water will not flow from these deep formations but should rise within pumping distance.

Minor supplies.—The following table summarizes minor village supplies:

Minor supplies.

City or town.	Nature of supply.	Pumping system.	Distribution.	Pressure.		Mains (miles).	Hydrants.	Taps.	Persons supplied.	Daily consumption.	Remarks.
				Domestic.	Fire.						
				Lbs.	*Lbs.*					*Galls.*	
Arion	Well 40 feet deep.	Gasoline engine.	Gravity from reservoir on high hill.	100	100	½	(?)	(?)	...	......	Good supply.
Charter Oak.	10 driven wells and 1 dug well (22 feet deep).	Steam pump, duplex.	Gravity from tank.	50–60	90	2	...	...	800	......	Good supply.
Dow City	Dug well	Gasoline engine.	Direct air pressure.	.....	....	$\frac{1}{5}$	...	...	...	......	Plant recently installed.
Manilla	2 wells 64 and 68 feet deep.	Steam pump, compound.	Gravity from tank.	25–40	....	2	26	65	300	9,000	Good supply.
Schleswig	Dug well 30 feet deep.	Gasoline engine.	Direct air pressure.	70	100	1	8	40	150	18,000	Shortage in dry weather.
Vail	8 driven wells and 2 dug wells 30 feet deep.	Gasoline engine and windmill.	Gravity from tank.	65	....	1.7	22	30	200	8,000–10,000	Good supply.

WELL DATA.

The following table gives data of typical wells in Crawford County:

Typical wells of Crawford County.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head below curb.	Remarks (logs given in feet).
		Feet.	*Feet.*	*Feet.*	*Feet.*	
G. Schelon	6 miles south of Charter Oak.	104	....	Gravel	— 46	Dug well. No rock.
H. Planggie	3 miles west of Charter Oak.	104	....	...do	— 72	No rock.
Charles Reynolds.	8 miles west of Dow City.	325	....	Sand	—265	Abandoned on account of quicksand. Yellow loam (water toward bottom), 45; bluish-black clay (bad odor), 50; blue clay, 216; "hard pan," 4; sand (water), 10; no rock.
Mr. Dunham	1½ miles northwest of Dunlap.	264	....	Sand and gravel.	—224	No rock.
W. Butterworth	Dow City	82	....	Sand	— 76	Do.
McCaffrey Bros.	6 miles north of West Side.	662	350	Sandstone.	—365	Yellow loam and blue clay, 35; sand and blue clay, 45; sandstone, limestone, sandstone (water), 312.
Henry Munt	Denison	180	....	Sand	....	Unused on account of lack of water. No rock.
Jonathan Miller	7 miles northeast of Denison (E. ½ SW. ¼ sec. 16, Milford Township).	492	460	....	....	Loess, 20; till, bowldery, 55; blue clay, bowldery, 385; limestone, blue-gray, 30.
D. C. Franklin	3½ miles east of Denison.	404	380	Sandstone.	30+	Sandstone at 380 feet.
J. Barnhoff	4½ miles southeast of Vail.	572	552	...do	—360	Loess, 20; clay, blue and yellow, pebbly, 80; clay, blue, 100; "potter's clay," 350; sandstone, gray, 22½.
George Span	6 miles northwest of Denison.	85	....	Sand	— 35	Water has bad odor. Auger was lifted by water. No rock.
Town of Manilla	Manilla	68	....	Gravel and sand.	— 12	Pumped by steam. No rock.
Clayton Baker	4 miles north of Manilla.	515	....	...do	—260	Yellow clay, 75; sand (water), 2; blue clay and pebbles, 408; "hardpan," 20; sand and gravel (water), 10. One of the deepest drift wells in Iowa. No rock.
Henry Naeve	1 mile east of Schleswig.	393	....	Sand	—323	No rock.

DICKINSON COUNTY.

By O. E. Meinzer.

TOPOGRAPHY AND GEOLOGY.

Dickinson County is wholly drift-covered. Its topography ranges from gently undulating in some localities to irregularly morainic in others. The surface is imperfectly drained, and the county contains several large lakes, such as Spirit, Okoboji, and Silver lakes, besides innumerable smaller lakes, ponds, and swamps. According to railway surveys the altitude is 1,469 feet above sea level at Lake Park, 1,413 feet at Spirit Lake, 1,441 feet at Milford, and 1,417 feet at Terrill.

The glacial drift is so thick in this region that the drill has very seldom reached the soft blue shale and white sand of the Cretaceous, upon which the drift is supposed to rest in all parts of the county. In the following approximate section of the deep well drilled for the Chicago, Rock Island & Pacific Railway at Lake Park the drift probably extends to the depth of 250 feet:

Section of deep railway well at Lake Park.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil, yellow clay, blue clay, black and yellow clay	250	250
Shale, clay, sand, etc.	554	804

UNDERGROUND WATER.

SOURCE.

The outwash deposits have small distribution but exist to some depth in the valley of the Little Sioux, where they are filled with excellent water that is recovered chiefly by means of driven wells. On account of the lack of drainage the upper part of the drift is usually saturated nearly or quite to the surface, and hence most of the wells are very shallow. At some distance below the surface the bowlder clay is compact and impervious, but at certain horizons it includes sand and gravel that are charged with water under pressure. The wells that extend to these artesian aquifers have a much more copious and reliable supply than the shallow seepage wells.

In the deepest wells, especially in those which penetrate the stratified formations below the drift, the artesian pressure is not sufficient to raise the water near the surface, and the pumping lift is therefore much greater than in the shallow seepage wells or in the wells that stop in deposits of sand and gravel at depths of 100 to 200 feet. At no point in the county are there prospects of obtaining flows by deep drilling, the water from deep sources probably everywhere remaining far below the surface. Conditions in wells in surrounding counties make it improbable that water will rise higher than 1,200 feet above sea level, which would be between 200 and 300 feet below the surface in most localities.

In the deep well at Lake Park, the section of which is given above, the water is reported to stand about 300 feet below the top of the well, or about 1,170 feet above sea level. This well is unsatisfactory because the head is low, the water is highly mineralized, and fine sand enters the well and impairs the pump. The water is not used in locomotives.

CITY AND VILLAGE SUPPLIES.

Lake Park.—The waterworks in Lake Park (population, 552) consist of an air-pressure system with about half a mile of mains, 9 fire hydrants, and 8 taps. The two wells upon which the system depends are both unsatisfactory. One is 6 feet in diameter and 50 feet deep and has a yield which varies greatly with the season but is always small. The other is a 6-inch drilled well that ends at 98 feet in fine sand which tends to clog the screen and thus shut out the water. At the time the plant was visited the maximum combined yield of the two wells was very small.

Spirit Lake.—The city well at Spirit Lake (population, 1,162) ends at about 100 feet in a bed of fine sand from which the water rises within 50 feet of the surface. This well furnishes the entire public supply, but when pumped at 300 gallons a minute it soon shows signs of exhaustion. The water is lifted into a surface reservoir from which it is forced by direct pressure through 1¼ miles of mains. There are 15 fire hydrants. A considerable portion of the people are supplied from this source.

Spirit Lake is 1,413 feet above sea level. According to Norton, after passing through the thickened drift of the moraine on which the town is situated, the drill will encounter shales and then enter sandstones of the Cretaceous, from which a large supply of water may be drawn. Should it be thought advisable to sink the well deeper dolomitic limestones will next be encountered, and at a depth of 600 to 700 feet the St. Peter sandstone may be expected. A 6-inch well 700 or 800 feet deep will test the capacity of this sandstone, and if the yield is inadequate it can then be determined whether a sufficient increase can be obtained by reaming the hole to 8 or 10 inches, whether the well should be sunk deeper in exploration, or whether a small group of 6-inch wells, of 700 or 800 feet depth, would be preferable. The water of the St. Peter should be of excellent quality, belonging to the calcic-magnesic alkaline class but containing no large amount of mineral matter.

EMMET COUNTY.

By O. E. Meinzer.

TOPOGRAPHY AND GEOLOGY.

Most of Emmet County consists of a gently undulating and poorly drained drift plain interspersed with numerous lakes and ponds. West Fork of Des Moines River flows through the western part, where it has developed a rather wide flood plain. Westward from this river the altitude increases rapidly and the topography becomes irregular and morainic.

The surface formation consists of glacial drift, except in the valley of the Des Moines, which is partly filled with outwash and alluvial deposits. Beneath the drift is a thick series of shale, sand, and sandstone which is not known to outcrop in the county and whose age therefore remains a matter of conjecture. It is probably Cretaceous but may in part be older, and it rests upon a limestone formation which is believed to belong to the Mississippian series.

The general character of the Cretaceous (?) shale and sandstone is indicated by the driller's logs of the well on the property of Mrs. Allen, in Estherville, and of the village well at Ringsted.

Section of well of Mrs. Allen, Estherville.

	Thickness.	Depth.
	Feet.	*Feet.*
Gravel	15	15
Clay, blue, and sand	195	210
Shale, blue	77	287
Hard quartz rock	¼	287¼
Sandstone, white (entered).		

Section of village well at Ringsted.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, blue	147	147
Shale, sandy	3	150
Sand, blue, and gravel	10	160
Sand, yellow	38	198
Clay and shale	42	240
Sand and shale	60	300
Shale, white	12	312
Shale, dark, sandy	8	320
Shale, sandy	44	364
Limestone (entered)	136	500

In the Estherville well the formations recorded below a depth of 210 feet are probably Cretaceous; in the Ringsted well the Cretaceous apparently begins at a depth of 147 feet. The limestone in the Ringsted well is undoubtedly Paleozoic and is probably Mississippian.

UNDERGROUND WATER.

SOURCE.

The water supply of this county is derived from outwash and alluvial sands and gravels, glacial drift, sand and sandstone strata (Cretaceous ?), and limestone (Mississippian ?).

The outwash and alluvial sands and gravels, which are practically restricted to the valley of Des Moines River, are very porous and are so situated that they are filled with water nearly to the surface.

Hence they constitute a very accessible source of supply and are tapped by numerous driven wells. The conditions, however, are such that contamination may easily occur, especially in a large settlement such as Estherville. The water is somewhat less mineralized than that from other aquifers.

Outside of the valley of the Des Moines the water supply is drawn chiefly from the glacial drift, though some of the deepest wells extend into the underlying stratified formations. The drilled wells differ greatly in depth and also in the height to which the water rises. In the vicinity of Estherville they range in depth from less than 100 feet to at least 446 feet, 160 feet perhaps being an average; in the vicinity of Gruver they range from 75 feet or less to 275 feet or more, most of the wells near Ryan and Swan lakes being less than 100 feet deep and those near the village of Gruver averaging deeper; in the vicinity of Armstrong they range from about 75 to 250 feet, 135 feet perhaps being an average. In many of the 2-inch tubular wells much trouble is caused by the incrusting of the sand screens, but this difficulty can be largely overcome by drilling wells of greater diameter and using independent pumps. (See pp. 192–193.)

In the Allen well at Estherville the water rises within 120 feet of the surface, or approximately 1,180 feet above sea level, and the well has been pumped at about 30 gallons a minute. In the deep well at Ringsted the water rises within 76 feet of the surface and is not greatly lowered when pumped at 40 gallons a minute. It is reasonably certain that below the limestone penetrated in the Ringsted well are older sandstones which would yield large amounts of water that would rise to a level 1,100 to 1,200 feet above the sea, but would probably not come nearer the surface than the water in the deepest wells that have thus far been drilled.

CITY AND VILLAGE SUPPLIES.

Armstrong.—The village well at Armstrong (population, 586) is 160 feet deep and ends in a bed of fine sand. The water stands 68 feet below the surface, or 1,172 feet above the sea, and pumping at 50 gallons a minute is reported not to lower it greatly. It is lifted from the well into an elevated tank from which it is forced by gravity through 1 mile of mains to 24 fire hydrants and about 40 taps. It is estimated that about 200 people are supplied and 7,000 gallons of water is consumed daily. The rest of the population depend on shallow private wells.

Estherville.—The people of Estherville (population, 2,404) depend for their domestic supplies on private wells, most of which are shallow. The public supply is taken from the river and is not considered safe for domestic use, though it is employed in large quantities for other purposes. There is a rather extensive system of mains with 24 fire hydrants. The pressure is applied directly by the pumps.

According to Norton a deep well at Estherville (elevation, 1,287 feet) would reach the base of the Cretaceous at 300 to 400 feet from the surface and would then enter Paleozoic dolomites. From these it would pass into the heavy blue and green shales of the Decorah and Platteville formations. The St. Peter sandstone should be reached about 800 feet above sea level, or about 500 feet below the surface, but it may lie 100 or 200 feet deeper. In exploration the well may be drilled a few hundred feet deeper than this estimate demands but should be stopped when the drill strikes heavy glauconiferous shales indicating the St. Lawrence horizon, the Algonkian (?) red shales, or crystalline rocks such as granite, quartzite, or schists.

Ringsted.—The waterworks in Ringsted (population, 313) consist of an air-pressure system. Water is obtained from the deep well already described (p. 852). Most of the people still use private wells.

IDA COUNTY.

By W. J. Miller and W. H. Norton.

TOPOGRAPHY AND GEOLOGY.

Ida County, lying well west of the flat country of the Wisconsin drift, is characteristically hilly, the western portion being a little more rugged than the eastern. The region is thoroughly dissected by many branching streams. The principal one, Maple River, enters from the northeast and leaves at the southwest. Little Sioux River cuts across the extreme northwest corner and Soldier River rises in the southern part.

The Kansan drift extends over the whole county and is completely covered by the loess. The total thickness of these two formations is unusually great, being in places almost 500 feet. The drift rests directly on rocks of Cretaceous age.

Except for local variations in thickness the drift deposits lie nearly horizontal. Of the underlying rock formations the Cretaceous beds are thought to dip noticeably to the west; the still older rocks are nearly horizontal or show a slight easterly dip. (See Pl. XVII, p. 824.)

UNDERGROUND WATER.

SOURCE.

The most clearly defined water horizon is at the base of the Kansan. The source of the water in many wells, however, is within the loess. Very little can be said about the water of the older rock formations, as but one well is known to extend into them.

So far as existing wells are concerned, the most important source of water in the county is either within the loess itself or in sands or gravels at its base. By far the greater number of farm wells in Ida County are dug and are only from 15 to 30 feet deep. A few bored wells reach a depth of 50 to 100 feet. The dug wells are especially likely to be unsatisfactory in very dry seasons, because their water often either greatly diminishes or fails altogether.

Although but few wells in the county reach it, the most persistent and satisfactory aquifer at a moderate depth consists of the sands or gravels at the base of the Kansan. The available well records indicate that this aquifer lies 300 to 480 feet or more below the surface and seldom fails to yield a large supply of good water. Locally good supplies of water are obtained from sand beds in the blue clay. The well at Holstein (2,004 feet deep) is the only one known to enter the older formations to any extent.

SPRINGS.

Springs are of little consequence in Ida County, though small seepages occur here and there along the low valley lands.

CITY AND VILLAGE SUPPLIES.

Battle Creek.—The town water supply of Battle Creek (population, 527) is taken from 10 drilled and driven wells, ending in gravel at depths ranging from 42 to 48 feet. The wells yield a good supply of medium hard water which is distributed by gravity (domestic pressure 35 pounds, fire pressure 80 pounds) through somewhat more than a mile of mains to 30 taps and 13 fire hydrants. About 150 people use the city water. The daily consumption is estimated at 6,000 gallons.

Holstein.—The city well (Pl. XVII) at Holstein (population, 936) is 2,004 feet deep and is 8 inches to 4 inches or less in diameter; it is cased with 8-inch pipe to a depth of 387 feet, 5-inch pipe to 722 feet, and 4-inch pipe to 1,465 feet. The original head was 270 feet below the curb; in 1908 the head was 300 feet below the curb. When drilling reached a depth of 1,500 feet a 26-hour test pumped 75 gallons a minute without lowering the water; on completion the well yielded 60 gallons a minute; in 1908, 75 gallons a minute. Water came from 390 feet in quicksand, from 1,200 feet, and from "below 1,500" feet; at 390 feet it stood 200 feet below the curb, at 900 feet 365 feet below the curb, at 1,590 feet 325 feet below the curb, and on completion 270 feet below the curb. The well was put down by J. P. Miller & Co., of Chicago, in 1897.

The water is pumped to a steel tank and is forced under gravity pressure of 40 pounds (domestic) or 100 pounds (fire) through 2½ miles of mains to 53 taps and 19 fire hydrants. The city water is used by about 300 people. The daily consumption is estimated at 9,000 to 12,000 gallons. The water is hard.

Record of strata in Holstein city well, based on driller's log (Pl. XVII, p. 824).

	Thickness.	Depth.
	Feet.	*Feet.*
Clay	390	390
Quicksand	50	440
Carboniferous:		
Pennsylvanian (?)—		
Shale	260	700
Mississippian (?) and Devonian (?)—		
Limestone	50	750
Shale	50	800
Limestone	80	880
No samples; limestone	20	900
Ordovician:		
Galena dolomite to Platteville limestone—		
Dolomite, gray; much chert and some rounded moderately coarse grains of quartz sand	100	1,000
No samples; limestone (?)	100	1,100
Limestone, magnesian, or dolomite; brown, with about 2 feet of red shale at 1,300 feet; shale noncalcareous, highly arenaceous, with coarse imperfectly rounded grains of limpid quartz	300	1,400
No sample	37	1,437
Shale, dark greenish gray, slaty, noncalcareous; caving badly after drill had penetrated the underlying sandstone	8	1,445
St. Peter sandstone—		
Sandstone; described as white, clean, very soft, and caving; called by driller St. Peter	40	1,485
Prairie du Chien group—		
Limestone (?), marly, arenaceous; described by driller as a "sandy rock which wears the drill;" sand grains brought in slush bucket; other drillings very light and float up on water; rock drills about 1 foot an hour and does not cave.	35	1,520
Shale, red; "at about 1,520 red marl was coming in and could not tell much about the formation from there down to 1,890 feet, as it was caving very badly all the way, and caved more or less from there down to 2,000 feet"	....	1,520
Sandstone; fine grained, blue-gray, dolomitic cement	....	1,575
Sandstone and dolomite; quartz sand, considerable red shale and some green shale from above, and a little gray siliceous dolomite	....	1,670
Chert, dark reddish brown, ferruginous; in small chips, slightly arenaceous, with minute particles of crystalline quartz; as similar chert and reddish argillaceous powder are found in nearly all the drillings below, this may have fallen in from 1,520	....	1,700
Sandstone and chert; sandstone, fine grained, in detached grains of clear quartz; many imperfectly rounded and minute white cuttings, showing quartz particles in dolomitic cement; chert dark, brown, ferruginous, dolomitic	....	1,720
Marl; in buff, slightly concreted masses; dolomitic, arenaceous, and argillaceous; quartz grains moderately fine, many imperfectly rounded; red chert, as above, with a few chips of yellow siliceous dolomite	....	1,740
Shale, blue, plastic, calcareous	5	1,755
Marl; chiefly quartz sand, with dolomite, yellow-gray, and white, soft, glauconiferous; some red chert	....	1,760
Marl, gray, dolomitic	....	1,775
Shale, blue, plastic, calcareous	....	1,785
Dolomite, gray, highly siliceous; microscopic particles of crystalline quartz, glauconiferous; considerable fine quartz sand	....	1,795
Marl or calciferous argillaceous sandstone	....	1,805
Dolomite, hard, dark gray, saccharoidal; possibly from above	....	1,810
Marl, arenaceous	....	1,815
Shale, blue, calcareous, slightly glauconiferous, minutely quartzose	2	1,827
Shale, green, hard, fissile, slightly calcareous	15	1,915
Dolomite and shale; dolomite, saccharoidal, mottled greenish gray and pink, interlaminated with hard green calcareous shale; quartzose and glauconiferous, in large chips	....	1,920
Marl, arenaceous, with fine rounded grains; chips composed largely of quartzose particles	10	1,930
Cambrian (?):		
Dresbach (?) sandstone—		
Sandstone, yellow, saccharoidal, soft; rounded grains of about 0.5 millimeter	41	1,971

Ida Grove.—Two wells, each 24 feet deep, furnish Ida Grove (population, 1,874) with a fairly good supply of hard water. The water is pumped by steam and is distributed by direct pressure (70 pounds domestic and 125 pounds fire) through 1¾ miles of mains to 200 taps and 20 fire hydrants. About 700 people use the city water. The daily consumption is estimated at 45,000 gallons.

The success of the deep well at Holstein, 10 miles north of Ida Grove, is distinctly encouraging. The succession of rocks is probably the same at both places, but any given formation or water bed may be expected to lie about 100 feet deeper at Ida Grove than at Holstein. Thus at Ida Grove (elevation above sea level, 1,225 feet) the St. Peter sandstone will be found at about 100 feet below sea level, or 1,325 feet below the surface. The drill may fail to strike the water vein reached at Holstein at 259 feet above sea level in Galena dolomite, but it may find other water-bearing crevices in this formation. Sufficient water may probably be found about 300 feet below sea level (somewhat more than 1,500 feet below the surface), but if not, drilling may be continued to about 1,900 feet to tap the lowest sandstone found at Holstein. The fact that Ida Grove stands more than 200 feet lower than Holstein not only brings the deep formations somewhat nearer to the surface, but also gives a higher head to the artesian water, which should come within 50 or 100 feet of the curb. In quality the water may be expected to be rather high in sulphates, but to be well within the limits of potability. The waters found above 700 feet should be carefully tested for quality, and possibly should be cased out on account of excessive mineralization.

WELL DATA.

Information concerning typical wells in Ida County is presented in the following table:

Typical wells of Ida County.

Owner.	Location.	Depth.	Source of supply.	Head below curb.	Remarks.
		Feet.		*Feet.*	
Mislow Bros	5½ miles east of Ida Grove.	210	Gravel and sand.	160	No rock.
M. Martin	4 miles southwest of Ida Grove.	115	....do....	40	Water bed at 81 feet. No rock.
A. Harper	2 miles southeast of Ida Grove.	215	....do....	115	Black loam, 4; yellow clay, 40; sand and clay and some water, 70; gravel and water, 3; yellowish clay and sand, 85; gravel and water, 13; no rock.
W. K. Van Wayne.	4 miles north of Ida Grove.	300	....do....	......	No rock.

LYON COUNTY.

By O. E. Meinzer.

TOPOGRAPHY AND GEOLOGY.

Lyon County is much better drained than the counties farther east. The gently undulating upland, whose general altitude is more than 1,400 feet above sea level, is somewhat dissected by water-courses that lead to Big Sioux River, which forms the west boundary of the county and occupies a well-defined valley about 200 feet deep.

The following geologic section is revealed in outcrops and wells:

Glacial outwash and Recent alluvium (in the valleys).
Loess (on the uplands).
Glacial drift.
Cretaceous shales and impure limestones.
Cretaceous sandstone (Dakota).
Sioux quartzite.

The Cretaceous formations outcrop in Big Sioux Valley south of Lyon County, and are penetrated in many drill holes in this county. The Sioux quartzite outcrops in small areas in the extreme north-western part of the State and probably underlies the entire county, though its surface is so irregular that within a short distance from an outcrop it may lie several hundred feet below the surface and hence it is not generally encountered even in the deepest wells.

UNDERGROUND WATER.

SOURCE.

On the uplands the shallow wells end in glacial drift, the depth to the Dakota sandstone is relatively great, and the water from all deep formations remains far below the surface when tapped by wells; in the valleys the shallow wells end in alluvial and outwash sand and gravel, the depth to the Dakota sandstone is not great, and the water from deep sources rises nearly to the surface. The valleys include only a small portion of the total area and grade into the uplands along the minor streams.

All the geologic formations except the loess and the Cretaceous shale will yield some water, but those most heavily drawn on at present are the glacial drift and outwash gravel. The latter is found in the principal valleys, where it furnishes large quantities of good water to shallow wells and constitutes the source from which all public supplies are obtained; the glacial drift everywhere underlies the upland, where it yields most of the private supplies on farms and in villages remote from streams. The loosely consolidated beds of drift near the surface are commonly saturated and yield a certain amount of water to shallow bored and dug wells; and seams of sand and gravel embedded in the impervious blue bowlder clay at greater depths contain water under considerable pressure, which is recovered by means of bored and drilled wells. The deep drift water is notably harder and more ferruginous than the water in the valley gravels. The Dakota sandstone contains a large store of mineralized water and supplies a few of the deepest wells. It is very imperfectly cemented and gives some trouble because of the tendency of its fine sand to rise with the water, especially when rapid pumping is attempted. The Sioux quartzite yields small supplies to wells in South Dakota and Minnesota, the water occurring in joints and also in the less cemented portions of the rock, but on account of the expense and difficulty of drilling through this formation, it is properly avoided in Iowa as much as possible. In some parts of the county water-bearing beds may exist between the Dakota sandstone and the Sioux quartzite, but, so far as known, no such beds have yet been reached by the drill.

In all sections of the county most of the wells are bored and commonly range between 15 and 50 feet in depth, but there are also many drilled wells between 70 and 500 feet deep, wells 150 to 160 feet deep being common east of Rock Rapids and wells of 190 to 300 feet west of that city. The difficulty with fine sand can to some extent be overcome by drilling wells of larger diameter and using independent pumps that will allow the water to flow into the wells under uniform pressure. (See pp. 192–193.)

The water from the Dakota sandstone is lifted by artesian pressure to approximately 1,225 feet above sea level, which brings it nearly to the surface in the Sioux Valley but leaves it about 100 feet below the surface at Rock Rapids and more than 200 feet below on much of the uplands. According to railway surveys, the altitude of Beloit, in the Sioux Valley, is 1,242 feet above sea level; of Rock Rapids, in the valley of Rock River, 1,345 feet; of George, in the valley of Little Rock River, 1,377 feet; and of Granite, Larchwood, and Inwood, all upland towns, 1,407 feet, 1,426 feet, and 1,473 feet, respectively. Drilling below the Dakota sandstone is not advised in this county, because it is improbable that much would be gained in quantity or quality of water or in artesian pressure. The Sioux quartzite would probably be encountered before the drill reached a depth of many hundred feet.

Near the Chicago, Rock Island & Pacific Railway station at Lester there is a 10-inch well, 70 feet deep, from which the water rises above the surface and flows several gallons a minute.

CITY AND VILLAGE SUPPLIES.

Alvord.—The village well at Alvord (population, 283) is 8 feet in diameter and is sunk to a depth of 30 feet into the gravel of the creek valley, obtaining great quantities of good water.

The waterworks system consists of an air pressure tank with about half a mile of mains, 8 fire hydrants, and 8 taps. Only a few homes have service connections and the consumption is small.

Doon.—The village well at Doon (population, 581) is 10 feet in diameter and 28 feet deep and ends in gravel, from which a large amount of relatively soft water can be drawn.

The distribution system comprises an elevated tank, about a mile of mains, 12 fire hydrants, and 42 taps. Perhaps 200 people are supplied, and approximately 7,000 gallons is consumed daily.

Rock Rapids.—The public supply of Rock Rapids (population, 2,005) is derived from a well 18 feet in diameter and 20 feet deep ending in the valley gravels.

The waterworks consist of a standpipe with about 3 miles of mains, 28 fire hydrants, and 250 taps. It is reported that a majority of the people are supplied and that about 30,000 gallons of water is consumed daily.

MONONA COUNTY.

By W. J. Miller.

TOPOGRAPHY.

Topographically, Monona County is clearly divisible into two portions. The western third is occupied by the Missouri River bottom, where the land is low, very level, and much of it swampy. Little Sioux River and its West Fork flow along the eastern border of this lowland. The eastern two-thirds of the county is characteristically very hilly and rugged. Important river channels are cut by Soldier, Maple, and Little Sioux rivers. The hilly and the lowland regions are sharply separated.

GEOLOGY.

Of the upper or surface formations three types are to be found. The lowland region is covered by alluvial or river deposits, consisting of sands, gravels, and clays. The hilly region is completely covered by the loess except locally where the principal streams have cut through it. Below the loess, in the hilly portion, comes the Kansan drift. The Kansan drift and the loess have been practically all removed by erosion over the lowland area.

Of the old rock formations, both the Cretaceous system (shales and sandstones) and the Pennsylvanian series (shales, sandstones, and limestones of the Missouri group) are represented. The Missouri group immediately underlies the alluvial deposits in the southern half of the river-bottom area; and the Cretaceous spreads over the remainder of the county.

Along the river bottom the alluvium rests directly upon the older rock formations. So far as known all the strata of the county are in a general way horizontal.

UNDERGROUND WATER.

SOURCE.

The sand and gravel layers of the river bottom afford an abundance of water. In the hilly country water is found in sand or gravel below the loess and in sand or gravel below the blue clay of the Kansan drift. Important water beds are doubtless present in the older rock formations, although little is known about them, as but two wells in the county are known to have extended into these formations.

By far most of the water of the county is obtained from shallow dug or driven wells, but the supply is often not as constant or satisfactory as it is in central Iowa, and in particularly dry seasons is considerably affected. The water, as a rule, is of good quality but hard.

Practically all of the water in the river-bottom district is derived from sand or gravel beds in the alluvial deposits. There is no single clearly defined water-bearing stratum of widespread extent, the alluvial deposits being very local. Nearly all the wells in this district are driven and range in depth from 15 to 80 feet, the average depth being about 30 feet. The head usually responds more or less to the rise and fall of water in Missouri River. In the region around Onawa the water in the deeper wells (60 to 80 feet) is heavily charged with oxide of iron. This water seems to come from under a hard yellow clay or "hardpan" whereas the water above the "hardpan" is softer and free from iron oxide.

In the hilly loess-covered region many of the dug wells extend into water-bearing sand or gravel below the loess, the depth to this so-called "first-water" level being between a few feet and 100 feet. Generally the water supply is not large and fluctuates according to seasons, even failing in some very dry seasons.

A larger and more constant supply of water is to be found in the sands or gravels beneath the blue clay of the Kansan drift. Well records show that this aquifer has been struck at depths ranging from 35 feet along the stream bottoms to a maximum of 300 feet or more on high ground in the eastern part of the county, but comparatively few wells reach it. Some wells appear to derive water from sand layers within the blue clay.

A few drilled wells enter the deeper rock formations. Satisfactory records, however, are lacking to show the source of water in these wells.

PROVINCES.

Monona County may be divided into two underground-water provinces—the river bottom, on which the water is found in the alluvial deposits and also in the deep-lying rock formations, and the eastern hilly region, where the water occurs in sand or gravel beneath both the Kansan drift and the loess and also probably in the deep rock formations.

At least two flowing wells are known to derive their water from the older rocks below the alluvial deposits. One of these wells, 863 feet deep, is at Onawa, and flows a large stream under considerable head. The other, more than 400 feet deep, is near Blencoe. A very general record of the Onawa well shows the source of water to be in limestone. No record of the Blencoe well could be obtained. The head of water is sufficient to permit an overflow on the lowland only.

Some flowing wells are known in the drift along the Maple River bottom near Castana. The river has here cut through the loess, and a well extending 30 to 40 feet downward into the blue Kansan clay strikes a bed of gravel with water under sufficient head to cause an overflow in the river bottom.

SPRINGS.

Springs of small size are numerous along stream courses where the bottom of the loess is exposed. The water emerges from the sand or gravel below the loess, as along Maple River in the vicinity of Castana. Thus these springs furnish examples of natural flow from the so-called "first-water level."

CITY AND VILLAGE SUPPLIES.

Onawa.—The Onawa city supply is drawn from a flowing well is forced by direct pressure by two steam duplex pumps through two-fifths of a mile of mains to 18 fire hydrants and 42 taps. Domestic pressure is 40 pounds and fire pressure 100 pounds. The supply is sufficient, but constant pumping is necessary. The water is hard. It is used by 200 people.

The well has a depth of 863 feet and a diameter of 12 to 8 inches; casing to 563 feet. It is located on the river bottom. The head is

15 feet above curb, and the flow 75 gallons a minute. Water beds were struck at 863 and 300 feet. Driller, J. H. Shaw, of Sioux City; date of completion, 1905.

Driller's log of city well at Onawa.

	Thickness.	Depth.
	Feet.	*Feet.*
Dark loam and clay	50	50
Gravel, coarse	80	130
Clay, blue, or shale	14	144
Sandstone, soft	4	148
Shale, blue	16	164
Sandstone, hard Shale Clay or shale, soft; thin layer	16	180
Shale	100	280
Limestone (small flow of water)		300
Shale		350
Limestone with flow increasing to bottom of well		

Minor supplies.—Minor supplies are summarized in the table below:

Minor supplies in Monona County.

Town.	Nature of supply.	Pumping system.	Distribution.	Pressure. Domestic.	Pressure. Fire.	Length of mains.	Fire hydrants.	Taps.
				Pounds.	*Pounds.*	*Miles.*		
Castana	Well 66 feet deep	Gasoline engine.	Direct air pressure.	40	40	0.7	12	40
Mapleton	12 driven wells 20 feet deep.	Steam duplex pump.	Gravity or direct.	70	100	2	16	92
Ute	Wells (driven) 60 ± feet deep.	Gasoline engine.	Gravity	38	38	1⅛	14	80 or 90

Town.	Persons supplied.	Daily consumption.	Remarks.
		Gallons.	
Castana	350	8,000	Ordinarily sufficient but hard.
Mapleton	400	15,000	Fair supply, but hard. Deep well contemplated.
Ute	450		Good supply, but hard. New mains being laid.

WELL DATA.

The following table gives data of typical wells in Monona County.

Typical wells of Monona County.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head above or below curb.	Remarks.
		Feet.	*Feet.*		*Feet.*	
Robert Seton	5 miles southeast of Onawa.	64		Sand	− 8	Driven well. No rock.
Town	Onawa	863	130	Limestone	+ 15	Flowing well, 75 gallons a minute; pumped by steam for city purposes.
Dr. Creik	Castana	115		Gravel and sand.	− 60	No rock.
Narcross Mill	do	45		do	+	Flowing drift well. No rock.
Mrs. Janess	1 mile east of Ticonic.	150	130	Drift sand	− 40	20 feet of dry shale below water bed.
Mr. Cloud	4½ miles south of Mapleton.	52		Gravel	− 34	No rock.
R. Perkins	Ute	265		do	−100	Do.
F. Shanahan	3 miles south of Ute.	58		do	− 44	4-foot open bricked well. No rock.
Chicago & North Western Ry.	Onawa	85		do		Steam-pumped for locomotives. No rock.

O'BRIEN COUNTY.

By O. E. Meinzer.

TOPOGRAPHY.

The surface of O'Brien County consists, essentially, of a gently undulating plain which in most of the county is more than 1,400 feet above sea level and in the north-central part reaches an altitude of more than 1,500 feet. Little Sioux River, which crosses the southeast corner of the county, has cut a deep trench into this plain and flows at a level of only a little more than 1,200 feet above the sea. The smaller streams have not yet dissected the plain to any great extent but occupy broad, shallow, and rather indefinite valleys through which they habitually meander lazily.

GEOLOGY.

The entire county is underlain by an accumulation of glacial drift, which was found to be 200 feet thick at Sanborn and which apparently is of considerable thickness at all points beneath the uplands. The upper portion of the drift consists of a loose, gravelly, more or less yellowish clay, but the greater part is a compact blue bowlder clay, containing in some localities embedded sheets and lenses of sand and gravel. In the principal valleys porous, gravelly water-laid deposits lie at the surface.

Below the drift are strata of soft blue shale, soft white sandstone, impure limestone, etc., the shale being much the most abundant. At least the upper of these strata are supposed to belong to the Cretaceous system. (See Pl. XVII.)

The following sections show to some extent the character of the drift and of the underlying stratified formations. Both are reported by the drillers and are in part approximations.

Section of Chicago, Milwaukee & St. Paul Railway well at Sanborn.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, yellow	75	75
Clay, blue	125	200
Shale, blue	160	360
Shale, blue and green, with strata of limestone	200	560
Sandstone, soft, white, with some shale	155	715
Shale, gray, and streaks of rock	50	765
Sandstone, white	45	810
Shale, blue and green, mixed with sandstone	200	1,010
Shale, green and white	246	1,256

Section of village well at Sutherland.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, yellow	50	50
Clay, blue	110	160
Sand and clay	30	190
Sand	20	210
Gravel, fine	2	212

UNDERGROUND WATER.

SOURCE.

