ROCKS AND SOILS:

THEIR ORIGIN, COMPOSITION AND CHARACTERISTICS;

CHEMICAL, GEOLOGICAL and AGRICULTURAL.

BY

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TO

Levi Stockbridge,

FARMER, TEACHER, INVESTIGATOR,

THESE PAGES ARE AFFECTIONATELY INSCRIBED WITH

THE DESIRE OF ACKNOWLEDGING THE

ESTEEM AND REVERENCE

OF

SON AND PUPIL.

PREFACE.

FIVE years ago I was requested to prepare a course of instruction in chemical geology for students in one of the American agricultural colleges. Since then it has been my privilege to deliver a series of lectures on the subject to six consecutive classes, first at the Massachusetts Agricultural College, and later here in the Imperial College of Agriculture. When I entered into an engagement with the Japanese Government, the continuation of such instruction was stipulated as a part of my duty.

These facts account for the compilation of the material here gathered. The reasons for now presenting the results to a larger audience are chiefly these: As the work has progressed, my students have repeatedly requested the preservation of the lectures in a more permanent and accessible form; while the magnitude of the field from which I have garnered, and the extremely scattered condition of the literature to which access was found necessary, have convinced me of the desirability of attempting to bring the materials together in a more readily accessible form,—an attempt not previously made, I believe. Hence the book must present some features peculiar to itself, and may, therefore, reasonably seek a favorable, or at least considerate, reception by those in whose interests it has been prepared.

The nature of the work is such that I have no claim for the presentation of new material; I have neither theories nor opinions of my own to force upon the public. Such personal views as are offered are only expressed where such a course was deemed essential to a clear presentation of the facts recorded. I have sought to give a lucid and concise statement of such facts as are recognized as *facts* in the light of the most recent and authoritative interpretation of the phenomena considered.

With this end in view, every available source of information has been utilized. A list of works of reference for those who desire further details has been placed in the Appendix. The nature of the work, its origin and scope, preclude the possibility of individual reference to each source of information; but wherever facts recorded seem to make such authority desirable, reference is made to the originals. Further than this, I desire to make acknowledgments to all whose labors have been found of assistance, and especially to express my indebtedness to the works of Credner, Dana, Johnson, Gohren, and Mayer.

My location so far from the place of publication has rendered personal supervision of proofs impossible; but I have every confidence in the ability and fidelity of the two friends to whom this task has been confided; and to them, Dr. Charles Wellington of the Massachusetts Agricultural College, and Mr. Henry G. K. Heath of New York City, as well as to the publishers, my thanks are due and heartily expressed.

I have hoped that the book might be especially acceptable to students and farmers, and with this hope the labor has been performed. Should my professional friends, however, find it a convenient and reliable compend of the subjects treated, my gratification will be proportionally increased.

H. E. STOCKBRIDGE.

SAPPORO, JAPAN, March, 1888.

PREFACE TO THE SECOND EDITION.

MORE than a year has elapsed since the original edition of this work was exhausted. During this interval publishers and author have been frequently importuned for the issue of a new edition, but other duties and the delays incident upon the collecting of new material have prevented an earlier completion of the work.

The author would have preferred to somewhat change the scope of the present edition by rewriting and combining Parts I and II and making them more specifically introductory to the subject-matter of Part III, that the work might be still more distinctly devoted to SOILS. For the present, however, this plan was not feasible, though the hope of its accomplishment is not relinquished.

The changes introduced are chiefly the correcting of errors incident upon the conditions under which the publication was originally issued. A few changes of statement, necessitated by the progress of the past seven years, have been made.

A new Chapter on the USE OF THE SOIL has been added to Part III. In this chapter it is believed the latest developments of science as related to soils are recorded and the most recent applications of the principles involved are elaborated. Several additional tables have been included in the Appendix which it is believed will add materially to the value of the work.

These tables are, in their present arrangement, new, part of them are original; but the author desires to acknowledge special indebtedness to the compilations published in the

"Handbook of Experiment Station Work" issued by the United States Department of Agriculture. He is extremely glad that the accumulation of American data has enabled him to make this new portion of the work more distinctly American; it should be borne in mind, however, that the original edition was not written in America nor entirely for Americans.

In its present form it is not only hoped that the book will be accorded the favor granted the first edition, but that the changes and additions will increase the practical utility of the work and bring it into still more intimate and friendly relations to progressive farmers.

H. E. STOCKBRIDGE.

NEW YORK, February, 1895.

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ROCKS AND SOILS.

PART I.

INTRODUCTION.

THE solid earth on which we live and from which we draw sustenance consists of material existing in two essentially different physical conditions as *rock* and as *soil;* one being more usually the surface decked with verdure, teeming with animal and vegetable life, and supplying us with all the requisites of happy existence; the other forming the unyielding foundation on which the great superstructure rests, here and there protruding above the surface as cliffs of sea-shore, rocky ledges, or summits of hills and mountains.

There is a constant change of condition between these two forms, all soils having been produced by the disintegration of rock, and being capable of reconversion to the former condition again; and both forms are equally recognized as geologically forming mere variations in form of one material considered as rock, consolidation being regarded as a mere accident of circumstance.

GEOLOGY is pre-eminently the study of rocks, their formation, transformation, and present distribution.

These rocks most frequently repose in beds of more or less nearly parallel layers known as strata, the rocks thus situated having been deposited from material held suspended in water, and being known as *stratified rock.*

The position of strata, though originally horizontal, may now be any degree of variation from this condition through the contortions of nature to which the pliable strata have been subjected.

The thickness of an individual layer or stratum may vary from a few inches to thousands of feet; and the total thickness of all known strata would be not more than twenty miles.

Below these deposited rocks exist *unstratified crystalline rocks.* Surface rocks may, however, be unstratified, and exist as solid mountains of granite or other crystalline rock, wholly free from all traces of stratification.

Dislocations of strata have occurred to most rock deposits, whereby the original horizontal position has been changed, a fact of the greatest importance in facilitating geological research, inasmuch as by its means a far greater part of the entire series of rock strata is thus made accessible than would otherwise be possible.

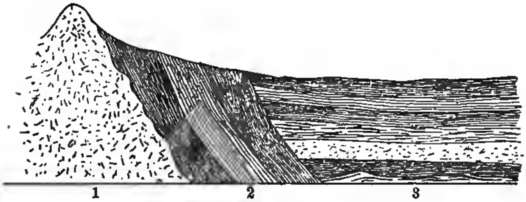

FIG. 1.—Dislocations of Strata.

Should these strata have become fractured and the layers displaced, the displacement is known as a *fault.* Should no actual fracture have occurred, a *fold* or *flexure* is the result; and if the upper surface or apex of the fold should be worn away a series of dips becomes exposed, the result being known as *denudation.*

It frequently happens that a series of strata become flexed, and that on top of the folds formed new strata of more recent origin may be deposited, producing the phenomenon of *unconformability of strata.*

The order of arrangement of strata is of the utmost importance, as it offers the only key with which to decipher these records of earth-history, since the strata were not laid down at one time, but form distinct leaves, each leaf recording the geological events of but a brief span of time. The chronological arrangement of these leaves is, therefore, the only means by which a logical presentation of all the facts of a given era or formation, and ultimately of all formations or eras, may be hoped for.

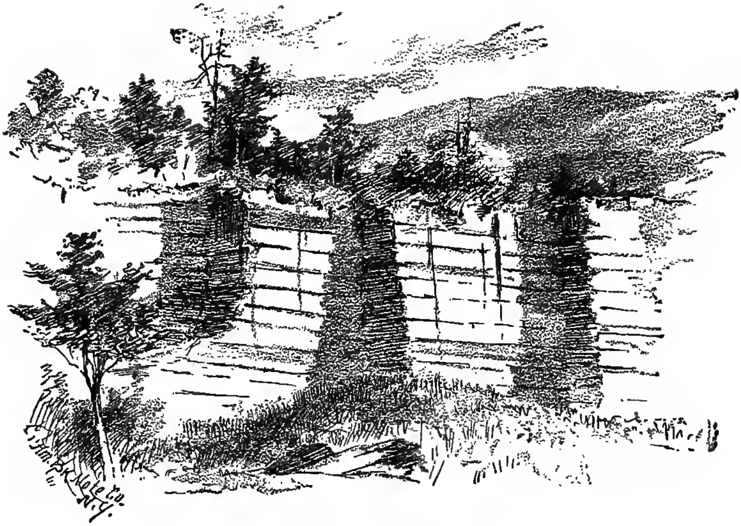

FIG. 2.—Strata and Joints. (*To face page* 2.)

Historical Geology is devoted to the study of these records of earth-history. *Chemical Geology* deals with the phenomena of rock-composition and rock-decomposition.

The original rock-crust of the Earth has been constantly subjected to disintegrating influences whose ultimate product is a geological formation, no longer solid rock, but more or less arable soil. The reactions accompanying this transformation of rock into soil form the proper sphere of *Agricultural Chemical Geology.*

With a province extending through all the phases of geologic time, this department of geological science is really a chemical history of the inanimate, inorganic world. A brief outline of this history as recorded in the rocks themselves is, therefore, essential to an understanding of the phenomena to be considered.

Authentic geological history begins only with the organized existence of the world, whose rock-formations are the records of its progress; but an earlier and prehistoric existence was necessitated—a period the essential conditions of which are none the less fact because incapable of ocular demonstration.

KANT'S HYPOTHESIS, the so-called "*nebular theory*," most satisfactorily and logically enunciates the occurrences of this world-formation epoch in cosmic history:—The entire planetary system, of which our Earth forms to-day so infinitesimal a part, had its origin in a misty, nebulous mass rotating from west to east, in a state of extraordinarily high temperature, about its own nucleus, our present sun. The outermost limit of this system reached far beyond the present orbit of the most distant planet. Through the radiation of heat into space resulted a cooling of this vapory mass; and the accompanying contraction and concentration were followed, of necessity, by an increased rapidity of rotation. So soon as the rapidity of this rotation reached and passed a certain limit, by the laws of centrifugal force there resulted the formation of equatorial rings, which, through unequal conditions and unequal cooling, became broken, each individual segment forming, in time, an independent nebulous sphere still rotating ever from west to east, the precursor of a distinct planet, in each of which, however, the phenomena of ring-formation might be repeated, as proved by the existence of planetary satellites and of the present rings of Saturn.

The period of transition from the original nebulous mist to the resulting world-body has been divided into five phases, as follows: *First*, the glowing, gaseous condition represented by planetary mist. *Second*, the glowing, liquid condition represented by the fixed stars with constant light. *Third*, the slag-formation, or the gradual appearance of a cool, non-luminous surface. The sun is now undergoing the transition from the second to the third phase; and this third phase is represented by innumerable fixed stars, red in color and not constant in light; stars which gradually but temporarily disappear from view are in the transition stage between the third and fourth periods. *Fourth*, the phase characterized by the violent bursting of the solidified crust by the heated, glowing mass within, and the sudden appearance or exudation of the same. This phase is at present witnessed in the sudden appearance of an illuminated star where before darkness alone was visible.

Fifth, the progressive thickening of the original crust, on which the watery vapors begin to condense, followed by the complete cooling of the heavenly body. Our Earth has passed successively through the first four stages of cosmic growth; and exists now in the fifth phase of world-evolution.

We have traced the earth's progression, from its original chaotic, nebulous, gaseous form, till the solid earth-crust, the original condition of the geologic world, the time and condition from which and with which geological history begins, appeared.

Geologically and chemically considered what was this condition? What were the characteristics of this era? This original solidification, these first rocks were how formed, and of what did they consist?

FUNDAMENTAL FORMATION. The chief geologic formations of to-day are sedimentary in origin. The sea from which the first sedimentary formation was precipitated must have possessed a bottom over which it expanded and on which it rested. Precipitation necessitates a foundation or fundamental material, and whether the occurrence be the result of mechanical suspension or of separation from chemical solution, it must have origin in pre-existing material, or in a previous rock-formation.

These axiomatic facts admit of but one conclusion, namely: that the entire geological series of sedimentary formations are secondary products of an older and non-sedimentary formation, the fundamental crust. The latter cannot be other than the original first product of the cooling of the molten mass of the earth-ball.

It is doubtful if this primitive rock still exists anywhere in the modern world sufficiently near the surface to be accessible; but possibly the gneiss of the archaic formation, the soft-structured but slightly-stratified lowest deposit of the archaic time, may be considered as the product of the surface cooling of the fluid mass. In which case data are at hand for the definite determination of the mineralogical and chemical composition of the first primeval solidification.

The mass of our terrestrial sphere, with its surrounding atmosphere included, has not materially changed from the beginning to the present; it is the same yesterday, to-day, and forever. Its material cannot have diminished; though, perhaps, through the gain of attracted meteoric matter, it may have infinitesimally increased.

New rock-formation occurs wholly by the transformation of previously existing rock forms by means of water and atmospheric influences, or through the cooling and solidification of molten rock masses. The material of every fresh sedimentary formation depends on the disturbing and rearrangement of older strata. The entire stratification from the most ancient complex to the precipitation occurring in the waters of to-day, has derived its material from the same chief source: the destruction, expansion, and re-formation of the original earth-crust. This latter must, therefore, have contained, and consisted of, the same materials from which the more recent, or sedimentary, deposits are formed.

The predominating constituent of all sedimentary rocks is silicic acid (SiO_2). The occurrence is sometimes in the form of quartz, and then as quartzite, sandstone or sand; sometimes in combination with bases forming silicates, the most common of all, or more so than all other mineral-forms combined.

Both silicates and bases are derived chiefly from the original crust; and the predominance of the silicates is due simply to the fact that the affinity of these bases is such that they could not exist in a molten condition in the presence of the acid without combining with the same. It therefore follows that the original rock-crust of the earth must have consisted chiefly of silicates of the more common inorganic or mineral bases. More definitely than this, the chemical composition of a formation itself beyond examination, and necessarily judged simply from its products, cannot be determined.

Geological like political history is divided into distinct ages, eras, or epochs, each characterized by distinctive features which render it independent and recognizable.

Four grand divisions of earth-history are recognized, the chronologic position and geological features of which must be borne in mind. These formation-groups, beginning with the first or most ancient, are as follows:

I. ARCHÆAN TIME.
II. PALEOZOIC TIME.
III. MESOZOIC TIME.
IV. CENOZOIC TIME.

CHAPTER I.

ARCHÆAN TIME.

THIS first division of geological history begins with an age preceding the existence of either animal or vegetable life on the Earth. The period was universal in extent, the rocks of this formation being the only ones of so extensive distribution; and yet, only the more recent deposits of Archæan origin still exist exposed to view, and none of these present indisputable evidences of organic existence.

The question of exactly when and where in the Earth's history the first forms of life made their appearance has long offered a field for assiduous investigation and discussion. The facts of modern biology seem to demonstrate that vegetable and even animal existence became possible when the temperature of the waters condensed on the Earth's cooled rock-crust reached 90° C., yet estimations made, indicate that the temperature of the Earth's surface at the close of the Archæan time was not above 38° C.

Though the remains of Archæan plants are themselves wanting, the best of presumptive proof is at hand to establish the fact of vegetable existence during this period. Graphite is a characteristic and widely distributed occurrence among the rock-formations of this time; and graphite is one of the three allotropic forms of elemental carbon found in nature, and is of undoubted organic origin.* Mineral coal of purely vegetable origin is known to have been transformed into graphite, and in New Brunswick the original coal-producing plants are to-day preserved in the form of graphite. The amount of this form of organic carbon existing in Archæan rocks is often 25% of the strata, and even traces of anthracite coal are claimed to have been discovered in certain Archæan layers of Norway.

These facts seem to demonstrate that the close of the Archæan time was rife with the very lowest forms of plant-life, cryptogams of the marine algæ and lichen types.

These vegetable forms doubtless preceded the arrival of the first animals, their existence being possible in waters of a higher temperature and earlier date. And the lowest animal organisms are so constituted as to feed on vegetable forms which must thus precede them. The first members of the animal kingdom called into existence were doubtless the lowest of Protozoans. It is even claimed that the remains of Rhizopods exist in the calcareous strata of Canada and Bohemia.† The close of the Archæan time probably found a world whose warm brackish waters were the habitat of hordes of Protozoan life finding sustenance in the abundance of algæ, making it their home.

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* There is no impossibility in an inorganic origin for graphite as well as for the diamond; but no evidence of such an origin is deducible.

† This conclusion is, however, based on analogy and not on the evidence of actual organic remains.

ARCHÆAN ROCKS are classed in two general groups, known as the—

I. PRIMARY GNEISS FORMATION.
II. CRYSTALLINIC SLATE FORMATION.

I. THE PRIMARY GNEISS FORMATION, or *Laurentian Period* of America, consists almost exclusively of metamorphic or crystallinic rocks, the oldest sedimentary deposits to which geologists have access. They existed originally in the fundamental crust, from which they were dissolved by the action of waters impregnated with silicic acid, and, aided by heat, from the solution or mechanical suspension thus formed deposits of gravel, sand and mud were made, from which the crystalline rocks were evolved by time's transmutation. The rocks thus formed embrace granite, mica-schist, gneiss, crystallinic limestone, quartzite, conglomerate, feldspar and apatite, besides many rocks of the hornblende series, as syenite and hornblende-gneiss.