At present nearly the entire water supply of the county comes from the upper part of the drift and the gravel deposits in the valleys. The upper part of the drift is sufficiently porous to furnish a slow seepage to dug or bored wells but can not always be relied on in dry seasons. At greater depths the drift consists chiefly of impervious blue bowlder clay, from which no water can be procured. Many deposits of water-bearing sand or gravel embedded in this blue clay form a reliable and satisfactory source of supply, but unfortunately such deposits are not everywhere found. In some wells, therefore, the drilling has been carried through the entire thickness of the drift and a certain amount of the soft bluish shale, and the wells have been finished in sandy strata which are apparently Cretaceous in age. These deep wells, as also some of the deepest drift wells, have not proved satisfactory because the water is highly mineralized and generally remains so far below the surface that the lift is great and because the fine incoherent sand in which they end is usually troublesome. Hence many of them have been abandoned and supplies from very shallow sources have again been resorted to, with the result that in seasons of drought there is on many farms a shortage in water for stock. Some farmers have dug large open wells in low-lying and poorly-drained localities where the supply from the surficial deposits is not readily affected by drought, and a number have extended pipe lines from these wells to the barnyards where the water is wanted. In many places such an arrangement is more satisfactory than a deep sand well would be. For suggestions in regard to finishing sand wells see pages 190–195.

CITY AND VILLAGE SUPPLIES.

Hartley.—The village well at Hartley (population, 1,106) is 130 feet deep and has been tested at 30 gallons a minute. The water is pumped into an elevated tank, from which it is distributed through the mains by gravity, only about 2,500 gallons being used daily. The total length of mains is about half a mile, and there are eight fire hydrants and 17 taps.

Paullina.—In Paullina (population, 796) the public supply is drawn from a shallow dug well which will supply 300 gallons a minute. The water is lifted into an elevated tank and thence distributed by gravity through $1\frac{3}{4}$ miles of mains to 18 hydrants and 93 taps. A large portion of the people are supplied, and it is estimated that approximately 6,000 gallons is consumed daily.

Primghar.—The public supply at Primghar (population, 733) was formerly obtained from a drilled well 420 feet deep, in which the water stood about 250 feet below the surface. This well proved so unsatisfactory that it has been abandoned for a dug well 15 feet in diameter and 15 feet deep, which ends in gravel with the water normally standing only 6 feet below the surface. The water is stored in a cylindrical air-tight tank from which it is forced through the mains by compressed air. The system is not extensive and supplies only a small portion of the population.

In the vicinity of Primghar a number of wells go to depths of about 100 to 140 feet, the water rising within 50 feet of the surface. They all end in sand or gravel, and most of them are giving satisfactory service. As examples of this group of wells may be mentioned those of G. B. Slocum (SE. $\frac{1}{4}$ sec. 25, T. 96 N., R. 41 W.), George Ward (NE. $\frac{1}{4}$ sec. 24, T. 95 N., R. 41 W.), L. Strangland (NW. $\frac{1}{4}$ sec. 19, T. 95 N., R. 40 W.), F. Scac (NW. $\frac{1}{4}$ sec. 6, T. 95 N, R. 40 W.), and the Chicago, Rock Island & Pacific Railway (at Calumet).

Among deeper wells in the same vicinity may be mentioned the old village well at Primghar, which is 420 feet deep; a well on the county poor farm (N. ½ sec. 5, T. 95 N., R. 40 W.), which is 408 feet deep; a well in the SE. ¼ sec. 1, T. 95 N., R. 41 W., which is 414 feet deep; a well in the NE. ¼ sec. 1, T. 95 N., R. 40 W., which is 370 feet deep; and a well in the SE. ¼ sec. 33, T. 96 N., R. 40 W., which is 380 feet deep. These wells end in fine-grained incoherent sand which causes trouble, and the water in them remains about 225 to 275 feet below the surface. Some of them have proved so unsatisfactory that they have been abandoned. In the abandoned Primghar village well the water is said to stand 250 feet below the surface (about 1,250 feet above sea level).

Sanborn.—The public supply of Sanborn (population, 1,174) is obtained from two dug wells, one of which is 56 feet and the other 62 feet deep. They end in gravel and yield about 60 gallons a minute. There are an elevated tank, about 2 miles of mains, and about 200 taps. The average daily consumption is estimated at 16,000 gallons.

The railway well at Sanborn (see p. 865 for section) goes to a depth of 1,256 feet, piercing the entire thickness of the Cretaceous and probably extending far into the subjacent Paleozoic formations. (See Pl. XVII, p. 824.) Its diameter is 8 inches to 436 feet, 6 inches to 721 feet, 4½ inches to the bottom; casing to 815 feet. The curb is 1,552 feet above sea level and the head 350 feet below curb. Water comes from 494, 503, 633, and 857 feet; capacity, 100 gallons a minute. Driller, S. Swanson, Minneapolis. Date of completion, 1896. The water in this well contains large amounts of mineral matter.

In some drilled wells about 150 feet deep in the vicinity of Sanborn the water rises within less than 100 feet of the surface. In a few between 300 and 400 feet deep the water remains farther below the surface.

Sheldon.—The public supply for Sheldon (population, 2,941) is drawn from shallow deposits of gravel, sand, and clay which are tapped by two wells 18 feet in diameter and 26 feet deep, two other wells 12 feet in diameter and 14 feet deep, and about 1,100 feet of tile laid 14 feet below the surface. There are an elevated tank, 6¼ miles of mains, 35 fire hydrants, and 238 taps. Approximately 1,000 people are supplied and 70,000 gallons of water is consumed daily, but most of the inhabitants still depend on shallow private wells.

In the vicinity of Sheldon several wells have been sunk to beds of fine sand at depths of 300 to 350 feet, and in these the water rises within 200 feet of the surface, or perhaps 1,225 feet above sea. In one well, which was sunk to a depth of 470 feet, the water is reported to remain 350 feet below the surface.

Sutherland.—The public supply at Sutherland (population, 664) is derived from a well 212 feet deep (see p. 865 for section). The water rises within 50 feet of the surface, and the well has been pumped at 100 gallons a minute. The waterworks consist of an air-pressure system. Nearly all the inhabitants have private wells, and the consumption of the public supply probably does not exceed an average of 2,000 gallons a day.

OSCEOLA COUNTY.

By O. E. Meinzer.

TOPOGRAPHY AND GEOLOGY.

The northeastern part of Osceola County is occupied by a pronounced morainal belt of Wisconsin drift. In this area the drainage is very imperfect, lakes, ponds, and swamps being interspersed in the most chaotic manner among irregular gravelly hills, mounds, and ridges. Here, also, is found the highest land in Iowa, the culminating point probably being Ocheyedan Mound, a massive accumulation of glacial material which stands in prominent relief on the plain southeast of the village of Ocheyedan and reaches an altitude of approximately 1,670 feet above sea level.[1] Bordering this morainic belt on the southwest and sloping gently away from it is a plain underlain by a sheet of gravelly glacial-outwash material which apparently thins out as the distance from the moraine increases and eventually, in the southwestern part of the county, gives way to the attenuated deposit of yellow claylike loess which is generally spread over the older drift sheets throughout the State.

Below the surface deposits lies a thick bed of glacial drift which consists in the main of a matrix of compact blue clay in which bowlders and pebbles are promiscuously embedded. At depths of several hundred feet occurs soft blue shale with some interbedded strata of fine-grained sand or sandstone which are believed to be Cretaceous in age. In no place in the county has this shale and sandstone series been found at or near the surface, and in only a few of the deepest wells has it been penetrated by the drill.

UNDERGROUND WATER.

SOURCE.

The glacial outwash material is largely so gravelly and porous that it is well adapted for absorbing and yielding water, and in the belt in which it occurs it supplies many shallow wells. Where the deposit is thin, however, or is so situated that it is readily drained, its supply is liable to fail in seasons of prolonged drought. In the morainic belt the material near the surface is also somewhat porous, being more or less gravelly and not closely packed together, and, owing

[1] Macbride, T. H., Ann. Rept. Iowa Geol. Survey, vol. 10, 1900, p. 195.

to the general absence of deep drainage channels, these semiporous deposits are saturated nearly to the surface, and hence supply water to wells that are dug or bored a short distance into them. In the deeper portions of the drift are found beds of sand and gravel which are generally filled with water under sufficient artesian pressure to flow into the wells rapidly, the yield being only slightly affected by variations in rainfall.

The Cretaceous sand strata supply a few of the deepest wells, but up to the present time they have proved of little value as water horizons. As nearly as it is possible to interpret the well data in terms of geologic formations, it seems that the most satisfactory drilled wells are those which end before penetrating the Cretaceous rocks. Little is known about the water-bearing formations below the Cretaceous, but the evidence at hand indicates that nothing would be gained, either in the quality of the water or in the artesian head, by drilling to these formations. On account of the high surface altitude the water from any of the lower horizons would remain several hundred feet below the surface.

The wells of the county can be grouped, rather arbitrarily, into four classes, as follows: (1) Wells that are dug, bored, or driven into the outwash gravels or upper loosely aggregated accumulations of glacial drift to a depth slightly below the normal ground-water level, and that depend on the seepage from these materials. This class includes perhaps four-fifths of the wells of the county. (2) Wells that are bored to depths of about 50 to 150 feet and reach beds of water-bearing sand or gravel or at least extend far enough below the ground-water level not to fail in dry seasons. (3) Wells that are drilled to depths between 75 and 225 feet, extending to deposits of sand or gravel from which the water rises under artesian pressure. These wells are tightly cased and depend entirely on the water-bearing beds in which they end; they are relatively few in number but have several advantages over the other types which recommend them for general use. (4) Wells drilled to greater depths and also tightly cased to the bottom. They are for the most part less satisfactory than the shallower drilled wells because they end more commonly in fine sand (probably Cretaceous) that interferes with the pump, limits the yield, and frequently fills the well, and their water is generally harder and more ferruginous and remains at greater depths below the surface. The difficulty with the sand can in a measure be overcome by drilling wells of larger diameter and using independent pumps.

CITY AND VILLAGE SUPPLIES.

Ashton.—The village well at Ashton (population, 518) is 6 inches in diameter and 65 feet deep and is cased to the bottom. It ends in a bed of sand from which the water rises to the surface, and it is reported to have been tested at 800 gallons a minute. The water is pumped into an air-tight tank from which it is forced through the mains by compressed air. Nearly all the inhabitants have shallow private wells and make small use of the public supply.

Sibley.—The waterworks at Sibley (population, 1,330) are supplied from a well 16 feet in diameter and 26 feet deep; they comprise an elevated tank, about 3 miles of mains, and about 25 fire hydrants. The average daily consumption is estimated at 11,000 gallons. The well furnishes sufficient water for present demands but is liable to fail in dry seasons.

Sibley is 1,502 feet above sea level. According to Norton, its high elevation and its nearness to the old land of pre-Cambrian crystalline rocks seen in the outcrop of Sioux quartzite a few miles west render the success of an attempt to obtain artesian water from the Ordovician and Cambrian water beds problematic. Beneath the exceptionally heavy drift of this region—reported at Ollendorff as 515 feet thick—the drill will find thick beds of the Cretaceous, comprising the shales and marls of the Colorado group and the underlying Dakota sandstone—the last furnishing an abundant supply of water. Whether the St. Peter sandstone extends this far to the west and north is unknown. According to the general lay of the formations, it should be found, if at all, within 600 or 800 feet from the surface, the depth depending not so much on the dip of the strata as on the depth to which the upturned edges of the gently inclined strata were worn down during the erosion periods before the Cretaceous submergence and on the thickness of the Cretaceous beds and drift deposited upon them.

PALO ALTO COUNTY.

By O. E. Meinzer and W. H. Norton.

TOPOGRAPHY.

West Fork of Des Moines River flows diagonally through the central part of Palo Alto County, occupying a wide but shallow alluvium-filled valley, on either side of which extends a monotonous and poorly drained drift plain. Westward from the valley this plain rises considerably, so that along the west margin of the county it is decidedly higher than elsewhere.

GEOLOGY.

The glacial drift rests upon a series of soft shales and poorly cemented standstones believed to be Cretaceous in age, beneath which lie limestones and other indurated Paleozoic formations. Both the glacial drift and the Cretaceous rocks seem to thin out somewhat toward the southeast corner of the county, thus allowing the Paleozoic limestones to come relatively near the surface. (See Pl. XVI,

p. 672.) The following well records throw light upon the geologic section of this region.

Section of abandoned city well at Emmetsburg.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil, yellow clay, gravel	25	25
Clay, blue	20	45
Sand, gravel, and yellow clay	5	50
Clay, blue	65	115
Gravel and sand	2	117
Clay, blue	88	205
Hardpan	½	......
"Quicksand"	60	....

Section of Chicago, Milwaukee & St. Paul Railway well at Emmetsburg.

	Thickness.	Depth.
	Feet.	*Feet.*
Drift, etc	225	225
Incoherent sandstone	109	334
Shale, red	22	356
Dolomite	32	388
Shale, sandstone, limestone, etc	484	872

Section of village well at Ayrshire.

	Thickness.	Total depth.
	Feet.	*Feet.*
Soil, yellow clay, sand and blue clay	160	160
Sand	2	162
Clay, blue, with sand	58	220
Shale	80	300
Sand; with seams of shale	73	373
Shale, red (entered)	....	....

Section of village well at West Bend.

	Thickness.	Total depth.
	Feet.	*Feet.*
Clay, yellow and blue	81	81
Sand, fine white, and blue clay	22	103
"Flint"	½	103½
Sand (entered)	7	110½

Section of the abandoned village well at West Bend.

	Thickness.	Total depth.
	Feet.	*Feet.*
Drift (similar to above section)	94	94
Sand	112	206
"Red marl"	20	226
Chert, etc	43	269
Sandstone, etc	23	292
Limestone	89	381
Shale, blue (entered)	....	....

The "quicksand" in the first Emmetsburg well, the incoherent sandstone in the second, the 73-foot bed of sand in the Ayrshire well, and the 112-foot bed of sand immediately below the drift at West Bend apparently represent the Cretaceous—probably the basal Cretaceous deposit. In each of the three localities this formation rests upon a bed of red shale which may be the red shale formation found in the vicinity of Fort Dodge. According to the sections, the thickness of the glacial drift is a little over 200 feet at Emmetsburg, about 220 feet at Ayrshire, and approximately 100 feet at West Bend.

UNDERGROUND WATER.

SOURCE.

The water supply of Palo Alto County is drawn from outwash and alluvial deposits, glacial drift, Cretaceous sand or sandstone, Mississippian (?) limestone, and older formations.

The outwash and alluvial deposits, which are virtually confined to the valley of Des Moines River, furnish water freely to shallow wells, and this water is generally not as hard as that from other sources. Outside of the valley most of the supply is obtained from the upper part of the drift or from beds of sand that lie at greater depths between deposits of bowlder clay, but many drilled wells end in the Cretaceous sand. In the southeastern part of the county a few end in the underlying limestone, and two—the railway well at Emmetsburg and the village well at Mallard—draw from still deeper sources.

The drilled wells have the greatest average depth on the high ground along the west margin of the county. Thus in the southern part of Lost Island Township and the northern part of Highland Township they are commonly about 300 feet deep; in the western part of Silver Lake Township many are about 250 feet deep; and in Booth Township depths up to 377 feet were reported. In Vernon Township depths of 250 to 300 feet are also common, but in general throughout the central and eastern parts of the county the depths are less. In the vicinity of Cylinder 100 feet is perhaps an average, and near the river many drilled wells end at considerably less than 100 feet.

Much difficulty has been experienced in finishing wells in the Cretaceous sand strata. This difficulty and its remedies are discussed on pages 190–195.

HEAD.

The depth at which the water stands in the wells varies with the altitude of the surface, being generally greatest in the deep wells in the western tier of townships, in many of which it stands from 100 to 175 feet below the top of the well, and least in the valleys and other low-lying areas farther east, where it may rise nearly to the top or in a few localities may flow. In the railway well at Emmetsburg the water rises within 33 feet of the surface, or 1,197 feet above the sea, and in the abandoned city well it rose within 40 feet of the surface, or 1,197 feet above the sea. At Cylinder it rises within 12 feet of the surface. Between Ruthven and Emmetsburg several flowing wells that end in the glacial drift evidently derive their head from the high area immediately west. Another group of flowing wells, apparently supplied from Cretaceous sand, is found in the valley of Prairie Creek in the vicinity of West Bend. To judge from the 1,050-foot well at Mallard and other deep-well data, no additional head would be gained by drilling to formations below the Cretaceous.

CITY AND VILLAGE SUPPLIES.

Ayrshire.—The village well at Ayrshire (population, 337) is 373 feet deep, ends in Cretaceous sand, and has been tested at 120 gallons a minute. (See p. 871 for section.) The waterworks, which consist of an air-pressure system, are not yet extensively used.

Emmetsburg.—In Emmetsburg (population, 2,325) it is estimated that about 1,600 people are supplied from the city waterworks. The public supply is taken from a dug well, 13½ feet in diameter and 25 feet deep, and the system consists of a standpipe, more than 8 miles of mains, 37 fire hydrants, and 320 taps. The average daily consumption is approximately 40,000 gallons.

The Chicago, Milwaukee & St. Paul Railway well (Pl. XVI, p. 672) has a depth of 874 feet and a diameter of 6 inches. The curb is 1,230 feet above sea level and the head 33 feet below the curb. The water comes from the St. Peter sandstone, the water of the Dakota sandstone having been cased out. Driller, W. E. Swan.

Driller's log of railway well at Emmetsburg.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	5	5
Clay, yellow	16	21
Clay, blue	204	225
Sand, dark	30	255
Sand, gray	79	334
Marl, red	22	356
Limestone, broken	10	366
Limestone, sandy	22	388
Shale, black	4	392
Limestone	30	422
Shale, gray	15	437
Limestone, magnesian	224	661
Shale, gray	65	726
Shale, blue	30	756
Sandstone, white	110	866
Granite	8	874

Record of strata of railway well at Emmetsburg (*Pl. XVI, p. 672*).

	Thickness.	Depth.
	Feet.	*Feet.*
Quaternary (225 feet thick; top, 1,230 feet above sea level):		
Soil	5	5
Clay, bright yellow, calcareous; with drift pebbles	16	21
Clay, blue, pebbly; more strongly calcareous than above	204	225
Cretaceous:		
Dakota sandstone (109 feet thick; top, 1,005 feet above sea level):		
Sandstone, moderately coarse, gray; mostly of clear quartz but contains many grains of pink and dark-gray quartz, jasper and flint	30	255
Sandstone, very coarse; similar in composition to the above; sample contains fragments of fine white kaolinic clay	79	334
Carboniferous (Permian?):		
Clay, fine, bright red; slightly sandy, noncalcareous	22	356
Undifferentiated strata:		
Dolomite, hard, gray and buff, fossiliferous; fragment of impression of one valve of a square-shouldered brachiopod; rough; subcrystalline	32	388
Shale, blue	4	392
Dolomite, light buff; the larger part of the sample consists of sand as at 225 feet	30	422
Shale, light blue, soft, calcareous	15	437
Ordovician:		
Galena limestone (224 feet thick; top, 793 feet above sea level)—		
Limestone, magnesian, gray	50	487
Dolomite, light buff, soft	90	577
Limestone, magnesian, hard, gray	104	661
Platteville limestone (95 feet thick; top, 569 feet above sea level)—		
Shale, blue, soft, highly calcareous	65	726
Shale, as above but darker and less calcareous	30	756
St. Peter sandstone (110 feet thick; top, 474 feet above sea level)—		
Sandstone; grains of clear quartz, smooth, well rounded, mostly 0.55 to 0.7 millimeter in diameter	110	866
Prairie du Chien group—		
Shakopee dolomite:		
Dolomite, light gray, subcrystalline	8	874

Graettinger.—Most of the people of Graettinger (population, 556) get their water from shallow wells that end in alluvial deposits, but perhaps one-fifth are supplied from the public waterworks, which include an elevated tank and a short system of mains. An abundance of water for the public supply is obtained from a dug well sunk 28 feet into alluvial deposits.

Mallard.—The waterworks at Mallard (population, 331) are supplied from a well 1,050 feet deep. (See Pl. XVI, p. 672.) They consist of an elevated tank, one-fourth mile of mains, 4 fire hydrants, and 6 taps. The average daily consumption is estimated at 3,000 gallons.

The well has a diameter of 8 to 4½ inches, casing to 1,000 feet. The curb is 1,228 feet above sea level and the head 66 feet below curb; capacity, 76 gallons a minute. Water was struck at 260 feet in fine sand and again at 1,000 feet in white sandstone. Driller, Swanson, of Minneapolis. Year completed, 1903.

Record of strata in Mallard city well (*Pl. XVI, p. 672*).

	Thickness.	Depth.
	Feet.	*Feet.*
Drift	380	380
Unknown	119	499
Limestone, argillaceous	11	510
Sandstone	90	600
Shale, blue, calcareous	45	645
Dolomite and limestone	100	745
Limestone with seams of shale	30	775
Dolomite	25	800
Limestone	80	880
Shale, light colored, calcareous	30	910
Limestone	20	930
Shale, blue, calcareous (Platteville)	60	990
Shale, hard, calcareous	20	1,010
Sandstone, white, noncalcareous (St. Peter)	40	1,050

Ruthven.—The waterworks at Ruthven (population, 655) are supplied from a dug well, 20 feet in diameter and 20 feet deep. The water is pumped into an air-tight tank, from which it is forced by air pressure through about half a mile of mains to 7 fire hydrants. The water is very little used except for fire extinction. There are many shallow private wells from which the domestic supplies are obtained.

West Bend.—The public supply at West Bend (population, 679) comes from a 110-foot flowing well. (See p. 871 for section.) The water will rise 3 feet above the surface, or 1,156 feet above the sea. It overflows at the surface at the rate of several gallons a minute, but is drawn down to 30 feet below the surface when pumped at 100 gallons per minute. It is lifted into an elevated tank and distributed by gravity through about a mile of mains to 10 fire hydrants and 20 taps. About 100 people are supplied and approximately 2,500 gallons are used daily.

An old city well at West Bend has a depth of 381 feet and a diameter of 6 inches to 284 feet and 4½ inches to bottom. The curb is 1,197 feet above sea level and the head 31 feet below the curb. The water is from 290 to 381 feet; capacity, 20 gallons a minute. The well was completed in 1895 by C. P. Thomas, of West Bend, and was abandoned some years later on account of the insufficiency of its supply.

Record of strata in city well No. 1 at West Bend.

[Based on driller's log.]

	Thickness.	Depth.
Quaternary:	*Feet.*	*Feet.*
Soil	5	5
Clay, yellow	16	21
Clay, blue	41	62
Sand and gravel	9	71
Clay, blue; and hardpan, blue	23	94
Cretaceous:		
Sand, yellow	112	206
Marl, red	20	226
Carboniferous (Mississippian):		
Chert, white, slightly pyritiferous; some fine green clay	43	269
Sandstone, in fragments of limpid quartz, with considerable chert, and some blue-gray limestone	23	292
Dolomite, white, somewhat arenaceous	6	298
Limestone, blue-gray	4	302
Dolomite or magnesian limestone, blue crystalline	4	306
Dolomite, crystalline, light blue gray, blue gray, and yellowish; 3 samples	25	331
Dolomite, blue and light gray, hard, compact, finely crystalline, argillaceous; 2 samples	8	339
Limestone, from light yellowish to dark blue gray; often mottled; in thin flakes; soft, earthy luster	11	350
Limestone, brown and buff, soft and argillaceous at 350 feet; crystalline and cherty below; 3 samples	12	362
Limestone, magnesian, gray, hard, compact; some shale; 3 samples	19	381
Shale, blue.		

PLYMOUTH COUNTY.

By O. E. Meinzer and W. H. Norton

TOPOGRAPHY AND GEOLOGY.

The upland surface of Plymouth County consists of a gently undulating prairie which descends gradually toward the southwest and is trenched by a number of valleys that trend southwestward, their direction no doubt being determined by the original upland slope. Big Sioux River, which occupies a rather wide valley, forms the west boundary of the county.

The surface deposits consist of alluvial and outwash deposits, loess, and glacial drift. In the Sioux Valley, in Sioux and Plymouth counties, a series of Cretaceous rocks, consisting in downward succession of shale and impure limestone (Benton) and sandstone (Dakota), is exposed. Between the glacial drift and the underlying Cretaceous lie sands of doubtful age.[1] (See Pl. VI, p. 258.)

UNDERGROUND WATER.

SOURCE.

Water in Plymouth County is derived from alluvial and outwash sand and gravel, glacial drift, sand of uncertain age, and Cretaceous limestone and sandstone.

The alluvial and outwash sand and gravel are confined to the principal valleys, where they constitute a valuable source of supply. The glacial drift, which has a much wider distribution, is relied on chiefly in the upland districts and furnishes most of the water used in the county. A number of drilled wells end in sand which lies at or near the base of the drift and may, at least in some places, be identical with the sand deposit of uncertain age in the Sioux Valley between the Cretaceous deposits and the drift.

The Cretaceous limestone crops out near Akron, where it gives rise to strong springs. It also supplies a number of drilled wells in the western part of the county. Though drillers do not recognize it farther east, it seems probable that if they would watch for it after the drill had penetrated shale, they would find it more widely distributed than it is at present known to be, and might find it a valuable source of water. No screens would be required in wells ending in this formation, and its depth is not great.

The Dakota sandstone outcrops in the Sioux Valley in the southwestern part of the county, where it supplies many drilled wells. The head of the water lowers toward the outcrops, as is shown by the fact that at Hull, Sheldon, and Primghar the water rises to about

[1] Bain, H. F., Rept. Iowa Geol. Survey, vol. 8, 1898, pp. 326, 327.

1,225 feet above sea level; at Hawarden to 1,150 feet; at Le Mars to 1,142 feet; and at Hinton only to 1,120 feet. In some sections of the county the water remains so far below the surface that it will perhaps never be extensively utilized, but in other parts it rises nearer to the surface and would be a valuable and reliable source of supply if it were not for the sand which tends to rise in the wells. Another disadvantage is the hard and ferruginous character of the water.

In the northeastern part of the county nearly all farm wells are bored or dug, are very shallow, and are commonly situated on low ground. Farther east and south most of the wells are drilled and many end in the Dakota sandstone at depths of 100 to 200 feet. In the Sioux Valley driven wells about 25 feet deep are widely used.

SPRINGS.

Many rather large springs emerge along Big Sioux River, the water in most of them coming from the limestone that outcrops in the valley. One spring of local note about a mile south of Akron yields several hundred gallons a minute; another occurs 4½ miles north of Akron, along the river.

CITY AND VILLAGE SUPPLIES.

Akron.—The public supply of Akron (population, 1,130) comes from 8 driven wells, each 24 feet deep. The water is pumped into a reservoir on the top of the valley cliff and is thence distributed by gravity pressure through about 1½ miles of mains to 9 fire hydrants and 62 taps. The average daily consumption is approximately 15,000 gallons.

Kingsley.—The public supply of Kingsley (population, 977) is furnished by 3 dug wells, each of them 16 feet in diameter and 20 feet deep. The water is pumped into an elevated tank and thence distributed by gravity through 1½ miles of mains to 24 fire hydrants and 63 taps. It is reported that about one-third of the population are supplied and that approximately 6,000 gallons of water are consumed daily.

Le Mars.—The waterworks in Le Mars (population, 4,157) are owned and operated by a private corporation. The water is obtained from 22 driven wells and is pumped directly into a system of mains about 12 miles long, which is tapped by 94 fire hydrants and about 850 service connections. It is estimated that approximately 750,000 gallons are consumed daily.

A well at Le Mars (Pl. VI, p. 258), owner unknown, has a depth of 1,560 feet, starting at an elevation of 1,275 feet above sea level.

Record of strata in deep well at Le Mars (Pl. VI, p. 258).[a]

	Thickness.	Depth.
	Feet.	*Feet.*
"Soil"	7	7
"Clay, yellow"	13	20
"Clay, blue"	44	64
"Sand and gravel"; hardened above	27	91
"Soapstone and slate"	89	180
"Sandstone, clays, and some lignites; in alternating strata"	138	318
"Sandstone; with some shale"	147	465
Sandstone, micaceous; of broken grains; noncalcareous		860
Sandstone; as above, many grains pink, reddish, and yellow		960
Gneiss (?); constituents orthoclase, quartz, and muscovite; reddish in mass		1,060
Gneiss (?); chiefly feldspar and mica		1,325
Schist, micaceous; brown in mass		1,560

[a] Strata below 560 feet were determined by the writer; all other statements are taken from Todd, J. E., Proc. Iowa Acad. Sci., vol. 1, pt. 2, 1892, p. 14.

The base of the Cretaceous may be placed at a depth of 465 feet, or 810 feet above sea level. The floor of crystalline rocks was unquestionably reached at 1,060 feet, or 215 feet above sea level. The sandstone at 960 feet may be compared in the number of pink, reddish, and yellow grains to the sandstones at Hull, which are found associated with intrusive sheets of quartz porphyry and may be pre-Cambrian in age.

A drill hole owned by C. R. Woodward (sec. 15, T. 92 N., R. 45 W.) east of Le Mars has a depth of 381 feet.

Record of strata in Woodward drill hole near Le Mars.

	Thickness.	Depth.
	Feet.	*Feet.*
Drift	25	25
Clay, bluish black, with bituminous matter and gypsum	25	50
Bituminous matter and gypsum	10	60
Soapstone and clay, organic matter colored by iron oxide, and carbonate of lime and magnesia	19	79
Sandstone, very hard, ferruginous, slightly calcareous	3¾	83
Calcareous sandstone, iron oxide; first seam of lignite, 1 inch; also sulphate of magnesia.	2½	85½
Stone, arenaceous, chalky, calcareous; marly partings contain nearly pure calcium carbonate	7½	93
Marl, calcareous	1	94
Calcareous fragments	1	95
Slate, rotten, bituminous, calcareous	6	101
Slate, slightly calcareous	11	112
Shale, calcareous	1	113
Slate, rotten, bituminous; and shale	12	125
Soapstone and slate	6	131
Shale, calcareous	1	132
Shale, calcareous and siliceous	5	137
Shale	8	145
Shale, very hard	1	146
Limestone, in bands; hard, bituminous	12	158
Slate, bituminous, and shale, with streaks of coal and limestone	4	162
Shale; hard slate and shale; wind veins blow sand out of top of well	13	175
Slate and shale; with limestone bands and openings	4	179
Conglomerate, hard	2	181
Sandstone, hard, ferruginous, calcareous, with slate streaks	6	187
Sandstone, reddish brown, ferruginous	8	195
Rotten siliceous rocks, slate and blackjack	6	201
Slate and fire clay, with streaks of hard coal	4	205
Sandstone, micaceous, with streaks of fine clay	6	211
Fire clay and slate	4	215
Sandstone, hard, micaceous	5	220
Slate, bituminous	2	222
Upper coal	2½	224½

Record of strata in Woodward drill hole near Le Mars—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Fire clay (6 inches) and sandstone (12 inches)	1½	226
Sandstone, dark; organic matter	5	231
Shale, bituminous	3½	234½
Coal	1½	236
Fire clay, fine coal	1	237
Soapstone and slate; limestone and coal streaks	5	242
Shale, arenaceous; coal in streaks	⅔	242⅔
Black oxide of iron (magnetic), hard, solid	6	248⅔
Same; with soapstone	4	252⅔
Gypsum and soapstone	6	258⅔
Soapstone, hard, ferruginous, with gypsum	4½	263⅙
Coal and slate	½	263⅔
Slate and fire clay; pyrite	4⅓	268
Soapstone	15	283
Chert	½	283½
Soapstone	16½	300
Slate, bituminous; with pyrite	6	306
Slate, bituminous, siliceous; with pyrite	9	315
Slate, fine grained; with pyrite	8	323
Sandstone, brown, ferruginous; streaks of coal and slate	11	334
Sandstone, brown, ferruginous; with heavy spar	....	....
Shales, quartz crystals	6	340
Shale, ferruginous, calcareous	10	350
Quartz rock and spar	14	364
Sandstone, ferruginous; with fluorspar	6	370
Shales, siliceous, with streaks of carbonaceous matter	6	376
Coal (solid vein)	5	381

All these strata are referred by Bain to the Cretaceous, although he would entertain the theory of a Pennsylvanian outlier in which the drill was still working at the bottom of the drill hole.

Remsen.—The waterworks in Remsen (population, 1,076) draw from two dug wells a supply which, though not great, is sufficient for the present requirement of approximately 13,000 gallons a day. There is an elevated tank, about a mile of mains, 15 fire hydrants, and 22 service connections.

POCAHONTAS COUNTY.

By O. E. Meinzer.

TOPOGRAPHY.

The surface of Pocahontas County is a monotonous, slightly undulating, poorly drained drift plain which has been modified to a minor extent by stream erosion. It rises gradually toward the west.

GEOLOGY.

The glacial drift appears to have a thickness of approximately 200 feet in the western part of the county, but it becomes thinner toward the east and especially toward the northeast, where in certain localities it is very attenuated, the underlying rock coming to the surface in at least one place.

Cretaceous deposits, consisting chiefly of beds of loose sand, lie below the drift in perhaps all parts of the county except in a small irregular area in the northeast, where the drift rests upon limestone of Mississippian age. (See Pl. XVI.) The Cretaceous deposits are not known to outcrop anywhere in the county, though they are constantly encountered in drilling, but Mississippian limestone is exposed in the quarry near the railway northwest of Gilmore and perhaps elsewhere. It is not improbable that remnants of the Pennsylvanian also exist in the county.

The small area in which the limestone is near the surface and the Cretaceous deposits are absent occupies the northern and eastern parts of Clinton Township (T. 92 N., R. 31 W.) and some adjoining territory. Its margin passes through the village of Gilmore, northwestward to a point west of Rolfe, and thence turns northeast. Along this margin the limestone surface descends with relative abruptness, passing beneath the Cretaceous accumulations to depths that are never reached in ordinary wells. In Gilmore this limestone surface was found to drop 80 feet between two wells 150 feet apart, and other similar evidence suggests that in some localities there may be a buried limestone escarpment.

UNDERGROUND WATER.

SOURCE.

The glacial drift, the porous Cretaceous sand strata, and the fissured Mississippian limestone are all three drawn upon for water. The first supplies numerous shallow wells, in many of which the yield is small and easily affected by drought; the second contains an abundance of good water, but yields it with difficulty because of the sand (for remedies, see pp. 192–195); the third has a large supply of water and is very satisfactory throughout the small area over which it lies sufficiently near the surface to be reached in ordinary drilling operations.

Near Fonda the drilled wells have an average depth of perhaps 200 feet, though some extend to more than 300 feet; near Laurens they range from less than 100 feet to approximately 375 feet and average perhaps 250 feet; near Pocahontas they average about 200 feet, but some are much deeper; near Palmer their average depth is between 100 and 200 feet; and near Rolfe they range from about 60 to 300 feet and average about 140 feet.

Two of the deepest wells in the county are the Chicago, Rock Island & Pacific Railway well at Laurens, which is reported to enter sand at 190 feet and to end in sandstone at 490 feet, and the old Blanden well, in regard to which no information was obtained.

HEAD.

The water remains farthest below the surface in wells on the relatively high area in the northwest and comes nearest to the surface in those on the lower ground in the southeast, where indeed in the valley of Lizard Creek several flows have been struck. Relative to sea level, however, the water rises highest in the northwest area and remains lowest in the northeast, where it is drained from the limestone into the Des Moines Valley. These conditions are shown in the following table, which is based on wells that end in the lower part of the drift or in the subjacent sandstone or limestone:

Head of the water in Pocahontas County.

Location.	Altitude of surface above sea level.	Height to which the water rises.	
		Below surface.	Above sea level.
	Feet.	*Feet.*	*Feet.*
Laurens	1,312	− 65	1,247
Fonda	1,234	− 14	1,220
Havelock	1,232	− 25	1,207
Pocahontas	1,225	− 20	1,205
Palmer	1,244	− 30	1,214
Lizard Creek	....	+	....
Rolfe	1,160	− 40	1,120
Gilmore	1,207	−100	1,107

DRAINAGE WELLS.

In the area of limestone wells a number of small swamps on the drift surface are being drained downward through wells into the underlying limestone. This method of drainage is of course possible only in areas where the head of water from the limestone is considerably lower than the ground-water table of the drift, but because of the leakage from the limestone in the valley of Des Moines River this is here the usual condition. Drainage wells have not proved entirely successful because of their rapid deterioration, which is probably due to the sediment that is carried into them with the water. Wells discharging into the sand strata have been less successful than those which empty into limestone, because the pores between the grains of sand are much smaller than the crevices in the limestone, and hence they conduct the water away less freely and are more easily choked with sediment.

CITY AND VILLAGE SUPPLIES.

Fonda.—The village well at Fonda (population, 978) ends in sandstone at the depth of 331 feet. It has been tested at the rate of about 400 gallons a minute. The water rises within 14 feet of the surface, or approximately 1,220 feet above sea level. It is pumped into an elevated tank from which it is distributed by gravity through about 3 miles of mains to which are attached 16 fire hydrants and 95 taps. It is estimated that about 600 people are supplied, and that 50,000 gallons of water are consumed daily.