THE DISTRIBUTION of these rocks is universal; but since only a very small portion of the Archæan world existed in an unsubmerged condition, the accessible Laurentian deposits are confined to a comparatively limited area. In America, the formation is limited practically to the Atlantic slope of the British possessions, though isolated localities of Laurentian rocks occur in, perhaps, all the New England States, in New York in the Adirondack region, along the Appalachian and Rocky mountain systems, and on the borders of Lake Superior. In Europe, the distribution is chiefly in Scandinavia, Scotland, Bavaria and Bohemia. In Asia, the formation is confined to the continent, and there chiefly north of the Stanovoi Mountains.

II. CRYSTALLINIC SLATE FORMATION, or *Huronian Period* of America. The rocks of this formation are deposited directly on those of the earlier Archæan period. Like their immediate predecessors, they are metamorphic in character, and of sedimentary origin.

The formation is wholly devoid of organic remains; and the definite boundaries of its occurrence are not accurately determined.

THE ROCKS of this period are chiefly of a slaty character, in conjunction with which occur conglomerate, quartzite, amphibole, jasper, limestone and dioryte, the last-named usually existing in the form of dikes sometimes supposed to be eruptive injections.

THE DISTRIBUTION of Huronian rocks is less extensive than that of the preceding Archæan form. They were first studied on the northern borders of Lake Huron; but are now recognized on the shores of Lake Superior, in Brazil, Venezuela, northern Africa, Spain, the Swiss Alps, Tyrol, Bohemia, Scandinavia and Scotland.*

AGRICULTURAL AND ECONOMICAL Characteristics of the Archæan Formation. Since soils invariably contain the ingredients of the rocks from which they were formed, their composition and characteristics partake of the general nature of the rocks underlying them.

As a natural sequence the soils of Archæan regions are predominatingly clays, frequently cold and unworkable, or soils thin and poor in character. The most interesting agricultural feature of the formation is the abundant occurrence in certain localities of apatite, native phosphate of lime which has recently been largely utilized for the manufacture of superphosphate of lime, the chief source of nutritive phosphoric acid.

Hornblende, so prevalent a rock-form of this era, invariably contains considerable quantities of iron ore; and this element is an almost universal occurrence through the period, and imparts the characteristic reddish color to many Archæan rocks. It most frequently exists in the form of magnetite (Fe_3O_4), hematite (Fe_2O_3), or in the form of titanic iron ore and franklinite, iron ores containing respectively titanium and zinc.

The iron deposits of the Archæan formation are thicker and more abundant than in any succeeding age. To them belong the Iron Mountain of Missouri, the iron ores of New

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* The statement by Credner (*Elemente der Geologie*, Leipsig, 1883, p. 405) that Huronian rocks exist in China and Japan is at variance with facts established by the most recent surveys.

York and Michigan, and, above all, the famous Swedish iron whose quality is unequalled.

Veins of lead, arsenic, cobalt, bismuth, copper, and silver ores of Archæan origin also exist, the veins of the noble metal occurring in Bohemia, Silesia, Norway and possibly Canada; sulphides being the prevailing form in which these metals exist. Aside from the minerals of economical significance, others of Archæan origin are noteworthy, including calc-spar, heavy-spar, fluor-spar, quartz, orthoclase, oligoclase, mica, tourmaline, garnet and topaz.

The crystallization of these minerals proves conclusively that the Archæan time was subject to the prevalence of eruptive phenomena, by the intense heat of which the transformation and subsequent condensation and crystallization were rendered possible.

CHAPTER II.

PALEOZOIC TIME.

THE geological period and formation-group directly following the Archæan is designated The Paleozoic Time, and is subdivided into four distinct formations or ages:

I. THE SILURIAN FORMATION
II. THE DEVONIAN FORMATION.
III. THE CARBONIFEROUS FORMATION.
IV. THE PERMIAN FORMATION.

This time begins practically with the rocks containing the first undisputed remains of organic life, which are chiefly wacke, slate, sandstone, limestone and conglomerate deposits.

I. SILURIAN FORMATION, or
Age of Inve·telrates.

This formation received its name from Murchison, who first thoroughly studied the rocks of the age in that portion of

Britain formerly inhabited by the Silures. The oldest known fossils are of Silurian origin, and the number of varieties represented in these rocks, and the number of individuals present, show gradual increase through the age, at the end of which species closely allied to those of to-day, or even still existing, are not unknown.

The formations of this age are of a very varied character, giving rise to a widely diversified arrangement and classification in the regions in which Silurian rocks abound. Two general subdivisions of the formation are, however, universal: *The Lower Silurian* and *The Upper Silurian.* In the lower strata of the former, usually designated as the *Primordial,* the earliest fossil remains exist, confined wholly to the lowest vegetable and animal marine types; while the upper Silurian furnishes the first land plant of geological history, a ground-pine (Lycopodium), occurring in the limestone of Cape Gaspé.

SILURIAN ROCKS, both upper and lower, are mainly sandstones, conglomerates, shales and limestones, the first-named being in the upper strata often of an argillaceous character. The change here occurring in the character of the rock-formation, that is, in the composition and structure, marks an era in the petrographic nature of the earth's surface, the varieties of rock now appearing in predominating force continuing to be the most frequent formations during all the succeeding ages of geological history or earth-progression, and are the most common deposits of the present era. The sand-beds, fundamental formation of the sandstone, the mud-beds, original form of shales and argillaceous sandstones, and limestone production have been constantly in progress, and are still to-day continuing the process of rock evolution or formation. And wherever during the world's history sandstone production has occurred, shale or limestone has been brought into existence near at hand; for the process of rock-pulverization producing the former, also results inevitably in the formation of the latter, sand-deposits and mud-deposits being but different effects produced by one and the same cause.

Among the petrographic characteristics of this era are also the appearance in certain localities of quartzyte, silicic slate, marl, and the important carbonate of lime and of magnesia known as dolomite, which not infrequently forms entire mountains, or even mountain-chains.

THE DISTRIBUTION OF SILURIAN ROCKS is of wide extent, though the area covered by them is less than that occupied by succeeding formations.

In America the chief deposits are found in Canada, in the angle between the Laurentian and Huronian regions, extending with a south-west trend along the Appalachian region into northern Alabama, and west from Minnesota and Wisconsin, there being important regions also in the central Mississippi basin, in the Rocky Mountains and in arctic North America.

In Europe, besides the English deposits, Scandinavia, Russia, the Hartz Mountains, Bohemia and west through Spain and Portugal, important Silurian regions exist; the Bohemian being particularly rich in both flora and fauna remains.

AGRICULTURAL AND ECONOMICAL FEATURES. Agriculturally considered, the regions of Silurian origin are of an inferior nature. The soils are predominatingly clay, and usually of an unproductive character; while the sandstone regions are not infrequently occupied by barren heaths. In certain Silurian localities, however, usually where the sandstones and calcareous deposits form conjunction, fertile lands occur whose productiveness in the presence of marl may be of a high order.

The peculiarity of the Silurian age, of by far the greatest importance, is the prevalence among its rocks of rich mineral deposits of iron, copper, zinc, lead, and less important ores. They exist most frequently in the form of impregnations and isolated enclosures in the surrounding rock-mass, the cavities having doubtless been filled from above.

The minerals usually occur in the limestone strata, and exist as sulphides. The American Silurian lead deposits existing in the upper Mississippi Valley being the chief deposits of the kind in the world.

One other peculiarity of the Silurian age is the isolated occurrence of anthracite coal-strata inserted between the layers of rock;* a noteworthy incident from the fact that coal un-

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* In "Etage H" of the Bohemian Silurian.

doubtedly of organic origin consists of very nearly pure carbon, and yet exists here as an occurrence of an era at first nearly devoid of all life either animal or vegetable, and the organic remains of which are almost invariably of animal salt-water origin. Of a similar nature are the deposits of a poor quality of mineral oil existing in many Silurian regions.

From the Silurian age also date a large proportion of the productive rock-salt deposits from which many of the most remarkable salt and mineral springs known take origin.

THE CLOSE OF THE SILURIAN AGE found a world mostly submerged beneath the waters of a shallow sea above which only here and there solid land had yet appeared; and on which only a few of the lowest forms of vegetable growth found a habitat; and the first land animals, scorpions, recently obtained from the Upper Silurian of Sweden, Scotland and New York.*

The waters, however, teemed with life of many forms; trilobites, graptolites, forameniferæ, corals, crinoids, and brachiopods, swam upon its surface, roamed through its depths, or reared their curious structures above the waves.

Only at the very end of the Upper Silurian Age did the fishes make their appearance, being the first vertebrates to cross the world's stage, and thus forming a landmark, bounding an era in geological progression.

During all the time embraced in the Silurian Age, our entire planet, from pole to equator, possessed a regular and equable temperature, a warm, humid, frostless climate unaffected by change of season—facts abundantly demonstrated by the uniform distribution of remains of certain species of extinct invertebrates, regardless of modern climatic conditions, proving the universal existence, during Silurian times, of like conditions of climate and atmosphere.

II. THE DEVONIAN FORMATION.

This forms the second epoch of Paleozoic Time, and is characterized as the *Age of Fishes.*

During this era, the invertebrates of the brackish sea which

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* Geike, Text-book of Geology (London, 1885), p. 665; *American Journal of Science*, March, 1886, p. 228.

covered so great a portion of the world, a fauna represented by the goniatites, snails and nautilus of to-day, though far from disappearing, lost the predominating character they possessed during the Silurian Age, and gave place to vertebrates, members of the order *Pisces*, thus marking a long stride in the organic progression traceable through geological history. Here, in the Devonian formation, occur the first ferns and coniferæ in numerous force, so that the flora of the age is as much characterized by vascular plants as is the fauna by the predominance of fishes.

This age of fishes is remarkable for the abundance of organic life which distinguished it. Its waters were the habitat of myriads of invertebrate animals whose fossil remains form the chief mass, or components, of many rocks traceable to a Devonian origin. The name now universally adopted is derived from Devonshire, England, in which locality the formation was first systematically studied.

DEVONIAN ROCKS. Petrographically considered, the rocks of the Devonian age possess much the same general characteristics manifested by their immediate predecessors of the Silurian age. The first rocks of Devonian origin consisted of the corniferous limestone.* Nevertheless, the predominating rock of the age was sandstone, which in frequency of occurrence so exceeds all other formations that the era is still often designated in England as the *Old Red Sandstone age.*

Other rocks of this formation, occurring more or less abundantly, are conglomerate, shale, slate and schist, often bituminous in character, yielding even 20 % of combustible material. The limestone of the Devonian period existed invariably in the form of the carbonate, and was not infrequently of organic origin, large areas of rock-formations of this age consisting chiefly of the petrified remains of the lower organisms of the Devonian era. The most interesting of these deposits being where the formation consists of the carbonate of lime in the form of vast fossilized coral-reefs. These calcium carbonates

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* So named from the presence of hornstone, a variety of flint, the Latin for "horn" being *cornu*.

are not infrequently accompanied by carbonates of iron, so that many profitable iron mines are located in Devonian regions, where the ore occurs in combination with carbonates, the result of organic petrifaction.

The formation is generally characterized as consisting of three distinct deposits, the lower, middle and upper Devonian; and local variations in each of these subdivisions abound, particularly in America, where local designations are very numerous, derived chiefly from the series as named in the State of New York.

THE DISTRIBUTION OF THE DEVONIAN ROCKS is wide-spread, there being no continent without them. The American region is confined chiefly to New York, Pennsylvania, Michigan, Ohio, Indiana, West Virginia, Kentucky, Tennessee, Georgia and Alabama; and the portion of Canada lying between Lake Huron and Lake Erie, also in Nova Scotia and New Brunswick.

In Great Britain the chief deposits are found in Cornwall, Devonshire, Herefordshire and Ayrshire.

On the continent of Europe the most noteworthy localities are in Westphalia, the Prussian Rhine Provinces where the Coblenz strata are especially well defined, in the Hartz Mountains, Poland, Russia and Scandinavia, in all of which regions the rocks are rich in petrifactions of both flora and fauna.

In Asia, Devonian rocks are distributed over a considerable part of the northern and eastern portion of the continent. In Japan, the oldest discovered rocks are Devonian in character; the first land of the Archipelago was evidently elevated above the sea during the Devonian age, forming many small islands connected into larger land-areas by continued elevation during subsequent ages.

AGRICULTURALLY AND ECONOMICALLY considered, the Devonian age presents more interesting features than are displayed by any preceding geological formation. Though the Devonian rocks occasionally become converted into soils too sandy to be productive, they more frequently form the most fertile soils of the regions in which they exist; many localities of Devonian origin being famous for their productiveness and agricultural value, as demonstrated in the Rhine Valley, in

Herefordshire, in the Genesee Valley with its proverbial wheatlands; the oak-openings of Ohio and the heavy pine-lands of Michigan being largely confined to soils of Devonian origin.

The industrial resources of this age are also of unparalleled importance. The shales are of unequalled quality for flagstones, while the limestones yield, in certain localities, large quantities of mineral oil, and not infrequently natural gas, which is utilized for illuminating, domestic and smelting purposes.

The great petroleum-producing regions of the world all belong to the Devonian formation. That this mineral oil is itself of Devonian origin is by no means proved. Indeed, it seems more probable that the oil, being organic in character, and a product of organic existence, chiefly vegetable, originated in an era more prolific in vegetation, namely, in the succeeding carboniferous age; and that it simply found receptacle, and became reservoired in the caves and caverns of the older and lower sandstone formation of the Devonian age. This supposition seems further justified by the fact that mineral coal, which is also organic in nature, occurs but very seldom during this epoch, while bituminous coal, more nearly yet allied to the oil in character, composition, and conditions of formation, never occurs as a product of the Devonian age.

The iron ore, a chief economical product of this age, is not infrequently the magnetic iron, but it most usually occurs as a carbonate in conjunction with limestone, and, like limestone, abounds in animal petrifactions. The Devonian red-iron-ore (Fe_2O_3) is very frequently of a phosphoritic nature, and the rock in which the ore occurs is not seldom impregnated with deposits of phosphorite, utilized as a fertilizing material, and is a not unimportant addition to the sources of agricultural phosphoric acid.

Other mineral deposits of an eruptive nature, but existing as products of this age, are the deposits of zinc, lead, copper, sulphur and arsenic which usually occur as sulphides, permeating the Devonian limestone strata.

Another metal of exceeding value is confined exclusively to rocks of this era. The great tin-yielding mines of Cornwall belong to this age, and have supplied the world with most of this indispensable metal ever since the adventurous Phœnicians, unaided by chart or compass, sought the shores of Britain for supplies of this essential ingredient of the implements of the Bronze Age in human history.*

The world which, during the Silurian age, had consisted of little but a surface of brackish water, with here and there solid rock-formations breaking the surface, began, during the Devonian age, to assume more the character of dry land, which now appeared with more definite form and complex contour, yet was, in all probability, wholly unoccupied by animals.

Toward the close of the age, the land flora became abundant, and reached a stage of development characterized by the existence of palms and gigantic ferns, with which indications of a tropical temperature the Devonian soil, though devoid of all animal life, was decked. The sea, above which this land appeared, passed, as the age advanced toward completion, through a gradual change in the character of its inhabitants. The few straggling fishes appearing in the uppermost Silurian rocks increased to become the distinguishing feature of the age; and, though innumerable brachiopods, cephalopods, crinoids and corals existed throughout the formation, vertebrates, that is, fish of the ganoid type, are the distinctive fauna of the Devonian formation.

III. THE CARBONIFEROUS AGE, or

Period of Coal Formation.

This formation embraces an era directly succeeding the Devonian, and forms chronologically the longest period of Paleozoic time, and is, perhaps, the most interesting and important era of Paleozoic history.

Both interest and importance centre in the peculiar and characteristic product of the Carboniferous age, an epoch the remains of which shed so much light on the geologic history

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* Rodwell, "Birth of Chemistry," p. 39.

of the world, and to-day play so great a *rôle* in the political and economical history of our time.

The formation embraces a time remarkable for the prevalence of gigantic ferns, palms, lepidodendrous and sigillarian vegetation, in profuseness and luxuriance never again occurring. Accompanying this flora was a fauna characterized by the appearance of the first land-animals, amphibians, the only air-breathing creatures existing in the midst of myriads of coral and crinoid life.* The Carboniferous age becomes, therefore, the era of vascular cryptogams as well as the age of amphibians; and marks the advent of air-breathing animals. While the vast deposits of mineral coal distinguishing the age owe their origin to the conditions of which they form a graphic record.

The Carboniferous age proper was preceded by a marine period, termed the SUB-CARBONIFEROUS AGE, during which much of the region now occupied by the continents of Europe and America was submerged by a shallow, temperate, brackish sea, from which limestone strata and occasional sand-beds were deposited. It was also during this time that the fragmental rocks forming the shales, conglomerates and sandstones of the Appalachian region, a deposit several times deeper than the limestone, were laid down.