Section of village well at Fonda.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and yellow clay; clay, blue	197	197
Sand and gravel	23	220
Clay, hard, blue, with gravel	53	273
Sandstone	7	280
Shale, blue and red; limestone, sandstone, etc.; sandstone (entered)	51	331

Beneath the strata reached by this well sandstones and shales of the Pennsylvanian may be expected, and shales which will merge into the great dolomitic series extending with little interruption to the shales of the Platteville immediately overlying the St. Peter sandstone. Norton's estimate places the St. Peter somewhat more than 1,300 feet below the surface. No flow can be expected, but by casing out the upper waters a less heavily mineralized supply than the present could, according to Norton, be obtained.

Gilmore.—The village of Gilmore (population, 689) has a public well but no waterworks. The well is 244 feet deep and enters limestone at the depth of 200 feet.

Laurens.—The village well at Laurens (population, 817) is 229 feet deep; the beds for the first 190 feet are reported to consist mainly of clay and for the last 39 feet of sand. The water rises within 65 feet of the surface, or 1,247 feet above sea level, and has been pumped at the rate of 35 gallons a minute. It is raised into an elevated tank, whence it is distributed by gravity through about a mile of mains to 6 fire hydrants and about 40 taps. It is estimated that 200 people are supplied, and that 12,000 gallons of water is consumed daily.

Pocahontas.—Perhaps one-third of the people of Pocahontas (population, 987) use water from the public supply, and the rest depend on private wells, many of which are shallow. The village well ends in sandstone at the depth of 248 feet, and has been pumped at the rate of 150 gallons a minute, The water rises within 20 feet of the surface, or about 1,205 feet above sea level. The waterworks consist of an air-pressure system with nearly 2 miles of mains, to which are attached 18 fire hydrants and about 40 taps. The average daily consumption is reported to be approximately 20,000 gallons.

Section of village well at Pocahontas.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay	120	120
Sand	108	228
Soft sandstone (entered)	20	248

Rolfe.—The village well at Rolfe (population, 954) is 108 feet deep, all but the first 8 feet of which is in limestone. The water stands 40 feet below the surface, or 1,120 feet above the sea, and has been pumped at 40 gallons a minute. It is lifted into an elevated tank from which it is distributed by gravity through a system of mains, about 7,000 gallons being used daily.

SAC COUNTY.

By W. J. Miller.

TOPOGRAPHY AND GEOLOGY.

Sac County may be divided into eastern and western topographic provinces. The eastern province is covered by Wisconsin drift and has the generally level surface characteristic of that deposit. North Raccoon River flows through it in a southerly and southeasterly direction, cutting its valley to a considerable depth below the general level. The western province is loess covered and is distinctly more hilly than the eastern. Boyer River flows across it from north to south. The western boundary of the Wisconsin drift practically constitutes the drainage divide in this part of the State and it is a region of unusually high land.

Of the drift formations, the Kansan extends over the entire county, being overlain by the Wisconsin in the east and by the loess in the west. Rocks of Cretaceous age may be found beneath the drift in all parts of the county.

The drift deposits are in general horizontal, and the older rock formations lie either flat or dip slightly to the east.

UNDERGROUND WATER.

SOURCE.

There are two important water horizons in the drift, one at the base of the Wisconsin and the other at the base of the Kansan. A large number of wells sunk to these horizons furnish a good supply of water of excellent quality except for its hardness. The Cretaceous and older rocks afford a third source of water.

Over the whole county the most certain and satisfactory aquifer in the surface deposits is the sand or gravel at the base of the Kansan drift. The drift is unusually deep over the region and this aquifer is known to be at a maximum depth of at least 480 feet, and has nowhere been struck at a depth of less than 130 feet. As a rule it lies deeper in the western part of the county because of the greater thickness of the drift there. In some wells, as in the abandoned wells at Odebolt and Schaller, water from this deposit is so highly mineralized and so full of organic matter as to be unfit for use.

In the eastern or Wisconsin drift-covered region an important water bed is the sand or gravel at the base of the Wisconsin. This aquifer ranges in depth from 50 to 100 feet, but in many places is missing. A few wells obtain a fair supply of water from local sand or gravel pockets within the blue clays of the Kansan or the Wisconsin drift.

In the western or loess-covered region water is obtained in some places from a sandy layer within or at the bottom of the loess. Many shallow wells derive water from this source, but the supply is often seriously affected by varying seasons.

As compared with the counties of central Iowa, Sac County contains but few "rock" wells. Such wells receive their water mostly from Cretaceous sandstone.

PROVINCES.

Sac County may be divided into two underground-water provinces—the eastern or Wisconsin drift-covered area and the western or loess-covered area. The chief difference between the two is that in the former there are two clearly defined water horizons, one at the base of the Wisconsin and the other at the base of the Kansan; whereas in the latter there is but one, at the base of the Kansan.

A few flowing wells are to be found in the eastern province. These wells, south of Sac City, are on low ground along a tributary of North Raccoon River, where the head is great enough for overflow. Good well records are not available, but it is thought that the water comes from the important aquifer at the base of the blue Kansan clay.

SPRINGS.

Some springs of considerable size are found along North Raccoon River, the most noteworthy ones being those leased by Sac City for a water supply. Other springs occur along the river, such as that on the William Harrold farm across the river from Sac City and a so-called "sulphur" spring on the M. Judd farm, 2 miles south of Sac City. All these spring waters are heavily charged with carbonate of lime and are locally called "petrified" springs because their waters incrust objects thrown into them. Some smaller springs or seepages are found along other stream courses.

CITY AND VILLAGE SUPPLIES.

Sac City.—The water supply of Sac City (population, 2,201) is drawn from springs. The water is led into a tank whence it is pumped by steam to a standpipe. The direct and gravity pressure is 80 pounds. There are 3 miles of mains, 27 fire hydrants, and 327 private hydrants. About 1,800 people use the water, which is plentiful but hard.

The springs, four in number, are located along a small branch of North Raccoon River about a mile north of the city. They emerge from the slope of the small branch stream of North Raccoon River, the water apparently coming from a gravel layer in the yellow Wisconsin clay. The flow is about 1,000 barrels a day, the supply being only slightly diminished in very dry weather. The temperature of the water ranges from 52° to 56°. The water incrusts boilers considerably. Each of the four springs has been carefully cleaned out, built up with cement tiling, and is kept covered and locked. A pipe leads from each spring into a 4-inch main which in turn extends about three-fourths of a mile southward to a reservoir at the pumping plant. From the reservoir the water is pumped into a standpipe.

The well of the Chicago & North Western Railway has a depth of 379 feet. It was completed before 1900 by William Burge, of Lisbon, Iowa.

Driller's log of well at Sac City.

	Thickness.	Depth.
	Feet.	*Feet.*
Till, yellow	15	15
Sand and coarse gravel, mixed	12	27
Clay, blue; mixed with cobblestones	85	112
Sand, gray and fine (water bearing)	5	117
Clay, blue; mixed with coarse gravel	77	194
Sand, gray; fine, ending coarse (water bearing)	8	202
Gumbo, hard, black; will not mix with water; will burn	3	205
Clay, dark blue and varying to a light color, but the last 5 feet mixed with coarse gravel and very hard	133	338
Coal, burns well	1	339
Hard substance; coal churned with it, so could not tell what it was	3	342
Clay, hard, blue, and gravel mixed	5	347
Sand, blue, fine at top, coarse at bottom; full of water; water rose 230 feet in pipe and the sand forced up 100 feet	6	353
Sandstone, compact, hard	8	361
Coal	1½	362½
Sandstone, light	14½	377
Slate	2	379

Sac City is 1,196 feet above sea level. Its artesian forecast by Norton is rather favorable on the whole, although a well tapping the chief water beds of the Iowa artesian system must necessarily be a deep one. The drift with its clays and sands may be expected to be thick, and below it occur various strata of Cretaceous and Carboniferous age, chiefly shales. Limestones and dolomites of the Mississippian and lower terranes extend with some interruptions of shaly beds for more than 700 feet to the shale of the Platteville. This green shale, which in many places is fossiliferous, caps the St. Peter sandstone, which should be here found at 100 to 200 feet below sea level, or 1,300 to 1,400 feet below the surface. For a town as large as Sac City the drill hole should be carried a few hundred feet deeper, or to 1,600 or 1,800 feet, in order to tap the large supplies usually to be found in the dolomites and sandstones underlying the St. Peter. The contract should be drawn for several hundred feet more than the most liberal estimate of needed depth, but drilling should be stopped on reaching the glauconiferous shales of the St. Lawrence formation. Casing may be needed in the shales of the Carboniferous, the Cretaceous, and the Platteville, and also in the Maquoketa shale, should this formation extend so far to the west; but below the Pennsylvanian the drill hole will be mostly in solid limestone to the Platteville, which immediately overlies the St. Peter.

Minor supplies.—Minor water supplies in Sac County are summarized below:

Minor supplies in Sac County.

Town.	Nature of supply.	Pumping system.	Distribution.	Pressure. Domestic.	Pressure. Fire.	Length of mains.	Fire hydrants.	Taps.	Persons supplied.	Daily consumption.	Remarks.
				Lbs.	*Lbs.*	*Miles.*				*Thousand gals.*	
Early	Well 15½ feet deep.	Gasoline engine and windmill.	Gravity.	35	+ 35	1	11	40	200	+ 4.0	Good supply of medium hard water.
Odebolt	2 wells 25 feet deep.	Steam engine.	...do...	48	100	1½	...	100	300	18.0	Good supply of hard water.
Schaller	Well 12 feet deep.	Steam pump	...do...	40	+ 40	±2	12	30	175	9 to 15	Fair supply of medium hard water.
Wall Lake.	Well 25 feet deep.	Gasoline engine. Triplex pump.	...do...	37	......	2½	12	140	750	51.0	Good supply of medium hard water.

WELL DATA.

The following table gives data of typical wells in Sac County:

Typical wells of Sac County.

Owner.	Location.	Depth.	Depth and rock.	Source of supply.	Head.	Remarks (logs given in feet).
		Feet.	*Feet.*			
A. J. Masteller	Southwest of Sac City.	180	......	Sand	− 90	Yellow clay, 25; blue clay, 25; black mud with very bad odor, 22; dry sand, blowing out air, 58; blue clay, 44; sand and water, 6.
F. H. Woods	1½ miles west of Sac City.	203	......	Sand and gravel.	....	
Town	Odebolt	356	......	Sand	....	Soil and muck, 10; sand and gravel, 1; blue clay, 80; yellow clay, with bowlders at bottom, 50; blue clay, with streaks hardpan and gravel, also struck "sea mud," 192; sand and water, 23.

Typical wells of Sac County—Continued.

Owner.	Location.	Depth.	Depth and rock.	Source of supply.	Head.	Remarks (logs given in feet).
		Feet.	*Feet.*			
Mrs. C. M. Hopkins	5½ miles east of Wall Lake.	62	....	Gravel....	− 30	
Town..............	Odebolt...........	25	....	...do.......	− 5	Open well, steam pump.
Chas. Hecthner....	7 miles southeast of Sac City.	80	....	...do.......	− 15	Bored, 2 feet tiling.
Walter Snecring...	5½ miles east of Sac City.	84	....	...do.......	− 25	Do.
Dan Rowe.........	5½ miles southwest of Sac City.	57	....	Sand and gravel.	+	Bored well, 2 feet tiling. Flows 1½-inch stream.
Geo. Speck.........	2½ miles north of Early.	350	....	...do.......	−240	
C. O. Porter......	6 miles southwest of Schaller.	432	....	...do.......	−266	Black soil, 4; yellow clay (some gravel), 75; sand, 2; blue clay and some gravel, 272; dry sand, 18; ocher clay and blue clay, 19; hardpan, 12; sand and gravel (water), 30.
J. C. Bodine.......	5 miles southeast of Schaller.	402	....	Sand......	− 68	
F. Fravert.........	3½ miles north of Odebolt.	129	....	Gravel....	− 40	
Mrs. E. Murrey...	Schaller...........	351	345	Shale (?)..	−242	Black soil, 4; yellow clay, 70; dark (blue) clay, 50; yellow clay and blue clay, 216; hardpan, 5; shale (water), 6.
C. N. Search......	2 miles south of Nemaha.	400	390	Sandstone	−140	Pumped by windmill and gas engine. Yellow clay (some gravel), 30; blue clay, 70; sand and some water, 15; yellow clay, 45; blue clay, 230; sandrock and water, 10.
Frank Smith......	4 miles north of Early.	480	468	(?)	−240	Water bed unknown, contains pyrites.
W. D. Holdridge..	9 miles southeast of Early.	260	240	Sand......	−140	Yellow clay, 40; blue clay, 60; yellow clay and sandy layers, 60; blue clay, 75; sand and water, 6; shale, 18; coal, 1½.
Wall Lake........	City...............	16	....	...do.......	−6 and −16	Maximum yield 147 gallons per minute; decreased account sand.
Chicago & North Western Ry.	Auburn...........	124	116	Sandstone	....	

SIOUX COUNTY.

By O. E. Meinzer and W. H. Norton.

TOPOGRAPHY AND GEOLOGY.

The gently undulating upland surface of Sioux County is trenched by the valleys of several southwestward-trending streams leading to Big Sioux River, whose deep and wide valley forms the west border of the county. The uplands are underlain by glacial drift with a thin veneer of loess, and the principal valleys contain deposits of glacial outwash and recently formed alluvium. Beneath the drift and the valley deposits lie Cretaceous shales, sandstones, and impure limestones, some of which are exposed in the Big Sioux Valley farther south.

UNDERGROUND WATER.

SOURCE.

The water supply is obtained from glacial outwash and recent alluvium, glacial drift, Cretaceous strata above the Dakota sandstone, Dakota sandstone, and lower formations.

The glacial outwash consists in large part of beds of coarse clean sand and gravel which, because of their great porosity, their favorable situation for receiving drainage and seepage from the uplands, and the impervious formations beneath them, contain a large and permanent store of water, of high value by reason of its abundance, its excellence, and the ease with which it can be obtained. Although this outwash occurs over only a small part of the county, the water is largely available for municipal supplies, because most of the cities and villages are located near streams. Though normally of good quality especial precautions are necessary to prevent its pollution, because, in most cases, the city is built on the valley slope which drains into the valley flat where the well is located.

The glacial drift furnishes most of the water used in the county and is relied on almost exclusively in the upland districts. Many bored wells end in the surficial portion of the drift, from which they derive supplies that are small in amount and that frequently fail completely in dry seasons. Deeper bored or drilled wells, however, reach seams of sand and gravel in the lower portions of the drift and thus tap water that is under considerable artesian pressure. Unfortunately in some parts of the county these deeper water-bearing beds are not found in the drift.

The deepest drilled wells penetrate the Cretaceous formations and are supplied from the Dakota sandstone, or perhaps in some places from higher sandstones or limestones. The Dakota contains large and permanent supplies but the water is hard and ferruginous and the sand causes trouble by entering the wells, especially if the latter are of the small "tubular" type or are pumped rapidly. In the northeastern part of the county the water rises to about 1,225 feet above sea level. In the creamery well at Hull it rises to 1,228 feet and in the deep wells at Primghar (O'Brien County) to about 1,225 feet. Farther southwest the head is lower, evidently because of outcrops of the formation in this direction and consequent leakage. At Hawarden the water rises apparently to only 1,150 feet above the sea, and at Le Mars to only 1,142 feet; farther southwest it remains still lower. In the northeastern part of the county the level to which water from this formation rises is about 200 feet below the upland surface. In the valley of Big Sioux River the artesian head is only slightly below the flood-plain surface, but there is no evidence that flows can anywhere be obtained.

The only well known to penetrate formations below the Dakota is the deep well at Hull, which obtained unfavorable results.

CITY AND VILLAGE SUPPLIES.

Alton.—The waterworks at Alton (population, 1,046) are supplied from large open wells sunk 20 feet into the saturated materials in the valley of Floyd River. Until recently the supply has not been adequate but a large new well has been dug which will probably yield more than sufficient to meet present demands. The system consists of a standpipe, 2 miles of mains, 20 fire hydrants, and approximately 100 taps. A large proportion of the inhabitants use the public supply.

Granville.—The village well at Granville (population, 400) is 4 feet in diameter and 40 feet deep. The waterworks consist of an elevated tank with a short system of mains and 3 fire hydrants. The water is used almost exclusively for fire protection, the domestic supply being drawn from numerous private wells.

Hawarden.—The public supply of Hawarden (population, 2,107) is derived from sixteen 2-inch driven wells 23 feet deep, which penetrate a layer of alluvial gravel. The water is pumped directly from these wells into about 2 miles of mains, with which are connected 16 fire hydrants and 159 taps. Approximately 800 people are supplied, the average daily consumption being about 50,000 gallons.

Hull.—The waterworks at Hull (population, 658) consist of a tank elevated upon a tower and one-fourth mile of mains with 4 fire hydrants. Little use is made of the water. The city well is 1,263 feet deep, and the diameter is 10 to 6 inches. The well is cased to 800 feet, and the water is reported to come in part from about that depth and in part from 340 feet, where the casing is said to have been opened. The curb is 1,433 feet above sea level, and the water stands at 230 feet below the surface, or about 1,205 feet above the sea, which is nearly the level to which the water from the Dakota sandstone rises in this vicinity. The supply is "abundant," the capacity being 29 gallons a minute. Temperature 58° F. The well was completed in 1892 by Rodgers & Ordway, of St. Paul, and was repaired in 1907 by inserting 306 feet of new casing.

Little is known of the sequence of strata except that the drift extends to at least 190 feet and that at 755 feet there begins a succession of alternating beds of sandstone and quartz porphyry whose record is given by Beyer.[1]

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[1] Ann. Rept. Iowa Geol. Survey, vol. 1, 1893, p. 168.

Description of strata below 755 feet in city well at Hull.

	Depth in feet.
Quartz porphyry, compact olive-green	755–800
Sand rock, fine-grained	800–802
Quartz porphyry	802
Sandstone, coarse-grained	825
Quartz porphyry	832–840
Sandstone, fine-grained	840–860
Conglomerate	866
Sandstone, fine-grained	880–900
Quartz porphyry; the drillings contain also angular fragments of quartz	900–930
Sandstone, fine-grained	930
Pebbles, waterworn; fine sand adhering	930–935
Quartz porphyry, decomposing	935–940
Quartz porphyry, perfectly fresh	944
Quartz porphyry, decomposing	949
Quartz porphyry	975–990
Sandstone	990
Quartz porphyry	1,194–1,220
Sandstone, fine-grained	1,228

The entire section is regarded as pre-Cambrian.

Ireton.—The waterworks at Ireton (population, 631) are supplied from 4 wells 3 feet in diameter and 12 feet deep. The water is pumped by a windmill from the wells into a reservoir, and by an engine from the reservoir into an elevated tank. About a mile of mains supplies 12 fire hydrants. The water is not considered fit for domestic use, and the people depend largely on rain water, which is stored in cisterns.

Orange City.—Until recently the public supply for Orange City (population, 1,374) was taken from a drilled well 215 feet deep, but difficulty with the screen made it necessary to abandon the well, and two shallow dug wells, whose combined yield is only about 4,500 gallons a day, were temporarily brought into service. There is an elevated tank and about a mile of mains with 9 fire hydrants and 28 taps.

A deep well was sunk in 1911 for city supply to a depth of 562 feet, by G. L. Savidge, of Sioux City. The diameters are 8 inches to 331 feet and 6 inches thence to the bottom. Water was found at 300 feet and in sandstone from 410 to 562 feet. The head is 25 feet below the surface. The pumping capacity at completion is stated to have been 20 gallons a minute. It is also stated that the well "will hold out at 75 gallons." The cylinder is placed at 321 feet below the surface of the ground. The well is cased with 8-inch casing to a depth of 331 feet, below which is 144 feet of 6-inch and 110 feet of 4½-inch casing, 60 feet of each of the latter sections being perforated with one-half inch holes to admit water. No packing was used.

The cost of drilling was $2 a foot. Unfortunately it proved impossible even with the cooperation of the town officials to secure any samples as the drilling progressed or any accurate log. A sketch of the well made by the driller indicated the following sequence:

Log of well at Orange City.

	Thickness.	Depth.
	Feet.	*Feet.*
Unknown, probably largely drift	331	331
Rock	8	339
Clay, blue	73(?)	412(?)
Sandstone; not very much water	30	442
Clay	70	512
Sandstone, white, soft	50	562
Clay, blue.		

Rock Valley.—The village well at Rock Valley (population, 1,198) is 10 feet in diameter and 30 feet deep, ends in gravel, and has been tested at 300 gallons a minute. The waterworks include an elevated tank, 1¼ miles of mains, 18 fire hydrants, and about 80 taps. Approximately 400 people, or one-third of the population, use the water, an average of 25,000 gallons being consumed daily.

WOODBURY COUNTY.

By W. J. Miller and W. H. Norton.

TOPOGRAPHY.

Woodbury County may be divided into two topographic provinces—the Missouri River bottom, which occupies the western side of the county, and the rugged highland region, which extends eastward from the Missouri River bottom. The line of separation between the two is rather sharp, the flat swamp lands of the river bottom coming abruptly against the characteristically very rugged hilly region.

The largest stream in the county is Little Sioux River, which flows across the eastern end. West Fork of Little Sioux River flows across the central portion of the county from north to south. Both these streams have numerous branches which greatly dissect the region.

GEOLOGY.

Of the drift formations, the Kansan and the loess are both well represented, each extending over the whole county except along the Missouri River bottom, where both are mostly eroded away. Clays and soft sandstones of Cretaceous age lie immediately beneath all of the drift, and good exposures may be seen along Missouri River. As far as known, all the geologic formations of the county lie approximately horizontal.

UNDERGROUND WATER.

SOURCE.

Water is obtained by shallow wells from the alluvium of the Missouri River bottom and from the loess. Deeper wells strike the aquifer beneath the Kansan or the Dakota sandstone. A well at Sioux City extends far into the Algonkian.

Except in and about Sioux City, most of the wells of the county are shallow surface wells, though there are a few deeper drilled wells. The numerous wells furnish a good supply of water, which is almost always hard.

In the drift deposits there are two water horizons—one in sand or gravel below, or sometimes within, the loess, and the other in sand or gravel below the blue Kansan clay. The combined thickness of the Kansan and the loess is much less in Woodbury County, as a rule, than in the next county to the east (Ida), and these water horizons are proportionately nearer the surface. The loess appears to range in thickness from nothing to 60 or 70 feet, and most of the wells of the county are shallow (20 to 80 feet) dug wells, whose water comes from the loess itself or from sand or gravel just below it. Many of these shallow-well supplies fluctuate according to seasons.

A much more clearly defined and persistent water horizon is that of the sand or gravel at the base of the Kansan, although comparatively few wells are deep enough to reach it, its depth ranging from less than 100 feet along stream bottoms to 300 feet in the high land. Locally, water-bearing sands may be struck within the blue clay itself.

Along the Missouri River bottom many shallow driven wells are obtained by going from 15 to 45 feet in the alluvial deposits, in which many sand or gravel layers are charged with water. The head of water in the wells generally responds to the rise and fall of water in Missouri River itself.

The Cretaceous rocks below the drift or alluvial deposits contain some important water-bearing beds, especially in the vicinity of Sioux City. The rocks and soft sandstones yield large supplies of water in numerous places at depths ranging from a few feet to 500 feet.

PROVINCES.

Woodbury County may be divided into two underground-water provinces—the Missouri River bottom, where many shallow wells derive water from Cretaceous sandstones, and the larger provinces east of the river bottom, where water is obtained largely from the loess and the Kansan drift and where a few deeper wells obtain water from the Cretaceous rocks. No flowing wells have been noted in the county.

SPRINGS.

Many small springs emerge from the loess or the Kansan drift along the main stream courses.

CITY AND VILLAGE SUPPLIES.

Sioux City.—Sioux City (population, 47,828) draws its supply from two groups of wells. The water is pumped by steam and is distributed under gravity and direct pressure of 110 pounds. The wells at the Main Street station are 97 in number, comprising 90 driven wells from 90 to 100 feet deep and 7 drilled wells more than 300 feet deep. Those at the Isabella Street station are 19 in number, 1 drilled to a depth of 371½ feet, and 18 driven to between 75 and 78 feet. The wells yield a good supply of medium hard water; 1,680,000 gallons are used daily. There are 58 miles of mains, 325 fire hydrants, and 4,500 taps.

The 371½-foot well at the Isabella Street station has a diameter of 10 inches. The water heads 24 feet below curb.

Record of strata in city waterworks well, Sioux City.

[Based on driller's log.]

	Thickness.	Depth.
Pleistocene:	*Feet.*	*Feet.*
Sandy clay	35	35
Fine gravel and water	13	48
Cretaceous:		
Gray shale or clay	32	80
Sandstone, fine grained, light colored, and water	36	116
Sandstone, yellow; with layers of shale	20	136
Shale, pink and blue	11	147
Shale, gray and blue	21	168
Sandstone, coarse	67	235
Sandstone, finer, light gray	27	262
Pyrite and lignite	31	293
Sandstone, fine, light gray	2	295
Sandstone, white, fine grained	19	314
Sandstone, darker and coarser	33	347
Sandstone, coarse; limestone fragments	11	358
Sandstone, etc., as above but coarser	3	361
Sandstone, very coarse; water	10	371

The well of D. A. Magee has a depth of 2,011 feet and a diameter of 6 inches to 1,270 feet; casing, 6 inches for 444 feet, and 4 inches for 230 feet more. The curb is 1,125 feet above sea level and the head at curb. Water beds lie at 65 feet (drift gravel), at 120 feet (yielding 120 gallons a minute), at 570 feet (heading 12 feet below the curb), at 1,250 feet (flowing 3 gallons a minute), and at 1,480 feet (pre-Cambrian). The discharge is 6 gallons a minute; temperature, 70° F. The well was completed in 1882 by Marrs & Miller, of Chicago.

The water of the well is strongly mineralized, containing large amounts of the sulphates of calcium, magnesium, and sodium, and has been sold for medicinal purposes.

Driller's log of Magee well (Sioux City Waterworks Co.) at Sioux City.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and clay	60	60
Gravel	25	85
Shale	54	139
Sand, white	2	141
Sandstone, brown	34	175
Sandstone, white	100	275
No samples	155	430
Sandstone, gray	110	540
Sand and limestone	30	570
Limestone, gray	50	620
Sand and limestone	35	655
Limestone, white	100	755
Sandstone, light colored	30	785
Limestone, gray	20	805
Shale	98	903
Limestone	10	913
Shale	12	925
Limestone	10	935
Shale	5	940
Limestone	5	945
Shale, sandy	35	980
No samples	50	1,030
Limestone	70	1,100
Shale	60	1,160
Shale and limestone	30	1,190
Limestone, gray	60	1,250
Marl, red; with sand	5	1,255
Sandstone, porous (St. Peter)	15	1,270
Sand and marl	25	1,295
Marl, sandy	20	1,315
Sandstone, micaceous, very hard; crevice giving water	165	1,480
Sandstone, brown, micaceous; and lime, very hard	380	1,860
Limestone, light colored	5	1,865
Sandstone and lime, very hard	146	2,011

Record of strata in Magee well at Sioux City.

	Depth in feet.
Cretaceous:	
Sandstone, light yellow; of fragmental quartz grains	210
Undetermined Paleozoic:	
Dolomite, light yellow gray; much fissile, green shale, in rounded lumps, and some quartz sand, both probably from above	530
Sandstone and limestone; mostly quartz sand, grains of moderate size, imperfectly rounded; also considerable limestone, light yellow gray, in small fragments, chips of hard crystalline gray-dolomite, and shale as above	540
Dolomite, gray; in sand; drillings largely chert	645
Dolomite, light buff; in sand, drillings chiefly white pyritiferous chert	780
Cambrian:	
Sandstone, bluish gray, argillaceous, pyritiferous, slightly calcareous; grains microscopically fine, subangular, 2 samples	840–855
Sandstone, white; some grains rounded and polished but most of them broken	970
Dolomite, highly arenaceous; embedded grains rounded, pyritiferous, and glauconiferous; pyrite in minute nodules	1,000
Sandstone, calciferous, pyritiferous, glauconiferous	1,010
Sandstone, light gray; grains minute, not rounded	1,030

Cambrian—Continued.	Depth in feet.
Sandstone, gray, calciferous; many rounded grains	1,035
Sandstone, medium dark blue gray, calciferous; grains minute; glauconiferous	1,070
Sandstone, highly calciferous, gray; minute angular particles of quartz, highly glauconiferous, with considerable green shale	1,160
Pre-Cambrian:	
Schist, soft, fine grained; speckled with white and dark green gray; so friable that a microsection could not be obtained; when pulverized it is seen to be composed of quartz and chlorite	1,260
Schist or gneiss; contains quartz, feldspar, white and pink feldspar, black ferromagnesian mica; and a translucent apple-green mineral, probably chlorite; 2 samples	1,320–1,350
Schists or gneisses, gray, brown, and black; micaceous, usually with biotite; much hornblende; 32 samples; at 1,860–1,865 samples are chiefly feldspar and quartz	1,727–2,000

The well of the Sioux City Brewing Co. has a depth of 215 feet.

Record of strata in well of Sioux City Brewing Co.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, brown, difficultly friable	30	30
Shale, dark drab; carbonaceous inclusions from 30 to 56 feet; minutely quartzose from 56 to 98 feet	68	98
No record	6	104
Sandstone, yellow; grains little rounded, seldom exceeding 0.4 millimeter in diameter	21	125
Sandstone, as above, but coarser; largest grains 1 mm. in diameter	15	140
Shale, drab, calcareous	75	215

Minor supplies.—The following table summarizes the smaller supplies of Woodbury County:

Village supplies in Woodbury County.

City or town.	Nature of supply.	Pumping system.	Distribution.	Domestic pressure.	Fire pressure.	Length of mains.	Fire hydrants.	Taps.	Persons supplied.	Daily consumption.	Sufficiency of supply.	Quality.
				Pounds.	*Pounds.*	*Miles.*				*M gallons.*		
Anthon	98-foot well.	Gasoline engine.	Gravity	....	....	....	....	....	....	....	Good supply.	Hard.
Correctionville.	18-foot well.	Electric motor; duplex pump.	...do...	45	100	1¼	20	50	350	75–90	...do......	Do.
Moville	32-foot well.	Gasoline engine	...do...	42	....	⅜	....	51	420	15.3	Fairly good supply.	Medium hard.
Sloan..	13 driven wells.[1]	Steam pump.	...do...	....	12	½	8	....	....	....	Good supply.	Hard.

[1] For fire use only.

WELL DATA.

The following table gives data of typical wells in Woodbury County:

Typical wells of Woodbury County.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head below curb.	Remarks (logs given in feet).
		Feet.	*Feet.*		*Feet.*	
H. Dolan	5 miles northeast Smithland.	24	......	Sand	147	No rock.
Oscar Button	1½ miles north Smithland.	120	......	...do	70	Do.
Town	Anthon	98	......	Gravel and sand.	20	Gas engine pump. Black soil, 4; yellow clay and some gravel, 20; gravel and water, 20; bluish-black clay, 20; gravel, sand, lignite and water, 34; no rock.
Henry Hein	4 miles northwest Correctionville.	400	350+	Sandstone	200	Yellow clay (gravel toward bottom), 35; blue clay, 250; gravel and water, 25; blue clay, 30; sand and shale, 52; sandstone (hard and white) and water, 8.
B. Delmater	1½ miles southwest Correctionville.	337	302	...do	200	
Hans Lahan	4 miles southeast Correctionville.	285	240	...do	210	Yellow clay with gravel at bottom, 40; blue clay, 200; shale, sandstone, and water, 45.
—— Margeson	7 miles west Moville	175	155	...do	95	
City	Sioux City	371⅓	136	Coarse sand.	24	Well not now used but will be cleaned and used again.
Omaha shops	...do	72–75	......	Gravel	28	3 wells driven along river bottom. Filling, 12; black soil, 3½; blue clay and yellowish sandy clay, 38; gravel and water, 20–22; blue clay; no rock.
Cudahy Packing Co.	...do	355	170	Sandstone.	19	Air lift. Gravel, 30–40; light-colored clay; white sandstone, 170; shale or clay, 202; sandstone, 205; white chalk rock, 300; sandstone (water), 325; light-colored shale, 350; shale, 355.
Logan Park Cemetery.	3 miles north of post office, Sioux City.	120	110	...do	60	Black soil and water, 40; blue clay, 47; sand and water, 3; yellow clay, 25; sandstone (soft), and water, 10; blue clay.
Macx Dreyfus	4 miles east of post office, Sioux City.	87	80	Shale	80	Gas engine. Feed yard.
Harriford Produce Co.	Sioux City	120	......	Gravel	20	Steam pump. Cold storage. Alluvium, 35; fine sand, 15; blue clay, 6; fine gravel, 14; hard blue clay, 4; coarse gravel, 2; clay and gravel alternating (water in last gravel layer), 44; no rock.
Town	Sloan	30	......	Sand	5–10	Driven; steam pump. No rock.

CHAPTER XV.

SOUTHWEST DISTRICT.

INTRODUCTION.

By W. H. Norton.

The southwest district includes 11 counties—Adams, Audubon, Cass, Fremont, Harrison, Mills, Montgomery, Page, Pottawattamie, Shelby, and Taylor. Over the northern counties the Cretaceous deposits lie immediately below the drift; over the remaining counties the drift is underlain by the Missouri group of the Pennsylvanian series. At Atlantic the Pennsylvanian shales, limestones, and sandstones are 725 feet thick and extend to 300 feet above sea level, where they give place to highly cherty limestones of the Mississippian series. At Council Bluffs, however, a distinct upwarp reduces the thickness of the Pennsylvanian to about 500 feet. At Glenwood the base of the Pennsylvanian can not lie more than 1,235 feet below the surface, 103 feet below sea level; at Bedford it occurs 1,340 feet below the surface or 242 feet below sea level; in the section of the drill hole at Nebraska City, Nebr., it is placed at 90 feet below sea level. (See Pl. XVIII.) At Clarinda a drill hole 1,002 feet deep failed to reach it. The map showing the elevation of the base of the Pennsylvanian (fig. 6) indicates a gentle downwarp whose axis extends from Polk County to Fremont County. If this interpretation of the data at hand is correct, the Pennsylvanian series on the uplands near the Missouri State line may attain a thickness of about 1,400 feet.

Of the Paleozoic terranes underlying the Pennsylvanian series very little has been disclosed by deep wells. At Bedford the Mississippian series appears to be at least 300 feet thick, not including a basal shale which is probably Kinderhook but which may be Devonian. Below the shale are about 200 feet of argillaceous limestones, red or pink in the lower portion, which rest on water-bearing dolomites and anhydrite marls that continue to a depth of at least 2,400 feet from the surface. Like the gypseous beds of eastern Iowa, they are referred to the Silurian. At Glenwood the succession is similar. Below the sandstone at the base of the Pennsylvanian lie the cherty limestones and basal shales of the Mississippian, resting on water-bearing dolomites. At Dunlap, on the north line of this area, a deep well

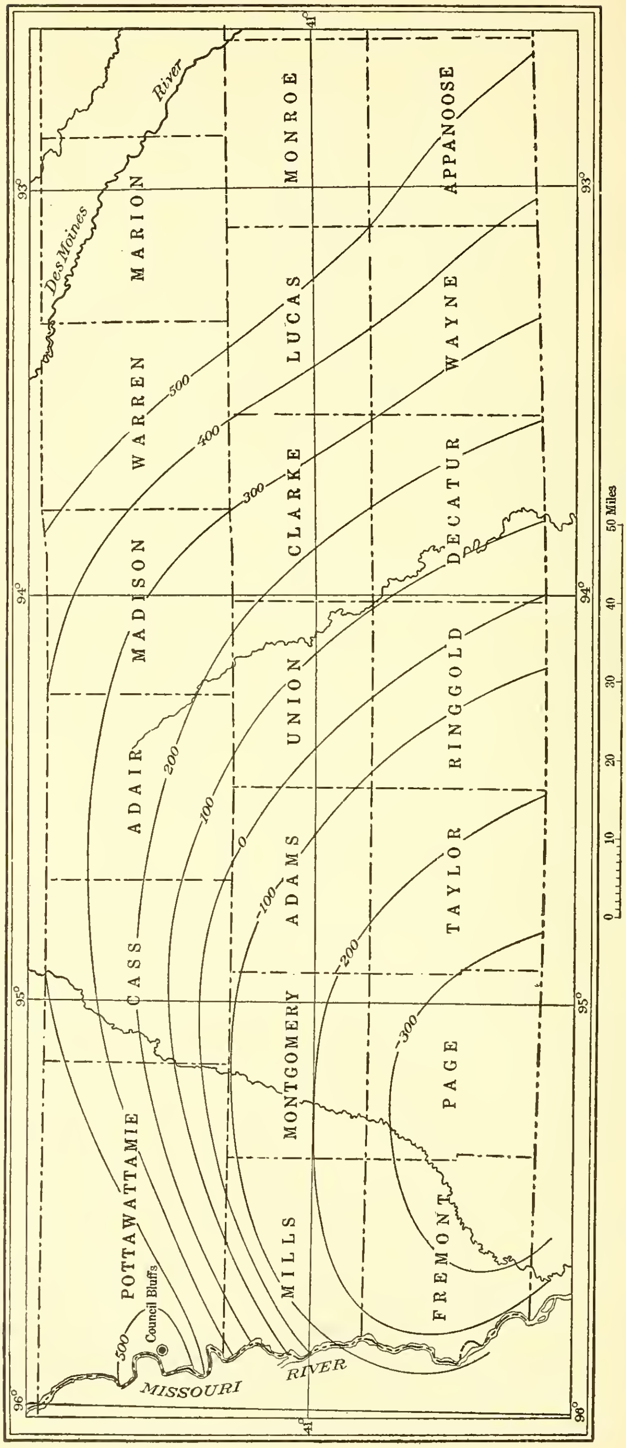
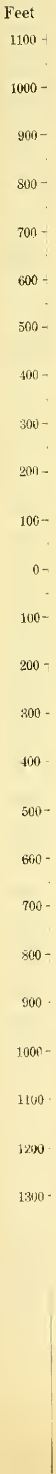


FIGURE 6.—Map showing by contours the elevation of the base of the Pennsylvanian in parts of southwestern and south-central Iowa.


Feet
1100
1000
900
800
700
600
500
400
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200
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900
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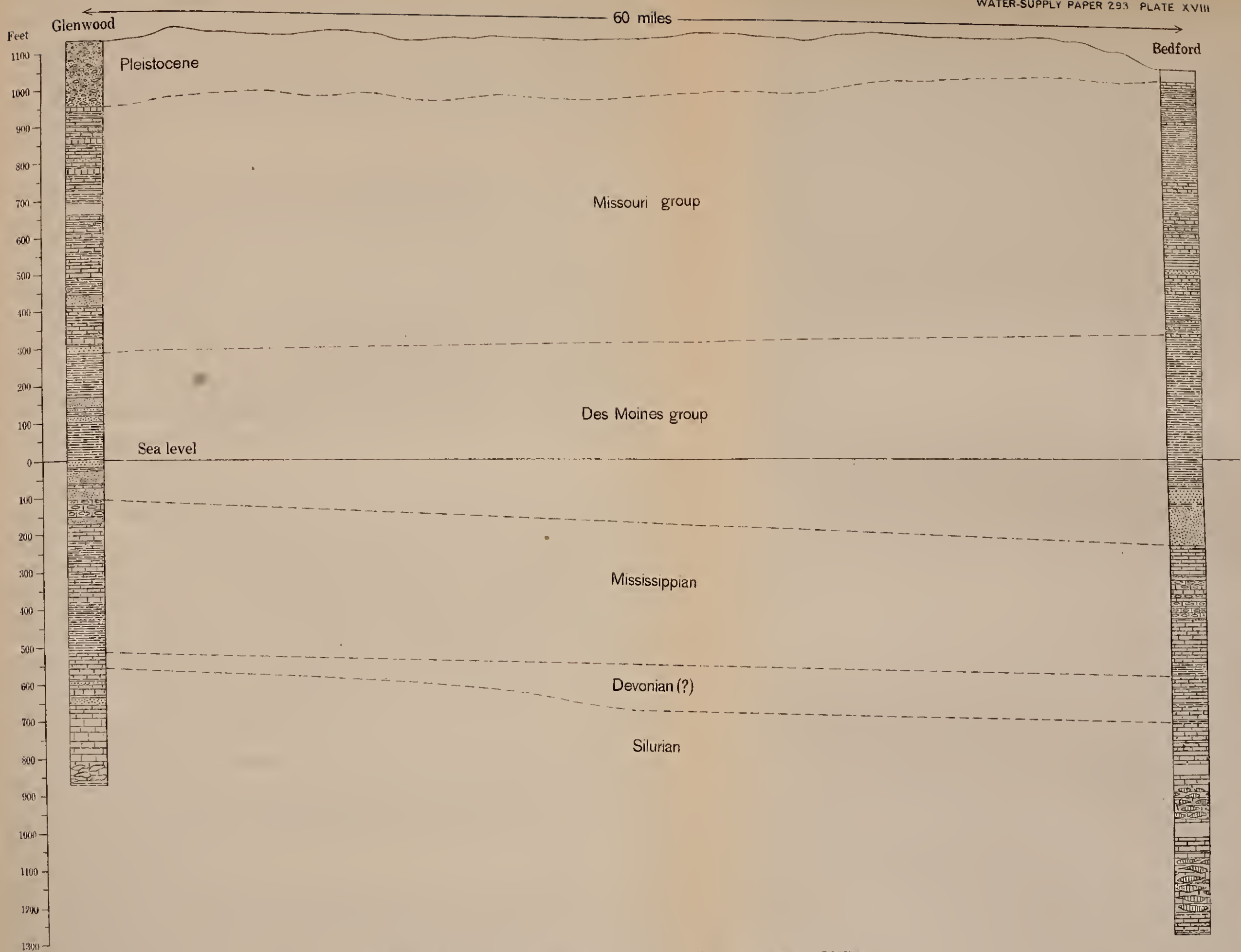
1100
1200
1300



GEOLOGIC SECTION BETWEEN BEDFORD AND GLENWOOD, IOWA
By W. H. Norton

THE NORRIS PETERS CO., WASHINGTON, D. C.

reached the Mississippian at 569 feet above sea level, and at 416 feet below sea level a calciferous sandstone or arenaceous dolomite which may be referred either to the St. Peter or to some lower terrane. The presence at 194 feet below sea level of a green shale resembling the green shales of the Platteville favors the latter reference; but the fact that the dolomite intervening between the shale and the supposed St. Peter is not arenaceous lends some countenance to the former hypothesis.

At Lincoln, Nebr., the State well, 2,463 feet deep, left the Pennsylvanian at 40 feet above sea level and entered the St. Peter at 827 feet below sea level, the intervening strata being largely magnesian limestones. The southwest strike of the St. Peter mapped for southwestern Iowa (Pl. I) thus appears to continue into Nebraska. On the other hand, there is in south-central Iowa a south-southwest strike of the St. Peter into Missouri. In the deep well at Forest City, Mo., according to the interpretation of the Missouri geologists, the Pennsylvanian extends to 760 feet below sea level and the base of the shales referred to the basal shales of the Mississippian in the Nebraska City section lies at 1,181 feet below sea level. The Paleozoic terranes reach their greatest known depth in territory adjacent to southwestern Iowa.

All of the facts at hand support the theory graphically shown in Plate I that the deeper Paleozoic strata of southwestern Iowa form a trough whose axis extends southwestward from Des Moines. Just where the axis of the trough crosses the southern boundary of the State is unknown. The fact that the base of the Mississippian is lower at Bedford than at Nebraska City leads to the inference that the axis may lie as far east as Page or Taylor County. The great thickness of the Silurian at Bedford leads to the same conclusion. If at Bedford the distance from the base of the Mississippian to the St. Peter is as great as at Nebraska City, the St. Peter would be reached at Bedford at about 2,000 feet below sea level. The hypothetic contours of the summit of the St. Peter in southwestern and south-central Iowa have been drawn by spacing the rise of the St. Peter from its assumed depth at Bedford to Nebraska City, Dunlap, Des Moines, Pella, and Centerville, assuming some increase in steepness toward the southwest.

The water-bearing beds of the drift and of the Cretaceous are described in the reports of the individual counties of this district.

The sandstone at the base of the Pennsylvanian series will afford moderate supplies of water which in the deeper valleys may rise near the surface. The Mississippian limestones supply moderate quantities of water at Council Bluffs, Logan, and probably at Woodbine, where they lie from 600 to 900 feet below the valley levels.

The magnesian limestones referred to the Silurian yield copious supplies of heavily mineralized water. At Glenwood the water is used for city supply; at Bedford it is not fit to drink. The quality of the water is probably best in the northern counties of the area, where the strata stand the highest. At Nebraska City there is a large flow of fresh water from the dolomites underlying the Kinderhook; at Council Bluffs dolomites referred to the Silurian yield copiously, and these and subjacent dolomites should afford generous supplies for scores of miles up the Missouri Valley and the valleys of its tributaries. Water may possibly be found in the St. Peter (Pl. I), but the depth to this formation is great—over most of the district too great for profitable drilling—the casing out of the mineralized waters of the Carboniferous is difficult, the quality of the water of the St. Peter is uncertain, and on the uplands the head of the water would be low. In the northern tier of counties the Silurian and Ordovician water beds are within a not excessive distance of the surface. At Logan, for example, whose elevation is 1,033 feet above sea level at the Illinois Central Railroad station, the St. Peter should be found about 1,650 feet below the surface or about 650 feet below sea level. A well 2,250 feet deep would thoroughly test the capacities of the chief water beds associated with the St. Peter. Water may be expected here in heavy arenaceous dolomites probably of Ordovician age. The capacity of the present well at Logan, which draws its supply from the Mississippian series, would no doubt be greatly increased if it were deepened to reach the horizons which furnish the main supplies at Council Bluffs. At Harlan the St. Peter is estimated at about 1,900 feet from the surface and the required depth for a deep well would range from 2,000 to 2,500 feet. At Audubon the St. Peter will probably be found about 2,000 feet below the surface.

Information of great value in interpreting the geology of southwestern Iowa is afforded by a drill hole sunk in 1911 and 1912 in search for oil and gas at Nebraska City, Nebr., by Ingersoll Bros., of Pittsburgh, Pa. Through the efforts of Dr. George L. Smith, of Shenandoah, Iowa, who has long studied the geologic problems of this section of the State, a log made out with special care was secured and a number of samples of the drillings were submitted for examination.

Driller's log of boring at Nebraska City, Nebr.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	4	4
Limestone	4	8
Shale	25	33
Limestone	2	35
Shale, red	5	40
Shale, blue	15	55

Driller's log of boring at Nebraska City, Nebr.—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Shale, red	5	60
Shale, blue	22	82
Limestone	5	87
Shale, blue	32	119
Red rock	6	125
Sandstone	2	127
Shale, blue	73	200
Limestone	9	209
Shale, black	6	215
Limestone, blue	5	220
Limestone, white	30	250
Limestone, blue	15	265
Shale, black, with oil	2	267
Limestone, white	15	282
Shale, blue	8	290
Limestone, white	45	335
Shale, blue	2	337
Limestone	17	354
Shale, blue	2	356
Shale, black	9	365
Limestone	15	380
Sandstone with mineral water, artesian	35	415
Shale, blue	20	435
Limestone, white	20	455
Red rock	3	458
Shale, black	10	468
Limestone	25	493
Shale, blue	15	508
Sandstone, with artesian mineral water	12	520
Shale, black	10	530
Limestone, white	40	570
Red rock	5	575
Limestone, bottom sandy, with water	40	615
Shale, blue	2	617
Limestone, white	60	677
Shale and limestone	5	682
Shale	3	685
Limy shale	5	690
Limestone	10	700
Shale, black	10	710
Sandstone, limy	15	725
Limestone	25	750
Limestone, blue	10	760
Shale, limy	25	785
Sandstone, very hard	8	793
Limestone	20	813
Sandstone	5	818
Limestone, very hard	5	823
Shale	10	833
Limestone	10	843
Shale, blue	20	863
Wanting	17	880
Limestone, blue	20	900
Shale, blue	25	925
Shale, black	15	940
Limestone, white	20	960
Shale, red	60	1,020
Rock, hard flinty	4	1,024
Soapstone, white	5	1,029
Sandstone, white; with big flow of water, saline between 1,040 and 1,050, passing gradually into limestone below	21	1,050
Limestone, cherty; with several small layers of shale toward bottom, none over 2 feet thick	190	1,240
Shale, blue; in last 50 feet hard thin shells of pyrite	200	1,440
Unknown, hole caving badly	20	1,460
Shale, white; casing set here	1	1,461
Sand, white	4	1,465
Sand, and lime, brown; big flow of fresh water rising to within 100 feet of surface	48	1,513
Sand, gray	4	1,517
Lime and sand, white	82	1,599
Shale, green and black	6	1,605
Limestone, sandy, white	65	1,670
Shale, green blue	5	1,675
Limestone, brown; show black shale	13	1,688
Limestone, brown; turning to white	38	1,726
Limestone, buff, sandy	35	1,761
Sandstone, white, hard, sharp	56	1,817
Limestone, white	5	1,822
Limestone, brown	30	1,852
Limestone, white	153	2,005

Driller's log of boring at Nebraska City, Nebr.—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Limestone, white, sandy	24	2,029
Shale, black	2	2,031
Limestone, white, sandy	6	2,037
Limestone, white	6	2,043
Limestone, blue, white, sandy	17	2,060
Limestone, white	42	2,102
Limestone, dark and shale	59	2,161
Limestone, shaly, dark; showed some sand	113	2,274
Limestone, buff; showed some mineral	35	2,309
Limestone, blue, hard	38	2,347
Limestone, brown, very hard	18	2,365
Limestone, white	137	2,502
Limestone, blue, white, sandy; drills into chips and cuts steel badly	22	2,524
Limestone, white, sandy, medium hard	20	2,544
Limestone, white	10	2,554
Limestone, blue white and darker, hard	13	2,567
Limestone, blue white, sandy	13	2,580
Limestone, black, hard	3	2,583
Limestone, dark, very sandy	22	2,605
Limestone, dark	14	2,619
Limestone, brown, sandy	44	2,663
Shale, black; alternating with limestone shells; wet sample gives odor of petroleum	24	2,687
Limestone, brown, very hard	15	2,702
Limestone, gray, sandy, very hard	17	2,719
Limestone, blue, very hard	7	2,726
Limestone, brown, very hard	25	2,751
Limestone, blue white, hard	3	2,754
Shale, black and blue; with shells, alternating hard and soft, fossiliferous.		

Description of strata of boring at Nebraska City, Nebr.[a]

	Thickness.	Depth.
Carboniferous:		
Pennsylvanian (1,020 feet thick; top, 930 feet above sea level):	*Feet.*	*Feet.*
No samples	1,020	1,020
Mississippian (420 feet thick; top 90 feet below sea level):		
Chert, white, sparingly pyritiferous; in large fragments; 1 fragment of non-magnesian, light gray-brown, fine crystalline-granular, compact limestone, and 1 diorite pebble from drift; 1 sample	220	1,240
Shale, light blue, plastic, argillaceous; somewhat calcareous, fine grained, massive; some fragments of light blue, finely arenaceous laminated shale, laminæ ¼ inch thick	200	1,440
Devonian and Silurian (720 feet thick; top, 510 feet below sea level):		
Dolomite; in fine yellow powder; crystalline grains; very small admixture of minute grains of quartz	20	1,460
Limestone, magnesian; or dolomite; effervescence moderately slow; buff in mass, in fine sand and powder; some minute quartz grains; 4 samples	35	1,495
Dolomite, light brown; in fine sand; a little chert, at		1,500
Limestône, magnesian; or dolomite; dark buff; moderately slow effervescence; in fine crystalline sand, at		1,515
Limestone, magnesian; or dolomite; as above; 1 sample	45	1,540
Shale, hard, light blue green, and darker, blue gray; slightly calcareous, at		1,665
Limestone; in light buff powder, rather brisk effervescence; with minute grains of quartz and flakes of cryptocrystalline silica, at		1,770
Limestone, magnesian; or dolomite; light buff; in sand; effervescence rapid at first, then slow; more or less residue of irregular and broken minute grains of quartz and cryptocrystalline silica; 3 samples, at		1,840
Dolomite, light buff, cream color, and whitish; in fine crystalline sand; residue of minute, irregular grains of quartz and flakes of cryptocrystalline silica; in some samples large residue of cryptocrystalline silica; 1 sample contains fragments of hard granular-crystalline vesicular dolomite; cavities drusy; 8 samples	27	2,012
Dolomite, light buff and light brown; in sand and powder; highly cherty below 2,060; 7 samples	130	2,160

[a] On March 25, 1912, the drillers reported that after passing through 29 feet of the Decorah shale the drill entered, at 2,783 feet from the surface, a white sandstone 64 feet thick, evidently the St. Peter, the Platteville limestone unexpectedly being absent. The top of the St. Peter here lies 1,853 feet below sea level. The St. Peter was found to be underlain by red rock and shale 22 feet thick and this in turn rested upon sandstone. The St. Peter and the strata below it were dry.

Description of strata of boring at Nebraska City, Nebr.—Continued.

	Thickness.	Depth.
Ordovician:		
Maquoketa shale (114 feet thick; top, 1,230 feet below sea level):	*Feet.*	*Feet.*
No samples	114	2,274
Galena dolomite (480 feet thick; top, 1,344 feet below sea level):		
Limestone, light gray and whitish, minutely granular-crystalline; oxidized on surface to buff; rather slow effervescence; contains minute cubes of pyrite and some gray chert, in chips; also limestone, soft, buff, minutely crystalline-granular; rather rapid effervescence at first immersion, but crystalline grains attacked rather slowly; considerable blue-gray flint in fine sand; fragment of pygidium of trilobite noted on one chip of same; much shale (2,274 feet); caving from above; blue green, hard, fissile, noncalcareous, nonarenaceous, nonglauconiferous	35	2,309
Chert, blue gray, mottled, and light buff; in small chips; a little soft crystalline-granular limestone, buff, of rather rapid effervescence; some hard green and gray fissile shale and pyrite	4	2,313
Dolomite, light gray, highly cherty, pyritiferous; some minute irregular grains of quartz; in fine sand, at	....	2,322
No samples	43	2,365
Dolomite, light buff, crystalline, granular, vesicular; in places cherty; in fine sparkling sand; 5 samples	159	2,524
Dolomite, buff and gray, cherty; a little hard fissile greenish shale, somewhat calcareous; 2 samples	51	2,575
No samples	45	2,620
Dolomite, buff, impure, considerable microscopic siliceous and argillaceous residue (described by driller as alternating layers of lime and dark shale)	24	2,644
Dolomite, dark buff, crystalline, granular; in sand; 3 samples	46	2,690
Limestone, mottled buff and gray, compact; rapid effervescence; pyritiferous; 2 samples	64	2,754
Decorah shale (top, 1,824 feet below sea level):		
Shale, dark green, hard, fissile, fossiliferous; *Stictoporella angularis* and *Dalmanella subæquata* var. *minneapolis*, identified by Ulrich.		

Analysis of drillings from 1,982 to 1,993 feet.[a]

$MgCO_3$	36. 63
$CaCO_3$	47. 00
$FeCO_3$	2. 38
SiO_2	13. 97
	99. 98

Omitting the silica, which occurs largely as chert, it will be noted that the percentages of magnesium carbonate and calcium carbonate are respectively 42.5 and 54.6, or nearly those of these constituents in dolomite.

The first 1,020 feet of the boring is clearly Pennsylvanian. The age of the large body of limestone between 1,020 and 1,240 is of special importance. In reamings there was found a fossil identified by the late Dr. Samuel Calvin as a thick, short-hinged variety of *Spiriferina kentuckiensis*, a species most common in the Pennsylvanian, but not unknown in the Mississippian. Reference of the bed to the Mississippian is favored by the occurrence of entirely similar thick cherty limestones at about the same horizon at Bedford and at Glenwood. At Nebraska City they underlie the shales of the Des Moines group and are with little doubt the westward extension of the cherty limestones of the Mississippian of southeastern Iowa.

[a] Made in chemical laboratory of Cornell College, Iowa, under direction of Dr. Nicholas Knight.

The absence of any body of cherty limestone of like thickness in the Missouri group in Iowa makes for the same reference. Assuming, then, that the limestone in question is Mississippian, it will be noted that the Pennsylvanian section at Nebraska City is almost wholly of the Missouri group, the Des Moines group having thinned to a few feet of shale at base. The same assumption gives the summit of the Mississippian at Nebraska City as 90 feet below sea level, practically the same as at Glenwood, and 150 feet higher than at Bedford. The base of the coal measures at Lincoln, Nebr., is about 100 feet higher than at Nebraska City. Apparently then the floor of the coal measures lies nearly horizontal over this area with the axis of the slight syncline lying between Bedford and Missouri River.

On the other hand, Dr. George L. Smith, of Shenandoah, Iowa, who has given much study to the Missouri group of southwestern Iowa, finds a considerable dip southward along Missouri River, a dip of at least 400 feet from the railway bridge at Plattsmouth to Nebraska City, and largely on this account he is convinced that the limestone in question is the Bethany limestone.

Beginning at 1,240 feet the drill passed through 200 feet of shale. This is correlated with the 130 feet of shale immediately beneath the Mississippian limestone at Glenwood and with a much thinner shale at the same horizon at Bedford. It may be referred to the Kinderhook, but in part may be Devonian. On the other hand, if the cherty limestone overlying the shale is the Bethany limestone, this shale represents the Des Moines group. Unfortunately no succession of samples of the shales were saved, so that their lithologic affinities are unknown. When the well had reached a depth of 1,330 feet, the driller described this shale as light blue and states that "in places it gets sandy and hard, but is practically one body of shale so far as we have gone." At 1,385 feet the same description, practically, is given. There is no evidence of the alterations in color which are common in the Des Moines.

From 1,440 to 2,160 feet the drill continues in magnesian limestones and dolomites. This body of limestone, 720 feet thick, nowhere so far as the drillings are in evidence carries gypsum or anhydrite as at Bedford and Glenwood. At 1,460 feet a parting of 1 foot of shale is recorded and at 1,665 another parting less than 10 feet in thickness.

This body of limestone is assigned to the Devonian and the Silurian without any attempt to draw a division line between them. The base also of the Silurian is in doubt, for the reference of the strata between 2,160 and 2,274 feet to the Maquoketa shale rests only on the statement of the driller's log, reporting here "alternating limestone and shale." From 2,274 to 2,754 feet extends an unbroken body of limestone and dolomite, which may be assigned to the Galena dolomite, since it overlies a shale which extends from 2,754 to 2,783 feet and which contains fossils proving it to be the Decorah. In the Decorah shale, at 1,824 feet below sea level, a definite and certain geologic datum is evident.

As the drill hole was sunk as an oil prospect no quantative or qualitative tests were made of the waters found at different horizons. To 400 feet the hole was dry. From the Pennsylvanian water-bearing beds were reported from 400 to 415 feet, from 508 to 520 feet, and at 615 feet. Small flows occurred also in the same terrane between 615 and 900 feet at intervals not exceeding 50 feet. A larger flow of salty water was encountered at the summit of the Mississippian at 1,040 feet. These waters rose slightly above the surface and yielded not to exceed two gallons a minute. They are described by Dr. George L. Smith as bitter, saline, purgative, and unpotable. At 1,050 feet casing was placed which shut them out, and all waters below this depth are said to be fresh. Between 1,461 and 1,480 feet, a flow was reached in the limestones underlying the shale referred by the writer to the Kinderhook, but which is the apparent equivalent of that at Forest City which the Missouri geologists have placed with the Devonian. This flow is described by the drillers as "immense;" at least it was not lowered by them in their work. The temperature is said to have been colder than spring water; the head was 125 below the surface. A measurement was kept of the height of the water in the drill hole, but no changes occurred below 1,480 feet to indicate that other veins had been reached. Below that level, however, the bailer brought up water which after going through the cold water of this flow was still a little warm.

ADAMS COUNTY.

By Howard E. Simpson.

TOPOGRAPHY.

Adams County comprises a portion of the old drift plain which slopes from the crest of the Mississippi-Missouri divide southwestward toward Missouri River. Though well up on the slope the plain is maturely dissected and thoroughly drained by the numerous tributaries of Nodaway River. The larger streams flow through broad, flat, preglacial valleys which are carved deeply into the underlying rocks and are partly refilled by drift and alluvium.

GEOLOGY.

The drift mantles all the country rock to depths of 15 to 150 feet, and is in turn overlain by the loess. Broad strips of alluvium, consisting of sands, gravels, and clays overlain with fine silt, border the larger streams, and sand and gravel fill the valleys beneath to a depth of 40 feet in many places.

In the northwest corner of the county the drift is underlain by heavy beds of soft, porous, brown sandstone—the Dakota sandstone of the Cretaceous. Over all the rest of the county the Dakota is missing and the drift is directly underlain by the Missouri group (Carboniferous), which consists chiefly of heavy beds of hard limestone alternating with shales and, rarely, a thin seam of coal. Below, these rocks grade into those of the Des Moines group. The limestone decreases, whereas the shale, sandstone, and coal increase. The whole has a thickness of several hundred feet.

UNDERGROUND WATER.

SOURCE.

The alluvial sands and gravels afford a plentiful supply of water to inexpensive driven wells ranging in depth from 15 to 50 feet. Most of the wells of the county, however, obtain their water from the drift. Many very shallow wells, 15 to 20 feet deep, are scantily supplied by surface waters seeping through the porous loess, and others reach the sandy layers which lie beneath. The water in all of these wells is scanty and is subject to pollution from organic matter washed in from the surface.

As the quantity of ground water near the surface has decreased as a result of more perfect drainage and the cultivation of the land, it has been found necessary to sink many of the wells into the sands and gravels which usually lie at the base of the drift and which furnish good water freely and permanently. These wells are lined with 18-inch tiling and will probably prove the best source of supply for upland farms over all the limestone region. Other wells obtain an ample supply in the local sandy layers above the base of the drift.

The Dakota sandstone yields the best and purest water obtainable in the county. Unfortunately, this soft sandstone underlies the drift only in the northwest corner of the county, and in some places it is too thin to furnish water abundantly. The water is only moderately hard and is free from undesirable minerals. It makes an excellent domestic and stock water. The limestones and shales of the Missouri group underlie the entire county, but because of their compact texture they afford only a scanty supply of hard water, and are penetrated only by wells which fail to find a suitable supply in the drift. Fortunately, this failure is rare, for though the limestone beds between shaly layers in many wells yield a supply of good hard water, several holes drilled to depths of 200 to 500 feet have been abandoned because of scantiness of supply. In such wells waters from the drift may be combined with those from the limestone by puncturing the casing opposite the higher beds. In the coal-prospect hole drilled at Carbon heavy water-bearing sandstone was found at a depth between 700 and 800 feet. The hole was 873 feet deep and, except for 16 feet of drift, was entirely in Pennsylvanian strata. The sandstone lenses, however, lie so deep and their occurrence is so uncertain that drilling for them is not warranted except where artesian wells are sought.

No flowing wells of importance are reported. A few weak flows are obtained on low ground, one such being on the farm of J. Mercer (sec. 28, T. 71 N., R. 33 W.).

SPRINGS.

Several good stock springs flow from margins of Dakota sandstone on the sides of the Nodaway River valley, typical ones being found on the farms of Joe Houcks and Peter Curry, 1 mile and 3 miles, respectively, north of Carbon. Other springs from sandy layers of drift occur at different points in the county, but none are important sources of water supply.

CITY AND VILLAGE SUPPLIES.

Corning.—Corning (population, 1,702) has one well, 169 feet deep, extending 131 feet below the alluvial deposits of East Nodaway River into the shales and limestones of the Missouri group. The well yields a scanty supply of hard water and is unused. A large open well sunk on the river bottoms 38 feet to bedrock is walled with brick laid in mortar. This well is 25 feet in diameter and furnishes the present town supply. The water comes in at the bottom from gravels overlying bedrock, stands at a level varying from 3 to 28 feet below the curb, and may be entirely withdrawn by heavy pumping. Two steam pumps having a capacity of 10,000 gallons each force the water into an elevated tank, from which it is distributed under gravity pressure of 60 pounds through 5 miles of mains to 27 hydrants and many private taps. Driven wells, ranging in depth from 30 to 100 feet, are common on the bottoms, whereas most wells on the slopes and in higher portions of the city are dug or bored. All these wells are in drift, and many of them draw from sands immediately overlying bedrock.

Prescott.—Prescott (population, 426) has a small public supply for fire protection. The water is obtained from shallow wells and distributed through a few hundred feet of mains to three or four hydrants located on the principal street.

Most of the wells at Prescott are bored and lined with tile to depths ranging from 15 to 40-feet, the alluvial and subloessial sands furnishing the water. On uplands the wells extend to the deeper drift sheets.

Minor supplies.—At Nodaway 30-foot sand points are common on all of the lower lands. Wells on uplands are bored 50 to 200 feet in drift. Near Carbon 40-foot points obtain plenty of water in the Nodaway bottoms. In Nodaway Valley, outside the alluvial belt, all 50-foot wells find abundant water in the drift. At Brooks and Nevinville wells range in depth from 20 to 70 feet, many being 35 feet deep. Mount Etna gets its water supply from driven and bored wells ranging in depth from 16 to 50 feet and averaging 30 feet. A clay overlies the water-bearing sandstone.

WELL DATA.

The following table gives data of typical wells in Adams County:

Typical wells in Adams County.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head below curb.	Remarks (logs given in feet).
		Feet.	*Feet.*		*Feet.*	
J. A. Mason....	NE. ¼ sec. 5, T. 71 N., R. 35 W.	276	150	Sandstone (Dakota).	106	Yield 3 gallons per minute for one-half day without lowering. Drift (Pleistocene), 150; sandstone (Dakota), 40; shales and limestone (Missouri), 86.
W. C. Day.....	NE. ¼ sec. 2, T. 72 N., R. 35 W.	403	68	.....do.......	......	A little water in Dakota sandstone, none below. Abandoned. Drift (Pleistocene), 68; sandstone (Dakota), 6; shale and limestone (Missouri) 329.
Corning........	River bottoms...	169	38	Limestone (Missouri).	30	6-inch drilled well cased to rock; put down for city supply but unused on account of hardness and scantiness. Alluvium, sand and gravel (Pleistocene), 38; shales and limestone (Missouri), 131.
Corning........	River bottoms..	38	38	.....do.......	3 to 28	Chief city supply; diameter, 24 feet. Soil and loam, 8; gumbo, 8; blue clay, 10; gravel, 12; limestone.
Lehmen Bros...	Corning.........	35	35	Gravel......	......	

AUDUBON COUNTY.

By O. E. Meinzer.

TOPOGRAPHY AND GEOLOGY.

Audubon County comprises a well-dissected upland over which are interspersed a number of rather wide alluvium-filled valleys.

The generalized upland section as reported by R. S. Gransbury, driller at Exira, is as follows:

Yellow clay containing lime concretions and pebbles, with hardpan and a little sand near the bottom.
Light-blue clay.
Hardpan.
Blue-black clay.

White hardpan.
Yellow hardpan.
Yellow and white cemented sand.
Limestone, shale, and sandstone.

The interpretation of this section seems to be as follows: The yellow clay is loess and weathered Kansan drift; the light-blue clay is unweathered Kansan; the blue-black clay is Nebraskan; and the overlying hardpan Aftonian; the white and yellow hardpan and subjacent cemented sand are Cretaceous, and the series of limestone shale and sandstone is Pennsylvanian.

The Cretaceous "hardpan" is said to be between 1 foot and 20 feet thick, and the "cemented sand" has about the same range but averages less than 10 feet. The Cretaceous deposits have not been found in all parts of the county. Drillers report them best developed near the eastern margin and generally wanting in the vicinity of Audubon and farther north. They consider them most likely to be reached by wells located on the divides between the principal drainage lines. The "cemented sand" is found at depths of 300 feet and more on the highest ground and at correspondingly less depths on lower ground near the valleys.

UNDERGROUND WATER.

SOURCE.

Water can be obtained from the alluvium, the drift and associated deposits, the Cretaceous sandstone, and the lower formations. Of the lower formations the upper Carboniferous strata are predominantly nonwater bearing, but their deeper beds are likely to furnish at least small amounts of water. Still lower formations yield larger supplies.

Though the Cretaceous sandstone yields more freely than any of the drift deposits, its water is under little pressure and flows into the wells at only a moderate rate, and must be lifted a great distance to be brought to the upland level. Two wells, reported by E. L. Gransbury as ending in the "cemented sand," may be cited as typical:

The well of F. Hays, located in sec. 13, T. 79 N., R. 34 W., has a depth of 340 feet and a diameter of 3 inches. Its water bed is 6 feet thick, and its head is 290 feet below the surface. Continuous pumping at the rate of 3 gallons per minute lowers the water level 20 feet. The water is hard and ferruginous.

The well of George McClain, located in sec. 35, T. 79 N., R. 35 W., has a depth of 218 feet and a diameter of 3½ inches. Its water bed is 5 feet thick, and its head 148 feet below the surface. Pumping at the rate of 6 gallons a minute lowers the water level 20 feet.

Many wells drilled to the Cretaceous on ridges in this and adjacent counties in years of extreme drought have on the return of more normal conditions been abandoned on account of difficulties arising from the depth, low head, mineralized water, and the incrusting of the sand screens. Two-inch tubular wells are not so successful as wells of larger diameter with independent pumps. In many places larger wells can be finished without screens by sand pumping and putting down fine gravel which tends to keep back the sand.

Most of the wells at present in use are of the shallow bored and dug types, are located on the lowest ground feasible, and depend on a slow seepage from the drift. They are fairly satisfactory except in dry years or where large supplies are required. Much of the difficulty resulting from inadequate yield could be overcome if, instead of a single hole, a series of holes were bored. If the wells are spaced about 25 feet apart and are not less than 2 feet in diameter they can be connected by boring horizontal holes an inch or two in diameter from the bottom of one well to the bottom of the next, so that the water contributed by all can be lifted by means of a single pump placed in any one of the wells. These horizontal holes can be bored most conveniently with an auger consisting of detachable links which can be added as the boring progresses. The links should be attached to each other like the links of the chains used in pipe tongs, so that the auger can be withdrawn without disconnecting them. The horizontal holes should be provided with iron pipes, to make sure that the connections are kept open; but if these pipes are small enough to fit loosely the seepage on the outside of them will, in some wells, add materially to the total yield.

In the valleys generous supplies can commonly be obtained by sinking inexpensive open or driven wells into the stream deposits. This source is utilized largely in settlements located along streams.

CITY AND VILLAGE SUPPLIES.

Audubon.—The city waterworks of Audubon (population, 1,928) are at present supplied from 5 shallow wells located in the creek valley. The principal well is 27 feet in diameter and 35 feet deep, and receives its water from sand and gravel near the bottom. The wells fill within 15 feet of the surface, and are frequently pumped at the rate of 10,000 gallons an hour for 5 consecutive hours. The water has a large amount of permanent hardness, as is shown by the analysis (p. 175). Boring was at one time carried to a depth of 95 feet and ended in dark-blue clay without water. The distributing system comprises an elevated tank and about 2 miles of mains, with 125 taps. The average daily consumption is 30,000 gallons.

Exira.—The village well at Exira (population, 787) is sunk in the river bottom to a depth of 28 feet, the last 2 feet of which are in gravel. It is 10 feet in diameter, is cased with brick, and fills with water to within 8 feet of the surface. Approximately 8,000 gallons are used each day, but the well would easily provide several times this amount. When the waterworks were installed, a series of 2-inch wells were driven to the same bed of gravel, but were not as satisfactory as the large well used at present. The waterworks include a standpipe, three-fourths mile of mains, 10 fire hydrants, and about 35 service connections. The water is said to be very hard and is used by only a small portion of the inhabitants.

Kimballton.—The village of Kimballton (population, 271) has a system of waterworks which draws from a well and includes one-fifth mile of mains, 4 fire hydrants, and 12 taps.

CASS COUNTY.

By Howard E. Simpson and W. H. Norton.

TOPOGRAPHY AND GEOLOGY.

Cass County is near the southwest corner of the State, well up the western slope of the Missouri-Mississippi divide.

Topographically it is a drift plain, sloping gently southwestward, cut in every direction by the channels of minor streams. Nishnabotna and Nodaway rivers flow southwestward across it in wide, deep, preglacial valleys, which they have cut in the underlying rocks and recut in the soft drift cover. The upland slopes to the north and east grade into gently rolling prairies; those to the south and west show more complete dissection and more mature drainage than those on the eastern side of the divide.

In the valleys of Nishnabotna and Nodaway rivers the drift rests on Carboniferous strata, here chiefly a series of heavy shales alternating with thinner beds of hard limestone (Missouri group). Over a large part of the county the drift rests on Cretaceous sandstone, known as the Dakota, which rests unconformably on the Carboniferous. On the uplands the drift has an average thickness of perhaps 200 feet, and consists of heavy beds of till overlain by a comparatively thin mantle of loess. Heavy deposits of sand and gravel are found in the bottoms of the larger valleys.

UNDERGROUND WATER.

SOURCE.

The water-bearing beds utilized in Cass County are the alluvial sands and gravels, the loessial sands, the drift sands, the Dakota sandstone, and the limestone of the Missouri group.