The Sub-carboniferous limestones are composed principally of organic remains, chief among them being the formation consisting so largely of crinoids, from which fact the term *crinoidal limestone* has been applied to the entire Sub-carboniferous limestone deposit, which like all calcareous rocks of organic origin exists as a carbonate.

THE DISTRIBUTION OF SUB-CARBONIFEROUS ROCKS seems to have been very general over all continents possessing deposits of the succeeding Carboniferous formation; and the era was one universally characterized chiefly as a time of limestone deposit, which product of the age forms the famous "moun-

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* Unless the Silurian scorpions prove to have been air-breathers, a question as yet unsettled, as there seems to exist a difference of opinion as to the habits of the few individuals recovered.

FIG. 3.—Landscape and Flora of the Carboniferous Age.

(*To face page* 18.)

tain-limestone" regions of Kentucky, Tennessee, and other American localities. The States of Michigan, Illinois, Ohio, Iowa, Missouri, Arkansas, Mississippi, Alabama, Virginia and Pennsylvania, all possess extensive areas of this formation; while in Europe, England, Wales, Ireland, Belgium and Russia furnish the chief localities of this pre-coal-formation era.

The true CARBONIFEROUS AGE, or period of coal-formation, directly succeeded the submerged or the Sub-carboniferous; and its distinctive product exists in a series of coal-beds, or coal-measures.

THE ROCKS OF THE AGE are chiefly shales, sandstones, limestones, and conglomerates. The limestone stratum is usually an intervening rock occurring between productive coal-measures; while the conglomerate most frequently exists at the base of a coal-vein, its foundation, as it were; and is known technically as the *millstone-grit.*

These coal-measures are distributed with considerable regularity and evenness over nearly the entire geographical world; and prove the age of which they were the product to have been of universal extent. They have filled the office of purveyor of fuel and light to the world of succeeding ages, from frozen Spitzbergen on the north to New Zealand on the south; and, encircling the globe from meridian to meridian, are sufficient to resist man's depletion for long ages of industrial activity still to come.

Some idea of the extent of the world's coal-supply may be gathered from the fact that the explored area of coal land of this period within the United States alone is 190,000 square miles; and on the North American continent 208,000 square miles.

The thickness of the Carboniferous rocks, that is, the entire depth of this formation is exceedingly variable, being in certain localities scarcely more than 100 feet, while in Nova Scotia a formation more than 14,000 feet thick has been traced. The maximum depth of the formation in Pennsylvania is about 9000 feet, though the coal-measure rocks themselves are not defined below 4000 feet from the uppermost stratum.

The beginning of the coal-formation era was marked by a great change in the petrographical character of the world. The submarine formations, the sandstones, shales and limestones of the Sub-carboniferous age, became hidden by deposits of sand or of gravel, which, in time, hardened into the gritty rocks forming the *millstone-grit*, the underlying bed on which the coal-measures rest.

Though rocks of similar character occur later through the coal strata, they are of more recent origin, and of less extensive occurrence, than those which mark the advent of the coal-formation era.

For this reason the rocks of the Carboniferous age may be classed in two distinct divisions, each characteristic of an epoch in the history of the formation, the *Millstone-grit* and the *Coal-measure*.

These two terms signify simply the two divisions of one and the same geological age, the characteristic production of which, the mineral coal, occurs as a phenomenon of only one era or formation of the age. The millstone-grit and the coal-measure are, as it were, two parallel formations, both belonging to one age; chronologically identical, but petrographically unlike. In other words, the rocks of the Carboniferous age containing mineral coal are of the coal-measure division, while the rocks of the same era which are destitute of productive coal-beds are assigned to the division of millstone-grit.

Aside from the rocks and coal of the Carboniferous age, one other occurrence is of importance: the frequent presence of iron ore in combination with the coal-deposits. Indeed, the Carboniferous rocks are very frequently impregnated with iron, always in the form of a carbonate, though often in quantities too small for economical working.

Another accompaniment of the productive coal-layers is the bed of clay on which they frequently repose.* The iron is not infrequently mixed with silica, one of the ingredients of the clay, thus forming what is known as clay-iron-stone; though the

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* This prevalence of coal, iron, limestone, clay and sand as products of one formation is of inestimable industrial importance: the iron to be smelted, limestone for its reduction, the coal for fuel, the sand and clay for building the furnace. The iron region of Pennsylvania is thus favorably situated.

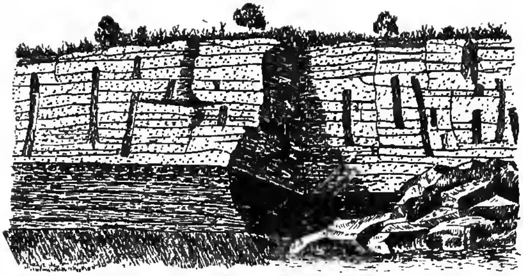

Fig. 4.—Carbonized Tree-trunks, imbedded in coal. (After Credner.)

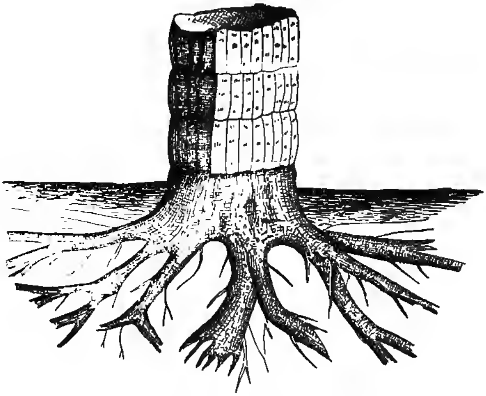

Fig. 5.—Carboniferous Tree-trunk from English coal-beds. (After Mantell.)

(*To face page* 21.)

pure carbonate is the mineral siderite, and in this mineral exist the most perfect remains of the organic life of the Carboniferous age.

The rock-formation of this era is exceedingly irregular in character and composition; each and every rock ever forming a part of the petrographical arrangement of the era; at times appearing in combination with every other rock of the age, and under every conceivable modification to be wrought with the given number of factors; the presence of rock-salt, gypsum and dolomite not infrequently lending complexity to the formation.

MINERAL DEPOSITS other than the coal and iron are characteristic of the age. Gypsum, rock-salt, and dolomite, though existing and increasing the rock-forms of the formation, are, in importance and abundance, surpassed by several minerals of distinctly eruptive origin; diabase and quartz porphyry being most frequently the imbedding rock, usually occupying a position between the strata of conglomerate, slate and sandstone. Scotland is the chief locality where this eruptive action of the Carboniferous age manifested itself. But the mineral wealth stored in the Carboniferous rocks through this action is found principally in the lead, zinc and copper ores of Northumberland, Derbyshire, Aix-la-Chapelle, and several localities in the neighborhood of the Great Lakes in the United States.

A different product of this same action is the asphalt-deposit of the Albert Mine in New Brunswick.

ORIGIN OF MINERAL COAL, and the Process of Formation. The fundamental facts of the history of coal-formation are, that the material consists of carbon, hydrogen, and oxygen, in average proportions of (for anthracite) C 95%, H 2.5%, and O 2.5%; that these ingredients are of undoubted organic origin; and that the organisms whence they were derived were unquestionably vegetable in character.

Were evidence other than the chemical composition of the product required, it is found imbedded in the coal itself, where whole tree-trunks, indeed forests of trees, in all the stages of transition, from perfectly preserved wood to wholly transformed coal, with delicate leaves and tiny rootlets intact, attest the truth of the hypothesis, and bear witness to historical and scientific facts recorded by Nature herself ages before the first modern mountain was raised above the sea, or the sea itself had assumed definite form.

A single glance at the era of which the coal-fields were the product must suffice for the present review of the Carboniferous age.

The separation of land from water had at the beginning of the epoch become more distinct; and the elevation of land above the sea which resulted in the formation of the continents of to-day went steadily forward during the continuation of the era. The first land-inhabiting and air-breathing animals made their appearance on the earth: scorpions, centipedes, thousand-legged worms and lizard-like amphibians; animals of so low an organism that the heavy carbonic-acid-gas-impregnated atmosphere of the time sufficed for the aerification of their sluggish blood. And on the earth thus inhabited forests of gigantic, palm-like, morass-thriving trees flourished in a climate poisonous, warm, and laden with moisture.

The rank vegetation of such surroundings, composed largely of the carbon so abundant in the atmosphere in which it grew, completed its growth, and fell into the morass from which it sprang.

Here under the partial exclusion of air, by the water present, a slow and imperfect decomposition set in, and a natural charcoal was formed.

Upheavals of nature followed; deluge of water was succeeded by avalanche of sand and mud; ages succeeded; heat and pressure did their work; brown-coal became bitumen, the latter became anthracite; mud and sand were transformed into rock.

Convulsion succeeded convulsion; inundation followed inundation; ages came and went; the process was repeated and continued till the vast deposits of the Carboniferous age were complete, and the age itself gave way before Time's geologic progression, and its records became a part of geologic history.

AGRICULTURALLY CONSIDERED, the Carboniferous age was productive of results, though incomparably less significant than the great industrial resources called into existence by it, still of an importance equalling, if not exceeding, that attained by any preceding geological era.

Hydrous calcium sulphate ($CaSO_4 + 2H_2O$) or gypsum, so universally valued as a fertilizer under the name of "land-plaster," and which when heated till its moisture is expelled becomes "plaster of Paris," so important a factor in many arts, is most frequently found as a product of the Carboniferous age. The soils of coal-formation regions are usually poor when the sandstones or shales form the surface-rocks; but where the "mountain limestone" of the Sub-carboniferous age is at the surface, soils of remarkable properties are the result,—their grazing qualities being unequalled. The renowned "blue-grass region" of Kentucky supplies the best possible evidence in support of the fact.

CLOSE OF THE CARBONIFEROUS AGE. The era of coal-formation was one of great length, and of unceasing change. Intervals of submergence followed the eras of luxuriant coal-forming vegetable growth. Great forests and jungles of acrogens and gymnosperms covered the continents; but angiosperms had not yet appeared. Water-insects and marsh-loving articulates teemed on land, vegetation and water; but higher insects were as rare as the flowering plants on which they live. Ganoids and sharks, but no osseous fishes, swam in the waters. A few straggling reptiles foreshadowed the approach of higher vertebrate life soon to appear; but the first representatives of bird and mammalian life had not yet entered the geological arena.

The continents were, for the most part, level expanses but slightly raised above the boundless waters. Modern contours were mostly lacking, and the few mountains simply traced the areas of Archæan and Silurian existence. The elevation of surface went gradually on; new conditions appeared, and the Carboniferous age, with all its phenomena, was at an end; and the arrival of new conditions ushered in a new era of geologic progression.

IV. THE PERMIAN FORMATION.*

This was the final era of Paleozoic time, and marks a transition epoch, a time and formation lying between the coal-building age and the era of higher development belonging to the *Mesozoic time* which followed.

PERMIAN ROCKS. Petrographically considered, the rocks of this formation are, in the eastern hemisphere, much more distinct from the coal-measures directly preceding them than in the western hemisphere. In Europe, two independent divisions of the formation are recognized, namely, the *Rothliegendes* and the *Zechsteinformation;* and from this double or parallel formation the term *Dyas* is given to the German Permian. On the American continent, however, no distinction of epochs is recognizable.

The lower and older strata consist mainly of sandstone, soft and crumbly and devoid of mineral deposits; the *New Red Sandstone* of England, and the *Rothliegendes* of Germany. These strata are followed by marlites and magnesian limestone, the *Zechsteinformation*, interspersed with gypsum, copper-bearing shales and the fetid organic-impregnated limestone known as *Stinkstein*, or bituminous limestone. Aside from the regular rock-formations of the Permian age occur eruptive stone, mostly granitic or porphyritic in character, and occasionally accompanied by eruptions of sand and ashes of indisputable volcanic origin.

THE DISTRIBUTION OF PERMIAN ROCKS is in America confined to a comparatively limited area, embraced within the States of Kansas, Nebraska and New Mexico.

In England the formation is of considerable extent, particularly in the northern portion of the country. It embraces two distinct formations, the New Red Sandstone and the magnesian limestone.

In Scandinavia and Russia the formation is also met

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* Dana makes the Permian a subdivision or "Period" of the Carboniferous age. But the independent formation is more frequently recognized.

with * ; but Germany is by far the region of chief Permian interest, the most typical presentation being in the Hartz Mountains, and in Thuringia, from the latter place stretching southward with outcroppings in Bohemia and the Alps.

THE VALLEY- AND BASIN - FORMING phenomena of the Permian age are especially worthy of note, and are beginning to attract no little attention. The limestone of this era is not infrequently gypsum, and is invariably formed from anhydrite by the absorption of water. This calcium sulphate, so readily soluble in water, becomes worn away, and caverns in the Permian formation are the result. These cavities frequently become filled with salt-water infiltrations, and, in time, the space originally occupied by the deposits of sulphate of lime become filled with solid masses of sodium chloride.

This substitute product, equally soluble in water, also becomes in turn dissolved, and a second hollow exists in the rock-mass, frequently roofed by the soft sandstone of the New Red Sandstone era. This frail covering not infrequently breaks through, and an abyss yawns where solid ground existed but a moment before.

These phenomena are advanced as explaining the frequent earth-cavings occurring in the vicinity of Mansfeld in Prussia, and other localities bordering the Hartz region in north Germany.

The territory thus dropping below the surrounding surface is not seldom of considerable extent; and becomes filled with drainage-water, surrounded by flat shores and moors or marshes, and even fertile meadows. The surrounding walls are usually not complete, and a natural outlet for the accumulating waters is thus formed; and through the bottom-land of the basin or valley into which the cavity becomes transformed a small stream flows, the *result* of the valley formation, and not its *cause* as previously supposed; the erosive action of so insignificant a stream not being equal to the task of such extensive valley-formation as exists, and which is rationally explained only by these known phenomena of Permian origin.

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* The Russian Permian occupies the extensive plain between the Ural Mountains and the Volga, in the ancient kingdom of Perm, from which fact the present name was given the formation by Murchison.

AGRICULTURAL AND ECONOMICAL RESOURCES. Rock-salt is not the only saline deposit dating from Permian times, as salts of the alkalies and alkaline earths are of frequent occurrence among the rock-stratifications of this era.

The famous salt region of Stassfurt, remarkable as the only known productive deposits of salts of potassium, and to-day the source of most of the potassium compounds of commerce, arts and agriculture, and producing not only sodium chloride and two salts of potassium, but salts of magnesium as well, besides supplying more bromine than all other sources of this element combined, is an important feature of the Permian formation.

Several metals are also of frequent occurrence in workable quantities in the Permian formation; among them being some which seldom occur as products of other ages. Notable among these being cobalt, nickel and baryta; besides which the era was productive of rich deposits of several forms of copper, of lead and of rock crystal.

The soils of magnesian limestone origin are most generally of indifferent agricultural value, shallow and unproductive. On the other hand, Permian soils formed from the New Red Sandstone division are invariably of the first quality, fertile, easily workable and productive.

THE END OF THE PERMIAN FORMATION marks the close of a period during which the Earth passed through a remarkable stage of development.

Beginning with a submerged epoch, it was characterized by the gradual evolution of continents till the solid land had assumed a form not unlike that which it bears to-day. The progress of organic life kept pace with the advance in continental growth, till endogens were supplanted by exogens, and the first lizard-like inhabitants of the solid land began to be displaced by higher vertebrate animals; the poisonous carbonic-acid-laden atmosphere of the Carboniferous age was succeeded by an atmosphere capable of blood-oxidation, and the *Reptilian Age* or *Mesozoic Time;* with the advent of which the world entered upon a new era, an epoch of more highly organized existence.

CHAPTER III.

MESOZOIC TIME, or

Age of Reptiles.

THIS third grand division of geologic time is divided into three distinct periods:

I. THE TRIAS FORMATION.
II. THE JURA FORMATION.
III. THE CRETACEOUS FORMATION.

The first of these is, in Europe, further subdivided into the *Buntersandstein*, *Muschelkalk* and *Keuper;* but, on the American continent, there is hardly an imaginary distinction between the Trias and the Jura formations.

The MESOZOIC TIME may be properly termed the mediæval time of the Earth's history, an epoch characterized by the culmination and decline of two great types in the animal world, the *Molluscan* and the *Reptilian;* an age noticeable for the existence of a flora and fauna more nearly allied to the organic life of to-day, and distinguished by the appearance of the first mammals, the first birds, the first modern or osseous fishes, the first true palms, and a vegetation consisting chiefly of dicotyledonous plants.

I. THE TRIASSIC FORMATION.

This formation, directly succeeding the Permian, derives its name from its triple division in Germany. It marks a most important epoch in organic progress as the period in which the remains of the first mammalian existence occur; and its rock-formations are among the richest of fossil-yielding deposits.

ROCKS. In the rock-formation of this period there is great similarity between the American and the European, inasmuch as both continents present a red sandstone as the chief petrographic product of the era; but with the local complications of the period pertaining to the continent of Europe we cannot deal.