In few other parts of Iowa can so satisfactory supplies of water be obtained so cheaply as in the gravel-filled valleys of the southwestern part of the State. The sands and gravels that fill the valley bottoms of Nishnabotna and Nodaway rivers and their larger tributaries to depths of 50 to 100 feet afford an inexhaustible supply of good water at depths ranging from 20 to 100 feet. The water is generally obtained by driving $1\frac{1}{4}$-inch pipe shod with a 3-foot point covered with No. 60 gauze mesh. The expense of such a well complete, with pump, is $15 to $25. Rarely is the sand so fine as to fill the point and thus destroy the well. When it does, the pipe may be drawn, the point cleaned, and the whole again driven.

On the uplands, especially in the eastern part of the county, where the loess is comparatively thin, many shallow wells obtain water from sands under the loess. In the western part, where the loess is thicker, many wells do not pass through the loess, but depend entirely on the slow seepage from this porous clay. Wells in the loess and its underlying sands are very likely to be contaminated by drainage from the surface.

In all parts of the county an excellent supply of water may be obtained from the gravels at the base of the drift at depths of 100 to 225 feet. The head is relatively low but strong. Many wells obtain a scant but wholesome supply from seepage and from local sand layers that lie at different depths within the till. Where cultivation and artificial drainage have lowered the ground-water level, dug wells have been dug deeper, and bored wells filled with large tiling or sewer pipe extending down to lower gravels of the drift are very common. The gravel between the drift sheets also yields water.

The Dakota sandstone is an aquifer of the first order and rarely fails to yield excellent water at depths ranging from 150 to 300 feet.

The limestone of the Missouri group affords a scant supply of hard water that is seldom utilized. It is important only on the slopes of the larger valleys, where the Dakota sandstone has been eroded away. It is rarely reached within 250 feet of the surface.

CITY AND VILLAGE SUPPLIES.

Anita.—The public water supply of Anita (population, 1,118) is obtained from a 207-foot well, which draws excellent water from the Dakota sandstone. It is somewhat hard and is said to pit the boilers. The water is pumped by gasoline engine into elevated tanks, from which it is delivered over the entire town under direct pressure of 50 pounds.

Atlantic.—The public supply of Atlantic (population, 4,560) is owned by the city. It is drawn from 30 drilled and driven wells, ranging in depth from 52 to 86 feet and in diameter from 4 to 6 inches, located in the "bottoms" of Nishnabotna River. The drilling is done inside a tube, the well being pumped out and the tube driven a few inches or feet at a time until it reaches a suitable aquifer, into which drilling is continued a foot or two to form a collecting pocket. A Cook strainer is pushed to the bottom and fixed on the end of the driven pipe. The wells are connected with T's to air chambers and so connected in groups and series that any individual or group may be cut off, the caps may be removed, and the sand pumped out at will. One of the 30 wells never produced at all, and this well and two others whose casings were broken in cleaning have been cut off.

The water-bearing bed, a sharp white sand with some gravel, lies 50 to 86 feet below the surface. Above it are many layers of clay silt alternating with beds of sand and gravel, some of which are water-bearing. Several years ago fifty 3-inch drive points penetrating some of these gravel layers were utilized, but they were abandoned on account of the insufficiency of the supply. The series could be pumped dry in about one hour.

When not pumped the water in the present wells ordinarily stands 13 feet below the surface, but the level varies with weather and rainfall. The wells respond within 24 hours to heavy rainfall or rise of river near by, but the water level lowers much more slowly than it rises. Under emergency pumping the water level has been lowered to 28 feet below the surface.

The water in these wells is distributed by direct pressure through 13 miles of mains to 104 fire hydrants and more than 1,200 taps. Four-fifths of the inhabitants of the city are supplied. The daily use is 500,000 gallons; the daily capacity of the plant is 2,500,000 gallons. The water pumped at night in excess of that used overflows into a reservoir where it is held in reserve for emergency. In case of fire the water from this pond is forced directly into the mains and the pressure is raised from 80 to 155 pounds. The contamination of the city mains with stale water from the pond is the unsatisfactory feature of this otherwise excellent system.

The water has been used in boilers and for manufacturing purposes by the Chicago, Rock Island & Pacific Railway, the electric light company, laundries, canning factories, starch factory and others, and is, on the whole, very satisfactory. It precipitates, on standing, a small quantity of the red sediment that is commonly found in drift-gravel waters, and some firemen find it helpful to use a small amount of boiler compound.

A prospect hole, drilled in 1888 by the Rust Artesian Well Co., of Ithaca, N. Y., for the Atlantic Coal & Mining Co., goes down 1,310 feet. The elevation of the curb above sea level is 1,150 feet. No record was preserved of water-bearing beds, as the contract required a dry hole at all times. It is said that drilling was stopped because the pressure became so great that it caused the casing to collapse. The hole is situated a short distance east of the railway station.

Samples of the drillings of this boring were placed at the disposal of the Iowa Geological Survey by Seth Dean of Glenwood. In the following record the determinations of strata are supplied by Mr. Dean and Mr. E. H. Lonsdale.

Record of strata in deep well at Atlantic.

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene? (no sample)	125(?)	125(?)
Carboniferous:		
Pennsylvanian (725 feet thick; top, 1,025 feet above sea level):		
Shale, blue	35	160
Shale, gravelly	35	195
Shale, red and blue, gravelly	5	200
Limestone, gray, sandy	15	215
Shale, red and blue, with soapstone	5	220
Shale, gravelly	5	225
Shale, purple, dark drab, and green, fine, unctuous; with pebbles (5 limestone, 1 vitreous sandstone, 1 coal)	35	260
Shale, gravelly	50	310
Clay, mottled red and blue	30	340
Shale, blue	15	355
Shale, red and blue, with gravel	5	360
Shale, blue, with slate	5	365
Sandstone and shale	50	415
Slate, black; soapstone, blue and green	5	420
Shale, varicolored, green, and reddish; fissile, practically noncalcareous	10	430
Sandstone	5	435
Shale	15	450
Shale and limestone	15	465
Shale, varicolored, green, and reddish; fissile, practically noncalcareous	....	....
Clay and soapstone	15	480
Sandstone	25	505
Shale, blue	12	517
Shale, dark gray, very finely laminated, somewhat calcareous	23	540
Sandstone, or sandy limestone	10	550
Shale, dark gray	15	565
Shale, dark brown gray, noncalcareous, arenaceous, pyritiferous	20	585
Sandstone, brown, highly ferruginous	5	590
Sandstone	10	600
Shale, sandy	30	630
Sandstone, very fine	30	660
Shale and slate	15	675
Shale, iron gray, finely laminated, noncalcareous	10	685
Sandstone, white, very fine	10	695
Clay, blue, with gravel	15	710
Shale, sandy	15	725
Sandstone	5	730
Shale, finely arenaceous, ocherous; some black	10	740
Shale, black, carbonaceous	10	750
Shale, blue, and slate	10	760
Shale, yellow, gravelly	40	800
Sandstone, gray, of finest grain, with much black shale; samples at 800 and 815	25	825
Limestone, sandy	5	830
Sandstone, brown	5	835
Sandstone, gray	15	850
Mississippian (420 feet thick; top, 300 feet above sea level):		
Limestone, white, nonmagnesian; white chert constitutes the bulk of the sample	35	885
Limestone, blue gray, argillaceous; quartzose residue, with large fragments of dark shale; probably from above	75	960
Limestone, yellow gray; sample chiefly dark-brown flint with some chalcedonic silica; a very little quartz sand	5	965
Flint, brown gray, calcareous; some chalcedonic silica; much shale in fragments	10	975
Flint, gray and black chalcedony; drusy quartz; some shale	5	980
Flint, brown, calcareous; some chalcedony; a little shale	5	985
Flint and chalcedony; 5 samples; drillings largely milk-white, translucent chalcedony, with brown calcareous flint and some limestone	45	1,030
Limestone, nearly white; much white chert; 2 samples	15	1,045
Chalcedony and flint; drillings remaining after original washing made up of chalcedonic silica and blue-gray and yellow siliceous fragments which effervesce in cold dilute hydrochloric acid, but do not disaggregate; pure limestone practically absent	30	1,075
Shale and flint; shale, blue gray, somewhat calcareous	5	1,080
Limestone, soft, light yellow gray; with silica as above, and some fragments of shale; 4 samples	40	1,120
Limestone, brown; much white chert	5	1,125
Limestone, lighter colored; drillings chiefly chert; only finest sand is limestone and even this is siliceous	5	1,130

Record of strata in deep well at Atlantic—Continued.

	Thickness.	Depth.
Carboniferous—Continued.		
Mississipian (420 feet thick; top, 300 feet above sea level)—Continued.	*Feet.*	*Feet.*
Limestone, light yellow, nearly pure; considerable shale in small fragments	5	1,135
Limestone; as above; much chalcedony and chert	5	1,140
Limestone, white, chalky, and light yellow	5	1,145
Chert; drillings of chert and chalcedony; at 1,145 feet a few rounded grains of crystalline quartz and particles of fine-grained sandstone; 4 samples, all of which in mass effervesce freely in acid	25	1,170
Flint; black, yellow, and red flint and jasper, with sand of rounded grains of quartz; fragments of limestone, chert, and chalcedony	10	1,180
Limestone, blue gray, cherty, and argillaceous	10	1,190
Chert, white and brown; some shale in sample	10	1,200
Limestone, cherty; gray in mass	25	1,225
Limestone; siliceous material constitutes one-tenth of sample by weight	20	1,245
Chert and shale, buff; chert effervescent; shale pink in fine grains, but slightly calcareous	10	1,255
Limestone, highly arenaceous and siliceous; chert and chalcedony; two-fifths of sample by weight insoluble	5	1,260
Sandstone, highly calciferous; limestone arenaceous; quartz in minute angular particles; white and yellow-gray; 2 samples	10	1,270
Devonian? (40 feet penetrated; top, 120 feet below sea level):		
Shale, fine, light gray, calcareous	15	1,285
Limestone, cream yellow, rather hard; in angular sand	25	1,310

Griswold.—The town of Griswold (population, 949) is supplied from a 200-foot drilled well which draws its water from drift within 70 feet of the surface. A standpipe is used for storage and the water is distributed through 1¼ miles of mains at pressure varying from 35 to 100 pounds.

Lewis.—The water supply of Lewis (population, 603) is chiefly from wells ranging in depth from 40 to 70 feet. The public supply is drawn from a dug well 7 feet in diameter and 68 feet deep, in which the water stands 50 feet below the surface. The well ends in sand and gravel overlain for almost the entire depth by clay. The water is distributed from an elevated tank under direct pressure of 43 pounds through nearly 1 mile of mains.

A well drilled on a valley slope in 1900 as a prospect for coal and artesian water passed through 7 feet of Dakota sandstone, probably the edge on the valley side, and continued down through coal measures to a depth of 562 feet, where it was abandoned. An excellent spring flows from the sandstone outcrop in the bluffs bordering Nishnabotna River and furnishes water for drinking and bathing at a summer resort established by D. W. Woodward.

Marne.—At Marne (population, 266) domestic wells are sunk 30 to 60 feet to sand layers in the drift. Many of the stock wells, demanding a larger supply, are sunk to the lower gravel layers, about 200 feet. The city well supplies an elevated tank from which water is distributed by direct pressure of 25 pounds for fire, street, and domestic purposes.

Massena.—At Massena (population, 490) there are few deep wells, most of the people relying on bored wells 20 to 60 feet deep. The city has no other supply than that afforded by open cisterns and hand pumps.

WELL DATA.

Information in regard to some of the typical wells in Cass County is presented in the following table:

Typical wells of Cass County.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head below curb.	Remarks (logs given in feet).
T. 76 N., R. 35 W. (FRANKLIN).		*Feet.*	*Feet.*		*Feet.*	
R. R. Bell	SW. ¼ sec. 24	189		Sand	179	Upper water bed at 40.
T. 76 N., R. 37 W. (WASHINGTON).						
W. B. Berry	NE. ¼ sec. 7	226		Fine sand	150	Very hard water.
W. J. Copeland	SE. ¼ sec. 11	150		Drift sand		
Julius Kirkpatrick.	NE. ¼ sec. 10	180		do	130	
T. 74 N., R. 37 W. (PLEASANT).						
Town	Griswold	100	100	"Blue rock"	70	Valley.
Do	do	200	70	Drift sand		No water below drift.
T. 75 N., R. 36 W. (BEAR GROVE).						
Sam Deverns	6 miles south of Atlantic.	365	100	No water		In limestone and shale.
T. 76 N., R. 36 W. (GROVE).						
F. C. Schain	SE. ¼ sec. 29	110		Drift sand	30	Good strong well.
Bert Frost	NE. ¼ sec. 19	218		Sand	163	
Polk Byrd	NE. ¼ sec. 6	150	124	Sandstone (Dakota).		Drift, 124; white sandstone, 4; red sandstone, 18; shale, 4.
C. V. Wilder	5 miles south of Atlantic.	128	128	Drift sand and gravel.		Abundant water in sand and gravel over limestone.
T. 77 N., R. 35 W. (BENTON).						
Thomas Kelly	4 miles southeast of Braydon.	295	245	Sandstone (Dakota).	220	Strong well, good water.
T. 77 N., R. 37 W. (BRIGHTON).						
L. S. Allen	NW. ¼ sec. 30	247	234	do	166	Limestone (Missouri) at 247 feet.
T. 77 N., R. 36 W. (PYMOSA).						
Winfield Wilbur	7 miles north of Atlantic.	283	250	Sandstone (Missouri).	200	Water in crevice of limestone.
T. 75 N., R. 34 W. (MASSENA).						
W. S. Shields	NW. ¼ sec 32	324	178	No water		In limestone (Missouri).
T. 74 N., R. 34 W. (VICTORIA).						
John Holste	NE. ¼ sec 20	240	207	do		Do.
T. 77 N., R. 34 W. (GRANT).						
Town	Anita	207	171	Sandstone (Dakota).	171	Hilltop: Pleistocene, 171; Dakota sandstone, 36; limestone (Missouri) at 207 feet.
T. 75 N., R. 37 W. (CASS).						
Town	Lewis	562	70	Limestone (Missouri).		Hillside: Pleistocene, 70; Dakota sandstone, 7; Carboniferous, 485. Water in limestone at 82. Abandoned because of caving; drilled for coal.

FREMONT COUNTY.

By O. E. Meinzer.

TOPOGRAPHY.

Fremont County is divisible into two distinct physiographic provinces: (1) The uplands, consisting of rugged hills and ridges separated by innumerable sharp ravines, and (2) the lowlands, consisting of broad valleys with flat, monotonous bottoms that include nearly one-half of the county's area. Between Missouri River, which forms the west boundary, and the abrupt margin of the uplands, stretches a flood-plain belt nearly 6 miles in average width; and the valleys of both forks of the Nishnabotna are also in most places several miles wide.

GEOLOGY.

The bedrock, composed of alternating strata of shale and limestone belonging to the Missouri group (Pennsylvanian), was at one time deeply buried under glacial drift which seems to include two distinct till sheets—a lower, dark, dense bowlder clay (Nebraskan) and an upper yellow and pale blue crumbling bowlder clay (Kansan). In certain localities beds of sand and gravel are also found between the two sheets, at the base of the drift, and perhaps at other horizons. Since its deposition much of the drift has been removed by erosion, for not only were countless ravines and gullies carved out of this material in the upland areas, but the wide, deep valleys were also excavated in it.

After weathering and dissection had progressed far, the region was mantled with yellow homogeneous silt known as loess, which, according to Udden,[1] has an average thickness in Mills and Fremont counties of about 60 feet and which along the ridge bordering the Missouri Valley attains a maximum thickness of 100 to 150 feet. Since the loess was deposited it, too, has been vigorously attacked by stream erosion.

In the valleys the rivers have laid down considerable quantities of alluvium, which consists largely of fine silt derived from the loess, but which includes also beds of sand and gravel, especially at some depth below the surface.

UNDERGROUND WATER.

SOURCE.

In this region much of the drilling into bedrock has been done for the purpose of finding coal, and such explorations for water as were made have generally yielded unfavorable results. At Hamburg a

[1] Udden, J. A., Geology of Mills and Fremont counties: Ann. Rept. Iowa Geol. Survey, vol. 13, 1902, p. 167.

hole was drilled into the Missouri strata to a depth of 180 feet, according to current reports, without finding water, and there are other indefinite reports of unsuccessful wells sunk into the upper part of this series. The deep wells at Glenwood (see pp. 928–932) discovered supplies in formations far below the surface.

On the lowlands hard but otherwise satisfactory water is obtained without difficulty from beds of alluvial sand and gravel that lie at very moderate depths and from which the water rises nearly or quite to the surface. The driven wells, which are here in common use, are inexpensive and fairly satisfactory, although some trouble is caused by the incrusting of the screens.

On the uplands supplies are obtained principally from the seepage out of the loess and glacial drift. Water-bearing deposits of sand and gravel exist in certain localities but seem to be too largely wanting to be generally relied upon. The loess is homogeneous in texture and so constituted that it allows the water to percolate through it very slowly. Hence, where it is thick its lower portion is saturated even on hills and ridges near deep valleys, and if wells are sunk into this saturated zone they receive a sure though meager seepage supply, the amount varying with the area of the infiltration surface, which, of course, depends upon the depth and diameter of the well. The glacial drift, especially in its upper layers, behaves in a somewhat similar manner, but since it is more heterogeneous in its structure it is also more diverse in its water-bearing capacity.

An ordinary dug well which extends through loess or drift to a short distance below the water level will usually furnish enough water for the small demands of a household, but will seldom supply a windmill continuously, and will frequently prove inadequate for stock farms. The yield can be indefinitely augmented by increasing the number of wells or projecting drifts out from the bottom of a well, the best method probably being to bore with a well auger a sufficient number of holes, perhaps 25 feet apart, and to connect the latter at the bottom with small pipes placed in holes bored with a link auger. (See p. 910.) The difficulty of obtaining enough water from these sources for municipal supplies is illustrated by the experience at Tabor and Sidney, but the solution here also seems to consist in increasing the infiltration surface.

Throughout the uplands many ravines and valleys have been cut below ground-water level and hence receive a slow seepage which gives rise to rivulets and creeks that are extensively utilized for stock and domestic supplies. Numerous springs also issue at the base of the cliff along the east margin of the Missouri Valley.

CITY AND VILLAGE SUPPLIES.

Hamburg.—In Hamburg (population, 1,817) the public supply has in the past been obtained from (1) a huge dug well situated at the edge of the valley and ending in fine sand, and (2) a spring which issues from the cliff that borders the valley. The total daily yield from these two sources is reported to be only about 20,000 gallons a day, which has not been enough to meet the demands. A system of 2-inch driven wells is to be installed at a point farther from the cliff, where the alluvium is thicker and yields more freely.

The water is pumped into a large cement reservoir situated on the loess ridge back of the city, 170 feet above the valley, and is thence distributed through 2 or 3 miles of mains to 22 fire hydrants and about 110 taps.

Sidney.—In Sidney (population, 1,019), located in the upland area, several unsuccessful attempts have been made to obtain an adequate supply for the public waterworks. There are two dug wells, one 15 feet in diameter and 55 feet deep, the other 6 feet in diameter and 58 feet deep, both ending in a bed of fine sand and connected at the bottom by a drift. The normal water level is said to be 20 to 25 feet below the surface, but the wells fill to a depth of less than 10 feet in 24 hours and together furnish only about 15,000 gallons a day. Two holes were also drilled to bedrock, at about 200 feet, without finding water except a small amount at 80 feet. The waterworks include a standpipe and about 2 miles of mains with 15 fire hydrants and 40 taps.

Tabor.—Tabor (population, 909) is on the upland nearly 300 feet above the Missouri Valley. Its public supply is taken from a dug well 12 feet in diameter and 114 feet deep. The first 80 feet appears to consist of loess and the rest of yellow "joint clay," which is probably drift. The clay in the last 2 feet is somewhat sandy. The well receives seepage from all levels below about 40 feet and will fill to within this distance of the surface. Its yield has not been definitely ascertained, but it is apparently small, though adequate for present needs. The water is only moderately hard and is considered otherwise good. The system of waterworks consists of two compression tanks, about one-half mile of mains, 7 fire hydrants, and 31 taps.

Thurman.—Thurman (population 336), like Hamburg, is located at the foot of the Missouri Valley cliff and gets most of its water supply from the alluvium. The waterworks, which are owned by a private company, depend on a 4-inch well that ends with an 8-foot screen at the depth of 92 feet. The water rises to within about 30 feet of the surface and has been pumped for long periods at the rate of approximately 20 gallons a minute without noticeable effect.

There is less than a mile of mains, with 8 fire hydrants and 12 taps. The pressure is obtained from a storage reservoir on the bluff about 100 feet above the village. The water is good, though somewhat hard, and it is estimated that an average of 7,000 gallons is consumed daily. The village well has about the same depth as the one that supplies the waterworks, but most of the private wells are driven to depths of only 15 to 30 feet.

HARRISON COUNTY.

By O. E. Meinzer and W. H. Norton.

TOPOGRAPHY AND GEOLOGY.

A striking contrast to the rugged and thoroughly dissected upland that occupies most of this county is presented by the broad expanses of flat, swampy lowland formed by the Missouri Valley in the western part, and by its largest branches, which extend diagonally southwestward across the county. This entire region is underlain by Pennsylvanian rocks (upper Carboniferous), which consist essentially of a succession of shale and limestones, aggregating several hundred feet in thickness. These rocks outcrop at a few points and have been pierced by the drill at Logan, Woodbine, and Dunlap. Over an indefinitely known area, especially in the northeast, they are covered by Cretaceous sandstone and shale; elsewhere they are overlain directly by glacial drift or alluvial deposits. The drift comprises two sheets, the dark Nebraskan below and the lighter Kansan above, separated in some localities by Aftonian gravel. On the weathered surface of the Kansan till rests a thick cover of loesslike clay. In the lowlands the alluvial deposits of clay, sand, and gravel are extensively developed.

UNDERGROUND WATER.

SOURCE.

Ground-water supplies in Harrison County are derived from alluvial deposits, loess, drift and associated gravels, Cretaceous rocks, and lower rock formations.

The deeper formations reached in the public wells at Logan, Woodbine, and Dunlap, have a certain value for municipal and other supplies, but their yield of water is not entirely satisfactory either in quantity or quality. The Pennsylvanian strata, though not totally destitute of water-bearing members, are generally so disappointing that it is not advisable to penetrate them unless it is the intention to drill to the lower aquifers.

A few wells in this region probably draw water from Cretaceous deposits. In some wells shale or "soapstone" was found below the drift, and beneath the "soapstone" a bed of sand or sandstone saturated with water; other drilled wells have not passed through shale, but have been finished in sand or sandstone at depths ranging from a hundred to several hundred feet—most commonly about 250 feet; still others have entered shale and limestone of the Pennsylvanian series without finding a satisfactory water-bearing bed. The drilled wells are 2 to 6 inches in diameter and are mostly finished with sand screens. Wells of small diameter are, however, not adapted to the conditions found in the uplands, both because of the limitations in yield and because of the rapidity with which their screens become incrusted. Cretaceous wells and other drilled sand wells should have a diameter of 4 or 6 inches.

In the uplands the two principal water horizons above the Cretaceous are at the contact zone between the loess and the Kansan and in the Aftonian gravel between the two drift sheets. Neither of these generally supplies water readily enough for drilled wells, although they furnish a satisfactory yield for bored wells. The upper of the two beds is characterized by white calcareous accumulations of "chalk," so commonly found near the bottom of the weathered zone of the Kansan drift, and also by sandy and gravelly seams that are frequently cemented into a "hardpan." The water which percolates slowly downward through the loess saturates the sandy and gravelly material at this level and is hindered from descending farther by the impervious unweathered drift. The Aftonian gravel is only vaguely recognized in wells and, indeed, is reached in few. Where sufficiently developed it ought to furnish more water than any deposit at a higher level.

In the lowlands generous supplies of hard but otherwise good water are obtained by means of inexpensive wells, the best type of which are driven or drilled and end in screens. The most copious yield is secured from the coarsest materials and these are most common near the bottom of the alluvial filling, but the amount of dissolved iron is generally greater in this deeper water than in that near the surface because it is less accessible to the oxygen of the atmosphere. The water from all parts of the alluvium rises to within a few feet of the surface and can be pumped at small cost by means of suction pumps. Examples of large supplies obtained from this source are afforded by the railway and city wells at Missouri Valley and the railway well at Dunlap. The wide distribution and great importance of the alluvium as an aquifer will be realized when it is remembered that the Missouri Valley wells are located on the Missouri bottoms 6 miles from the river, and that the Dunlap well is located near the northeast corner of the county, many miles from where the Boyer Valley opens into the Missouri.

CITY AND VILLAGE SUPPLIES.

Dunlap.—The public supply of Dunlap (population, 1,155) is obtained from a well 1,535¾ feet deep, 6¼ inches in diameter, cased to 400 feet. The curb is 1,151 feet above sea level; original and present head, 47 feet below curb. The tested capacity is 80 gallons a minute. The well was completed in 1887 by J. P. Miller & Co., of Chicago, and was repaired about 1903 by inserting smaller casing. The strata penetrated are indicated by the following section:

Record of strata in Dunlap city well (Pl. XI, p. 382).

	Depth in feet.
Pleistocene:	
Unknown	0–50
Sand	50–70
Gravel; pebbles of northern drift and sand	70–95
Gravel; pebbles of northern drift, at	150
Cretaceous and Carboniferous (Pennsylvanian) (307 feet thick (minimum); top, 926 feet above sea level):	
Shale, drab, at	225
Shale, pink, at	300
Sandstone, grains varying widely in size and imperfectly rounded, at	392
Shale, dark drab, at	400
Shale, black, noncalcareous, at	450
Shale, pink and purplish, at	480
Carboniferous (Mississippian) (288 feet thick; top, 619 feet above sea level):	
Limestone, white, soft, chalky; with gray-green shale, at	532
Limestone, white, hard; of finest grain	600
Limestone, light yellow-gray, cherty, at	650, 703
Limestone, gray, finely crystalline; fracture subconchoidal, at	797
Devonian (?), Silurian, and Ordovician (715¾ feet penetrated; top, 331 feet above sea level):	
Limestone, magnesian or dolomite, brown and buff; 3 samples	820, 875, 890
Shale, light green-gray, calcareous; 2 samples	970, 980
Limestone, magnesian, light yellow-gray and shale, green; all in concreted powder, at	1,006
Limestone, highly argillaceous, yellow; in almost white powder; 3 samples, at	1,010, 1,050, 1,093
Shale, gray-green, calcareous, at	1,150
Limestone; as at 1,010 feet; 2 samples, at	1,184, 1,241
Shale, bright green, noncalcareous, at	1,295
Dolomite, buff, pyritiferous, slightly arenaceous, at	1,375
Dolomite, buff; much chert carrying disseminated crystals of pyrite; a few grains of limpid quartz, some of which are rounded; a little chalcedonic silica, at	1,400
Dolomite, highly arenaceous; or calciferous sandstone; grains varying in size, many coarse, imperfectly rounded, at	1,517
Dolomite, white; in fine powder; with arenaceous rounded grains, quartzose and cherty residue; at bottom of well, at	1,535¾

The arenaceous dolomite at 1,517 feet possibly represents the St. Peter, but it is also possible that the St. Peter is absent, and that the shales and clayey limestones from 1,010 to 1,295 belong to the Platteville, and the dolomite from 1,375 down to the Shakopee.

The samples are said to have been taken at every "change" of rock.

The water is lifted into a standpipe and thence distributed by gravity through one-half mile of mains. It is used by a small proportion of the people and the daily consumption does not exceed 10,000 gallons. The water is very hard. Large supplies of less mineralized water are available in the valley at no great depths below the surface.

The Chicago & North Western Railway well at Dunlap is sunk into the stream deposits of Boyer River valley. The section is as follows:

Section of Chicago & North Western Railway well at Dunlap.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, sandy	20	20
Sand	12	32
Sand, coarse (water bearing)	23	55
Clay, blue (entered).		

This well is 12 inches in diameter and ends with a 14-foot screen. With the suction pipe extending 40 feet below the surface, it is reported to be pumped at the rate of 300 gallons a minute and to furnish about 100,000 gallons daily.

Logan.—The public waterworks at Logan (population, 1,453) were until recently supplied from two wells—a shallow open well and a deep drilled well—both located in the valley. The open well is 20 feet in diameter, is cased with brick, and ends at a depth of 32 feet in a bed of sand resting upon rock. It fills with water within about 10 feet of the surface but its yield is not great. The water is hard, though otherwise good.

The public supply is used by most of the inhabitants, and the daily consumption is estimated at 30,000 gallons. The pressure is secured from a reservoir located on the upland. The supply for the Illinois Central locomotives is taken from large dug wells in the valley.

The drilled well is 840 feet deep, 10 to 6 inches in diameter, is cased with 30 feet of 8-inch pipe to rock, and 570 feet of 6-inch pipe, heads 30 feet above the curb, and has a natural flow of 13 gallons a minute. The water bed is shale at a depth of 650 feet. The well was drilled in 1902 at a cost of $2,000. The water is called "mineral." It is generally liked by the people and is said to be soft and wholesome and to have a mild laxative effect.

Fortunately for the interests of science one of the citizens of Logan Mr. C. N. Wood, obtained at his own expense from the drillers a fairly complete set of samples of the drillings, and submitted them to the Survey for examination. The following table presents the interpretation of the samples:

Record of strata in city well No. 1 at Logan.

	Thickness.	Depth.
Carboniferous:		
Pennsylvanian:	*Feet.*	*Feet.*
Unrecorded	22	22
Limestone, blue-gray, earthy, soft, and light buff, harder; in large chips; rapid effervescence	12	34
Shale, greenish, practically noncalcareous; some yellow and red shale; chips of light yellow limestone; in molded masses	8	42
Shale, copper red, calcareous; a few cuttings of limestone	18	60
Limestone, light yellow and blue gray, compact; and sandstone, micaceous, fine grained, light blue-gray	10	70
Shale, drab and blue or greenish gray	40	110
Limestone, grayish buff, very fine grained, compact; smooth fracture; fossiliferous; in large flakes	5	115
Limestone; as above, with greenish crystalline limestone and some reddish clay staining surfaces of limestone cuttings	10	125
Shale, red and greenish, hard, calcareous; in cuttings; some limestone chips	5	130
No samples	25	155
Shale, blue gray and drab; some yellow limestone cuttings; some fine-grained greenish laminated sandstone	10	165
Limestone, blue-gray, close textured, earthy; in rather large chips; fossiliferous; with some reddish-brown shale from above (?)	4	169
No sample	15	184
Limestone, highly argillaceous, blue-gray, earthy, soft	6	190
Shale, highly calcareous; in chips; cemented by rusted iron cuttings, evidently from tools dropped in the well	15	205
Shale, reddish	40	245
Shale, black, coaly	15	260
Shale, light greenish gray, somewhat calcareous, plastic; in molded masses	15	275
Limestone, dull luster, light gray	5	280
Shale, drab, fissile, calcareous; some limestone cuttings	6	286
Shale, dark drab and green-gray, hard, fissile, calcareous	4	290
Sandstone, gray, micaceous, fine grained; grains imperfectly rounded	15	305
Shale, yellow, plastic; in molded masses; a little ocherous limestone	20	325
Limestone, yellow, argillaceous; in fine cuttings; fragments of joints of crinoid stems; chips of shale of various colors	25	350
Shale, orange and other colors, plastic	50	400
No samples	155	555
Mississippian:		
Limestone, drab, argillaceous, slightly gritty; much translucent milky-white chalcedonic silica; in small cuttings; some grains of crystalline quartz	5	560
Limestone, gray; in fine sand; much chalcedony; some quartz grains imperfectly rounded	20	580
Limestone, gray, yellow-gray, and light drab; fine crystalline, granular; some white cryptocrystalline silica and some shale in powder and small cuttings	5	585
Limestone, light buff in mass; fine crystalline granular; some cryptocrystalline silica and some quartz sand	10	595
Limestone; as above; and some white; in coarse sand	15	610
Limestone, whitish and light yellow gray; some rounded quartz grains	10	620
Limestone; as above; a very little cryptocrystalline with white silica and some quartz sand	15	635
Limestone, pure white, fine grained	20	655
No samples	(?)	(?)
Limestone, blue-gray and light yellow-gray; in fine sand (sample labeled "to 770")	(?)	770
Limestone, white; in fine meal	10	780
Limestone, light grayish white; in fine sand; this and all other limestones of the samples effervesce rapidly in cold dilute hydrochloric acid	41	821
No samples, but reported to be no change in strata	19	840

Another city well has recently been drilled at Logan. The depth is 954 feet and the diameter 6 inches; casing, 6 inches to bottom of well. The curb is 1,033 feet above sea level and the head 80 feet above curb. The flow is 200 gallons a minute, the principal supply being at 940 feet; other water beds are at 36 and 454 feet. The well, which cost $5,000, was drilled by L. E. Nebergall, of Omaha, Nebr., in 1911.

Missouri Valley.—The public supply of Missouri Valley (population, 3,187) is obtained from four 6-inch wells located a short distance from the margin of the valley. The wells pass through clay, "hardpan," etc., and end with 10-foot to 14-foot brass screens at a depth of 85 feet in a bed of gravel from which the water rises within 4 to 5 feet of the surface.

By means of a suction pump at the surface, the wells are usually made to yield 550 gallons a minute, but they are reported to have been pumped for 17 hours continuously at about 600 gallons a minute. The water is rather hard and in time seals the screens with chemical precipitates. A dug well with a group of sand points was at first installed but was not so satisfactory as the wells now in use.

The water is stored in a large cement reservoir on the top of the bluff and is delivered under considerable pressure through about 6 miles of mains to 60 fire hydrants and 500 taps. It is used by a large proportion of the people, the average daily consumption from November 1, 1908, to November 1, 1909, having been 170,500 gallons.

The Chicago & North Western Railway owns two wells, about 25 feet apart, sunk through the alluvial deposits to a depth of 90 feet and finished with screens in a bed of gravel that is said to rest on rock. The water rises within 5 or 6 feet of the surface, and the pump cylinders are placed 14 feet below the surface, with suction pipes extending lower. According to the man in charge, nearly 200,000 gallons of water are taken from these wells every day.

Persia.—The waterworks at Persia (population, 358) consist of a tank elevated upon a tower and connected with about 1 mile of mains. The supply is at present drawn from a well 4 feet in diameter, sunk about 50 feet into clay from which it receives a seepage of hardly more than 2,000 gallons per day. A hole bored to a depth of over 100 feet discovered a bed of quicksand at about 60 feet which yielded only a small amount of water. There is, however, little question that an adequate supply for the waterworks can be obtained without deep drilling.

Woodbine.—The public supply of Woodbine (population, 1,538) is derived (1) from an 840-foot flowing well whose small natural flow (12 gallons a minute) is augmented perhaps threefold when an air lift is applied; and (2) from a dug well, 18 feet in diameter and 26 feet deep, which ends in a bed of sand and gravel but does not seem to furnish much water. The deep well, which was put down by J. Shaw in 1905, is 12 to 6 inches in diameter. Altogether about 25,000 gallons of water are consumed each day, requiring the operation of the air lift for 6 hours. The waterworks include a standpipe and about 3 miles of mains. The deep water is said to be very hard and to produce much scale in boilers.

No record of the strata has been preserved, but the succession is probably closely that of the Logan deep well (p. 924) and the water bed is Mississippian.

MILLS COUNTY.

By O. E. Meinzer and W. H. Norton.

TOPOGRAPHY AND GEOLOGY.

The surface of Mills County consists of hilly upland areas separated by broad tracts of flat lowland through which the principal streams meander. The unconsolidated deposits consist of glacial drift, loess, and alluvium; the bedrock, to a depth of 670 feet in the deep well at Glenwood (Pl. XVIII), consists almost exclusively of alternating strata of shale and limestone belonging to the Missouri group of the upper Carboniferous. In some localities thin beds of sandstone, referred to the Cretaceous, lie between the Missouri strata and the drift.[1]

UNDERGROUND WATER.

SOURCE.

The thick Missouri group contains so little water, and that little is so highly mineralized, that wells should not be sunk into it unless it is intended to go to great depths for artesian supplies, as in the Glenwood wells (pp. 928–932). Ordinarily, water must be obtained from surface sources or from the deposits above the Missouri. The lowland and upland ground-water conditions differ radically. In the lowland areas abundant quantities of hard but otherwise good water are obtained by driving inexpensive points to beds of alluvial sand and gravel at slight depths; in the upland areas more meager amounts of equally satisfactory water are obtained from large wells dug or bored into the loess or drift. In the former areas large supplies can be developed by driving a sufficient number of sand points, connecting the wells at the top, and drawing from all simultaneously; in the latter it is difficult to obtain large supplies, but the yield can be increased indefinitely by expanding the infiltration surface. In some localities layers of sand or sandstone (either Aftonian or Cretaceous) are encountered and copious supplies obtained, but such water-bearing layers are not everywhere found.

[1] Udden, J. A., Geology of Mills and Fremont counties: Ann. Rept. Iowa Geol. Survey, vol. 13, 1903, p. 161.

SPRINGS.

Springs are abundant in Mills County. Seeps which give rise to rivulets occur in many of the deep ravines that have been cut into the uplands below the surficial water level, and many springs also issue from the cliffs bordering the main valleys, the water coming from Aftonian gravel, from the base of the drift, or from more or less porous materials at other levels.

CITY AND VILLAGE SUPPLIES.

Glenwood.—The public supply of Glenwood (population, 4,052) is pumped from a deep drilled well (Pl. XVIII, p. 898) having a depth of 2,000 feet and a diameter of 10 to 4¾ inches, cased to 1,773 feet. The curb is 1,132 feet above sea level. The original head was 171 feet below curb; head in 1909, 180 feet below curb. The original tested capacity was 60 gallons a minute; tested capacity in 1896, 83 gallons a minute; tested capacity in 1908, 108 gallons a minute. The well was completed in 1891 at a cost of $7,265 by the American Well Works Co., of Aurora, Ill.

Character of water in Glenwood city well.

	Depth of water bed.	Head below surface.
	Feet.	*Feet.*
Fresh	154	....
Salt	716	176
Salt	825	15
Fresh	1,008	40
Fresh	1,210	126
Fresh	1,668	100
Fresh	1,794	40
Fresh	1,836	171

The following data concerning pumping tests have been supplied by Seth Dean: On January 28, 1890, the pump was started at 10 a. m., pumping 50 gallons a minute. The temperature of the water rose from 60° F. at 10.15 a. m. to 66° at 11.30 a. m., to 68° at 12 m., and to 69° at 3.15 p. m.

A second test was made July 26 and 27, 1892, after the salt water had been cased out. The pump was started at 4.30 p. m., pumping 60 gallons a minute. The temperature of water rose as follows: 4.50 p. m., 60°; 5 p. m., 62°; 5.40 p. m., 66°; 6 p. m., 69°; 8.17 p. m., 72°; 2.45 a. m., 72½°; 9.45 a. m., 72½°; and 11 p. m., 72½°. Probably the gradual rise in temperature is caused by the increasing proportion of water drawn from the lower vein.

The well was repaired about 1904 by replacing some joints of casing, but without effect on the discharge. The cylinder (not more than 6 inches in diameter) is set about 280 feet below the curb. The pump is run continuously 16 hours a day, at a speed of 16 to 17 revolutions a minute; running the pump faster does not increase the yield.

Record of strata in city well at Glenwood (Pl. XVIII, p. 898).

	Thickness.	Depth.
Quaternary (175 feet thick; top, 1,132 feet above sea level):	*Feet.*	*Feet.*
Soil	2	2
Loess	152	154
Gravel and coarse sand (water bearing)	6	160
Sand, coarse	5	165
Till, yellow; greenstone, and other pebbles	10	175
Carboniferous:		
Pennsylvanian:		
Missouri group (670 feet thick; top, 957 feet above sea level):		
Limestone, soft, light and darker gray, cherty	2	177
Limestone, dark blue, argillaceous, pyritiferous	10	187
"Shale, black carbonaceous"	1½	188½
Clay, blue, shaly	6½	195
Shale, iron gray	8	203
Limestone, gray; earthy luster	24	227
Shale, dark blue-gray, fissile, disks of crinoid stems and fragments of a Productus	5	232
Limestone, gray; luster, earthy; compact, moderately hard; with crinoid stems, echinoid spines, and fragments of brachiopods	8	240
Shale, black, carbonaceous	4	244
Limestone, soft, yellow-gray, with Fusulina	13	257
Shale, blue	7	264
Limestone, light yellow, fossiliferous	9	273
Shale, dark red	16	289
Limestone, brecciated; sample consists of two large unfractured masses of very hard limestone breccia; limestone gray or reddish; matrix greenish gray and argillaceous, but hard	25	314
Sandstone	9	323
Limestone, argillaceous, bluish gray	17	340
Shale, blue	2	342
Limestone, compact	5	347
Shale, greenish gray, arenaceous, calcareous	3	350
Limestone, hard, gray; highly cherty at 358 feet	13	363
Shale, hard, greenish gray, highly calcareous	10	373
Limestone, light greenish gray, highly argillaceous	5	378
Limestone, light yellow-gray, compact, fine grained	18	396
Shale, black, carbonaceous; and greenish gray, hard	9	405
"Marl, white"	2	407
Limestone, hard, gray	8	415
Shale, gray; and limestone, argillaceous	4	419
Shale, varicolored	19	438
Limestone, gray, close textured	18	456
Limestone, hard, blue, highly argillaceous; crinoid stems and fragments of brachiopods	11	467
Shale, black, carbonaceous; impure gray limestone	3	470
Sandstone	6	476
Limestone, white and light gray, close textured; earthy luster	15	491
Slate, black	5	496
Limestone, yellow-gray, fossiliferous, crystalline to earthy	12	508
Shale, dark and greenish gray; with Chonetes	11	519
Limestone, light yellow-gray, soft, fossiliferous	10	529
Shale, green, calcareous	21	550
Limestone, white, soft, crystalline to earthy	20	570
Shale, gray, highly calcareous, fossiliferous	10	580
Shale, black, carbonaceous, dark drab	15	595
Limestone, white and light colored; in places fossiliferous, with 1 foot of "coal?" at 612 feet, and brown chert at 635 feet; 9 samples	43	638
Shale, varicolored, arenaceous; with minute angular particles of limpid quartz; 2 samples	47	685
Sandstone, greenish gray, close and fine grained, argillaceous and calcareous; some siliceous limestone, hard, subconchoidal fracture; with much shale at 706 and 711 feet; vein of salt water at 716 feet	35	720
Coal and black shale	1	721
Shale, blue	4	725
Limestone, gray, hard; fracture subconchoidal; close textured; fossiliferous and flinty at 732 feet; 4 feet of blue shale at 730 feet	15	740
Slate	12	752
Limestone, arenaceous	3	755
Shale, dark blue, calcareous; and black, carbonaceous	3	758
Sandstone, dark brownish gray; calcareous; ferruginous; argillaceous; fossiliferous, with Chonetes and other brachiopods	6	764
Limestone, lighter yellow-gray; highly fossiliferous in places; shale at 783 feet	27	791

Record of strata in city well at Glenwood (Pl. XVIII, p. 898)—Continued.

	Thickness.	Depth.
Carboniferous—Continued.		
Pennsylvanian—Continued.		
Missouri group (670 feet thick; top, 957 feet above sea level)—Continued.	*Feet.*	*Feet.*
Shale, black, slaty	2	793
Shale, gray	7	800
Limestone with shale	15	815
"Shale, blue with sandstone band"	10	825
Sandstone, fine gray, micaceous; vein of salt water	20	845
Des Moines group (390 feet thick; top, 287 feet above sea level):		
Shales; some fossiliferous, in places carbonaceous; mostly noncalcareous; of various colors; limestone at 868 and 885 feet, and 956 feet; coal at 956 feet; pyrite at 901 feet; 17 samples	117	962
Limestone	3	965
Sandstone and shale, fossiliferous	24	989
Sandstone, gray, soft, argillo-calcareous, fine grained	9	998
Shale, hard, brittle, noncalcareous, green and brown	10	1,008
Sandstone, gray, water bearing	17	1,025
Shale, hard, brittle; of various bright colors; finely laminated; fracture splintery; noncalcareous	20	1,045
Shale, arenaceous	36	1,081
Shale, black, carbonaceous	7	1,088
Fire clay, gray; in molded masses	6	1,094
Shale, black and gray; some sandstone	8	1,102
Limestone	3	1,105
Shales, varicolored, hard, brittle, noncalcareous	23	1,128
Sandstone, fine grained; with shale; 2 samples	22	1,150
Shale; mostly black, brittle, splintery	10	1,160
Sandstone; 4 samples	30	1,190
Shale, black, hard, fissile	5	1,195
Chert, gray, with shale, limestone, and sand	10	1,205
Sandstone, gray; grains of moderate size; imperfectly rounded; 2 samples.	30	1,235
Mississippian:		
Chert; with limestone, chalcedonic silica, and quartz sand; the latter sometimes seen embedded in the chert; 5 samples	45	1,280
Sandstone, argillaceous; in dark-gray powder	20	1,300
Chert; with chalcedony, limestone, and at 1,305 feet much shale; 5 samples	70	1,370
Shale, highly calcareous; in blue-gray concreted powder; residue after washing, pyritiferous chert, quartz sand; a little glauconite, and nonmagnesian limestone; 3 samples	35	1,405
Limestone, cherty, argillaceous; blue gray; 3 samples	60	1,465
Limestone, gray; 2 samples	45	1,510
Shale, highly quartzose and calcareous, in light blue-gray powder; 3 samples; quartz particles minute	90	1,600
Shale, green, massive	44	1,644
Limestone; in flakes; some light yellow-gray; some soft and white; nonmagnesian; compact; some chert at 1,649 feet	24	1,668
Limestones, magnesian, or dolomites, crystalline; drab, buff and brown; largely in sand; effervescence slow; 4 samples	41	1,709
Limestone, brown and gray; considerable green shale at 1,720 feet	24	1,733
Limestone, magnesian; or dolomite, brown, rough crystalline; 4 samples	32	1,765
Sandstone, gray; grains of limpid quartz imperfectly rounded, with some crystals	19	1,784
Limestone, magnesian; or dolomite, buff and yellow; 3 samples	28	1,812
Limestone, somewhat magnesian; moderately rapid effervescence; in brown and buff crystalline sand; 2 samples	20	1,832
Limestone, magnesian; and dolomites, crystalline, vesicular, brown and buff	68	1,900
Dolomite, light yellow-gray, cherty; 3 samples	24	1,924
Dolomite, greenish gray; argillaceous residue	6	1,930
Dolomite, light gray; much gypsum; water bearing	8	1,938
Gypsum; in light-yellow concreted powder; now highly indurated	3	1,941
Dolomite, gray; flakes of gypsum and selenite; 4 samples	39	1,980
Limestone, gray, somewhat magnesian, seleniferous, argillaceous	10	1,990
Shale, soft, greenish, calcareous	5	1,995
Dolomite, gray; in powder; highly seleniferous	5	2,000
Shale, hard, green, very slightly calcareous.		

The distribution system consists of two standpipes and about 3 miles of mains with 16 fire hydrants and 146 taps. The water is rich in sulphates and chlorides, but is freely used for drinking and culinary purposes and is also employed in several stationary boilers with fairly satisfactory results. It is estimated that 50,000 gallons are consumed in an average day, which requires the operation of the pump during a large part of the time.

The supply for the State Institution for Feeble-minded Children at Glenwood was formerly obtained from a well 1,910 feet deep which was similar to the city well. The curb is 980 feet above sea level; casing, 8 inch to 822 feet, 7 inch to 1,011 feet, 6¼ inch to 1,103 feet, $5\frac{3}{16}$ inch to 1,515 feet, and 4½ inch to 1,640 feet; casing perforated at 1,450 and 1,600 feet. The original head was 5 feet below curb; head at present, 10 feet below curb. Temperature, 66° F. The well was completed in 1897 at a cost of $4,800 by F. M. Gray, of Milwaukee.

The driller's log, which evidently does not record all the strata passed through, is as follows:

Driller's log of well No. 1 of the Iowa Institution for Feeble-minded Children at Glenwood.

	Thickness.	Depth.
	Feet.	*Feet.*
Drift	35	35
Limestone	5	40
Shale, black		45
Limestone, blue	20	65
Limestone	10	100
Shale, red	30	140
Limestone	40	200
Shale		256
Shale, red	10	280
Limestone	15	305
Shale, black	20	340
Shale, blue	30	360
Limestone	10	430
Slate, black	5	445
Rock, soft, white	4(?)	475
Shale, blue	20	479
Shale, red	30	499
Limestone	10	529
Shale, black, coaly	1	549
Sandstone	7	550
Sandstone, with salt water	7	575
Shale, blue	10	625
Limestone	5	640
Limestone with pyrite (approximate base of Missouri group in city well)	2	655
Shale, green	10	690
Shale, red		715
Miner's slate	10	732
Soapstone	10	780
Miner's slate with pyrite		820
Shale, sandy, with salt water		865
Sandstone	5	990
Limestone		1,010
Sandstone		1,032
Sandstone (approximate base of Des Moines group in city well)	10	1,065
Limestone, brown	12	1,103
Quartzite, red	3	1,115
Limestone, magnesian	23	1,198
Limestone, gray	64	1,226
Sandstone, white	5	1,351
Soapstone	20	1,410
Soapstone (approximate base of Mississippian in city well)		1,460
Limestone	20	1,509
Limestone, gray		1,535
Soapstone	3	1,580
Soapstone	2	1,600
Limestone, sandy	50	1,700
Gypsum	2	1,750
Limestone, gray	30	1,772
Limestone, bastard		1,850
Limestone, hard, gray		1,896
Bottom of well		1,910

The first water bed was struck at 570 feet. The water was salty and stood at 6 feet below the curb. The capacity was about 30 gallons a minute. At a depth of 1,008 feet another water bed was found, whose water rose within 60 feet of the surface and yielded 75 gallons a minute. At a depth of 1,160 feet the water rose to the surface and 70 gallons a minute were pumped. At a depth of 1,356 feet the water fell to 6 feet below the curb. Water was also found at depths of 1,668 and 1,836 feet and at the latter depth stood 5 feet below the surface and was pumped at the rate of 70 gallons a minute.

During the early part of the winter of 1897 a pump was placed in the well and operated by electric motors. These proving unsatisfactory, a Fairbanks-Morse steam pump was installed in 1900, the cylinder being placed 500 feet below the curb. Breakage of the rods necessitated frequent repairs, and in August, 1901, the working barrel worked loose and dropped to the bottom of the 6-inch casing. On August 22, 1901, the cylinder was replaced at a depth of 100 feet, but 10 minutes' pumping lowered the water below the foot valve. When the cylinder was placed 163 feet below the surface, pumping 20 strokes to the minute lowered the water below the foot valve in 1 hour; pumping at 13 strokes to the minute the pump delivered 40 gallons of water a minute. Early in September the cylinder was set at 228 feet below the surface; by running the pump at 18 strokes a minute for 10 hours 54 gallons of water a minute were obtained, but at the end of this period the water stood below the foot valve. From this date until March, 1902, the well was used only to supply drinking water, the general supply being taken from Keg Creek. In March and April, 1902, it was found that 54 gallons a minute could be obtained by operating the pump at 19 strokes a minute. On May 5, the cylinder having again worked loose, it was reset 266 feet below the surface. During the summer the pump delivered 45 to 50 gallons a minute, according to the conditions of the leathers and the length of time the pump was run. In February, 1903, a new and larger cylinder, 5¾ inches in diameter, with a discharge pipe 6 inches in diameter, was set 294 feet below the surface. At 18 strokes to the minute this cylinder gave 50 to 75 gallons of water a minute up to January, 1906, with the following interesting exceptions: On June 13, 1905, the water began to fall noticeably. The leathers were found in fair condition. The failure continued until on July 20 no water could be pumped. On August 1 the yield was but 5 gallons a minute and the water contained a large amount of sediment. At the same time the city well of Glenwood was able to furnish but a small supply of water. After August 4, however, no sand or sediment was noted in the well, and running 10 hours a day the pump delivered about 60 gallons a minute. In January, 1906, it was found that with a stroke of 18 a minute and running continuously for 24 hours a yield of 50 gallons was obtained.

With the exception of a period of some six weeks in 1905, maximum pumping did not exhaust the supply, and the pump was run in 1906 for 24 hours a day. The needs of the institution, however, had become much larger than the well could supply. Furthermore, the well became infected with the germs of typhoid fever. Water taken directly from the discharge pipe was found by the State bacteriologists to contain the colon bacillus in large quantities and to have been contaminated by surface drainage, evidently through corroded or otherwise leaky casings. The location of the well is favorable for such contamination.

It was decided to sink an additional well to the water bed at about 1,000 feet to obtain a larger supply and to shut out the surface water finding access to well No. 1 by recasing it to 120 feet. The second well was carried to a depth of 975 feet and was then abandoned. It had a diameter of 15 to 6 inches; casing, 15 inches to 124 feet, 12 inches to 557 feet, 10 inches to 769 feet, 8 inches to 860 feet, and 6 inches to bottom. The curb was 1,060 feet above sea level. The log follows:

Driller's log of well No. 2 of the Institution for Feeble-minded Children at Glenwood.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, yellowish	10	12
Clay, reddish, very hard and dry	13	25
Clay, yellowish, as from 2–12	20	45
Clay, dark yellow, moist; easy to dig	50	95
Gravel and fine white sand, water	5	100
Limestone, white; under which was 2 inches of yellow clay	1	101
Shale, blue-black	29	130
Limestone, white, very hard	2	132
Shale, black	5	137
Limestone, blue, hard	10	147
Shale, black	5	152
Limestone	23	175
Shale, blue	20	195
Limestone, white	20	215
Clay shale, red	15	230
Shale, white slate	35	265
Limestone, hard, gray	30	295
Limestone, hard	15	310
Shale, blue	10	320
Limestone, very hard	25	345
Gravel and shale	10	355
Limestone, soft	5	360
Shale, red	25	385
Limestone, white	25	410
Shale, blue	10	420
Limestone, hard	10	430
Shale and lime	5	435
Slate, blue	5	440
Slate and lime	25	465
Shale, blue	10	475
Limestone	40	515
Lime and shale	10	525
Slate and shale	35	560
Limestone, blue	5	565
Shale	15	580
Shale, blue	30	610
Coarse sand and limestone	10	620
Slate, black, white, and red	15	635
Shale	35	670
Limestone, soft	5	675
Sandstone; salt water rising to 175 feet below curb	30	710
Shale, blue	30	740
Slate, black	10	750
Shale, blue, and sand	30	780
Shale, black	60	840
Shale, blue, and slate	20	860
Shale and limestone	30	890
Shale	20	910
Shale, dark, and 1 foot of limestone	25	935
Clay, red, and some limestone	15	950
Sand	5	955
Shale, dark blue	20	975

Because of the failure to obtain a sufficient amount of water in well No. 2 to supplement that of the first well, the second was also abandoned and a supply found in shallow wells on the Missouri River flood plain about 2½ miles from the institution.

Though no pumping test seems to have been made of the capacity of well No. 2, there is little or no doubt that sufficient water was not obtained. The drilling was stopped at 85 feet above sea level, and the water beds of the sandstone at the base of the Pennsylvanian were not reached in well No. 1 until the drill had gone 28 feet below sea level. Had the well been drilled 113 feet deeper probably 75 gallons a minute would have been obtained from this sandstone.

Water for the institution is now obtained from a system of eight 6-inch driven wells in the Missouri Valley about 1 mile east of Pacific Junction. The eight are spaced about 26 feet apart, and end with 8-foot screens in alluvial sand at a depth of 32 feet. The casings are all connected at the top, and the water, which normally stands about 7½ feet below the surface is drawn by two duplex suction pumps 4 feet below the surface. The pumps are usually operated at the rate of 450 gallons a minute without producing any noticeable effect upon the supply. The water is only moderately hard but contains an undesirable amount of dissolved iron that is successfully removed by aeration.

Hastings.—The Chicago, Burlington & Quincy Railroad well at Hastings (population, 393) is 24 feet deep and apparently ends in the alluvium of the valley. It is said to yield about 32,000 gallons in 8 hours.

Malvern.—The public supply of Malvern (population, 1,154) is drawn from 14 driven wells located in the valley only slightly above the level of Silver Creek. Some of the wells are 3 inches and others 4 inches in diameter. They pass through about 24 feet of soil and clay and end with 3½-foot screens in a bed of sand, reported to be fine grained and between 2 and 13 feet in thickness. It seems that the yield, which was originally not great, has decreased gradually by the incrusting of the screens until the entire system will not yield over 100 gallons a minute when pumped continuously. A dug well, which was 22 feet deep and ended at the top of the sand stratum, was originally used but was abandoned for the present system because of its meager yield. It is also reported that the Chicago, Burlington & Quincy Railroad at one time drilled to a depth of about 300 feet without success.

The waterworks consist of an elevated tank and approximately 4 miles of mains, with 18 fire hydrants and about 65 taps. The average daily consumption is reported to be 9,000 gallons.

Pacific Junction.—The Chicago, Burlington & Quincy Railroad has a pumping station in the valley between Pacific Junction and the asylum wells. The water is drawn by suction from six 4-inch driven wells 35 feet deep. The pump usually lifts about 200 gallons a minute, which amount the wells are reported to yield except during very low water in the summer.

MONTGOMERY COUNTY.

By Howard E. Simpson.

TOPOGRAPHY.

Montgomery County lies near the extreme southwest corner of Iowa. Its surface is an old drift plain carved into broad parallel ridges and valleys by the streams that flow across it in a direction slightly west of south, toward the Missouri. The broad, flat bottoms of the valleys and the mature dissection of the ridges indicate that a long time has elapsed since the whole was a broad level plain sloping in the direction now followed by the master streams. These streams, the Walnut, East Nishnabotna, Tarkio, and West Nodaway rivers, and their tributaries thoroughly drain the county, so that it contains no standing surface water.

The drift thickly covers the entire county except some areas in the large valleys whose bottoms are filled with sand and gravel and silt and on whose sides it has been here and there eroded away, exposing the bedrock beneath. That this till is very old may be inferred from the facts that it is deeply leached, that many of its igneous bowlders are entirely disintegrated by weathering, and above all that its surface is maturely dissected. Well records do not indicate its division into Kansan and Nebraskan, as they do in counties north and east; whether the drift is Kansan or Nebraskan has not been positively determined. The uplands are mantled with the fine grayish yellow loess that is characteristic of the Missouri Valley region.

GEOLOGY.

The bedrock immediately below the drift on the uplands and ridges is the soft, porous Dakota sandstone (Cretaceous). This is wanting in all the river valleys, the preglacial streams which occupied these having cut deeply into the shales and limestones of the Missouri group (Pennsylvanian), which lies just beneath. The result is that sandstone under the uplands alternates with shale and limestone under the valleys in parallel belts running almost north and south across the county. This fact, together with the presence of heavy alluvial deposits over the shale and limestone, is of prime importance in a consideration of underground water in this county. The strata of the county dip slightly west of south.

UNDERGROUND WATER.

SOURCE.

The most clearly defined water-bearing beds are the alluvial sands beneath the valleys and the Dakota sandstone beneath the uplands. Together these afford an abundant supply of good water for most of the county. Besides these the entire county is underlain by the drift and limestone horizons. Only on upland slopes that are not underlain by sandstone nor overlain by alluvium and in places where, owing to deep dissection, the drift is well drained, is there lack of good underground water in Montgomery County.

Most important of all aquifers are the deep beds of sands underlying the till of both the first and the second bottoms of each of the several rivers. These afford an inexhaustible supply of water at depths of 20 to 100 feet over belts ranging in width from a few hundred yards to 2½ miles and extending across the county from north to south. The water is medium hard and locally carries sufficient iron compounds in solution to form a red precipitate on standing, yet is on the whole very wholesome where not contaminated by organic matter in towns and cities.

Water is generally obtained from this bed by means of driven wells sunk at very slight cost. Ordinarily there is sufficient clay above the sands to seal out immediate surface waters and prevent contamination. In the cities and towns, however, a large amount of sewage enters through the cesspools dug into or through the surface soil and clay and through open wells which mingle surface waters and the sand waters. Pollution may be easily determined by analysis, and where found all private shallow wells should be closed and the public supply taken from some point above the city where it is free from contamination.

Over the uplands many shallow wells obtain a supply for domestic use or for small farms from the waters that gradually seep through the porous surface clay, the loess. The lower portion of the loess generally consists of fine sands, and these are the more common sources of supply for wells 10 to 20 feet deep. Loess wells are usually of the dug type and are unsatisfactory, as their supply greatly diminishes or fails entirely in dry seasons.

In recent years bored wells drawing on the sands and gravels at or near the base of the drift are replacing the shallower wells. These wells range in depth from 30 to 75 feet and obtain a larger and purer supply. A few wells obtain a supply from local lenses of sand or gravel in the bowlder clay.

Where found beneath the uplands the soft brown sandstone immediately under the drift is a most excellent aquifer, the purest and best. It ranges from a few feet to 100 feet in thickness and is found at depths ranging up to 150 feet. Only on the margins of the uplands is it inadequate. When this water is obtained care should be taken to case out all others.

The limestone of the Missouri group is everywhere present under the sandstone or directly under the drift and affords a very scanty supply of hard water. This should be sought only when higher beds fail or are contaminated. Failure to procure ample supply from higher sources will rarely occur except on the lower upland slopes and uplands in the western edge of the county—that is, where the drift is deeply eroded and well drained and is neither overlain by alluvium nor underlain by sandstone. In such places it will probably be necessary to utilize waters from all sources by casing to limestone and by puncturing the casing opposite each horizon.

PROVINCES.

Montgomery County comprises several underground-water provinces. The first, or valley bottoms, consists of the first bottoms, the part now flooded in times of high water, or the flood plain; and the second bottoms, the terraces of the old valley floor, now above all ordinary floods and occupied by splendid farms and in many places by towns and villages. These second bottoms vary in width from a few hundred yards to 2 or 3 miles. On them the entire supply of water comes from driven, dug, or bored wells, which draw water from the alluvium. In the deeper portions, where silt is underlain by heavy beds of sand, driven wells are chiefly used, and such wells should be used wherever possible, as they prevent the mingling of surface waters with the supply used. In cities and towns on the bottoms care should be taken to determine by frequent analysis whether such wells are contaminated, and if contaminated, the private wells should be closed and free public water provided from a location above the town or from some source too deep for contamination.

The higher uplands underlain by sandstone constitute the second province. These are not all continuous or even connected, but this sandstone is one of the best aquifers in the State. Most wells in this region are shallow and obtain water from the drift, but where a large, pure, and permanent supply is desired the sandstone is sought.

The third province, that of the limestone, occupies the higher lowlands and the lower uplands of the western edge of the county and lies in general on the slopes between the other two. Though the limestone is everywhere present, it is sought only where the alluvial and sandstone aquifers are wanting and where the drift is so broken and dissected as to be thoroughly drained. The limestone is a last resort and the water is frequently so scanty as to require a careful combining of the waters of all beds to make the supply sufficient, when the quality may not be satisfactory.

The shales of the Des Moines group, lying underneath the Missouri group, are very impervious and therefore dry in this part of the State.

FLOWING WELLS.

Several small flowing wells have been reported, the aquifers of which are the drift or the Dakota sandstone. The best is that of A. Monson on very low ground in the NE. ¼ sec. 19, T. 72 N., R. 36 W.; at a depth of 50 feet it obtains a fairly good flow from a conglomerate layer of the Dakota sandstone. Another well, drawing its supply from drift sands, is on J. P. Maben's farm near the center of sec. 21, T. 72 N., R. 36 W. Water flowed for a time from the tubular well on the farm of J. R. Jones (NE. ¼ sec. 16, T. 73 N., R. 39 W.), but soon ceased. The source is unknown. A flow was also struck in the 35-foot test hole put down on the slope 15 feet south of the new city well at Red Oak. This comes from the Dakota sandstone. A flow was not obtained, however, in the larger well. Small flows may usually be found in Dakota sandstone on low slopes. These may be of value in a small way for stock wells, and may be classed as artificial springs. No important flows can be expected from shallow wells.

SPRINGS.

Where the deeper valleys cut through an excellent aquifer, such as the Dakota sandstone, and leave it exposed over the valley sides, a number of excellent springs are found. Some are of the usual drift variety and are formed at outcropping edges of sand and gravel beds in the heads of ravines and on valley sides. The stronger, however, come from the Dakota sandstone where it overlies the shales and limestones of the Missouri group, and flow perennial streams of pure cold water. The best known of this class are the "Sand Springs" just south of Red Oak (N. ½ sec. 33, T. 72 N., R. 38 W.).

CITY AND VILLAGE SUPPLIES.

Elliott.—All wells at Elliott (population, 528) are driven, the average depth being 30 feet. A good cover of soil and clay overlies the sand, which occurs at a depth of about 20 feet. The valley bottom in which such wells may be obtained is three-fifths mile wide. On the uplands beyond, wells are bored, dug, or drilled. Most common are the wells bored 60 to 80 feet to sand and gravel and lined with 12 to 18 inch sewer pipe. Others penetrate the sandstone.

The public supply is obtained from a battery of twelve 2-inch drive points connected in series by 4-inch pipe to a 12-horsepower gasoline pump with a capacity of 200 gallons a minute. Mains 900 feet long connect the pump with 5 hydrants. The system is used only for fire protection, when a pressure of 20 pounds is obtained.

Red Oak.—Drive points are the common wells on the lowland portion of Red Oak (population, 4,830), the usual depth being 25 to 40 feet, though a few reach 60 feet. On the upland portion tubular wells are in very general use. The water heads at 10 to 12 feet below the surface; in wet weather at 4 feet.

A section is as follows:

Section of well at Red Oak.

	Depth in feet.
Soil	1–6
Gumbo	6–10
Clay, yellow	10–20
Sand, ferruginous (first water)	20–25
Clay.	
Gravel (second water)	40–50

Villisca.—Driven wells on lowlands all about Villisca (population, 2,039) find sheet water in sand at 15 to 35 feet. On the higher land wells 35 feet deep in alluvium or drift obtain an abundance of water. Few deep wells are reported. Sheet water in sand would probably not be found in Jackson Township except in the western tier of sections.

The public supply is obtained from a spring well at the bottom of the slope between the town and the river. This well is a large, square hole 20 feet deep walled with rock, pointed up with mortar, and roofed over. From this a tile extends into the source of a spring which is evidently in the drift of the hill. The water is pumped into a tank by a triplex electric engine having a capacity of 100,000 gallons a day. A steam pump of equal capacity is held in reserve in such a way as to give gravity pressure of 55 pounds on the main business streets and 68 pounds at the plant. In case of fire 125 pounds direct pressure by electric and steam pumps may be obtained. Mains $2\frac{3}{4}$ miles long connect with 22 fire hydrants and about 120 taps, supplying one-tenth of the people.

A small tank is maintained for the city electric-light pumping plant and for street-sprinkling It draws its supply from the river, since the city water scales boilers badly and is low in dry seasons.

In emergency the tank supply may be cut off and after the well is drained the river may be drawn upon for unlimited supply. This has, however, been found necessary but once or twice in the history of the plant.

The water is so unfit for domestic use and so unsatisfactory for boilers and the supply furnished in dry seasons is so scant that a new system is contemplated.

WELL DATA.

The following table gives data of typical wells in Montgomery County:

Typical wells of Montgomery County.

Owner.	Location.	Depth.	Depth to rock.	Source of supply.	Head below curb.	Remarks.
T. 73 N., R. 36 W. (DOUGLAS).		*Feet.*	*Feet.*		*Feet.*	
R. W. Corbin..	SE. ¼ sec. 8........	220	50	Coal (Missouri)...	160	
W. Gardner....	NE. ¼ sec. 17......	210	149	Limestone (Missouri).	150	Hard water.
T. 73 N., R. 37 W. (PILOT GROVE).						
Mrs. G. Halbert	N. ½ sec. 11........	180	100	Sandstone (Dakota).	160	Fine water.
S. Tripp.......	SW. ¼ sec. 26......	278	100	....	....	No water; limestone well.
T. 73 N., R. 38 W. (SHERMAN).						
J. W. Griffith..	1 mile northwest of Stennett.	178	27	....	....	Do.
D. L. Rush....	NW. ¼ sec. 27.....	270	40	....	....	Do.
D. W. Brick...	W. ½ sec. 7.........	50	40	Sandstone (Dakota).	....	Plenty of water.
J. E. Good.....	NW. ¼ sec. 21.....	161	....	Sand and gravel..	81	No rock.
T. 73 N., R. 39 W. (LINCOLN.)						
J. H. Arkin....	NE. ¼ sec. 12......	160	....	.....do............	140	Do.
T. 72 N., R. 39 W. (GARFIELD.)						
Mrs. M. E. Tolman.	SE. ¼ sec. 26.......	245	....	Sand.............	100	Plenty of water. No rock.
G. W. Buchanan.	NW. ¼ sec. 35.....	175	....	Sandstone (Dakota).	75	Strong well; no rock.
T. 71 N., R. 39 W. (WEST).						
T. G. Haag.....	NW. ¼ sec. 1.......	140	....	.....do............	115	Strong well.
J. Larsen.......	NW. ¼ sec. 3......	177	....	.....do............	....	Plenty of water.
J. E. Frank....	S. ½ sec. 14........	125	60	.....do............	....	Soft water.
T. 71 N., R. 38 W. (GRANT.)						
S. Anderson....	SW. ¼ sec. 22......	175	90	.....do............	....	
T. 72 N., R. 38 W. (RED OAK.)						
J. A. McLean...	SE. ¼ sec. 15.......	212	....	.....do............	....	
T. 72 N., R. 36 W. (WASHINGTON.)						
A. Monson.....	NE. ¼ sec. 19......	50	....	.....do............	....	Flowing well.

PAGE COUNTY.

By O. E. MEINZER.

TOPOGRAPHY.

Page County is crossed by several streams, all of which meander through wide, flat-bottomed valleys that are nearly parallel and have a general southward or slightly southwestward trend. The two largest are Nodaway and East Nishnabotna rivers. Between the valleys extend intricately dissected upland belts having a relief of about 200 feet.

GEOLOGY.

The entire county is underlain by the Missouri group (Pennsylvanian), which consists essentially of shale with numerous thin strata of limestone and a few coal seams, the total thickness of the series, as determined by deep drilling at Clarinda, apparently being nearly 700 feet. (See Pl. XVIII.) Below the Missouri is the Des Moines, another thick series belonging to the Pennsylvanian and consisting predominantly of shale but differing from the Missouri chiefly in containing less limestone and more sandstone.

The upper surface of the Missouri group lies for the most part below the valley level and is encumbered with a heavy deposit of glacial detritus, out of which the valleys have been excavated, and the hill topography of the interstream belts, with their 200 feet of relief, more or less, has been carved. At a number of places a thin layer of sandstone has been found between the glacial drift and the shale or limestone of the Missouri group, and this is considered by Prof. Calvin as probably Cretaceous.[1]

The upper surface of the drift is thoroughly weathered and is widely overspread with a few feet of loess. The broad valleys are filled with alluvium, in some localities to depths of more than 50 feet. The alluvium, especially near the top, consists chiefly of fine-grained loesslike sediments, but it also includes beds of sand and gravel.

UNDERGROUND WATER.

SOURCE.

The alluvial deposits are the most reliable source of water in Page County. They are very important, not only because they occur over a considerable part of the county, but also because they are available to the principal cities and villages. They furnish the public supplies at Clarinda, Shenandoah, and Essex, the locomotive supplies for both the Wabash and the Chicago, Burlington & Quincy railroad companies, the hospital supplies at Clarinda, the industrial and domestic supplies in essentially all the valley towns, and the domestic and stock supplies on a large number of farms.

The bulk of the alluvium consists of clay and silt that will not yield water, and much of the rest consists of fine sand that gives up its water slowly, but fortunately there also exist, commonly at considerable depths, beds of gravel, through which the water percolates more freely. A large number of the private wells end in sand and provide only scanty supplies, but where the demands are greater, as for public and industrial uses, the gravel beds are utilized, although even these are sharply limited in their yield. It needs to be said, however, that the small capacity of both private and public wells is, to a certain extent, due to the chronic clogging of the screens by fine sediment and by precipitates from the water.

For domestic and stock purposes, driven wells are largely employed. A pit is commonly dug nearly to the water level and the pump cylin-

[1] Calvin, Samuel, Geology of Page County: Iowa Geol. Survey, vol. 11, 1901, p. 439.

der is placed at the bottom, where it will be protected from frost. Many pits are sunk some depth below the water level, so that the water rising in the driven well overflows into the pit, from which it is pumped. The manifest advantage of such an arrangement is that a reserve of water accumulates during the intervals that it is not drawn upon, and hence water can at times be pumped more rapidly than the rate at which the well will yield. A serious disadvantage of such an arrangement, or of any that establishes communication between the well and pit, is that the water is always in danger of contamination, especially in the settlements, where cesspools and privies are in common use.

In the upland areas, between the streams, the ground-water conditions are more precarious. The drift contains beds of sand and gravel, but if these lie above the valley level they have been drained of their water wherever they are widely distributed and are freely porous. If the drill or auger penetrates to the valley level it may perhaps discover a stratum of drift sand or of Cretaceous sandstone that is filled with water, but it is more likely to encounter the shale and limestone of the Missouri group, which is an unpromising source of water, as to both quantity and quality. The imperfectly porous parts of the drift, such as are commonly found in the uncompacted upper portion, do not readily lose their water by leakage into the valleys, and hence it is that in spite of their meager yield they are relied upon for supplies on most of the upland farms. Many of the shallow wells in the hilly areas are in large ravines, where the prospects of procuring sufficient seepage are better than on valley sides or hilltops. The leakage from the sandy and gravelly seams in the drift produces numerous springs, some of which are found in the smaller draws near the tops of the divides. The water from the drift, especially from its upper part, is, like that from the alluvium, of good quality except that it is hard.