The New Red Sandstone formation of America demands more careful consideration; and next to this, the most important and frequent rock occurrence of the epoch is an impure limestone. There are three separate Triassic regions defined on the North American continent: the Atlantic-border region, between the Appalachian range and the coast; the Western Interior region, including most of the Rocky Mountains; and the Pacific-border region, extending westward to the Pacific.

To this era belong the sandstones of the Connecticut Valley, the deposits in New Jersey and south through the Carolinas, and the Palisades of the Hudson.

The sandstone of the period passes through all gradations, from the fine-grained "freestone," undoubtedly a deposit from calm, shallow water, to the coarse "pudding-stone" conglomerate, the latter often occurring far-removed from its native bed, showing evidence of long transportation, and the exertion of mighty force for its accomplishment. Both sandstone and conglomerate are usually of granitic or gneiss origin; and frequently occur in very irregular stratification, proving the presence of strong water currents during the time of deposition.

A peculiar feature of the Triassic rock-formation consists in the singular ripple or rain-drop markings on the upper surface of the strata, due, without doubt, to the extreme shallowness of the water from which the precipitation took place, and the consequent partial surface-exposure of the rock above the water-level.

Another peculiar occurrence in the Triassic formation is the so-called "bone-bed" found in England and in Germany, as well as in America: a limestone formation characterized by the prevalence of innumerable fossilized bones of lower animals, especially of members of the orders *reptilia* and *amphibia*.

ERUPTIVE PHENOMENA. The entire Triassic region of America is characterized by the remarkable outcroppings of igneous rocks.

These ridges or dikes consist of trap of unmistakable volcanic or eruptive origin, which must have been ejected in a molten condition through extensive fissures made in the Earth's crust. The most remarkable feature of the occurrence is found in the fact that these eruptions seem to have been confined to the Triassic region, and occur but seldom except as accompaniments of the Triassic formation.

The Palisades of the Hudson, and Mounts Tom and Holyoke in Massachusetts, are superior examples of this igneous formation.

The eruption invariably occurred through the sandstone rock; and not seldom the sandstone was converted by the intense heat into a hard grit, and was torn and rent by the force of the accompanying explosion.

Another result of this phenomenon was the evolution of vapors, whose condensation resulted in the tourmaline, hematite and garnet crystals so frequently found in these trap-formations. Copper, iron and barium ores are also among the results of this eruptive action.

Among Triassic phenomena, however, is one so characteristic of the period that it may well be termed *the* Triassic feature.

This is the frequent occurrence of FOOTPRINTS OF BIRDS AND BIRD-LIKE REPTILES in the sandstone formation of this age. These occurrences are nowhere more abundant, more characteristic, or more perfectly preserved, than in the Connecticut Valley.

It remains a still-unsettled question whether any of these footprints were actually made by true *aves;* but the probabilities tend to prove that they all, or nearly all, owe their origin to the presence on the Earth of animals closely allied to both bird and snake, possessing, in a marked degree, characteristics of both, yet distinct from either. That such animals existed is not a hypothetical conclusion based on the well-known similarity between the sub-kingdoms *Reptilia* and *Aves;** nor on

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* The recognized points of similarity between birds and reptiles are as follows: They are either oviparous or ovoviviparous; the embryo possesses the amnion and allantois; they are devoid of mammary glands; they never possess gills; the skull is joined to the vertebral column by an occipital condyle; each half of the lower jaw consists of several distinct pieces, and the jaw is not united directly to

the evolution theory that, in the progression from the lower order to the higher, an intermediate existence must have been passed. Beyond all controversy, such creatures are known to have existed: their fossil remains attest the fact; and they undoubtedly belong to the epoch of Triassic formation; they were of a lower organization than the birds which succeeded them, and must have chronologically antedated the latter. They unquestionably left their footprints on the sands of *their* time, while true birds were but just appearing on the face of the Earth, swimming in its waters, and traversing its sands, as the Triassic era drew to a close.

AGRICULTURALLY AND ECONOMICALLY considered, this age is not one of marked features. The soils formed from Triassic sandstone are, however, usually of a fertile nature, and in many localities are of unusual productiveness; the soils of the Connecticut, Hudson, and Rhine valleys furnishing the best evidence of this fact. The "bone-bed" deposits disintegrate into superior soils, and the deposits themselves have been utilized as a source of manurial phosphoric acid.

The chief rock-salt deposits of Europe belong to this formation, the purity of the product being a noteworthy feature. Freestone, "landscape marble," gypsum, local deposits of coal, and "pudding-stone marble" are also valuable products of the Triassic formation.

THE CLIMATE AND LIFE of Triassic times were those of mild temperatures over the entire Earth's surface; but the first evidences of zones of unlike climate began to appear and herald the change approaching. The poisonous atmosphere of the preceding era had been purified through the assimilation of carbon by the vegetation and its subsequent conversion into stores of coal.

A decided step forward occurred in the organic existence of the world; animals requiring better air and more perfect blood-

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the skull but to an intervening quadrate bone; the alimentary canal terminates in a cloaca which receives the secretions and excretions from bowel, kidney, and sexual organs; the red-blood corpuscles are oval and contain a nucleus; the cavities of the chest and abdomen are not separated by a diaphragm; the hemispheres of the brain are not united by the *corpus callosum*.

oxidation make their appearance. One mammal, a marsupial, the *Dromatherium sylvestre*, one individual alone of which species has been recovered from its place of preservation in the Triassic rocks, marks the culmination of Triassic life.

II. THE JURASSIC FORMATION.

The middle member of the Mesozoic group most closely resembles the preceding formation in the composition of its strata; but the absence of marine fossils being one of the most characteristic features of the Triassic rocks, so the presence of large numbers of these individuals furnishes the chief and best evidence of the Jurassic character of a formation of Mesozoic time. Indeed, the age is distinguished by the prevalence of new and more highly developed marine animals in innumerable varieties, and more closely allied to the representatives of the same orders with which we are to-day acquainted.

Ammonites, belemnites, corals of the form of to-day, gasteropods and mollusks in unprecedented number now appear; while the shark-like fishes begin to be supplanted by the fish of modern times. Reptiles become less abundant, and birds become more abundant; while the single Triassic mammal, semi-oviparous, is succeeded by several varieties of low-organized, but placental, mammals.

ROCKS. Aside from the prevalent rocks of the Triassic period, limestone, slate and clay are frequent occurrences during the Jurassic era; and the limestone is not seldom in the form of gypsum. Jurassic strata occur in America in the Black Hills, in Colorado, and over considerable portions of the Pacific slope.

The European Jura is subdivided into the *Lias*, or black Jura, the *Dogger*, or brown Jura, and the *Malm*, or white Jura. But in America no subdivision has been attempted, or can be found to exist.

THE CLIMATE of the Jurassic period, as is proved by the even distribution of life over the Earth's surface, was one of equableness; and the predominating forms of life indicate a tropical, or semi-tropical, temperature for the entire Jurassic world.

The existence of Jurassic fossils of undoubted marine origin, high above the present sea-level, proves that the water-level of the world was then much higher than now; or rather, that the continents have undergone a material elevation since the day when salt-water mollusks were stranded high up among the Rocky Mountains.

THE DISTRIBUTION OF JURASSIC ROCKS finds chief display in Europe, where the formation bears invariably a triple character. The extensive formation of England extends across the Channel, through France, Germany and the Alps, from a spur of which the name "Jura" is derived. The three subdivisions are each distinctive, and present features typical of European geology.

The American region is confined almost exclusively to arctic latitudes, and to localities in Dakota, Colorado and the Pacific coast. This latter region stretches southward into the Andes.

THE AGRICULTURAL AND ECONOMICAL characteristics of the period are of significant importance. The soils of Jurassic origin are predominatingly clays, and largely heavy and tenacious; but marl is of frequent occurrence, in which case the soils are capable of becoming the best of wheat-lands, and of furnishing most valuable pasturage. Gypsum is the only mineral product of agricultural value.

But the great deposits of gold- and silver-bearing quartz in Dakota, Colorado, Nevada, and California, the richest gold-producing regions of the world, are confined to the Jurassic formation.

THE ERUPTIVE DISTURBANCES which were so noticeable a feature of the Triassic period were but mere trifles compared with the eruptive development which closed the Jurassic era. Whole mountain-ranges date from this time, and were forced above the surrounding surface by internal power which built up barriers of igneous rock in the midst of Jurassic deposits. The entire Sierra Nevada formation is of such origin; and, like these eruptive strata, is characterized by the presence of extensive veins of pure quartz.

The heat of the eruption converted the water present at the place of outburst into alkaline solutions of silica, which, filling the crevices and lower levels, solidified and became silicon dioxide or the *quartz reefs*. And in these reefs of quartz exist to-day the gold, silver and other metals gathered from the surrounding softer formations, and afterwards condensed and solidified with the mass of the solution. And to this phenomenon is due the existence of these auriferous quartz veins in the midst of the surrounding Jurassic formation, and gives the period an interest and value it might otherwise fail to attract.

With these convulsions of nature, carried on with such grandeur and on a scale of as significant magnitude as of geological and industrial importance, the Jurassic period came to a close, and was followed by the final epoch of Mesozoic time.

III. CRETACEOUS PERIOD, or

Era of Chalk-formation.

This epoch closes the Reptilian age, and is signalized by the extinction and disappearance of innumerable species of mollusks and reptiles, and the appearance of many modern types of plants; so that the period is distinguished by a great revolution in the flora of the Earth. Though the palms and conifers of the Jurassic period did not disappear, they were now, for the first time, accompanied by members of the great order ANGIOSPERMS, which includes the maple, oak and most of our modern fruit and forest trees.

THE DISTRIBUTION OF THE FORMATION in America is unimportant from its extent, and is divided into the so-called earlier and later Cretaceous epochs, in neither of which, however, with a single exception located in the State of Kansas, does a true deposit of chalk occur; though deposits assigned to this formation exist along the Atlantic coast from New Jersey to South Carolina, across the Gulf States, up the Mississippi Valley, over the interior portion of the continent, in the Rocky Mountains, and on the Pacific slope.

The most typical, the most diversified, and the most thoroughly studied Cretaceous formation is in England, where the chalk deposits and Cretaceous rocks cover a large portion of the territory; and where the chalk cliffs glistening in the sun, contrasted against the blue of the sky, and flanked by the green of field and wood, form a most striking, beautiful and characteristic feature of the landscape.

The English formation is subdivided into the *Lower-greensand*, *Gault*, *Upper-greensand*, *Chalk-marl* and *Chalk;* which names indicate clearly the character of the CRETACEOUS ROCKS which consist chiefly of beds of Greensand, of marlite, clay, and shell-limestone; while many American deposits contain hornstone corresponding to the flint of England.

The Cretaceous formation, petrographically considered, is exceedingly irregular in composition. Its deposits pass through all gradations from fine, pure quartz sand, sandstone, conglomerate, hard and soft limestone, marl, magnesian limestone, chalk and flint; so that many localities classed as belonging to this period possess but the slightest possible resemblance to other deposits of the same era. It, therefore, follows that the petrographical features of the formation often fail to determine its geological position, which must depend on its paleontological characteristics for correct designation.

AGRICULTURAL AND ECONOMICAL INTERESTS of unusual importance characterize the Cretaceous formation; the period not infrequently yielding mineral coal, gold, copper, iron, chromium; and, most important of all, the chief quicksilver-producing regions of the globe are of Cretaceous origin. The great natural deposits of cinnabar (HgS) occurring in the metamorphic rocks of California, Mexico and Spain being of the chalk-formation era.

Eruptive stones cannot be considered characteristic of the Cretaceous epoch, but are of occasional occurrence accompanied by zinc, calc-spar and strontianite, and not infrequently consisting mainly of basaltic rocks; while mineral asphalt is a characteristic accompaniment of Cretaceous eruptive action, the chief asphalt mines of France and Germany existing in districts belonging to this formation.

CHALK ($CaCO_3$) of organic origin, the characteristic product of the Cretaceous formation, is a nearly pure, unsilicious carbonate of lime, consisting almost wholly of the remains of microscopic foraminifera, aquatic by nature, and deposited by precipitation from the sea-water of the Mesozoic time. A cubic inch of chalk may contain upward of a million of these small Rhizopods.

It is generally conceded that the flints so prevalent in formations of Cretaceous origin are not of a metamorphic character, but are the product of the aggregation of silicious infusoria belonging to the same era as the foraminifera, and, like them, deposited then as they are to-day in the waters of the deep sea.

The *Greensand* of this period owes its characteristic color to the presence of silicate of iron, and is of considerable agricultural value as a fertilizer known as "marl," and is extensively excavated in New Jersey. Its agricultural value is due to the presence of silicate of potash, and of phosphate of lime of unmistakable organic origin, as proved by the presence of bones and shells of marine animals.

The soils belonging to this period are, as a rule, of exceptional fertility, especially those in proximity to the upper *Greensand*, with its supplies of potash and phosphoric acid. The clay soils of this formation, though in themselves heavy, become remarkably productive when in contact with a substratum of chalk, being in England noted as producing barley of rare quality, and being chiefly devoted to the culture of this grain for malting purposes. Hops and wheat are also remarkably successful crops grown on this soil.

No more interesting or instructive comment can be made on the agricultural properties of Cretaceous soils than the fact that "Rothamstead," the renowned experiment farm of Sir John Lawes, is situated in a Cretaceous region. The soil has now borne forty-five consecutive crops of wheat without manuring, and still, at the end of this protracted drain upon its resources, produces more than twelve bushels of grain per acre, a yield almost equal to the average product of the United States.

The soil which has thus, at the end of nearly half a century of constant depletion, shown itself incapable of exhaustion is typical of a large area of soils of Cretaceous origin. It consists of a tenacious yellow clay, thickly interspersed with nodules of flint. Beneath this surface-formation, at a depth of twelve feet, exists the chalk, containing abundant organic remains of a phosphatic nature, and potassium being present in appreciable quantities.

As a result of this fortunate conjunction of circumstances, the gradual but constant decomposition of the mineral constituents present as products of the Cretaceous formation supplies the plant with all the essentials for its growth and maturity, with the single exception of nitrogen. The addition of this one ingredient to the chalk-formation soils of "Rothamstead" would render them practically of exhaustless fertility.*

THE CLIMATE of the Cretaceous period is characterized by a gradual lowering of temperature from that of the epochs preceding it; and the regular and even temperature universal on the Earth during the Paleozoic age had now, at the close of the Mesozoic time, assumed more of the zone aspect of to-day, though nowhere is there evidence of anything approaching a frigid temperature; yet evidences of the occasional existence of floating ice are not wanting. The climatic conditions of the Cretaceous period were those of transition from the warm or temperate condition characteristic of the primeval and mediæval Earth to the frigid era which ushered in the modern epoch of geologic history. Only a slight transformation was required for the beginning of an era of ice and frigidity, and this change occurred here at the close of the Cretaceous era, when disturbances took place which revolutionized the geographical aspect of the world, and swept it free of the organic life which then characterized it.

The European continent forced itself above the waters surrounding the archipelego of which the Europe of Mesozoic time consisted. The mighty range of the Rocky Mountains reared its peaks thousands of feet above the highest pre-Cretaceous level. The change of elevation brought frigid, ice-bearing currents down with resistless force upon the temperate lands of the chalk-formation era, sweeping from existence with their frigid, blighting breath almost every vestige of the lower semi-tropical fauna and flora of the Earth.

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* The relations between nitrogen and mineral matter as food for plants are considered in PART THIRD.

The characteristic features of Mesozoic time vanished; new conditions prevailed; and a new era, the CENOZOIC TIME, was at hand.

CHAPTER IV.

CENOZOIC TIME.

THE primeval stage of organic existence gave way to an era of greater advancement which was, in turn, supplanted by a mediæval epoch. The lapse of ages continued, progression the watchword, till both these phases were relegated to the past, leaving only their petrified history behind; and the modern era of geologic evolution, the recent period or *Cenozoic time*, appeared.

Invertebrates, fishes, reptiles, predominated in turn, and characterized each an epoch in the series we are tracing; and now all retreat to the insignificant position they must occupy in an age marked by the numerical superiority of the order to which the *genus homo* is assigned. Mammals now predominate, and the arrival of man, for whose reception the world has passed through all this epoch after epoch, and age on age, of preparation, is near at hand.

THE CENOZOIC TIME, characterized by the predominance of mammalian animals, is divided into two periods, the distinction between which being marked by the evidences of man's presence on the Earth. These epochs are:

I. THE TERTIARY FORMATION, or *Age of Mammals.*
II. THE QUATERNARY FORMATION, or *Age of Man.*

I. THE TERTIARY FORMATION.

This age was characterized as the period during which the Earth's surface began to assume its present geographical form and appearance, and became the dwelling-place of a fauna and flora more closely resembling its modern inhabitants, a considerable number of species of which have not become extinct, but live to-day, representatives of races predominating then.