CITY AND VILLAGE SUPPLIES.

Clarinda.—The public supply at Clarinda (population, 2,832) is drawn from five 6-inch wells, all of which are situated in the valley and end with screens in a 9-foot bed of gravel that lies below about 50 to 60 feet of clay and sand and rests upon shale. The water is hard but otherwise good. It rises within about 20 to 30 feet of the surface, and the wells will furnish an average of about 50 gallons a minute each. It is reported that either of the two wells at the Lee electric-light plant, situated 75 feet apart, will yield 100,000 gallons in 24 hours, but that together they will yield only 130,000 gallons. The aquifer seems to be entirely reliable and not to be affected by dry seasons, but the wells deteriorate rapidly and must be renewed every few years. A system of small driven wells, previously used for the public supply, was not satisfactory.

The water is pumped by the electric-light company into a standpipe, from which it is carried to the consumers by gravity. About 175,000 gallons are used daily.

At the State Hospital for the Insane three 6-inch wells start from slightly higher ground than the city wells and go to a depth of 77 feet, evidently ending in the same bed of gravel below alluvial clay and sand above Carboniferous shale. The gravel is here said to be a little over 7 feet thick. The three wells are reported to have a maximum capacity of 106,000 gallons, 96,000 gallons, and over 100,000 gallons, respectively, in 24 hours. The average daily consumption is about 110,000 gallons. The water is considered excellent for drinking and for general domestic use and serves very well for boilers, though it is somewhat hard.

A boring at Clarinda was carried to a depth of 1,002 feet in search of coal. Water flowed from the boring for a short time during the progress of the work. The driller's log, which seems to have been carefully kept, contains 40 entries, including records of shale of various kinds, limestone, marl, and coal. The drill seems to have passed from the Missouri group into the Des Moines at about 700 feet, but apparently did not reach the Mississippian.

An accurate and detailed log (109 entries) of a diamond-drill hole at Clarinda, 840 feet deep, is published by the Iowa Geological Survey.[1] From this log and an inspection of the core, Leonard places the base of the Missouri group at about 715 feet.

The driller's log first mentioned is given below:

Driller's log of coal prospect at Clarinda.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay and gravel	50	50
Shale, with thin streaks of rock	50	100
Shale, brittle	20	120
Marl, black	5	125
Shale, black	20	145
Shale, blue	5	150
Limestone	5	155
Shale, light	15	170
Limestone, very hard	25	195
Shale	20	215
Soapstone, changing to shale	85	300
Limestone	20	320
Shale, black	20	340
Marl, red	4	344
Soapstone, impure, red	36	380
Shale, blue	120	500
Limestone	20	520
Shale	72	592
Shale	28	620
Stone, dark colored	10	630
Shale	30	660
Coal, impure	8	668
Limestone	11	679
Rock and shale	21	700
Coal	5	705
Shale	5	710
Shale	10	720

[1] Iowa Geol. Survey, vol. 12, 1902, pp. 29-31.

Driller's log of coal prospect at Clarinda—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Shale and coal	9	729
Shale	11	740
Shale	80	820
Coal	5	825
Limestone	5	830
Shale, black and blue	20	850
Slate and shale	35	885
Slate, gray	5	890
Shale, white	5	895
Shale	41	936
"Drift"	4	940
Shale, blue and black	48	988
Soapstone	14	1,002

Coin.—The Charles Schick well at Coin (population, 591), a prospect hole for gas and coal, has a depth of 888 feet, casing from 800 feet to bottom. Salty water is said to flow from well. Below a depth of 62 feet the rocks penetrated probably belong to the Pennsylvanian series.

Driller's log of Charles Schick well at Coin.

	Thickness.	Depth.
	Feet.	*Feet.*
Material containing wood, at	....	45
Gravel	2	62
Limestone, very hard	2	64
Limestone and black shale, alternating every 2 to 4 feet	....	....
Caving rock and water, at	....	190
Shale and coal blossom	12	217
Limestone	8	225
Coal	2	227
Shale and limestone, alternating every 2 to 4 feet	153	380
Shale, black, tarry	4	384
Shale, etc.; rapid alternations	456	840
Coal and slate	9	849
Stopped drilling to case well on account of caving; casing broken and tools lost; well abandoned, at	....	888

Essex.—The public supply at Essex (population, 776), as at Clarinda and Shenandoah, is drawn from alluvial gravel. A 6-inch well passes through 40 feet of clay and sand and ends with a 6-foot strainer in a bed of gravel from which the water rises to a level 12 feet below the surface. According to estimates made the maximum yield does not greatly exceed 20 gallons a minute. The water is reported somewhat hard but otherwise good. It is stored in two compression tanks, from which it is delivered by air pressure through over a mile of mains to 12 fire hydrants and 41 taps. It is used by perhaps one-fifth of the people, who consume approximately 4,000 gallons daily.

Shenandoah.—The city waterworks at Shenandoah (population, 4,976) are supplied from one 10-inch and six 6-inch wells, which pass through about 45 feet of alluvial clay and sand and end with screens in a bed of gravel. The water level fluctuates somewhat but is commonly about 16 feet below the surface. The casings of the seven wells are connected with a pump placed in a pit approximately at water level, and this pump draws by suction from all the wells simultaneously at the rate of about 200 gallons a minute, which approaches the maximum capacity of the system. It is probable that this small yield is largely due to the deterioration of the 6-inch wells, which have been in service for a period of years. Before the wells at present in use were put down, a series of small driven wells was used.

The water is pumped into a standpipe from which it is distributed through 9 or 10 miles of mains to a large number of fire hydrants and taps. It is extensively utilized for domestic purposes and is also used in the locomotives on the Wabash Railroad. The total daily consumption is about 125,000 gallons.

The well of M. W. Smith in the NW. ¼ sec. 21, T. 69 N., R. 39 W., is 710 feet deep and 4 to 2 inches in diameter. It is cased to rock. The curb is 1,024 feet above sea level and the head is above the curb. The flow is now 1,000 gallons a day, but was greater, the yield having diminished. The water is salty and is used for stock. The well was completed in 1887.

POTTAWATTAMIE COUNTY.

By O. E. Meinzer and W. H. Norton.

TOPOGRAPHY.

Most of Pottawattamie County consists of an upland carved by stream erosion into innumerable steep hills and ravines, but Missouri River, which forms the west boundary of the county, and Nishnabotna River and other affluent streams, which cross the county in a southwest direction, occupy wide valleys whose broad, flat, monotonous bottoms are in striking contrast to the rugged topography of the uplands.

GEOLOGY.

The region is underlain by Pennsylvanian strata, consisting chiefly of shales and limestones that outcrop at several localities but are commonly buried under 100 to 200 feet of unconsolidated materials of Pleistocene and more recent age. At a few points in the eastern part of the county a Cretaceous formation, mainly sandstone, has been found in exposures and wells between the Pennsylvanian and Pleistocene series. On the uplands the Pleistocene consists in downward succession of loess, yellow clay somewhat resembling loess, Kansan drift, Aftonian gravel, and Nebraskan drift.[1] The numerous wide valleys all contain thick deposits of alluvium.

The deep geology of the western part of the county, near Council Bluffs and Omaha, Nebr., has been almost entirely unknown. A very few samples of the drillings of the deep well of the Willow Springs distillery at Omaha, examined by Norton in 1896, showed that a magnesian limestone series begins about 1,055 feet from the surface, or about sea level, and continues thence to the bottom of the boring at a depth of 1,780 feet, interrupted, so far as shown by the samples, only by a thin shale at 1,250 feet and a white sandstone at 1,430 feet. The logs of several wells at Council Bluffs and Omaha are on record but are vague and contradictory. The great depth of the Pennsylvanian in southwestern Iowa has led to a belief that at Council Bluffs, as at places farther to the east and south, the coal measures might well extend down to sea level.

The drillings at Miller Park, Omaha, and at Fort Crook (see pp. 954–958) agree in testifying that at about 550 feet above sea level there begins a series of limestones and cherts, 500 feet thick, containing in many places milk-white translucent chalcedony. In view of its nature and its thickness this series can hardly be attributed to any higher terrane than the Mississippian. At least this hypothesis seems preferable to the hypothesis that the Des Moines group changes from clay shales to limestones of Mississippian facies on nearing Missouri River at this latitude.

Apparently, then, there is in this area a rather sharp upwarp that brings the Mississippian floor of the coal measures 650 feet higher at Omaha than at Glenwood, 18 miles to the southeast, so that they have a dip of 36 feet to the mile. The southward dip is corroborated by the testimony of well drillers, who report a much greater dip.

The heavy shales of the Kinderhook group, which are regarded as the base of the Mississippian at Glenwood, are absent at Omaha and Council Bluffs, so that it is difficult to draw any line of separation between the Mississippian and the Devonian, and it is quite possible that more or less of the limestones assigned to the former really belong to the latter. The thickness of the Mississippian is not excessive, for at Glenwood it measures somewhat more than 400 feet. At Logan, also, farther north, where it should be thinner, the Mississippian extends from at least 478 feet above sea level to 212 feet above sea level, giving a minimum thickness of 266 feet. The Mississippian at Logan, however, may begin 150 feet higher up, there being a gap in the record; moreover, its lower limit does not seem to have been attained.

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[1] Udden, J. A., Geology of Pottawattamie County: Ann. Rept. Iowa Geol. Survey, vol. 11, 1901, pp. 233 et seq.

At about 50 feet above sea level at Fort Crook a series of dolomitic limestones begins. At 70 feet above sea level at Miller Park, Omaha, dolomites are first encountered, although limestones, more or less magnesian, are found 100 feet higher. These magnesian limestones and dolomites are the uppermost beds of a thick series of rocks that are widely spread over western Iowa and eastern Nebraska. They probably represent different formations, but in the absence of fossils any identification or even demarcation seems impossible. In exception, it may be noted that a thick body of magnesian limestone and dolomite occurring at Glenwood and at Bedford well up toward the summit of the series may be referred with some confidence to the Salina (?) formation of the Silurian, on account of its content of gypsum and anhydrite. In the Council Bluffs section these minerals are absent, and the upper beds may be assigned to the Silurian solely on account of their place in the series.

At Fort Crook the magnesian series is interrupted by limestones of slight magnesian content from 1,070 to 1,125 feet. At 1,220 feet (150 feet below sea level) occurs a hard, bright green shale interbedded with dolomite, the whole being 30 feet thick. All limestones below this shale are thoroughly dolomitized. At 1,340 feet (270 feet below sea level) they are slightly arenaceous. At the Willow Springs distillery, Omaha, a white sandstone occurs about 400 feet below this. At Miller Park, Omaha, a red arenaceous shale with thin layers of sandstone intervenes at 75 feet below sea level. This may represent the hard green shale found in the Fort Crook well at 150 feet below sea level.

The formation to which the dolomites below the green and red shales belong is quite uncertain. In facies they resemble the dolomites of the Prairie du Chien group except in their generally nonarenaceous nature. But the Silurian dolomites at Bedford are of great thickness. The drill was still in them at 2,400 feet, which would give them a minimum thickness of 575 feet. There seem, therefore, to be no data by which the lower limit of the Silurian dolomites at Council Bluffs can be determined.

It would not be inconsistent with some of the data to refer the bright-green and the red sandy shales found from 75 to 150 feet below sea level to the base of the Platteville. This would imply an upwarp of the lower Paleozoic in the Council Bluffs area of far greater steepness than any known in the State. It would correspond with the already inferred upwarp of the Mississippian floor of the coal measures, but it would be considerably steeper, lifting the St. Peter about 1,000 feet higher than the general stratigraphy would indicate. At Lincoln, Nebr., where the St. Peter is fairly well identified in the State well, it occurs nearly 900 feet below the summit of the magnesian limestones, and if the green shale at Fort Crook at 150 feet below sea level marks the top of the St. Peter, it occurs at but 100 feet (or at most at but 200 feet) below the same datum, although the Mississippian has thinned out to the west from Omaha to Lincoln. For this reason it would seem somewhat more probable that the St. Peter lies below the lowest terranes pierced by the Omaha wells.

UNDERGROUND WATER.

SOURCE.

Water is found in (1) the alluvium; (2) in the loess, drift, and associated deposits; (3) in the Cretaceous deposits; and (4) in the lower formations.

In the lowland tracts water can be secured from alluvial sand or gravel in sufficient quantities for all ordinary purposes. When not polluted this water is of good quality, though it contains rather large amounts of calcium and magnesium. Driven wells are in common use and the water rises nearly or quite to the surface.

Two 12-inch wells drilled in the Missouri Valley at Council Bluffs for the Chicago & North Western Railway have the following section:

Section of Chicago & North Western Railway wells at Council Bluffs.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, soft, yellow	24	24
Mud, soft, gray	20	44
Sand, soft, gray, muddy	20	64
Sand, gray	16	80
Sand, coarse, and gravel	16	96

These wells were finished with 10-inch screens in the basal sand and gravel from which the water rose within 10 feet of the surface, and was lowered 15 feet 4 inches by pumping 300 gallons a minute for nine hours.

The loess and the upper part of the bowlder clay are slightly porous and contribute a slow seepage to dug or bored wells sunk below the ground-water level. Beds of sand and gravel are numerous. The Aftonian gravel appears to be widely distributed, and in some places attains considerable thickness. Along the cliffs north of Council Bluffs, where it is especially well developed, it gives rise to numerous good springs. According to Andrew Graham, park commissioner, 31 springs in this vicinity, presumably all issuing from the Aftonian, together yield 1,250,000 gallons a day. Sand and gravel also occur in certain localities between the drift and the bedrock.

Most of the water in the numerous sand and gravel deposits is not under much pressure and generally does not flow readily into drilled wells of small diameter, though it may constitute a very satisfactory source for large bored wells. The difficulty with many of the bored wells is that they fail to reach water because well augers can not bore into gravels that are firmly cemented, as they are in many places. In seeking municipal, industrial, or stock supplies in the upland regions, explorations should if necessary be carried to the Pennsylvanian strata, which can easily be recognized.

The conditions found in drilling in Fairmont Park, on the loess-covered uplands at Council Bluffs, may be regarded as typical. The first hole was sunk through 125 feet of loess and bowlder clay, 2 feet of yellow sand, and finally through about 13 feet of red or yellow rock, stopping at 140 feet (about at the valley level) without water. The second hole was started on ground about 20 feet lower than the first and was carried through about 100 feet of loess and bowlder clay, 2 feet of gravel, 8 feet of red or yellow rock, and 155 feet of rock, consisting of alternating shale and limestone strata. Finally, at a depth of 265 feet, it was abandoned, for it did not find sufficient water to supply a well of small diameter, although in the first 100 feet there were seeps that would probably have sufficed for a well of large diameter. The third hole was started on ground perhaps 110 feet higher than the first and was sunk to a depth of 280 feet. Near the bottom the drill passed through 2 feet of brown sandstone, 10 or 15 feet of yellow clay, and 3 feet of clean white sand and gravel, ending in a few feet of red or yellow rock. The water from the sand and gravel rose about 40 feet in the well, and with the cylinder at the bottom it can be pumped at about 6 gallons a minute. It is apparently of good quality. A fourth hole encountered 6 feet of sandstone instead of 2, and 4½ feet of gravel instead of 3; its maximum yield is 8 gallons a minute instead of 6.

Locally the Cretaceous sandstone will yield freely, but it is so generally absent that for the county as a whole it is not of much consequence.

The deep beds, which have been tapped by a number of wells in Council Bluffs and Omaha, yield moderate amounts of water rich in sodium sulphate. Between them and the water-bearing beds that are nearer the surface lie several hundred feet of Pennsylvanian strata, which are unpromising as a source of water, although a few wells seem to draw from them.

The thick body of limestones referred to the Mississippian carries artesian water at several levels. In the Missouri Valley at Council Bluffs small flows may be expected at depths between 620 and 740 feet and stronger flows between 800 and 815 feet (245 to 235 feet above sea level).

The magnesian limestones and dolomites referred to the Silurian (often called sandrock in drillers' logs because of the sharp sparkling crystalline sand to which they are crushed by the drill) are tapped by most of the artesian wells of the area. Water is found in them at 950 feet to 1,150 feet below the Missouri Valley at Council Bluffs.

Other water is found in deeper dolomites referred with great uncertainty to the Silurian. Like the water from the Silurian dolomites at Bedford, these deeper waters are highly mineralized. These beds are the source of the main water at Fort Crook (1,560–1,580 feet) and were tapped also at Willow Springs distillery (1,600–1,700 feet).

CITY AND VILLAGE SUPPLIES.

Avoca.—The public supply at Avoca (population, 1,520) is derived from four 5-inch driven wells which stand 30 feet apart on the Nishnabotna bottoms and end at a depth of 28 feet with 6-foot screens in a 13-foot bed of sand and gravel, from which the water rises to within a few feet of the surface. The combined yield of the 4 wells was roughly estimated at 250 gallons a minute. The water is hard and the screens become incrusted in about 2 years. Before the present wells were put down a less successful system of small sand points was used. The water is pumped by the electric-light company into a standpipe and is delivered through about 4½ miles of mains to approximately 100 buildings. It is used by one-third of the people and 25,000 gallons are daily consumed. Water for the boilers at the electric-light plant and mill is drawn from the river; that for the railway locomotives is taken from a large dug well on the river bank; that for the boiler at the brickyard is drawn from rain water stored in a cistern; and that for the canning factory is taken from a well similar to the village wells.

Carson.—Carson (population, 640) is located at a place where the Nishnabotna Valley is greatly constricted, apparently owing to outcropping bedrock. The waterworks, which are in private ownership, draw from a dug well about 6 feet in diameter and 40 feet deep that extends largely through fine sand from which the water is with difficulty separated. The yield is between 10 and 15 gallons a minute. The supply is pumped by water power into a small tank on high ground and distributed by gravity through a system of mains with limited service. The railway locomotives are supplied from a well that is similar to that at the waterworks.

Council Bluffs.—Water at Council Bluffs (population, 29,292) is obtained from four distinct sources: (1) Missouri River, which supplies the public waterworks and most of the railway companies, and furnishes the most satisfactory boiler water; (2) alluvial sand and gravel, which in the valley yields generous quantities of hard water that is widely used for a variety of purposes; (3) loess and drift materials, which on the uplands furnish meager supplies of good water that must generally be lifted from near the bottoms of the wells, as at Fairmont Park; and (4) rock formations at greater depths, which provide moderate amounts of sodium-sulphate water that in some cases rises above the valley level. The deep water is used at the State School for the Deaf and at several industrial establishments, but it is avoided for locomotive boilers.

For the public supply the water is lifted from the river by a centrifugal pump into sedimentation basins and is thence elevated by duplex pumps into a storage reservoir, from which it is distributed by gravity. The system consists of about 34 miles of mains with 288 fire hydrants and 4,500 service connections. The water is widely used by the people and by the railway companies, and approximately 2,500,000 gallons is consumed daily.

Well No. 1 of the school for the deaf is 1,012 feet deep and 3 inches in diameter. The curb is 1,010 feet above sea level. The original head was 50 feet above curb, but the present head is only 10 feet above. The original discharge was 50 to 60 gallons a minute; the discharge in 1889 was 11 gallons a minute; the discharge in 1908 was 3 gallons a minute and the present pumping capacity is 15 gallons a minute. The well was completed in 1885. In 1894 several hundred feet of new casing was inserted, with the effect of temporarily increasing the flow. This well now flows into an artificial pond and furnishes auxiliary supply for fire protection.

Record of strata of well No. 1 at school for the deaf, Council Bluffs.[a]

	Thickness.	Depth.
	Feet.	*Feet.*
Shale,, red, calcareous	280	280
Shale lavender colored, noncalcareous	10	290
Shale, bluish, calcareous; some small chips of limestone	35	325
Shale, dark gray, fine grained, slightly micaceous, noncalcareous	25	350
Shale, blue, tough, calcareous	5	355
Shale, blue, calcareous; some chips of limestone	45	400
Shale, light gray to green, pyritiferous; a few chips of limestone	70	470
Shale, reddish brown, calcareous	30	500
Shale, dull red, siliceous, noncalcareous; 2 samples	100	600
Shale, blue gray, very weakly calcareous; 2 samples	90	690
Sandstone, white, transparent; quartz grains rather sharp; some calcareous particles	55	745
Limestone, white; much quartz sand	15	760
Shale, greenish; some fragments of limestone; calcareous, slightly pyritiferous	50	810
Sandstone, fine, calciferous	20	830
Limestone, dark; mixed with some shale and sand	30	860
Sandstone, very fine; some calcareous grains	60	920
Shale, green gray, slightly calcareous	60	980

[a] From descriptions of drillings by J. A. Udden and by a member of Iowa Geological Survey.

Well No. 2 at the school for the deaf has a depth of 1,080 or 1,100 feet and a diameter of 6¼ inches to 482 feet, 5½ inches to 618 feet, and 4 inches to bottom. The casing is 4-inch pipe to 482 feet. The original discharge was 40 gallons a minute; discharge in 1908, 6 gallons; pumping capacity, 30 gallons a minute. Date of completion, 1889. The well is pumped and furnishes 35,000 gallons a day.

Log of well No. 2, school for the deaf, Council Bluffs.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface material	90	90
Shale	300	390
Sand	80	470
Limestone	100	570
Shale	250	820
Limestone	100	920
Sandstone	40	960
Limestone	50	1,010
Sandstone	30	1,040
Shale	35	1,075
Sandstone	25	1,100

The Geisse Brewery well is 1,114 feet deep and 9 to 3 inches in diameter. The curb is 1,047 feet above sea level and the original head was 55 feet above curb. The original discharge was 175 gallons a minute. The water comes from limestone. Date of completion, 1886(?).

The well of the Chicago, Milwaukee & St. Paul Railway at the roundhouse is reported to be 750 or 860 feet deep. The curb is 980 feet above sea level and the present discharge 3½ gallons a minute. A gradual lessening of flow has been noted. No pumps are used. Driller, W. H. Gray & Bro., Chicago.

Driller's log of well of Chicago, Milwaukee & St. Paul Railway.

	Thickness.	Depth.
	Feet.	*Feet.*
Drift	70	70
Limestone	100	170
Shale	480	650
Sandstone	100	750

The J. G. Woodward & Co. candy factory well was 830 feet deep. It obtained a flow of 15 gallons a minute from water bed at 725 feet, which had decreased to 5 gallons a minute by 1904. The well was deepened in 1904 to 847½ feet and the flow increased to 12 gallons a minute. Water at present is pumped at the rate of 60 gallons a minute with cylinder 140 feet below surface. Date of completion, 1901.

The Bloomer Ice & Cold Storage Co. well is 1,280 feet deep and 12 to 8 inches in diameter. The head is 80 feet above curb. A slight flow of ferruginous water at 700 feet was cased out, the main flow coming from 1,000 to 1,100 feet. The original discharge was 105 gallons a minute; the discharge in 1909 was 75 gallons a minute; the temperature was 62° F. The well was completed in 1906 at a cost of $5,500, by L. E. Nebergall, of Omaha.

The owner of the well states (from memory) that limestone was struck at 95 feet, beneath 3 or 4 feet of blue shale. A coal seam 2 or 3 inches thick was found at about 700 feet, with shale above and below it, and a very coarse conglomerate gravel with flattened pebbles at about 1,100 feet. From 1,150 feet to the bottom the well is in limestone.

Omaha, Nebr., and adjoining towns.—Some assistance in the interpretation of the difficult section at Council Bluffs is afforded by records of wells at Omaha, Lane, and Fort Crook, Nebr. These records were collected by J. H. Lees, assistant State geologist of the Iowa Geological Survey, and by correspondence.

Driller's log of Riverview Park well at Omaha, Nebr.

	Thickness.	Depth.
	Feet.	*Feet.*
Drift	94	94
Limestone	70	164
Shale	10	174
Limestone	86	260
Caving shale; streaks of limestone	87	347
Limestone	48	395
Streaks of lime and shale, caving badly, at		460
Caving shale to		569
Lime and shale	41	610
Sandy shale, caving badly in places	132	742
Limestone	108	850
Shale, caving considerably	149	999
Limestone, with streaks of shale caving badly	101	1,100
Limestone	58	1,158
Sandstone	72	1,230
Shale streak, at		1,233
Limestone; streaks of shale	147	1,380

Log of Young Men's Christian Association well, Omaha, Nebr.

[Elevation of curb, 1,070 feet above sea level.]

	Thickness.	Depth.
	Feet.	*Feet.*
Earth	102	102
Limestone	198	300
Shale, red and black	200	500
Limestone	20	520
Shale, black	50	570
Limestone	170	740
Shale and limestone	50	790
Limestone	284	1,074
Sandstone	60	1,134

Log of Booth Fisheries Co. well, Omaha, Nebr.

[Elevation of curb, 1,045 feet above sea level.]

	Depth in feet.
Loam and clay	40
Clay, blue, struck blue rock	50
Bedrock	61
Shale	78–88
Limestone and shale	93
Shale	98
Shale; trace of red rock	115

	Depth in feet.
Clay, blue; trace of red rock	125
Rock	130
Limestone	180, 200
Clay, blue	210
Shale, red	260, 280
Clay, blue	290, 315
Shale, gray	370
Shale, red	380
Shale, red and gray	400, 410
Shale	412
Shale, reddish	420
Rock	428
Shale, red, and clay	440
Shale, gray	520
Limestone	550
Limestone and clay; a small overflow	620
More water	740
Limestone	792
Limestone; more water	805
Through limestone; more water	812
Shale; flow 46 gallons a minute	815
Limestone, milky	850
Bad cave	950
Limestone, hard; water somewhat milky; 60 gallons a minute	970
Hard rock; 67 gallons a minute	1,047
Bottom of well (flow of 110 gallons a minute)	1,094

Log of Union Pacific Railway well, Lane, Nebr.

[Curb, 1,091 feet above sea level.]

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, sandy	50	50
Sand	2	52
Shale, blue	53	105
Limestone	45	150
Shale, black	13	163
Limestone	20	183
Shale	2	185
Limestone	15	200
Shale	2	202
Limestone	48	250
Sandstone	4	254
Limestone	7	261
Shale	159	420
Limestone	295	715
Shale	10	725
Limestone	10	735
Shale	15	750
Limestone	10	760
Shale	6	766
Limestone	146	912
Shale	8	920
Limestone	26	946
Shale	4	950
Limestone	41	991
Shale	9	1,000
Limestone	318	1,318
Shale, blue	67	1,385
Limestone	33	1,418
Shale	7	1,425
Sandstone	8	1,433
Shale	10	1,443

Log of Union Pacific Railway well, Lane, Nebr.—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Sandstone	9	1,452
Shale	16	1,468
Sandstone	12	1,480
Limestone	90	1,570
Sandstone	12	1,582
Limestone	8	1,590
Sandstone	18	1,608
Limestone	104	1,712
Shale, green	12	1,724
Sandstone	105	1,829

Record of strata of deep well at Fort Crook, Nebr.

[Furnished by Frank Phillips, Government engineer.]

	Thickness.	Depth.
	Feet.	*Feet.*
Unrecorded	65	65
Sand, coarse	4	69
Sand; gravel up to three-fourths inch diameter; pebbles of quartzite, greenstone, granite, etc	6	75
Till, blue; small pebbles, some of coal; facies of Kansan drift	28	103
Gravel; up to 1 inch diameter; well rounded; cuttings of gray crystalline limestone; rapid effervescence in cold dilute hydrochloric acid	10	113
Limestone; as above, some grayish white fossiliferous cuttings	2	115
Limestone, light yellow gray; rapid effervescence; subcrystalline; *Fusulina cylindrica*	7	122
Limestone, gray-white; in small chips	12	134
Limestone, blue gray, soft, earthy; large irregular chips, fossiliferous; crinoid stems and joints and *Fusulina cylindrica;* some shale	4	138
Limestone, gray, subcrystalline, encrinital; some green shale	2	140
Limestone, green gray, hard, fossiliferous; rapid effervescence	13	153
Shale, black, fissile	5	158
Limestone, grayish white, encrinital; in flaky chips	22	180
Shale, black	15	195
Limestone, light gray, earthy; some black shale from above	5	200
Limestone, white, fossiliferous; in large flaky chips; some blue shale	13	213
Shale, green, small particles of white limestone	8	221
Limestone, gray and white, soft, earthy	9	230
Limestone, blue-gray, fossiliferous, compact	10	240
Shale, red, slightly calcareous	60	300
Sandstone, blue-gray, fine grained, micaceous, calciferous, in chips; some red shale	27	327
Limestone, blue-gray, highly argillaceous; some pyrite	13	340
Limestone, blue-gray; shale, black, reddish, and yellow; fragments of Productus	5	345
Limestone, cream colored, earthy; rapid effervescence	10	355
Limestone, light gray, earthy	5	360
Shale, black, coaly	5	365
Shale, light green, calcareous	15	380
Shale, blue, calcareous, plastic	5	385
Sandstone, dark blue-gray, calcareous, micaceous, laminated, fine grained; in chips	5	390
Limestone, light buff and gray; rapid effervescence; blue shale	10	400
Shale, varicolored, blue, gray, yellow, red	70	470
Shale, gray; some coal; in thin flakes	30	500
Sandstone, light gray, micaceous; grains minute and highly irregular in shape; in fine sand	10	510
Limestone, sandstone, and shale; limestone and sandstone in fine sand; shale, black fissile, in flakes of some size and perhaps from above	37	547
Chert, white	3	550
Chert, white, and limestone; some sand and shale	15	565
Limestone, light buff and white; chert; some sand in drillings, rapid effervescence	10	575
Limestone, light buff and white; rapid effervescence; chert; some sand	5	580
Limestone, white and gray; rapid effervescence; some chert and chalcedonic silica	10	590
Chert and chalcedony; some limestone, of rapid effervescence; 3 samples	50	640
Limestone, light gray; rapid effervescence; chalcedony and chert; all in fine sand; all samples below the sandstone at 500 contain more or less quartz sand of irregular and minute grains	18	658
Chert, white and gray; limestone, light gray; limestone in sand, chert in large chips	26	684
Limestone, white and light gray, compact; rapid effervescence; some chert	6	690
Limestone, light gray and white; some laminated, compact; rapid effervescence; some crystalline darker; some chert	40	730
Limestone, white and light gray, macrocrystalline, soft, fossiliferous	32	762
Limestone, compact, white, rather soft; rapid effervescence; larger part of water-worn chips of shale of various colors and some gray sandstone, both evidently from above	8	770

Record of strata of deep well at Fort Crook, Nebr.—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Limestone, white and light gray; in small flaky chips	23	793
Sandstone, light gray; grains diverse in size and irregular in shape; considerable white limestone; all in fine sand; 2 samples	65	858
Shale, blue, plastic	8	866
Limestone, light gray; rapid effervescence; sample consists of limestone, some quartz sand and chert, and black shale and pyrite; all in fine sand	6	872
Limestone, white, soft and dark gray, subcrystalline, hard; in flaky chips	15	887
Limestone, light gray, dense; in small angular cuttings	13	900
Limestone, light gray; rapid effervescence; some chert	26	926
Limestone (?), cuttings of limestone, chert, shale of all colors, and grains of quartz; probably due to caving	24	950
Limestone, light-buff, some white; considerable chert and quartz sand in drillings	30	980
Chert, blue, mottled; limestone of rapid effervescence; some quartz sand	20	1,000
Limestone, light buff; much blue chert; slow effervescence, indicating large content of magnesia	4	1,004
Limestone, light gray and white, compact; in flakes; rapid effervescence	11	1,015
Limestone, light buff and light gray, subcrystalline; effervescence slow; some particles rapid (see analysis below)	3	1,018
Dolomite, dark brown, crystalline; in sharp sand; effervescence slow	37	1,055
Dolomite, light buff; in fine sand	3	1,058
Dolomite; as at 1,055 feet	2	1,060
Shale, blue, plastic, calcareous	5	1,065
Dolomite, light buff	5	1,070
Limestone, buff, in mass; rapid effervescence; much white and light-gray limestone; some black shale and quartz sand; resembles upper limestones	10	1,080
Limestone, dark and light gray; rapid effervescence; in minute cuttings; black shale from above	45	1,125
Dolomite, light buff; in finest crystalline sand, without shale, and with negligible quartz sand; 3 samples	95	1,220
Shale, bright green, hard, noncalcareous, nonarenaceous; in sand; many chips of dolomite	30	1,250
Dolomite, gray; in finest sand; 2 samples (see analysis below)	90	1,340
Dolomite, white; in finest sand; some quartz sand in drillings, grains fairly well rounded, some with secondary enlargements; many broken; quartz sand from 5 to 10 per cent of drillings	120	1,460
Dolomite, light gray and whitish; in finest sparkling crystalline sand, almost free from quartz sand	100	1,560
Dolomite, white, macrocrystalline; in coarse sand (see analysis below)	20	1,580
Dolomite, light buff; cherty in fine sand practically free from quartz	185	1,765

Analyses of drillings from deep well at Fort Crook, Nebr.

[Made in chemical laboratory of Cornell College, Mount Vernon, Iowa.]

	1,018 feet.	1,340 feet.	1,580 feet.
Silica (SiO_2)	5.41	17.92	11.46
Iron (FeO)	1.37	1.23	2.60
Water (H_2O)	2.26	2.08	2.01
Calcium (CaO)	26.20	19.64	20.73
Magnesium MgO)	21.06	20.65	22.73
Carbon dioxide (CO_2)	43.73	38.18	41.21
	100.03	99.70	100.74

A complete set of samples of the drillings taken from the deep well in Miller Park, Omaha, was preserved by the drillers, J. P. Miller & Co., of Chicago. The surface at the well as reported by the city engineer is 1,007 feet above sea level. The depth to the principal water bed is 810 feet; another water bed is at 1,150 feet. The natural flow is about 150 gallons a minute; temperature, 60° F.

Record of strata in deep well at Miller Park, Omaha, Nebr.

	Thickness.	Depth.
	Feet.	*Feet.*
Silt, light, greenish yellow, calcareous, argillaceous; mainly fine, angular quartzose particles; some hard chips of white limestone, at		50
Limestone, light, blue gray, and light yellow, earthy, subcrystalline; rapid effervescence in cold dilute hydrochloric acid; in large cuttings	11	70
Shale, red, according to label	10	75
Limestone, white, soft, earthy; in large chips	15	90
Limestone, white, soft; in thin flakes; with green shale	10	100
Limestone, white, earthy	10	110
Limestone, white and light gray, compact, fine grained, earthy; in flaky chips	20	130
Shale, blue; and limestone, white, soft, earthy, blue-gray, fossiliferous	15	145
Shale, red; and limestone, light blue-gray, hard, fine grained; some lithographic with conchoidal fracture, some partly crystalline	10	155
Limestone, blue-gray and pinkish, earthy; some fine grained, conchoidal fracture; reddish shale	10	165
Limestone, drab, conchoidal fracture; reddish and greenish shale	10	175
Shale, drab, argillaceous; calcareous nodules	10	185
Shale, red	10	195
Shale, blue	10	205
Shale, blue, plastic	40	245
Shale, blue, plastic, calcareous	10	255
Limestone, gray; in fine angular sand	10	265
Shale, red; some green plastic shale	10	275
Shale, blue, plastic, slightly calcareous	10	285
Limestone, blue-gray, fossiliferous; crinoid stems; in small chips in mass concreted with drab and black shale	10	295
Shale, blue, plastic; 2 samples	20	315
Limestone, buff; in fiue angular sand	10	325
Shale, black	10	335
Shale, red; some green, at		335
Shale, green and purple; some hard silico-calcareous cuttings	10	345
Limestone, gray; some pinkish; a little colored flint, with yellow, green, and reddish shale	10	355
Shale, reddish and yellow; and sandstone, blue gray, fine grained	10	365
Limestone, gray; in fine angular sand	20	385
Shale, greenish yellow; 3 samples	30	415
Shale, blue, plastic	20	435
Shale, blue, somewhat calcareous	10	445
Shale, black and yellow-green	10	455
Shale, black and reddish	10	465
Limestone, white and gray; some white chert	10	475
Chert and limestone, white and gray	10	485
Limestone, blue, highly argillaceous, hard and white, saccharoidal; some chert	10	495
Limestone, white and light gray; much white chert	20	515
Limestone, light gray; in fine sand; with powder of shale in light blue-gray concreted masses	10	525
Chert and chalcedonic silica; much black, drab, and reddish shale from cave	20	545
Shale, drab; gray limestone and chert	10	555
Limestone, medium dark blue-gray, dense, earthy; in rather large chips; some flint, and crystalline quartz, apparently geodic; also blue shale	10	565
Limestone, light yellow-gray; some greenish gray; in fine sand, at		565
Chert, light gray, in small chips; a little limestone of same color	10	575
Chert, gray; a little light gray or whitish limestone	10	585
Chert, gray, drab, and white; a little chalcedonic silica and gray limestone	20	605
Limestone, light gray; much chert; some fine grains of clear quartz, partly rounded	20	625
Limestone, light gray and yellow; considerable chert and bluish chalcedony and some quartz grains	10	635
Shale, blue and light green; in molded masses; small, hard, dark blue-gray, nodular masses at 635 feet; calcareous and argillaceous	50	685
Limestone, light yellow-gray; and hard blue argillaceous	10	695
Limestone, light yellow-gray, dense, fine grained; in flaky cuttings	10	705
Limestone, white, soft, earthly; some hard crystalline; with rare fragments of crinoid stems, white and bluish-white chert, and small quartz crystals; in medium-sized chips	10	715
Limestone, cream colored, hard, fine grained; in coarse meal	10	725
Limestone, white and light gray; soft; in small flakes	10	735
Lfmestone, light yellow gray	10	745
Limestone, white and light gray; 2 samples	20	765
Limestone, white and cream colored; dull luster; in flakes; soft	20	785
Limestone, white, subcrystalline; in sand; minute rounded grains suggest oolitic or foraminiferal tests; with shale, green, noncalcareous	10	795
Limestone, gray, of rapid effervescence; some subcrystalline limestone of slow effervescence. Latter is the first limestoue whose slow effervescence indicates any considerable magnesian content; shale green, practically noncalcareous; in chips	10	805
Limestone, white and yellow gray; with chert, and some quartz sand; and shale, green, pyritiferous; in chips	10	815
Limestone, white; rapid effervescence; with shale in chips; much fine quartz sand; shale, from 785 to 825 feet, probably due to caving	10	825
Limestone, white and light yellow, crystalline; effervescence rather slow; with shale, blue gray, highly pyritiferous	10	835
Limestone, white or light yellow-green, crystalline, and in part saccharoidal; much blue-gray noncalcareous shale	10	845

Record of strata in deep well at Miller Park, Omaha, Nebr.—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Limestone, buff; slow effervescence; much white chert; fine cuttings	10	855
Limestone, gray; with white chert; effervescence slow; in fine cuttings	10	865
Dolomite or magnesian limestone, light gray; in very fine crystalline powder; slow effervescence; 2 samples	20	885
Limestone, light brown; moderately slow effervescence; in crystalline sand; a few fine rounded grains of quartz	10	895
Limestone, brown; in sand; effervescence rather rapid	10	905
Limestone, light yellow, crystalline; some of moderately slow and some of rapid effervescence	10	915
Limestone, light yellow-gray, subcrystalline; in fine cuttings; effervescence rapid	10	925
Limestone, light yellow and brown, crystalline; effervescence moderately slow	10	935
Dolomite or magnesian limestone, buff, crystalline, compact; effervescence slow; in small cuttings; 3 samples	30	965
Dolomite or magnesian limestone, crystalline, cherty, light gray; slow effervescence; 2 samples	30	995
Limestone, light gray and yellow; in fine sand; effervescence moderately slow	10	1,005
Limestone, light gray, blue-gray, and drab; hard; effervescence rather slow; much quartz sand of rounded grains	10	1,015
Limestone, light gray; rather slow effervescence; cuttings of hard, white, calcareous shale; all in sand; 4 samples	40	1,055
Shale, bright green, hard; in small chips; calcareous; with limestone, buff; effervescence rather slow; some calcite; in fine sand	10	1,065
Shale, green, plastic, in molded masses but with individual fissile fragments embedded; calcareous	10	1,075
Shale; as at 1,065 feet; some chips of light-gray limestone; rapid effervescence	10	1,085
Limestone, buff; some mottled with dark drab; rather slow effervescence; some green shale	20	1,105
Dolomite or magnesian limestone, clean, bright yellow, fine, crystalline, granular; effervescence slow; with embedded minute ill-rounded grains of silica; a little white chert; 2 samples	20	1,125
Limestone, light yellow and whitish; moderately rapid effervescence; much green shale; all in fine sand; 2 samples	20	1,145
Sandstone, white, fine; well-rounded grains of crystalline quartz; some pink limestone of rather rapid effervescence	20	1,165
Limestone, pinkish and light buff, subcrystalline; moderately rapid effervescence; some gray, of much slower effervescence; in chips, and shale, dark red, very slightly calcareous, arenaceous; in chips; and sandstone, of grains as above, with dark-red matrix of shale	10	1,175
Limestone, light gray; rapid effervescence; some white chert; and sandstone, of fine well-rounded grains	10	1,185
Dolomite or magnesian limestone, light blue and yellow-gray, compact, with white chert; effervescence slow; some quartz sand and green shale, probably from above; 8 samples	84	1,269

Driller's log of Miller Park well, Omaha, Nebr.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, soft	30	30
Hardpan and gravel	40	70
Hard limestone	25	95
Shale and streaks of limestone	12	107
Limestone	13	120
Shale	5	125
Limestone	10	135
Shale, red	40	175
Limestone, hard	5	180
Shale, blue	45	225
Limestone	5	230
Limestone, hard	3	233
Shale	62	295
Limestone, hard	20	315
Shale	35	350
Shale, black	15	365
Limestone	7	372
Shale, yellow, and limestone	38	410
Shale, blue	45	455
Limestone	20	475
Shale, white	12	487
Limestone	20	507
Shale, black	10	517
Limestone, hard	14	531
Shale, blue	6	537

Driller's log of Miller Park well, Omaha, Nebr.—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Limestone	5	542
Shale, blue	12	554
Limestone	3	557
Shale	5	562
Limestone	23	585
Shale	5	590
Limestone	25	615
Shale	4	619
Limestone	20	639
Shale, white	33	672
Limestone, hard	48	720
Caving rock	4	724
Limestone	116	840
Sand (water-bearing)	2	842
Limestone	7	849
Shale	6	855
Limestone	85	940
Shale	12	952
Limestone	108	1,060
Shale	7	1,067
Limestone, hard	8	1,075
Shale	30	1,105
Limestone	20	1,125
Sandstone	4	1,129
Marl, sandy, red	15	1,144
Limestone	125	1,269

Minden.—In Minden (population, 423) there are two pumping stations each with two wells, none of which supply much water. The first well is 8 feet in diameter and 40 feet deep, is cased with brick, passes through clay and gravelly streaks from which it receives seepage, and furnishes about 5,000 gallons a day. The second is 16 inches in diameter and 60 feet deep, is cased with tile, penetrates a bed of quicksand, and yields perhaps 10 gallons a minute. The two new wells at the pumping plant recently installed are 20 inches in diameter and 58 or 60 feet deep, are cased with tile, and also end in quicksand. There is a standpipe, 1½ miles of mains, 22 fire hydrants, and 41 service connections. The water is liked by the people and is widely used for domestic purposes. The average daily consumption is estimated at 10,000 gallons, which amount is now easily provided by the wells. The Chicago Great Western Railway has in the past utilized a spring and a shallow well that have not been satisfactory. It is reported that the railway company at one time drilled to a depth of several hundred feet without success. The well at the canning factory is similar to the village wells.

Neola.—The public supply at Neola (population, 926) is obtained from one 5-inch and about fifteen 2-inch wells that end with screens in a thick bed of alluvial sand and gravel at depths of 45 to 50 feet, from which the water rises within about 14 feet of the surface. With a suction pump placed 6 feet below the surface this system of wells has been made to yield 145 gallons per minute. Some of the small wells have been in service a long time and their supplies have probably been shut off or greatly diminished by the incrusting of their screens. The water is of good quality though it has considerable temporary hardness. There are 2 miles of mains, 24 fire hydrants, and numerous taps. The pressure is obtained from a storage reservoir situated on high ground. The water is used extensively for domestic purposes and it is estimated that 50,000 gallons are consumed daily. Both railway companies draw locomotive supplies from the valley gravels.

Oakland.—Oakland (population, 1,105) is located in the Nishnabotna Valley and has a gravity system of waterworks that derives its supply from a series of driven wells that end in alluvial sand at a depth of about 22 feet.

Walnut.—In Walnut (population, 950) two wells were drilled to a depth of about 200 feet into a bed of incoherent fine-grained water-bearing sand. Numerous unsuccessful experiments were made to separate the water from the sand, but the wells were finally abandoned. At present the supply comes from a reservoir formed by damming a ravine at the south margin of the village and from four shallow wells in the same locality. Three of the wells are bored to about 60 feet, where they are said to strike gravel; the other is a dug well 10 feet square and about 30 feet deep. The supply from this system is small and precarious and is not considered satisfactory. The waterworks include a standpipe and 2 miles of mains. Only small use is made of the water, the consumption being perhaps not over 3,000 gallons a day.

SHELBY COUNTY.

By O. E. Meinzer.

TOPOGRAPHY AND GEOLOGY.

Shelby County consists of a hilly but fertile loess-covered upland interrupted by several wide alluvium-filled valleys that trend southwestward. The hill topography, with a general relief of 100 to 200 feet, is carved out of a thick accumulation of glacial drift and associated deposits, below which is hidden a thin layer of Cretaceous sandstone and shale and a much thicker series of Pennsylvanian shale, limestone, and sandstone.

UNDERGROUND WATER.

SOURCE.

The water-bearing formations underlying the county are the alluvium, the loess, drift, and associated deposits, the Cretaceous sandstone, and the lower formations.

The Pennsylvanian strata will furnish little water, but moderate quantities can be secured from formations at greater depths. The Carboniferous and deeper waters are rich in sodium sulphate.

The Cretaceous beds, which consist of poorly cemented sandstone and soft shale or "soapstone," where present, lie next above the Pennsylvanian. They have apparently been reached in a number of wells, but since most of these wells are old and a large proportion have been abandoned little definite information in regard to them remains. The sandstone contains water, which, however, is not under much head and hence does not enter the wells rapidly and must be lifted from considerable depths. Moreover, the sand screens that are used readily become incrusted, shutting out the supply. From the meager data at hand it seems that the water is harder than that from more shallow sources but is less mineralized than the deeper water. In future work it should be understood that better results can be expected from 4-inch and 6-inch wells than from small 2-inch wells, which are poorly adapted to this region.

The bulk of the county's water supply is obtained from bored and dug wells, whose advantage lies in their large circumference and resultingly extensive infiltering surface. These wells are commonly sunk at low points into the unconsolidated materials, from which they derive meager contributions at several levels, the most water probably being obtained (1) at the contact between the loess and the subjacent gravelly and weathered drift and (2) at the contact between the two drift sheets that appear to exist here.

In the principal valleys fairly abundant supplies can be obtained by sinking inexpensive open or driven wells into the alluvial sand and gravel, and it is from this source that a large part of the water for public waterworks and locomotives is obtained.

CITY AND VILLAGE SUPPLIES.

Earling.—The waterworks at Earling (population, 323) are supplied from two pumping plants, each of which draws from two dug wells. The four wells, all situated on low ground, range in depth from 21 to 51 feet and depend chiefly on slow seepage from clay. They fill each day to a level within about 8 feet of the surface and will together easily supply 15,000 gallons, which is about two and one-half times the average daily consumption at present. The water is only moderately hard and is used by nearly one-half of the people. The waterworks include a tank elevated upon a tower on high ground, one-half mile of mains, 8 fire hydrants, and 40 taps.

Harlan.—The public supply of Harlan (population, 2,570) is drawn from eight 6-inch wells located in the valley near the river. They extend through yellow clay, tough blue clay, and fine sand into coarse sand and gravel, in which they are finished with 12-foot screens at a total depth of 43 feet, and from which the water rises to a level 20 to 24 feet below the surface. The pump, which is in a pit

8 feet below the surface and therefore has a vacuum of 12 to 16 feet before pumping is begun, has been operated rapidly enough to lift 275 gallons a minute and is usually run at the rate of 175 gallons a minute for about 18 out of every 24 hours. It is propelled by water power. The water is stored in a standpipe situated on high ground and is delivered by gravity through about 4 miles of mains to 41 fire hydrants and 380 service connections. It is used by most of the inhabitants and by the three railway companies. About 200,000 gallons are consumed daily, one-third of which goes to the railway locomotives. The water is only moderately hard and is fairly good for use in boilers (see p. 175 for analysis).

Kirkman.—Kirkman (population, 180) has an air-pressure system of waterworks supplied from a dug well 6 feet in diameter, which extends through clay to a depth of 47 feet and ends in a bed of gravel. The well fills to a level about 25 feet below the surface. It furnishes approximately 2,000 gallons a day and would yield considerably more. The water is only moderately hard and is used to some extent for domestic purposes.

Panama.—The waterworks at Panama (population, 232) consist of a gravity system with limited service supplied from a 6-foot dug well that extends to a depth of 43 feet and depends on clay seepage. In the driest season the yield of this well was reduced to 2,000 gallons a day, but it normally yields several times this amount.

Portsmouth.—The public supply of Portsmouth (population, 347) is obtained from four driven wells located in the valley. They end with screens in sand and gravel at a depth of about 50 feet, the water rising to within 16 feet of the surface. Two of the wells are together pumped at the rate of 50 gallons a minute by means of a suction pump at the surface. The water is lifted into a tank on the upland and is distributed by gravity through 1¼ miles of mains to 10 fire hydrants and about 30 service connections. It is used by nearly one-half of the people, and approximately 7,500 gallons are daily consumed.

TAYLOR COUNTY.

By O. E. Meinzer and W. H. Norton.

TOPOGRAPHY AND GEOLOGY.

Taylor County is deeply trenched by numerous valleys that trend in general southwestward, between which are hills, ridges, and isolated tracts of comparatively level upland. The glacial drift, where not dissected, is of considerable thickness. At the bottom it is very dark and at the top it has been colored yellow by oxidation. At intermediate horizons are found "hardpan" and a few beds of sand

and gravel. The base of the drift has been so little exposed that it is not known to what extent sand exists between the bowlder clay and bedrock. Widely spread over the weathered drift is a coat of clay, rarely as much as 25 feet thick, and apparently averaging much less, which is essentially free of pebbles and grit and which is ashy and plastic at the bottom, but is generally yellow and loesslike at the surface. In some of the valleys the alluvial deposits are well developed. As far as is known, the bedrock belongs to the Missouri group (Pennsylvanian), and consists chiefly of limestone and shale. In the deep well at Bedford (Pl. XVIII, p. 898) this group is supposed to have a thickness of 722 feet, the total thickness of the Pennsylvanian being considered to be 1,300 feet.

UNDERGROUND WATER.

SOURCE.

Almost the entire water supply for Taylor County comes either from surface sources (streams, cisterns, and artificial "ponds") or from shallow wells sunk into the upper layer of drift or into the valley deposits. Some wells have been drilled to the deeper parts of the drift and a few into the underlying rock strata, but the information concerning such wells is exceedingly scant. Some have been finished successfully, but a large number were failures. Since no reliable and satisfactory deep-water bed has yet been discovered beneath this county, it seems advisable for domestic, stock, industrial, and even public purposes to seek to develop supplies near the surface. The method of boring a number of shallow wells of large diameter and connecting them at the bottom with drifts is being employed on stock farms with good results.

CITY AND VILLAGE SUPPLIES.

Bedford.—The supply for the public waterworks in Bedford (population, 1,883) is from several wells of large diameter, located in the valley and sunk through about 28 feet of clay into a 10-foot bed of sand that rests upon limestone. The sand is saturated with water but it is so fine grained and incoherent that there is difficulty in separating the water from it, and the total yield of the system of wells is consequently only about 6,000 gallons a day, an amount that is entirely inadequate. The water is pumped into a standpipe and thence distributed through the mains by gravity pressure. A 2,400-foot hole was drilled at Bedford (Pl. XVIII) without finding a satisfactory supply, and plans are now being considered for further developing the supply from the bed of sand at present utilized, or for installing a filtration plant for purifying the river water. Without much doubt the yield from the sand bed could be indefinitely augmented by boring more wells or in other ways increasing the infiltration surface.

The well of the Bedford Developing Co. is 2,400 feet deep and 10 inches in diameter to a depth of 2,008 feet. The curb is 1,098 feet above sea level and the head 265 feet below the curb. Water was found at 1,180 to 1,228 feet in sandstone; and water which had previously stood at from 15 to 30 feet below the curb dropped to 90 feet. A strong flow of water was struck at 1,560 to 1,580 feet, water rising to a point 298 feet below the curb. Water struck at 1,920 to 2,005 feet rose to a level 284 feet below the curb and, after pumping test, to 265 feet (a pumping test at 2,009 feet gave 150 gallons a minute). Water was also struck at 2,020 to 2,168 feet. Driller, J. P. Miller Co., of Chicago; date of completion, 1909.

The water was too salty for drinking. In all tests the pumps drew fresh water for about 40 minutes until upper veins of uncertain location were exhausted. The water at 1,177 or 1,180 feet, in the basal sandstone of the Pennsylvanian, was supposed by the owners to be salty, but by the drillers the salt water was located at the 1,580-foot vein. The test at the 1,661-foot vein also brought up water not fit for any city use. In order to test the lower water beds the well was reamed to 2,008 feet and a 3-inch pipe was inserted and packed to this depth. The pumping test gave 100 gallons a minute through this pipe, but the water was extremely salty. It is much to be regretted that the water of the basal Pennsylvanian sandstone was not tested as to both quality and quantity.

Record of strata of deep well at Bedford (Pl. XVIII, p. 898).

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene:		
Drift, no samples or record	38	38
Carboniferous:		
Pennsylvanian:		
Missouri group (722 feet thick; top, 1,060 feet above sea level):		
Limestone, light gray, nonmagnesian, soft; earthy luster; permeated with minute ramifying smooth-surfaced masses of calcite	6	44
Limestone, argillaceous, light gray, soft; earthy luster; and shale plastic	6	50
Shale, drab, unctuous, noncalcareous; 8 samples	40	90
Shale, bluish drab, calcareous	5	95
Limestone, earthy, light blue-gray	5	100
Shale, drab, calcareous; 3 samples	15	115
Limestone, light blue-gray, soft, argillaceous; with shale	5	120
Shale, drab, calcareous	5	125
Limestone and shale; limestone, soft, whitish; rapid effervescence; numerous Fusulina; encrinital; 5 samples	25	150
Limestone, light gray, soft, earthy; a little chert	5	155
Shale, greenish drab; some limestone with crinoid stems	10	165
Shale; as above; some black carbonaceous and a little blue-gray limestone	5	170
Limestone, light brown, white, gray, hard, compact; and greenish shale	5	175
Limestone; light blue gray, argillaceous; and light yellow-gray with crinoid fragments; greenish shale	5	180
Limestone, yellow, gray, hard	5	185
Shale, dark brick red, calcareous; 2 samples	10	195
Shale; greenish drab, calcareous, siliceous; and ocher yellow, hard, siliceous, calcareous; 2 samples	10	205
Shale, hard, greenish drab; so highly siliceous with minute particles of quartz that it might be termed an argillaceous sandstone	5	210
Shale, greenish drab, plastic, pyritiferous; some hard yellow fossiliferous limestone	15	225
Shale, blue drab, soft, laminated; harder siliceous layers	25	250
Shale, drab, laminated; 6 samples	30	280
Shale, drab, with some laminæ of black coaly shale	5	285
Shale, green, fossiliferous	5	290

Record of strata of deep well at Bedford (Pl. XVIII)—Continued.

	Thickness.	Depth.
Carboniferous—Continued.		
Pennsylvanian—Continued.		
Missouri group (722 feet thick; top, 1,060 feet above sea level—Continued.	*Feet.*	*Feet.*
Shale, green, fossiliferous; some drab limestone and chert	5	295
Shale, hard, red; 2 samples	5	300
Limestone, hard, drab, with shale	10	310
Shale, drab, fossiliferous	10	320
Limestone, hard, fine grained, siliceous	5	325
Limestone, yellow-gray; and white, soft; earthy luster; 3 samples	15	340
Shale, green and black, carbonaceous	5	345
Limestone, soft, yellow, macrocrystalline	10	355
Shale, drab; 5 samples	25	380
Shale, drab; some drab limestone	5	385
Shale, drab; with sand of flinty drab limestone	5	390
Shale, reddish; with dark, green-gray argillaceous limestone	5	395
Shale, red; a little brown siliceous limestone	10	405
Shale, drab; 4 samples	15	420
Limestone, light yellow-gray; crystalline in sand; 4 samples	20	440
Shale, greenish drab	10	450
Limestone, light yellow-gray; much shale	5	455
Shale, greenish; some drab limestone, flinty	10	465
Limestone, light yellow-gray	10	475
Shale, drab; 4 samples	20	495
Limestone, white; large fragments of shale	21	516
Shale, drab; some black at 516, with limestone at 525; 4 samples	19	535
Limestone, white and gray	15	550
Shale, black, fissile, combustile; and hard, gray limestone	5	555
Shale, dark drab	10	565
Shale, greenish; with white limestone in concreted powder	5	570
Sandstone, white; microscopic grain; calciferous; with shale	5	575
Limestone, white and light gray	10	585
Shale, dark drab	5	590
Limestone, hard, gray, siliceous; shale	5	595
Shale, dark drab	5	600
Limestone, yellow-gray, rather hard; much shale in large fragments	15	615
Shale, dark drab; nodules and masses of gray chert	15	630
Shale, light brown, calcareous	5	635
Shale, greenish; with gray limestone and chert	5	640
Limestone, gray; much shale	5	645
Shale, drab; black at 645; gritty at 650 and 655; with limestone at 670; sandy at 670, 675, 695, 700; coaly at 705	65	710
Sandstone, fine, gray; 3 samples	15	725
Shale, dark drab; some black; fissile	10	735
Limestone, gray, finely arenaceous	10	745
Shale, drab and reddish brown; 2 samples	10	755
Limestone, light gray	5	760
Des Moines group (580 feet thick; top, 338 feet above sea level):		
Shale, varicolored; highly arenaceous at 765 and 770; reddish brown at 785, 790, 940, and 1,065; black at 855, 1,045, 1,055, and 1,060	400	1,160
Sandstone; drillings mostly shale	5	1,165
Shale, black	15	1,180
Sandstone, fine, white; much shale in drillings; 8 samples	40	1,220
Shale	5	1,225
Sandstone	10	1,235
Sandstone, in fine gray meal, the particles of which resemble flint macroscopically but are composed of minute quartzose grains with considerable yellow chert at 1,250, with considerable shale in all drillings; 10 samples	50	1,285
Sandstone, clean, fine, yellow-gray, composed of minute irregular grains	5	1,290
Sandstone, coarser; some grains reaching 1 mm. in diameter	5	1,295
Sandstone, green-gray, fine grained	5	1,300
Sandstone, yellow-gray, coarser; grains irregular in shape and far from uniform in size	5	1,305
Sandstone, fine, gray; shale in drillings probably from above	35	1,340
Mississippian (355 feet thick; top, 242 feet below sea level):		
Limestone, gray; rapid effervescence	5	1,345
Limestone, yellow-white, soft; earthy; 4 samples	20	1,365
Limestone, gray, rather hard, conchoidal fracture; lithographic texture	15	1,380
Limestone, soft, gray, earthy, argillaceous	20	1,400
Limestone; as above; and gray, fine-grained sandstone	5	1,405
Limestone, light drab, argillaceous	20	1,425
Limestone and chert; drillings largely chert and chalcedonic silica	10	1,435
Limestone, drab; less chalcedony	5	1,440
Cherts, white and gray; in places brown, and limestones, often siliceous; 17 samples	85	1,525
Limestone, soft, gray, earthy; a little chert	5	1,530
Limestone, soft, white, and light gray; saccharoidal; some chert	5	1,535
Cherts and limestone; limestones nonmagnesian; 14 samples	85	1,620
Limestone, buff; slow effervescence; much gray chert	5	1,625
Limestone, brown; moderate effervescence	5	1,630
Limestone, brown; rapid effervescence; calcite crystals	15	1,645

Record of strata of deep well at Bedford (Pl. XVIII)—Continued.

	Thickness.	Depth.
Carboniferous—Continued.		
Mississippian (355 feet thick; top, 242 feet below sea level—Continued.	*Feet.*	*Feet.*
Limestone, gray, oolitic; rapid effervescence; 4 samples	20	1,665
Shale, blue, fine grained, gritless, calcareous; in concreted powder; 6 samples (Kinderhook?)	30	1,695
Devonian (130 feet thick; top, 597 feet below sea level):		
Limestone, light gray; rapid effervescence	10	1,705
Limestone, light blue-gray, compact, fine grained; in thin flaky chips	10	1,715
Limestone, yellow; in sand; rapid effervescence	15	1,730
Shale, drab, clayey, highly calcareous	5	1,735
Limestone; white and mottled gray at 1,735; gray from 1,740–1,755; buff at 1,755 and 1,760; light gray, subcrystalline, dense at 1,765 and 1,770; all of rapid effervescence	40	1,775
Shale, or highly argillaceous limestone; gray, in nonconcreted power	10	1,785
Limestone, buff; in fine meal; rapid effervescence	15	1,800
Limestone, gray; in fine meal; rapid effervescence; argillaceous at 1,810; 5 samples.	25	1,825
Silurian (575 feet thick; top 727 feet below sea level):		
Limestone and shale; limestone, gray in meal, rapid effervescence; shale, brick red, highly pyritiferous, in fine meal and powder not concreted; some fine ill-rounded quartz grains at 1,830; color of mass of drillings, brick red	20	1,845
Limestone, yellow; drillings pink from admixture with fine meal and powder of red shale, probably from 1,825; limestone in meal and sand, crystalline; rapid effervescence; some irregularly rounded quartz grains in drillings which also may be from above; 14 samples	70	1,915
Dolomite, dark gray; in fine crystalline meal; some calcite	20	1,935
Dolomite, buff	10	1,945
Dolomite, dark gray, argillaceous	5	1,950
Unknown; drillings washed away	20	1,970
Dolomite, light brown; in crystalline meal	7	....
Marl, in fine white powder, not concreted; calciferous, argillaceous; large amount of anhydrite	4	2,009
Dolomite, as at 1,970; calcite rhombs and a few crystals of anhydrite	6	2,015
Dolomite, light yellow; in finest crystalline meal; numerous crystals of anhydrite	20	2,035
Dolomite, light brown; in floury meal; residue of anhydrite	35	2,070
Dolomite, light greenish gray, argillaceous; much anhydrite and dolomitic marl	5	2,075
Dolomite, light gray, less argillaceous; considerable anhydrite	10	2,085
Dolomite, bright yellow; in meal; considerable anhydrite	15	2,100
Dolomite, brown; in coarser meal	5	2,105
Dolomite, light brown; in much finer meal; anhydrite rather plentiful	....	2,105
Limestone; somewhat magnesian, judging from effervescence; light yellow and buff; argillaceous; some anhydrite in drillings	15	2,160
Dolomite, buff; in fine crystalline, sparkling meal	8	2,168
Dolomite, light gray, argillaceous; in finest powder, not concreted	2	2,170
Dolomite; in fine brown or yellow meal, not concreted; some anhydrite	35	2,205
Anhydrite marl; in light cream colored or whitish powder; 10 samples	55	2,260
Anhydrite marl; in bright-buff powder; dolomite	20	2,280
Anhydrite marl, cream colored; 9 samples	45	2,325
Dolomite and anhydrite; in fine buff meal	15	2,340
Anhydrite marl, argillaceous; in yellow powder	10	2,350
Shale, slightly calcareous and gypseous; in gray powder	5	2,355
Dolomite, light buff; in fine meal	5	2,360
Shale, calcareous; in gray powder	5	2,365
Dolomite; in fine buff meal	5	2,370
Limestone, magnesian, or dolomite; in gray powder and meal; residue argillaceous and cherty and with considerable anhydrite	15	2,385
Dolomite, buff; in angular sand	10	2,395
Shale, calcareous; considerable anhydrite	5	2,400
Dolomite; some gypsum.		

Analyses of drillings from Bedford deep well.[a]

	Depth.					
	1,830 feet.	1,920 feet.	2,100 feet.	2,240 feet.	2,300 feet.	2,400 feet.
$CaCO_3$	45.42	53.80	53.23	36.07	11.76	36.71
$MgCO_3$	17.32	44.18	37.38	11.63	3.12	44.75
$CaSO_4$	....	....	....	32.92	76.53	5.20
Al_2O_3	1.70	....	.73	.34	.61	.07
Fe_2O_3	11.07	....	2.02	.82	2.72	.81
MgO	....	....	....	5.10	....	....
SiO_2	21.30	....	4.29	11.53	1.29	2.22
H_2O	2.05	....	1.66	2.48	3.73	9.69
Total	98.86	....	99.31	100.89	99.76	99.45

[a] Made in chemical laboratory of Cornell College, Mount Vernon, Iowa.

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Q.

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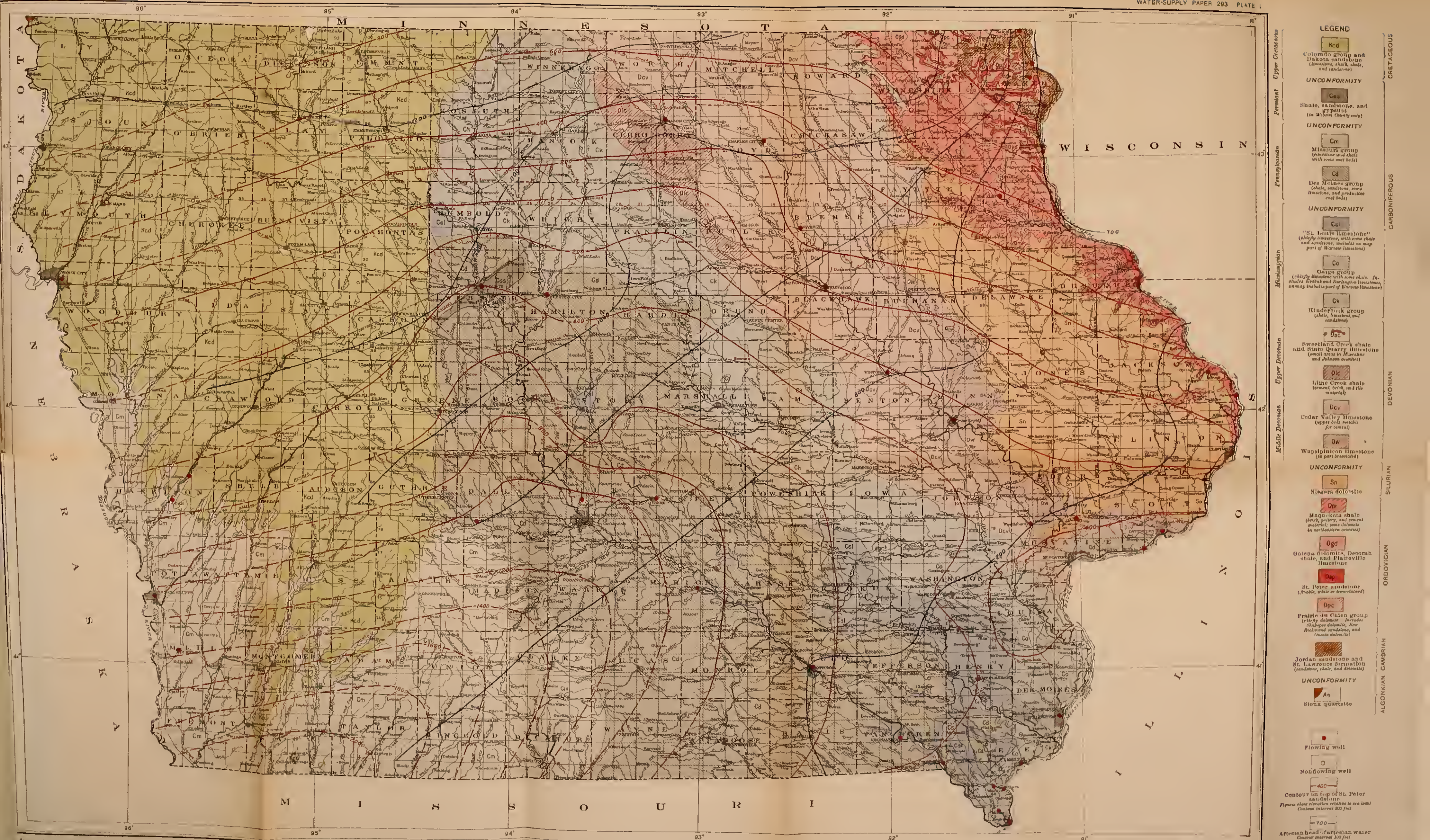
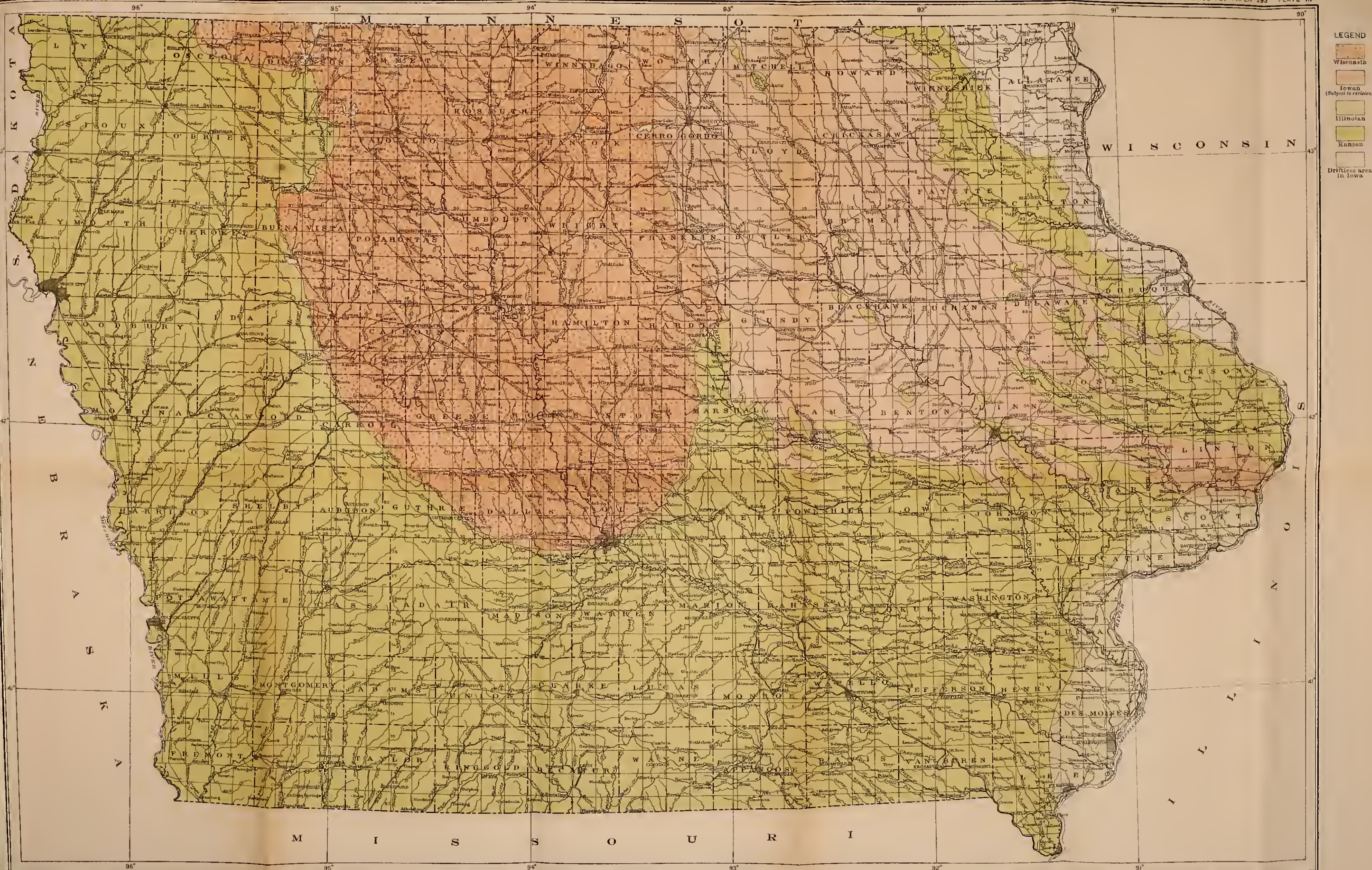


GEOLOGIC MAP OF IOWA SHOWING ARTESIAN CONDITIONS AND ELEVATION OF ST. PETER SANDSTONE

Scale 1/500000

1912

Geology by Iowa Geological Survey
Structure contours and artesian data by W. H. Norton



Base compiled from U. S. Geological Survey atlas sheets, Land Office data, surveys by Mississippi and Missouri River commissions, county maps, and other sources.

Compiled from reports of the Iowa Geological Survey

MAP OF IOWA SHOWING DRIFT SHEETS

Scale 1/500000

10 0 10 20 30 40 50 Miles

1912