The chief characteristics of the Tertiary world, by which it becomes more closely allied to the world of to-day, are as follows: *First*, a continual increase in distinctness of demarkation between solid land and sea. Gradual elevation and depression of the surface, always, however, with a final gain of elevation on the part of the land, and a constant withdrawal of the waters. A condensation of the sea; the drying up of marshes; the draining of lakes whereby rivers flowed where inland seas once had been, and valleys succeeded great basins filled with the fresh or brackish waters of ages of accumulation,—these were distinctive Tertiary phenomena resulting ever in land formation and water-repression within boundaries closely conforming to those with which we are still familiar.

Second, the formation of modern mountain-chains. The chief of the lofty mountains of the world date from the Tertiary age; the highest peaks of the Pyrenees and Alps, of the Himalayas, Andes and Rocky Mountains, being of this recent origin. The elevation of such lofty summits inevitably changed the water-sheds and river-courses of the previous era; and exerted no inconsiderable influence on the fauna and flora of the Earth, through the resulting meteorological and climatic modifications.

Third, the formation of climatic zones. During the earlier periods of the history of our planet, it possessed, from pole to equator, an even temperature, the record of which endures to-day, and informs us that Silurian corals and the luxuriant vegetation of the Carboniferous world, alike, flourished with equal perfection of growth under equatorial skies and in the midst of polar seas; for the interior heat of the Earth was still so manifest at the surface, that the uneven distribution of the sun's rays was of little influence on terrestrial temperature.

Gradually, but constantly, as the surface-crust became thicker, the external temperature became lower, till now at the beginning of the Tertiary age the surface-manifestation of internal heat had nearly ceased, and modern climatic distinctions were the result. As a natural and inevitable consequence, the fauna and flora which had before been so evenly and regularly distributed over the Earth became restricted to habitats whose confines they could not pass with impunity; and whole races of animals and plants became exterminated through the action of new climatic influences. The *survival of the fittest* ensued; and the existence of those species unprepared for the new surroundings in which they were placed became a part of geological history.

Fourth, the total extinction of many animal and vegetable forms, and the restricted existence of others. The life so characteristic of earlier ages, of Carboniferous, Cretaceous and later formations, but more particularly the giant Reptilia of the Mesozoic epoch, passed away with scarcely a living representative to preserve the memory of their existence; and a new order, a higher development, succeeded them; a modern era began.

Fifth, the extraordinary development of animal and vegetable types whose first appearance on the Earth is characteristic of Mesozoic time. The *Angiosperms,* which first came to notice as remains in the upper chalk-formation, become now the prevailing type of forest tree; mammals, the first feeble and imperfect representatives of which class date from the upper Triassic period, now first assume the typical mammalian form of *monadelphian,* placental animals whose young are brought into the world in a more fully matured condition.

The oldest typical mammal dating from the Tertiary age was the so-called *Anoplotherium,* which possessed several characteristics of the ruminant family, and was followed by true ruminants and carnivora, till the fauna lacked only the *genus homo* to present all the species of the world of to-day.

Sixth. The gradual appearance of innumerable varieties of mollusks identical with the marine fauna of to-day. So near did the youngest Tertiary or most recent period of the age approach the present, that from 60 to 90 per cent of these molluscan varieties imbedded in Pliocene formations are identical with the present or living members of the same family.

The features, then, by which the Tertiary age may be distinguished are chiefly these: deciduous trees, mammals, bivalves and gasteropods become the predominating representatives of the organic world; with a gradual separation or division of the Earth into climatic zones, each with its distinctive fauna and flora, and depending for its characteristics upon its remoteness from the equator. These climatic influences approach nearer and nearer those of to-day, and become complicated through the rearing of lofty mountain-summits with their various zones of temperature. And as the ancient conditions recede, and those of the modern world approach, the number of animal and vegetable forms identical with those of to-day assume ever an increasing ratio. The diversity of terrestrial conditions and of organic life far surpasses anything that had preceded them, and marks the last stage of progression before the arrival of that still existing.

THE TERTIARY AGE has been divided into three separate epochs or eras, as follows:

1. *Eocene* (dawn of the recent), with species nearly all extinct.
2. *Miocene*, whose species are less than half living.
3. *Pliocene*, the species of which era are more than half still living.

THE ROCKS of the Tertiary period are divided into two kinds: those of fresh-water deposition, and those precipitated from salt or brackish water, the marine deposits. So characteristically different are these two formations in their essential features, that the character of the rocks serves as an accurate register of the extent of salt- as of fresh-water occurrence during the Tertiary formation.

Beginning with the first or oldest deposits, we find beds of sand or clay, followed by compact sandstone, beds of loose shells and earth, shell-rocks and calcareous sandstones. These rocks are of a firm texture, suitable for building purposes.* Then follow marls and clays, with carbonate of lime from pulverized shells, compact solid limestones, greensand identical

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* St. Augustine, Fla., the oldest city of European building in America, consists chiefly of edifices built of this stone.

with that of the Cretaceous formation, and buhrstone used for millstones.*

As is seen by the list, Tertiary rocks are as a formation much softer than those of any preceding era, yet the epoch produces hard slates and sandstones wholly indistinguishable in themselves from those of earlier strata.

Like the Cretaceous age, the Tertiary also contains beds, or deposits, of a silicious Infusoria, and of calcareous Rhizopods.†

The Tertiary limestones are largely made up of fossilized Rhizopods, called Nummulites, existing often at great altitudes, forming many Alpine and Himalayan summits; beds of a kindred nature occurring among the Coast Range in California.

DISTRIBUTION OF THE ROCKS. Geographically considered, this age was one of most extensive domain; and all the continents possess examples, and no insignificant ones, of the formation. It was the last epoch of the Earth's history preceding the advent of man; and as such embraces much of the new land-formation bordering the oceans of the world, being to a great extent the formerly submerged surface exposed by the final receding and restriction of the waters.

In America, this area includes Cape Cod, the islands off the Massachusetts coast, most of the coast south of New Jersey, the peninsula of Florida, portions of the Mississippi Valley, where distinctive water-sheds for the Mississippi and Ohio rivers existed, the streams each emptying independently into the sea, and only becoming united at their mouths toward the close of this era. The Rocky Mountain region and the Pacific coast also present well-defined marine beds of Tertiary origin.

In Great Britain, the Tertiary deposits are chiefly Eocene, and are confined to a triangular region, embracing southeastern England, surrounding London, and extending inland nearly to Salisbury. Northern France contains beds of a similar nature. Germany, Switzerland, Italy, Greece, northern Africa, southern Asia, most of Japan, and the islands of the Indian Archipelago, possess Tertiary deposits.

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* South Carolina yielding a famous quality.

† Dana's "Manual of Geology," pp. 493 and 512.

THE VOLCANIC OR ERUPTIVE ACTION with which the age came to a close manifested its power over the entire Earth; and the display of the activity then begun has not yet disappeared as a real and vital force, present and manifest. For the volcanic and earthquake actions of the present are most intimately connected with, and in all essential characteristics most closely allied to, the phenomena of Tertiary times.

Several distinct epochs of eruptive action seem to have passed over the Earth during the Tertiary age; or rather, different portions of the Earth's surface were undoubtedly subjected at varying intervals to the influences of eruptive action.

The chief result of this occurrence, as witnessed to-day, is evidenced by all the great mountain-chains of the Earth, which either date wholly from a Tertiary origin, or by this action were elevated thousands of feet above the highest altitudes previously attained. Long periods often elapsed between these intervals of eruption, so that the formations resulting therefrom are of varying age; but always of the same petrographic character, the rocks being igneous in nature, and consisting principally of basalt, porphyry, and other plutonic rocks.

Most of the active volcanoes of our day date their periods of activity from Tertiary times,—the lava of modern Vesuvius having its exact counterpart in the formations antedating the era of man.

THE AGRICULTURAL AND ECONOMICAL features of this age are in many respects unique. In America, the soils are chiefly of a sandy nature, and frequently of slight agricultural capability; but clays also are characteristic of the period, and a conjunction of the two often results in a soil of extraordinary fertility,—clay with a sand subsoil being a favorite and productive arable land, while the clays alone form superior pasture-lands. Above the Tertiary clays extensive heaths and marshes abound, wholly sterile, but capable, by drainage, of being converted into valuable meadows. The extensive artificial cranberry-meadows of the Cape Cod region and of New Jersey belong to this class of phenomena, and exhibit the transformation of worthless wastes into unusually valuable land.

In England, areas of similar nature are well known; while in

Japan such tracts form extensive districts along the coast, and between the highlands of most of the islands.

Deposits of phosphate of lime, of animal origin, are unique features of the Tertiary of America and England. South Carolina, in the so-called "Charleston basin," possesses the world's largest supply of this essential manurial material. The deposits exist in the form of hard phosphatic rocks, which are extensively mined and exported to all the States and to most European countries for manufacture into superphosphates for fertilizing purposes. The rock abounds in fossil remains, but is itself probably of a fossilized guano nature.

The crag-formation of England, embracing the larger part of the English Tertiary, is also remarkable as containing vast quantities of hard flinty nodules consisting often of even 60% of calcium phosphate. The subsoils of this region formerly so abounded in these fossils that extravagant prices were given for the right of digging and removal for use in the commercial fertilizer industry; but the supply of these so-called coprolites has of late years become much depleted.*

An interesting occurrence of the Tertiary age, and one of no little scientific and agricultural importance, is the fact that grasses, to the growth of which more than half of the arable world is devoted, date from the middle of the Eocene; no graminaceous fossils existing in older formations, and the fauna of pre-mid-Eocene times having been wholly unfitted by its dentition for existing on any form of grass.†

Coal and lignite abound in most Tertiary regions. The former is invariably either soft or brown coal, and is not uncommonly of very superior quality. Deposits of this fuel are worked in Colorado and many Rocky Mountain regions, in England, Germany, India and Japan. The last-named country possesses exhaustless resources of superb Tertiary coal in several localities both of Nippon and Yesso. The lignite, sometimes confused with brown coal, possesses its original woody texture,

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* "Elements of Agricultural Chemistry and Geology," Johnston and Cameron (13th ed.), p. 101.

† *American Naturalist*, June '86, p. 546.

and forms a fuel resembling charcoal, though more durable. Its chief deposits occur in Continental Europe; Hesse and Brunswick both furnishing large supplies of this fuel.

Bog iron ore ($2Fe_2O_3+3H_2O$) exists frequently in Tertiary formations, and often in valuable deposits.

The *infusorial earth*, consisting of the remains of the minutest infusoria, and so important a factor in the scientific and political world of the present generation as an ingredient of dynamite, is an abundant product of Tertiary life. The chief deposits exist in Germany and in the State of Virginia, though occurring widely as a formation of this era.

THE CLIMATE OF THE TERTIARY AGE was, at the beginning, over at least a portion of the Northern Hemisphere, one of tropical or semi-tropical nature; and this character extended to the regions of the midnight sun, fossil evidences being abundant that even Greenland and Spitzbergen possessed during these early times a climate of comparative mildness, being luxuriant in the verdure of the temperate zone, and the home of vast forests of deciduous trees, through which roamed the mammoth and other gigantic mammals which became extinct races by means of the same causes to which are due the death of the forests and the advent of perpetual and impenetrable snow.

Gradually as the centuries of Tertiary time rolled away, the formation of our modern climatic zones became perfected; the cycle of formative phases was complete; preadamic conditions, surroundings and influences were at an end; man's domain was ready for his occupancy, and the last epoch of geological history arrived.

II. THE QUATERNARY FORMATION, or *Age of Man.*

The appearance of man on the Earth marks the arrival of a new geologic age; all efforts to establish evidences of the existence of pre-quaternary man having failed when put to the further test of scientific inquiry.* The Quaternary period is

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* Lyell, "The Antiquity of Man" (London, 1873); de Nadaillac, *Les premiers hommes et temps préhistoriques* (Paris, 1883).

divided into two epochs or formations: 1. *The Diluvium*, or formation immediately following the Tertiary; and 2. *The Alluvium*, or period of to-day, which embraces the modern deposits and formations still in process of completion, the peat-bog being a characteristic illustration of this class of phenomena.

The American Quaternary is, however, classified more explicitly as—

1. THE GLACIAL PERIOD; 2. THE CHAMPLAIN PERIOD; and 3. THE RECENT PERIOD, or period of TERRACE formation.

The intermediate epoch, or Champlain period, is wholly American, and of secondary importance here; while the Glacial is the characteristic epoch of the Quarternary age.

The phenomenon of the age was the gradual moving down from polar regions, over the three northern continents, of enormous masses, fields and mountains of ice, resembling in nature enormously aggravated glaciers, resulting in the so-called *Drift* formation.

Heretofore the phenomena of geological history had possessed a southern trend or tendency; their field of action having been mostly confined to the southern portions of the continents. But now there is a radical change in the location of active geological progression. The continents which have heretofore been gradually extending themselves toward the south have reached the limit of this expansion; and the active phenomena of the period approaching are all northern in their origin, and exert themselves most powerfully in regions never since wholly freed from the bonds of ice and snow.

THE GLACIAL OR DRIFT-FORMATION PERIOD.

This was an era distinguished by the presence of enormous fields of inland ice and glaciers which covered the greater part of the North American and European continents, half of Asia, and large areas in South America;* moving gradually but irresistibly southwards, burying all nature beneath its frigid

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* Confined to the higher altitudes, or to the vicinity of the Pacific coast.

mantle, passing unresistingly over lofty mountains, and grinding rocks to powder and gravel which became deposited in its path, a formation of veritable *Drift* material.

As the term implies, this formation consists of gravel, sand, clay, and boulders existing in an unstratified condition, which have evidently been transported from a distance, usually from localities of higher altitudes. So powerful and resistless was this action, that rocks hundreds of tons in weight were transported many miles, and that, too, independently of grade, surface-slope, or incline.

Drift may occasionally exist in a stratified condition, possessing the same composition as the unstratified, except that the lower stratum is usually of clay interspersed with enormous boulders which confer the name *Boulder clay* upon this level. The unstratified Drift is invariably wholly devoid of the remains of marine life, though vegetable material is of frequent occurrence. The stratified formation occasionally presents marine fossils.

The material of the Drift varies with the geological character of the region whence it was transported. The usual distance of transportation seldom exceeded one hundred miles; and the course pursued was invariably from the north, or in a southerly direction. In Europe, the southern limit of this glacial action was in northern Austria; while in America a more southern limit was attained,—portions of the States of Maryland, Virginia, Kentucky and Tennessee being of unmistakable Drift origin.*

The western limit of this phenomenon was near the Mississippi River of to-day. There were also smaller glacial regions in the Rocky Mountains and the Andes. The amount of ice depending on the amount of precipitation, the chief seat of the phenomena must have been confined to the vicinity of the great oceans.

The characteristic phenomena of this era were of a kind clearly establishing the identity of their cause. Aside from Drift deposits, the abrasion of the surface-rocks was universal,

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* *American Journal of Science*, 1886.

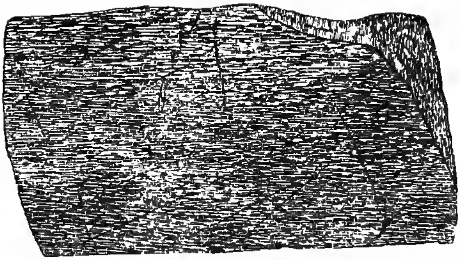

FIG. 6.—Glacial Scratches. (After Hitchcock.) (*To face page* 47.)

so that the entire rock-formation in Drift regions is left in a scratched, grooved, furrowed, or polished condition. The bottoms of valleys, the bed-rock beneath the accumulated *débris*, are usually scratched, so that it seems the Drift itself must have been deposited after the era of abrasion, while the height of the grooving above the sea, on the sides of the valleys, or on mountain-peaks, shows to a nicety the depth of the icy inundation to which the continent was subjected. Instances in the White Mountains exhibit these markings at an elevation of 5500 feet; and the complete burial of mountains under the moving millstone of ice is strikingly illustrated by Mount Holyoke, whose summit is a surface of furrowed and polished trap, enduring evidence of the chastening process to which it was subjected.

Closely allied to this furrowing of surface-rocks is the occurrence on all continents subjected to glacial action of *Fiord Valleys*,* deep, narrow, cañon-like channels grooved in the rock, occupied by the sea, and extending often long distances inland; the tide pouring through them like the waters of swift-flowing rivers, confined within dark and narrow chasms, winding sometimes a hundred or more miles from the sea between towering rocky walls.

ORIGIN OF THE GLACIAL-PERIOD PHENOMENA. The causes of the change in climate resulting in the phenomena of the glacial period were chiefly these: The preceding Tertiary age had been one of unusual increase in elevation above the sea, an era of continent-formation closed by an unprecedented period of lofty mountain elevation. The rearing of these mountain-summits far above the greatest elevation previously attained was necessarily followed by a marked lowering of temperature throughout the region subjected to the action. To augment this reduction of temperature, the great changes of surface-elevation over entire continents resulted in disturbances of the relations before existing between land and sea; old currents were annihilated, and new currents came into being.

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* The coasts of Maine and of Norway presenting most characteristic illustrations of these phenomena.

The upheaval of land was chiefly in the south; the waters displaced were driven northwards; and to occupy the space vacated, frigid currents poured in from the polar regions, followed by an era of ice and arctic cold over all the land subjected to their influence. The Northern Hemisphere became buried beneath the icy burden, so powerful a factor in moulding the geological features of the age in which it existed and exerted its force.

That other causes than continental elevation might have exerted an influence on the change of temperature ushering in the Diluvian epoch is extremely probable, as explained by Prof. Müller, particularly with reference to the supposed second period of glacial action; but he advances the change in elevation as the paramount influence resulting in the reign of cold, and calls attention to the fact that, at the beginning of the Diluvian period, the English Channel and much of the German Ocean were high and dry above the sea-level of the time.*

The Cause for the Southward Movement of the Ice-mass. As already stated, surface-incline exerted no influence on the direction of glacial movement; and the course of advance was invariably from the north.

Most of the new ice was, of course, made at the place of lowest temperature; and as climatic zones already existed, this region of greatest cold was farthest from the Equator, that is, toward the north. It therefore followed that all new ice was added to the mass at the north; all *increase in weight and pressure* took place at the north. The chief melting, the loss in mass and weight, occurred at the south. The latter was, therefore, the point of least resistance. The mass of accumulated ice moved steadily onward in this direction, driven by the resistless force of the weight increasing at the north. And this movement continued till amelioration of temperature re-

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* "In einem früheren Zeitabschnitt der Diluvial-periode, ehe die erwähnte grosse Senkung eintrat, welche die europäischen Tiefländer unter den Spiegel der Nord- und Ostsee tauchte, ragten diese Länder hoch über dem Meere empor, wenigstens so hoch, dass nicht nur der Canal von Calais, sondern noch ein grosser Theil der Nord- und Ostsee trocken lagen."—MÜLLER, *Die ältesten Spuren des Menschen in Europa*, p. 13.

duced the mass through melting at the south faster than it accumulated through freezing at the north, when this mighty force gently melted away and disappeared, leaving only its records deeply graven on the geologic page over which it moved.

The occurrences of this era were undoubtedly the result of the action of ice in some form, for the magnitude of the results accomplished preclude all idea of their having been produced by the action of water. But the power of ice might have been exerted in two ways, or the ice might have existed in either of two forms: either as *moving glaciers*, or as *floating icebergs.*

THE ICEBERG THEORY presupposes the inundation of a large portion of the Earth's surface where continents now exist. Indeed, the Drift formation and region of to-day must coincide with the area of submergence. New England must, then, have been submerged to a depth equal to the highest elevation at which the impress of floating ice is exhibited, or at which the groovings and scratchings of to-day attest the action.

But opposed to this theory is the fact that throughout the Drift area no marine fossils remain at an elevation greater than 500 feet. The average distance of Drift transportation is hardly more than 50 miles, yet icebergs carry their imbedded masses and rocky burdens even thousands of miles. Masses of ice floating in the currents of a frigid sea, or driven hither and thither by the winds, could hardly have scored so regularly the entire surface of the country, or have so systematically followed the courses of the valleys. A more reasonable hypothesis in explanation of the phenomena is

THE GLACIAL THEORY ·* the truth of this supposition being indicated by the following facts.

The very phenomena characteristic of this period are being produced to-day by glacial action; stone and gravel being taken up by the advancing glacier, and transported any distance, either long or short.

The scratching and grooving made by glaciers still extant are identical, in every respect, with those of the Drift formation.

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* Agassiz, *Système glaciaire* (1847); Geikie, "The Great Ice Age" (London, 1873).

The Rhone glacier in Switzerland offers the best field for observing the results of modern glacial action, from the fact that the glacier is gradually receding toward its parent ice-field, leaving in its path a perfect record of the results attained. The deep gorge, down which it moves like a massive, frozen waterfall, bears high on its sides indisputable abrasions of surface-rock; and the deposition of ice-polished boulders attest glacial action, while the infant Rhone flowing from beneath the ice-mass, and, muddy with the sediment and pulverized rock of sub-glacial origin, passes over an expanse of loose pebbles and boulders, at first so recently bared by the icy inundation that no vestige of vegetation appears; but as distance from the ice-wall and remoteness from glacial action increases, a few scattering sedges appear, and the vegetation continues to gain in quantity and quality till, a mile from the present face of the glacier, verdant meadows begin.

The *débris* remaining in the bed of the vanishing glacier presents every feature characteristic of the Drift of Diluvian origin; and the Rhone glacier is but the feeble remnant of a mightier glacier of Diluvian time, filling with its comrades the entire region between the Alps and Jura; and over whose entire territory the results of its presence still exist, counterparts of the phenomena still taking place as the Rhone glacier recedes and decreases, just as all the mighty mass of which it is so slight a remnant vanished with the Diluvian epoch.*

The presence in temperate climates of varieties of Alpine or polar plants may be explained on the ground of glacial transportation.

The number of plant forms thus assigned an arctic origin is very great. They exist in various parts of Europe, and on most of the higher peaks of the Alleghanies, the Adirondacks, White Mountains, and Green Mountains, in America.

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* The rate of annual retrogression of the Rhone glacier is marked each September by the Swiss national survey, and is by no means insignificant, the average yearly rate of disappearance being about 30 metres; and sometimes far exceeding this amount. In 1882 the amount of recession having been, as measured by the author, 58 metres. Amelioration of climate in the Alpine region of Europe keeps pace with this recession of its glaciers.

THE EROSION of the glacial period consisted of two kinds: the abrasion caused by the stones at the under surface; and a scooping action resulting from the forward movement of the ice.

The chief erosive results accomplished by the glaciers were produced directly by the water, accumulating beneath the moving ice-mass in consequence of the constant melting of the same. These sub-glacial streams were loaded with the jagged stone masses broken from the rocks over which the glacial pathway lay. These, rolled and whirled and revolved against the rocks in contact with which they were driven by the waters, or pressed by the ice, became like so many millstones or polishing wheels, driven for the purpose of reducing the rock-surface to gravel, sand or clay.

Where such action continued for a great length of time, particularly if the moving stone was harder than the rock against which the erosive action was exerted, deep well-like excavations, extending perpendicularly into the softer strata for many feet, were often the result. A noteworthy occurrence of such phenomena exists in the sandstone strata near the Lake of Lucerne, where in the "Gletscher Garten," close by Thorwaldsen's renowned Lion of Lucerne, in an area hardly one acre in extent, 32 of these deep whirlpool pits appear; the chief of them being 26 feet wide and 30 feet deep; and in the bottoms frequently remain the one or more hard stone masses to whose rotation by the sub-glacial waters through centuries of time the deep erosion is due.

The rate of motion could never have exceeded one foot per day, yet the pressure was so great and the weight so enormous that all depressions of surface were filled or destroyed. The lower level of the moving mass adjusted itself to the surface over which it passed; the loosened material was taken into the ice-mass, where, by the motion or agitation resulting from the constant change of level, it was kept in perpetual movement; stones were ground against stones, and the fine *débris* from such action became deposited as pebbles, sand and earth,—the glacier being among the chief soil-producers of geological history.

The deeper river valleys owe their excavation to the erosion of the glacial period, the result being partly due to direct action of the glacier, but mainly to the existence of sub-glacial streams laden or armed with *débris* from the glacier itself.

Not river-valley only, but also lake-basin excavation is attributed to glacial action. Sometimes the effect being the result of direct excavation. Or the outlet of a deeply excavated valley became filled with glacier residue, Drift, till the valley became a water-shed, and the stream a lake. Such was the origin of many a deep lake in the Swiss Alps, reflecting the green of vineyard and forest against the white of mountain summit, with blue of sky above.

Following the phenomena of glacial origin came the formation of the Diluvian and Alluvian eras, classed together as a distinctive period, the Champlain, of America, existing chiefly in the vicinity of the lake of this name.

THE ROCKS of the period were of two kinds: those dropped from the glacier after the period of thaw began, being invariably unstratified; and those which fell into water on being severed from their original mass, or deposited, where they were taken up and transported by water in which they became somewhat stratified.

During the Diluvian period of Cenozoic time the Earth completed its formative history,* and MAN, the highest type of mammalian life, made his appearance, and assumed sway over the lower creatures of nature's domain. "That Man was a contemporary of the Diluvian animal world, no doubt can now be entertained."†

The fauna with which he was coexistent was one clearly fitted for arctic life; and man himself at this early stage of his history was of an Esquimau character,‡ inhabiting a world which, though supporting hordes of animal life, was still largely given over to glacial action and vast areas of snow and ice.

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* So far as we of to-day are concerned this is true, yet the age in which we live is doubtless but an era in the progression toward a more advanced epoch to follow.

† Credner, *Elemente der Geologie*, p. 742.

‡ Müller, *Die ältesten Spuren des Menschen in Europa* (Basel, 1876), p. 30.

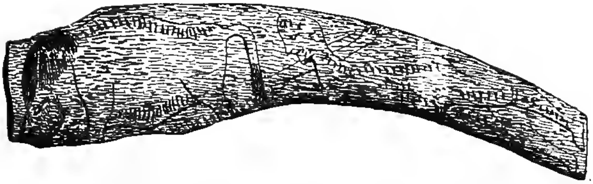

FIG. 7.—Hunter in the act of spearing a Diluvial Buffalo. Carved on Reindeer Horn, and recovered from the caves of Southern France in 1869. (After Nadaillac.) (*To face page* 53.)

The mastodon, mammoth, rhinoceros, reindeer and bear, which constituted the predominating mammalian life, were of gigantic form, and were protected from the severity of their native climate by coats of heavy hair and wool.

Not only are human bones found mingled with the remains of all these animals, together with the rude weapons by which they were often slain, but in many of the caves once forming the only dwellings of the human race, beneath the accumulated *débris* of Diluvian convulsions, and ages of subsequent accumulation, pieces of bone and ivory have been exhumed carved with representations of the animals with which men were then most familiar.

The number of the remains of gigantic elephantine forms recovered from Diluvian regions in all parts of the world is well-nigh innumerable.

In North America, they are chiefly of the family *mastodon giganteus*, preserved principally in the peat-beds of New York, New Jersey and in the regions of the Missouri River. In South America, the *megatherium* was recovered from the central plateaus, often at an elevation of more than 7000 feet.* In Europe and northern Asia, the predominating form was the *mammoth*.

"There is not in all Asiatic Russia, from the Don to the extremity of the promontory of Tchutchis, a stream or river in the banks of which they do not find elephants and other animals now strangers to that climate. These are washed out by the violent floods arising from the thaw of the snows; and have attracted universally the attention of the natives, who collect annually the elephants' tusks to sell as ivory." †

Credner estimates the number of individuals thus unearthed during the last 200 years at 20,000. ‡

The two earliest periods of human history have been often named, from the animal races most abundant then, as the *period of the mammoth*, and *period of the reindeer*. But the distinction thus made is of doubtful accuracy.

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* Von Humboldt, "Cosmos."

† Buckland, *Reliquiæ Diluvianæ* (London, 1823), p. 183.

‡ Credner, p. 739.

The geologic periods covered by man's existence, from the time of the earliest and rudest remains to the period of authentic history is divided into the—

1. STONE AGE.
2. BRONZE AGE.
3. IRON AGE.

The terms thus applied are, however, of more convenience than of strict accuracy.* The people of Asia and Egypt entered upon the Bronze Age of their history while Europe was still only in the midst of its period of Stone; and the Bronze of northern Europe was not displaced by Iron till the third century A.D.; and many savage people have not yet emerged from the Stone Age of their existence, and may never advance beyond this stage.

Prehistoric man, as is attested by the relics left behind when he disappeared from the world, was at first a dweller in caves and caverns, a shelter supplied him with no constructive effort of his own. But these first men seem to have been succeeded by a race of perhaps universal lake- or river- dwellers; for the pile-supported residences first discovered in the Lake of Zurich, and later in all the Swiss lakes, have since been supplied with counterpart structures in Ireland and Scotland and throughout Northern Germany.†

But though the human race thus occupied the lowlands and even the water itself, their four-footed contemporaries were not limited in habitat. Yet the great altitudes from which bones of Diluvian quadrupeds are sometimes recovered is no proof of so lofty a habitat, but rather evidence of more extended and mightier glacial action.

Buckland‡ records the discovery of such relics in central Asia at an elevation of 16,000 feet. And though he adduces the fact in support of a universal deluge, our present knowledge draws evidence of the unusual depth to which the Asiatic plateau must have been inundated by the Diluvian ice.

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* Heim, *Aus der Geschichte der Schöpfung* (Basel, 1872), p. 30.

† De Nadaillac, *Die ersten Menschen der Prähistorischen Zeiten* (1884), pp. 68–76.

‡ l. c., p. 223.

The recovered evidences of man's progressive existence during the Stone Age are as follows: 1. Buried human bones, and flint implements, with chippings caused by the manufacture of the latter. 2. Arrow-heads and other implements made of horn and bone, chiefly of the reindeer of the Diluvian epoch. 3. Bored or notched bones, teeth or shells. 4. Cut or carved wood, bone, horn, ivory or stone, often carved in the shapes of living species, or engraved with their likenesses. 5. Bones split that the marrow might be extracted for food. 6. Charcoal and other traces of fire used for cooking or warming. 7. Fragments of pottery.

This era was succeeded by the BRONZE AGE,* to which period belongs Trojan history. Then followed the IRON AGE, extending to the present, and covering most of the years of authentic history.

Lyell † asserts the existence of a veritable Copper Age between the eras of Stone and Bronze; and numerous facts seem to demonstrate the truth of this hypothesis. Switzerland, Hungary and America furnish incontestable evidence that men existed whose weapons and implements were of pure copper; while the excavations made by Dr. Schliemann in Troy demonstrate that the Trojans themselves used copper long ages before their knowledge of bronze began, or while the latter was esteemed as a precious metal, and regarded in the same category with gold and silver.‡

THE AGRICULTURAL INTEREST OF THE DILUVIAN PERIOD centres chiefly in geologic evidences of the birth of agriculture, resulting from human necessity.

Man's first step as an agriculturist, his first advancement from a gatherer of wild fruits and slayer of his fellow-animals, was doubtless made when he first domesticated some of the latter, and compelled them to minister to his needs.

The second period of the *Stone Age* doubtless witnessed this stride in human progress. Nadaillac records the change in

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* De Nadaillac ("Prehistoric America," p. 180) proves no age of bronze to have existed in America, though evidences of an age of copper abound.

† Lyell, "Antiquity of Man," p. 10.

‡ Rodwell, "Birth of Chemistry," pp. 30–40.

these words: "Two great facts predominate the new phase upon which humanity now entered: agriculture and the breeding of domestic animals. Fire was doubtless the agent which in the hands of these men rendered agriculture possible. Thanks to the potent action of this element, forests were reduced to ashes, and meadows, henceforth to be indispensable, took their places, and cultivation began. And the caves in which these progenitors dwelt were invariably located in close proximity to the fertile valleys and unfailing streams. . . . In the caves innumerable bones of cattle and sheep are found, but of wild animals all traces are lacking. These facts, as well as the character of the weapons and implements, make it evident that the people of this period subsisted chiefly on the products of their herds."* Again, the same investigator, in recording the characteristics of the Lake-dwellers of Switzerland, remarks: "During the long winter months domestic animals require regular feeding; therefore, wherever these animals exist we may expect to meet with evidences of agriculture."†

And in support of the assertion, the earliest submerged dwellings of the Swiss lakes, those with abundance of Stone Age implements, abound in remains of domestic animals; and in the houses of the next era, together with copper and bronze implements and remains of smelting-furnaces proving the metal to have been of home manufacture,‡ exist, side by side, bones of sheep, swine, cattle, dogs and cats, with wheat, barley, peas and beans.

The fact seems proved by incontestable evidence that agriculture, beginning in the middle of the Stone Age among all peoples, has progressed as man himself has advanced; and that, through all human history, the agriculture of a people has furnished the best evidence of the degree of civilization to which they have attained.

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* *Les Hommes préhistoriques.*

† l. c.

‡ Müller, l. c., p. 48.

THE ALLUVIAN FORMATION.

These deposits are those of recent origin, even now in process of formation.

The chief phenomenon of the period was the formation of the so-called *Terraces*, numerous in most lands, but nowhere more characteristically presented than in the valley of the Connecticut. They usually possess flat summits which have been levelled by the erosive action of water. These different levels rise tier above tier from the river-bed; and often border the stream in unbroken lines for miles of its course; each level or terrace having been at one time the bed of the stream, the repeated receding of which left the striated or terraced formation, so picturesque in its effect on the landscape of the present.

THE RECENT, modern or present period possesses ROCKS of four distinct modes of formation:

Of Mechanical origin, due to the action of water from which they are universally deposited; as, for instance, the alluvial of river valleys or bottoms, and estuary or delta formation.

Of Chemical origin, as stalactite formations, silicious deposits from hot springs, and deposits of bog-iron-ore.

Of Organic origin, as peat-beds, sea-beach deposits of shells, coral formations, bird excrement or guano, and Rhizopod and other deep-sea-mud deposits.

Of Igneous origin, as lavas and other ejections from volcanoes, or fissures in the Earth's surface.

THE AGRICULTURAL ASPECTS of the Alluvian period are, so far as their geological conditions are concerned, the features of to-day. The soils are invariably of fresh-water deposit, and consist of the most finely pulverized material detached from the rock-mass by the disintegrating forces, and, borne away by the rains, gains access to streams, and by them is swept seaward, either to be deposited along the valleys traversed, or carried on to increase the delta-formation being built up at the river's mouth.

But whether the formation exist as inland river-bottoms, or as islands formed at river-mouths, it is invariably the most fertile of soils, and not infrequently rendered exhaustless by constant accretions of water-sediment coming with every flood.

The changes and formations of this era, however, are of the present. Their history is unfinished, but embraces the chemistry of the processes by which the Earth's surface was brought into the condition in which it became man's dwelling-place; and is made to furnish sustenance for the ever-increasing needs of the ever-multiplying human family.

PART II.

ROCK COMPOSITION AND DECOMPOSITION.

CHAPTER I.

CLASSIFICATION AND COMPOSITION OF ROCKS.

HAVING followed the Earth through the various phases of its formation till the world of to-day, the inhabitable home of man, has been evolved by ages of geological progression, we find the solid portion of our planet, the geological structure as finally completed, composed of rock and soil, the latter containing all the chemical elements of the former, from which it was produced by physical and chemical action and change.

The chemistry of the soil, then, its composition and characteristics, can be studied only through the rock from which it was formed.

As the soil is the product of rock decomposition and transformation, so is the rock the product of mineral aggregation. The properties and decomposition of rocks are, therefore, fundamentally determined by the properties of the minerals composing them.

THE SYSTEMATIC CLASSIFICATION OF ROCKS offers difficulties which have as yet prevented the production of an arrangement which shall combine the advantages of answering the demands of our present scientific knowledge of the origin and composition of rocks with the simplicity required of a practical working system.

Proposals and attempts at a solution of the difficulty have been made by chemists, geologists and mineralogists; and still one of the most eminent of them all admits that "as yet no one has succeeded in producing a perfectly consistent and comprehensive system." *

Systems based on chemical composition, on physical properties, and on the origin of rocks, have been introduced, and have found advocates and followers. But rocks are not definite compounds; no fixed composition can be assigned to, or discovered in, rocks of a given kind; and still greater uncertainty arises from the fact that a given composition as determined by analysis may belong to many rocks of widely-varying nature. The analysis presenting results of 72% SiO_2, 11% Al_2O_3, 2.8% FeO and Fe_2O_3, 1% CaO, 1.2% MgO, 1.2% K_2O, 2%, Na_2O 8.4% H_2O, might answer equally well for granite, gneiss, felsite, granulite or quartz-porphyry.

It therefore follows that a classification based on chemical composition fails to furnish the requisites of accuracy and simplicity. Physical properties are hardly more satisfactory as a means of determination.

Rock-origin, therefore, remains the most acceptable and widely adopted basis for rock-classification. But even here we are met by variations of application both important and numerous. From a mineralogical standpoint, the arrangement of all rocks into five varieties,—

I. Igneous Rocks;
II. Metamorphic Crystallinic Schists;
III. Sedimentary Rocks;
IV. Rocks of still doubtful origin;
V. Rocks consisting of but one mineral;

—as proposed by Von Cotta, is perhaps the most acceptable.

Still, Dana's division into three groups—

I. Fragmental;
II. Crystalline;
III. Calcareous;

—offers advantages of simplicity and conciseness.

For our purposes, however, as students of *rocks as related to soils*, still greater simplicity is attainable without the sacrifice of either exactness or accuracy.

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* Von Cotta, "Rocks Classified and Described" (1877), p. 115.

All rocks may be considered either as crystalline or as non-crystalline. We adopt the former as our first division, and the "Fragmental" or "Sedimentary" will form the second group, while the "Calcareous" of Dana may be assigned to either section as the individual rock chances to be of crystalline structure or not. For our purposes, then, rocks are of two kinds:

I. Crystalline;
II. Non-crystalline.

Each group is further considered as embracing rocks both *simple* and *complex*, according as one mineral alone, or more than one, enters into the composition of the individual.

I. CRYSTALLINE ROCKS.

The cause of crystallization varies with different kinds of rocks, three methods or conditions of crystallization being recognized.

1. *Solidification through cooling*, resulting in rocks known as *igneous* or *eruptive*, embracing all varieties of rock resulting from exudation of molten material through fissures in the rock crust of the Earth, of which the trap dikes form the best illustration.

2. *The action of long-continued heat below the point of fusion*, resulting in *metamorphic rocks*, that is, transformed rocks, the conversion of sedimentary or non-crystalline rocks into rocks of a crystalline texture, the conversion of mud, sand or gravel into granite and gneiss, furnishing examples of such transformation, which does not affect the order of deposition or stratification.

3. *Chemical Precipitation.* All natural waters hold carbonic acid gas (CO_2) in solution, which compound greatly increases the solvent power of the water. Alkaline carbonates are more readily attacked by this dissolving agent, the insoluble monocarbonates being thus converted into soluble bicarbonates. If now the water holding the compound thus formed be subjected to heat or become evaporated, the excess of carbonic acid being volatile is again set free, and an insoluble carbonate is again formed. Lime is the base, and limestone the rock, most

often thus affected; the abundant stalactite and travertine formations of so many regions owing their origin to this chemical reaction. Silicic acid (SiO_2) present in waters effects a similar transformation by the conversion of soluble compounds into insoluble silicates which become deposited because of the conversion. Geyser regions, the hot waters of which are so impregnated with silicic anhydride, furnish extensive areas of such deposits.

Waters containing an alkaline solution may dissolve the silica of tripolite, infusorial earth, a deposition of which results in the formation of flint or chert.

Having reviewed the origin of the crystallization of rocks, let us consider the chemical composition of the minerals composing these rocks, and which, through them, enter into the composition of our agricultural soils.

CRYSTALLINE ROCKS (SIMPLE).

QUARTZ constitutes not only the principal mass of most rock-formations, but exists in several isolated forms, as rock-crystal, quartzite and quartz-sand. Chemically speaking, the mineral is anhydrous silicic acid or silica (SiO_2). It forms transparent hexagonal crystals, so excessively hard as to scratch glass.

FELDSPAR is, next to quartz, the most abundant mineral in nature. It is a green, yellow, brown or gray compound of SiO_2 with alumina and one or more alkalies or lime. There are several distinct varieties of the mineral according to composition and manner of crystallization. These are: Orthoclase, or Potash feldspar; Oligoclase, or Soda-lime feldspar; Albite, or Soda feldspar; and Labradorite, or Lime-soda feldspar. The feldspars are one of the most frequent constituents of many common rocks, and form also the chief material for the natural production of kaolin.

ZEOLITES embrace an extensive group of non-magnesian, hydrous silicates, closely resembling the feldspars and also nearly akin to the Augites. They may be colorless, white, gray, reddish or flesh-colored; and contain a great deal of water, even 20%. They are easily decomposed by the weaker acids.

AUGITE and AMPHIBOLE or HORNBLENDE group. In these minerals the SiO_2 is combined with magnesium, calcium, iron, and manganese instead of the alumina and alkalies of the preceding forms. The *Augite* is usually black and glassy, and but slightly or not at all attacked by acids. It is a compound of SiO_2 with lime, magnesia and iron protoxide, in which alkalies wholly disappear. A notable feature of the mineral is the not infrequent presence of considerable quantities of phosphoric anhydride (phosphoric acid, P_2O_5). *Amphibole* or Hornblende may consist of silicate of alumina and magnesia, or a silicate of alumina and lime. The first is black or black-green; the latter is brown to black.

MICA consists of silicates of alumina with potassium, magnesium, calcium, iron and manganese; and is an exceedingly abundant mineral, occurring, as it does, in almost every variety of rock. In color it is silver-white, gray, blue-green or brown, yellow and black. Its peculiar characteristic is the ease with which it splits or separates into layers of marvellous thinness. A distinction is drawn between potassium and magnesium *mica;* the latter, aside from its obvious difference in chemical composition, being harder and nearly black in color.

TALC is a silicate of magnesia, containing traces of iron protoxide and alumina. It possesses a peculiar fatty feel, is very soft, and in its massive state is known as soapstone.

SERPENTINE possesses a composition identical with that of talc, except that the magnesia of the former is usually replaced in part by iron-protoxide, and it is green in color.

OLIVINE occurs as small round spots in basaltic and other eruptive stones. It consists of silicate of magnesia and a varying proportion of silicate of protoxide of iron.

NEPHELINE is a whitish-gray or yellowish-gray glistening compound of SiO_2, alumina and soda; and is wholly decomposed by the action of hydrochloric acid (HCl).

LEUCITE is an anhydrous silicate of alumina and potassa, existing chiefly in volcanic rocks. It occurs in hard, white, 24-sided crystals formed by heat in lava, and was the mineral in which the element potassium was discovered by Davy.

TOURMALINE consists under varying circumstances of a score of different elements, so that no definite composition can be given it; silicon, boron, iron, phosphorus, potassium, sodium, lithium, calcium, magnesium, fluorine, manganese and aluminium, at times being present in it. The mineral is of a variable black, green, and red color, usually very dark, however. It is an essential ingredient of shorl, and often occurs in granite, forming beautiful columnar crystals.

IRON MINERALS. Many compounds of iron occur as constituents of mineral varieties, or form the mass of rock-formations; and play an important *rôle* in the decomposition of rocks and the resulting formation of soils. These are: Iron spar, carbonate of iron; Red Iron stone, iron oxide; Brown Iron stone, iron oxyhydrate; and Iron Pyrites, or bisulphide of iron (FeS_2).

APATITE is a native phosphate of lime, usually combined with some chlorine and fluorine, besides occasional other ingredients, as, for instance, the compact earthy variety known as phosphorite. The mineral is crystalline, usually green or yellowish; but in Norway a pinkish variety exists. With the exception of phosphorite, the Apatite minerals all form more or less beautiful crystalline masses.

CALCITE, or carbonate of lime, is very widely distributed throughout nature, forming in its different amorphous forms marble, chalk, coral and the very great number of limestone varieties.

MAGNESITE is the native carbonate of magnesia, but is of comparative rarity, though closely resembling crystalline calcite.

DOLOMITE consists of a union of the carbonates of magnesia and lime in variable proportions. It is crystalline, and exists in many so-called marbles, besides being widely distributed of itself, and occurring as an ingredient of hornblende and some augite rocks.

GYPSUM, or hydrous sulphate of lime, has many characteristics akin to those of dolomite. It is very abundant and soluble, and exists in most agricultural soils; ground, it is the so-called "land plaster," and, burned till its water of crystallization is expelled, it becomes the "plaster of Paris" of the arts. It is never a component part of crystallinic rocks; but some of the varieties, as alabaster, are susceptible of a most beautiful polish.

ROCK SALT, or sodium chloride, is one of the most abundant of all minerals, existing not only in the solid or rock form, but also, from its unusual solubility in water, existing in most mineral springs, and forming the chief mass of the saline constituents of salt waters.

CRYSTALLINE ROCKS (COMPOUND).

The rocks of this division are most frequently grouped into two classes according to chemical composition, the content of silica being the dividing factor.

Those rich in silicic anhydride (SiO_2) are brought together as ACIDIC ROCKS; while those poor in this constituent are designated BASIC ROCKS.

The first class, as a rule, embraces rocks of a light color, vitreous in character, and containing large quantities of quartz.

The second class is more frequently open in texture, usually of a dark color, contains small amounts of quartz, and correspondingly large quantities of lime.

AVERAGE COMPOSITION OF ACIDIC AND BASIC ROCKS.

	Acidic.	Basic.
Silica, SiO_2,	60—80	45—55
Alumina, Al_2O_3,	8—16	10—20
Iron Protoxide, FeO, Iron Sesquioxide, Fe_2O_3,	1—15	1—15
Lime, CaO,	1—5	1—10
Magnesia, MgO,	0—4	1—6
Potash, K_2O,	1—6	1—4
Soda. Na_2O,	1—6	1—5
Water, H_2O,	0—8	0—7

1. *Acidic Rocks.*

These consist of combinations of orthoclase, sanidin, oligoclase, quartz, mica and hornblende.

GRANITE consists of quartz, orthoclase and mica, possessing no appearance of cleavage; the feldspar is usually flesh-colored, and reflects light brilliantly; the mica varies from silver-gray to black in color, and exists in thin scales. The rock is exceedingly hard and abundant, and exists both as eruptive and metamorphic.

SYENYTE consists of othoclase, oligoclase and hornblende, or, in place of the latter, augite or mica. The rock is distinctly grained and crystallinic.

GNEISS differs from granite in its slate-like structure, the composition of the two rocks being the same, but the relative quantities of the individual constituents varying. Gneiss is quite irregular in appearance, and is known as red gneiss and gray gneiss, and as silicious and non-silicious gneiss.

GRANULITE is granite or gneiss without mica. It is slaty in texture, fine-grained, and contains frequent small garnets.

PORPHYRY consists of a compact mass in which orthoclase or orthoclase and quartz in fine grains lies bedded. The ground-mass may, or may not, contain quartz: this is true porphyry or quartz-porphyry. The quartz-free is the so-called orthoclase-porphyry.

TRACHYTE consists of rough, porous, finely-crystallinic rock, in which larger crystals of hornblende and mica are imbedded. The ground-mass is usually of a yellow, gray or reddish color. It is of eruptive origin, and cleaves into thin plates.

PHONOLITE is composed of compact, finely-crystallinic masses in which are imbedded hornblende, sanidin and magnetite. The chief mass is of a yellowish or greenish-gray color, and separates easily into thin large tables and large pillars. The stone possesses a remarkable resonance of sound which gives it the name ringing-stone.

MICA-SCHIST consists chiefly of mica, but contains much quartz and some feldspar. On account of its mica it separates

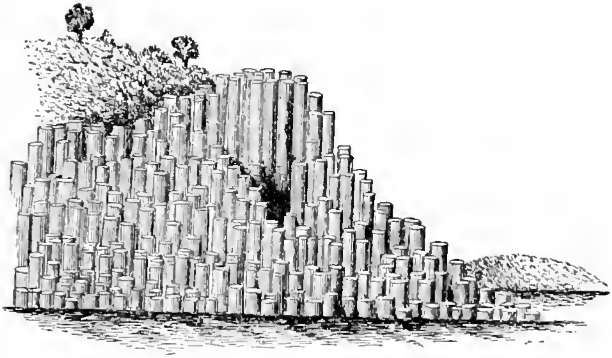

Fig. 8.—Basaltic Columns. (After Dana.) (*To face page* 67.)

readily into slabs, is very schistose. Both of the micas are usually present, but the black mica is generally most abundant. The color varies from silvery to black, according to the amount of mica present. It is metamorphic, and often crumbles with great ease.

MELAPHYRE is usually a fine-grained, compact quartz-free-stone, consisting of feldspar, augite, olivine, magnetite and green protoxide of iron silicate. It is dark-colored, unstratified, but deposited in flat single layers, often occurring between the strata of coal-deposits, and in the Permian formation.

BASALT is a dark-gray, sometimes nearly black, eruptive stone, exceedingly hard, consisting chiefly of augite and magnetite; while different varieties contain besides feldspar, nepheline, leucite and mica. The coarser-grained basalts are known as doleryte, and the fine-grained as anamesyte; while the stone whose mass seems to the naked eye homogeneous and uncrystalline is termed basaltite. This rock is invariably unstratified, but deposits of it may occur in the formations of any age. The chief and remarkable peculiarity of the basalt is its separation into regular 5–7-sided pillars, sometimes of enormous length.

2. *Basic Rocks.*

These rocks consist of a union of the various feldspars with augite, pyroxene, hornblende or mica, with the occasional presence of magnetic iron ore and olivine; and are marked by a total absence of quartz.

DIORYTE is a grained crystallinic mass composed of feldspar and hornblende. There are several varieties of the stone, distinguished by being composed of hornblende poor in lime and rich in magnesia, with oligoclase, in which lime and iron hornblende are united with lime feldspar.

CLAY-SCHIST is so fine-textured, that its crystallinic structure is often not visible to the naked eye. It is generally nearly black, and consists of clay combined with more or less quartz and mica. Many clay-schists contain carbonates in their composition; and often well-preserved organic remains are present. Ordinary *slates* comprise the largest portion of these rocks, the roofing slate being the best and most common example.

CHLORITE-SCHIST is grayish-green in color, remarkably even and regularly stratified. It contains usually some quartz, feldspar, mica and talc.

DIABASE is a crystal-grained stone, consisting of feldspar, augite, chlorite and titanic iron. It is quartz-free, though a so-called quartz-diabase is known. Calcite exists in all diabase, and no stratification is ever present. The rock is quite abundant, particularly in the so-called metamorphic formation.

HYPERYTE is a granite-like stone, unstratified, and exists chiefly in Labrador.

GRANULAR LIMESTONE is a nearly pure calcium carbonate, usually coarsely crystalline. It is white, or nearly so, in color, possesses fine lustre, assumes a beautiful polish, and is commonly known as *marble*.

II. NON-CRYSTALLINE OR FRAGMENTAL ROCKS.

These are the sedimentary rocks of geologists, and are secondary products resulting from the decomposition of eruptive or metamorphic rocks, and subsequent deposition from water. They are simply consolidated beds of gravel, sand or mud. Each part of the material forming these beds consists of particles of pre-existing rocks, fragments of the same, altered more or less by decomposition; hence the term Fragmental.

CONGLOMERATE is composed of fragments of crystalline rocks imbedded in calcareous or siliceous binding material. If the pebbles are water-worn, the product is *pudding-stone*; if angular, the rock is called *breccia*.

The conglomerate varieties are numerous, varying with the character of the pebbles and the kind of binding material.

GRIT consists of hard gritty material, chiefly sand and pebbles. It is the "millstone-grit" of geology, so named from its frequent use as millstones.

TUFA is invariably of volcanic origin. Volcanoes, in a state of eruption, emit enormous quantities of scoriaceous masses of varying sizes and called "bombs." These are accompanied by masses of volcanic sand and ash. These materials are frequently swept by the winds long distances from the point of eruption before they are finally deposited by gravity; having, however, become assorted by the same force during their passage, the materials of corresponding size and weight being collected together.

If, now, the material becomes deposited in water, or, as is so often the case in volcanic eruptions, water is an accompaniment of the action, the exuded material becomes regularly stratified, the layers presenting various shades of yellow, gray and brown; and by decomposition becomes capable of sustaining vegetable life, but never forms desirable agricultural soils.

SAND and GRAVEL. The former of these two communicated materials is almost exclusively of quartz origin; while the latter contains in addition pebbles and stones in almost numberless variety.

SANDSTONE results from the solidification of beds of sand. They consist of particles of rock not reduced to solution by water, but gathered together and deposited by the same, and then solidified either by pressure or other means. Silica, being the rock constituent, at once most abundant and most insoluble, forms the chief and commonest material for sand, and, hence, for sandstone formation. The rock produced is invariably stratified, and not infrequently consists of nearly pure quartz. Sandstones may also be calcareous and argillaceous. The Connecticut River "freestone" is a sandstone containing feldspar and glistening particles of mica.

GREEN-SAND is essentially a mixture of the silicates of iron and potassium. It occurs chiefly in the Cretaceous and Tertiary formations, and is a valuable manurial substance.

CLAY consists chiefly of silicate of alumina. It is palpable and plastic; may be colored by mineral constituents either white, yellow, red, brown or even black. It is mainly a product of feldspathic decomposition.

SHALES are rocks embracing soft, slaty, compacted siliceous clays which by metamorphism become argillaceous slates.

ALLUVIUM is the finely-divided earthy deposit from running waters, more especially during the time of floods. It forms the river "bottoms" and delta formations of proverbial fertility.

CHALK is a carbonate of lime of organic origin, consisting of the remains of calcareous infusoria. It is the characteristic deposit of the Cretaceous formation.

MARL consists of calcium carbonate mixed with earthy matter and often appreciable quantities of fragments of shells. It is of considerable importance as an artificial fertilizer.

CHAPTER II.

DISINTEGRATION THROUGH INTERNAL FORCES.

HAVING established the important facts of rock-composition as related to their subsequent conversion into soils, before tracing the chemistry of their transformation, before discussing the changes effected by rock-decomposition, another class of phenomena, an intermediate stage, presents itself, and demands review, that all the steps in the geological progression whose ultimate end is soil-production may be considered in logical sequence, as natural law moves on from cause to effect.

The surface of the Earth, its rocks and soils, solid land and expanse of waters, has been, through all geological time, subjected to the action of forces which have constantly modified the surface conditions of the Earth, and finally brought it to the form and contour in which it now exists.

These forces are the factors of *Earth Development*, and their study forms the domain of DYNAMICAL GEOLOGY.

Volcanism in its various forms of manifestation, the action of water, of air. and of organic life, are the primary causes through whose agency the present physical conditions of the geological world have been effected.

These are the great "*development forces*" through the exertion of which rock-masses were formed and transformed in obedience to natural laws.

So far as the activity of these forces is accompanied by direct chemical action and a resulting modification of rock-structure is concerned, they belong to the agents of rock-decomposition, and demand consideration among the factors and causes of soil-formation.

But their activity is not seldom of a passive or adjunct nature, whereby the modifications of surface conditions as resulting from the exertion of these forces are *indirectly* the cause of many of the phenomena of rock-disintegration.

As such, the forces belonging to the sphere of Dynamical Geology become important factors in any consideration of the principles of AGRICULTURAL CHEMICAL GEOLOGY.

Among the natural phenomena thus demanding attention as indirect factors concerned in the conversion of rock-masses into agricultural soils, those of a Volcanic, Eruptive or Thermal nature are of paramount importance.

I. VOLCANOES.

The term volcano is applied to a mountain or hill which is, or has been, connected with the Earth's interior by means of a canal through its centre, the external opening of the canal being designated *the crater.*

According to individual structure and mode of formation, Von Seebach divides volcanoes into *Stratified* and *Homogeneous;* the material of the former being, through successive periods of eruption, deposited in layers or strata; the latter having been formed from molten material which has solidified into a homogeneous solid mass.

The form and appearance of the individual volcano depends almost entirely on the material of which it is composed. Lava, tufa and ash each resulting in cones of characteristic form and contour.

THE LAVA CONE originates in fluid material, molten stone, which, flowing from the crater in streams, expands over the territory reached, forming low hills, or even terraces of regular shape, or circular banks around the point of eruption. This form is best illustrated by Mt. Loa, Kilauea, and other Hawaiian volcanoes.

THE TUFA CONE owes its origin to the eruption of tufa, ash and sand, mixed usually with hot water. The pulpy mass thus formed rises in rings or circular waves around the crater, flows over the sides and gradually rears a cone around the crater, which latter attains a shallow, basin-like form.

THE ASH AND SAND CONE is formed from the fine impalpable material thrown from the crater often to considerable height, and which, by falling back near its point of exit, builds up around the crater a cone of dry, pulverized, volcanic *débris*, consisting of ash, sand and *lapilli*. The material becomes arranged by gravity, so that it forms a well-stratified formation, the fine and coarse material following each other in successive layers.

Volcanic action is not confined to the land alone ; but may exist beneath the sea, or may bring into existence islands which are formed above the waves in a single night, and become permanent abodes, with final formation of soil from the decomposed eruptive matter. The island of Santorin in the Grecian Archipelago having had such an origin in the year 1866.

A noteworthy characteristic of the stratified volcanoes is the fact of their almost universal location in the near vicinity of salt water. The chief of such volcanoes all being situated either on islands or along the coast of continents, facts which point to the sea as the source of the water which gives character to their phenomena.

THE CONDITIONS AND CAUSES OF ERUPTION may be traced to a chemical origin.

The heat of the Earth's interior is such that not only are all the elements of which the solid earth is formed reduced to a state of fusion, but the temperature is sufficient to decompose many inorganic compounds, and to reduce the constituents to a gaseous state.

The craters of most active volcanoes, therefore, while in a state of quiet, become filled with the gases thus evolved: hydrogen, chlorine, sulphur-dioxide, sulphurous acid, hydrogen-chloride, sulphuric acid, carbonic acid, boracic acid, and, above all, hydrogen-oxide gas, or *steam.*

These gaseous substances are all explosive compounds under confinement, and mixtures of certain of them are of themselves violently explosive, hydrogen with chlorine and hydrogen with oxygen being among the most powerful explosives known to chemical science ; the former exploding violently by the action of sunlight, the latter in the presence of heat.

Others of these compounds are combustible or inflammable, as hydrogen and hydrogen sulphide.

If, now, the explosive gases become ignited or the gas-production abnormally increases, or, more powerful yet, if the crater has become closed through the solidification of lava, the accumulated and confined force within breaks through all barriers, and the volcano enters upon a state of activity more or less protracted as the accumulated force is great or limited.

Two immediate causes for the final eruption of lava, ash and gas are recognized, each of which may result in eruptive action independently, or both may combine as the factors producing a given outburst.

First, the gradual but constant cooling of the earth's surface is accompanied of necessity by a corresponding contraction of mass. This contraction naturally forces the fluid contents of the Earth's interior into such crevices as are open to them, where they either solidify as eruptive veins, or burst forth in the form and with the phenomena of a volcanic eruption.

Second, and more important both through frequency and magnitude of results, is the eruption in which water is the prime factor.

Notice has already been drawn to the fact that the chief active volcanoes of the Earth are situated in close proximity to the great oceans. Sea-water has access to the crevices of the Earth's surface, and enters the pores of the world's great rock-mass. Impelled both by gravity and capillarity, it works its way gradually downwards, forced deeper and deeper by the increasing weight of the pressing water-mass above, till finally the region of constant fusion is reached.

Here the enormous pressure to which it is subjected prevents a conversion into gas, evaporation and steam-formation are impossible, and the water is forced to unite with the molten mineral matter and form a magma.

This mixture is forced, either by its own expansion or by the Earth's contractive pressure, upwards into every gallery or crevice of the inner surface, and rising surface-wards, explodes immediately on gaining an altitude at which the pressure becomes sufficiently reduced to permit the conversion of water into steam. Ash, *lapilli* and bombs fly heavenward through the opening or crater; the Earth quivers and trembles with the recoil; gases in stifling clouds roll upward; the molten minerals of the magma flow from the fissures; and the volcano is in a condition of active eruption.

The final outburst or eruption is preceded by quiverings and tremblings of the Earth with the efforts of the pent-up force within to find vent; deep rumblings and rollings like subterranean thunder ensue; explosion follows explosion with increasing rapidity; the snow melts from the lofty summit; the mountain streams and springs become dry; the seething lava in the crater bubbles higher and higher, and finally bursts over the crater-walls, and flows, a glowing burning mass, down the mountain-sides. A pillar of smoke rises over the cone; clouds of ashes darken the heavens; masses of red-hot rock, *lapilli*, are thrown aloft; and flashes of lightning dart from the electric charged pillar of smoke, followed by peals of thunder. The gases forming the column of vapor rising from the crater, the pinie, may become ignited, and tower, a pillar of fire, over the doomed region below.

The eruption may be accompanied by an outpouring of waters, resulting in the precipitation of showers of sand and ash, darkening the heavens, and not seldom floating hundreds of miles before finding a final resting-place.

THE LAVA STREAM begins its flow after the tremblings, explosions, quakings, *lapilli*, and showers of ash and sand have reached their height; and with the outflow of lava, the violence of the eruption ceases; relief for the pent-up forces within is gained, and the period of normal activity sets in. The molten stream rolls over the crest of the crater, or pours through crevices opened for its exit in the mountain-sides, and often expands into extensive fields, where it cools in dense undulating masses; successive eruptions building rock-accumulations pile on pile in picturesque and rugged grandeur, to await the slow disintegration of time.*

The craters of the larger volcanoes seldom emit lava, but from them gases and volcanic dust are poured forth in stifling clouds; while the molten material finds exit through fissures lower down the mountain-cone.

The duration of lava-flow is seldom very protracted, though in isolated instances the outflow has continued for more than two years.†

The rate of motion, also, may vary from glacier-like slowness to avalanche precipitancy, depending for rapidity on density and surface incline.

The thickness or depth of the moving stream is most usually measured by inches, but frequently rolls on, a devastating, overwhelming scorifying flood many feet in depth, cooling but gradually, and often possessing a molten interior years after all onward flow has ceased; and even after vegetation has gained a footing on the cooled and disintegrated surface.

ROCK TRANSFORMATION AND DECOMPOSITION are frequent and normal results of volcanic action. We have seen that water-gas ‡ is not the only gaseous product of volcanic action. The sodium chloride and other components of sea-water become decomposed into their gaseous constituents, but these even are not all.

It is commonly believed that the molten interior of the Earth consists of a magma permeated by hydrogen, oxygen, nitrogen and chlorine, accompanied by sulphur and carbon in large quantities, in the presence of all the mineral ingredients of rocks

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* The ascent of Vesuvius presents most forcible illustration of the peculiar phenomena, the products of successive eruption, in all the stages between hot lava and decomposed rock supporting advanced vegetable growth, abounding.

† Credner, *Elemente der Geologie*, p. 162.

‡ The author takes the liberty of introducing this word as the equivalent of the German *Wasserdampf*, for which neither *steam* nor water-vapor is a synonym, not being a gas, but having already undergone condensation and precipitation.

and the water-vapor absorbed at the original condensation of the cosmic nebula.

By decrease in pressure these gaseous substances expand or explode, and are forced into the outer world, accompanied by all the phenomena of volcanic eruption; or may quietly escape through fissures in the Earth's surface existing in volcanic regions.

The hydrogen sulphide and sulphurous acid, on gaining access to atmospheric oxygen, become oxidized into sulphuric acid, the most powerful of mineral acids, which attacks the silicic-acid compounds, and combining with the bases present, forms multitudinous new compounds from every rock-mass with which it comes in contact.

Eruptive rocks, thus acted on, lose their dark color, their density, tenacity and hardness, being finally transformed into porous, easily-disintegrated tufa or clay-like compounds.

The more common products of the action of volcanic vapors on rock-forms are alum, sulphate of iron, and calcium sulphate or gypsum, including the variety alabaster.

It thus appears that volcanic action not only results in the extensive formation of new rock material which becomes in time by natural disintegration capable of furnishing vegetable nutriment, but the volcano, thus adding to the mass of undecomposed rock of the earth, contains within itself the very agents required for the decomposition of the same, and furnishes the means for the chemical transformation and ultimate decomposition of every rock subjected to its action; thus becoming an active agent in the process of soil-formation, and the conversion of insoluble mineral matter into direct plant-food.

II. THERMAL WATERS.

HOT SPRINGS are widely distributed over the earth, particularly in volcanic regions; still they not infrequently occur far removed from the scene of active volcanic action, especially along extensive lines of fault.

Their temperature is generally due to volcanic origin, but also frequently owes its cause to the depth of its source. It has been experimentally determined that the temperature of the Earth increases 1° C. for every 33 m. of descent from the surface. It therefore follows that all waters of subterranean origin below a depth of 3300 m. must be heated to their boiling point of 100° C.

Hot springs consist only occasionally of pure waters, from the fact of the greater dissolving power of hot water than of cold. The springs are therefore mineral in character. The greater part of the famous medicinal waters of Europe are of a medium-high temperature.

The most abundant mineral constituents of such springs are compounds of carbonic and silicic acid and chlorine, with calcium, magnesium and sodium. Sulphates are usually present if the waters exist in volcanic regions.

The outlets of these subterranean streams are, from the presence of these mineral compounds, usually surrounded by deposits of carbonates, silicates and hydrates; the silicious deposits, in particular, often forming high walls around the place of outlet. The amount of mineral matter thus dissolved from the rocks, with which the waters come in contact, and deposited along the external courses of the springs, is enormous. One illustration will be convincing.

The famous *Carlsbad* hot spring is estimated to deposit an annual burden of 2500 kg. of calcium fluoride, 600,000 kg. of sodium carbonate, 11,000,000 kg. of sodium sulphate, besides vast amounts of calcium carbonate and sodium chloride.*

GEYSERS are the form of thermal waters producing phenomena of greatest magnitude, and of interest proportional to the singularity of their nature.

They are intermittent in action; and the columns of water thrown from them are not infrequently forced upward more than a hundred feet, to descend in clouds of steaming spray.

The chief geyser regions of the world are in Iceland, New Zealand, and the Yellowstone Park in the United States; while other countries furnish many isolated individual geysers, Japan possessing a numerous representation.

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* Credner, pp. 171–2.

The chief geyser of Iceland is that of Hekla. Its outlet is surrounded by silicious deposits which have reared a mound 32 feet high and 215 in diameter. In the centre of the dome thus formed, a basin 7 feet in depth and 60 feet in diameter exists, into the bottom of which opens a channel 10 feet in diameter and of fathomless depth.

The water of the basin varies in temperature from 76°–89° C., but increases in the channel till at a depth of 98 feet a temperature 27° C. above the boiling-point is recorded.

The intervals between the periods of activity vary from 24 to 30 hours; and the final outburst is supposed to be due to causes similar to those resulting in volcanic eruptions.

At the depth at which vaporization of the water would be possible, that is, the depth at which the water temperature reaches 100° C., the pressure of the enormous column of water prevents all conversion into vapor, and no overflow is possible.

But the heat of the superheated liquid radiates gradually into the cooler waters above till they reach the vapor-point, when an explosion occurs, resulting in throwing the immense volume of water 120 or more feet into the air. Falling back into the basin, the enclosed waters are again cooled below the boiling point, and the process begins anew, to repeat itself again after each lapse of 24 or more hours.

The American National Park abounds in geysers of unsurpassed grandeur and magnitude, in keeping with the wonderful phenomena for which the region is renowned.

Streams of hot water and a boiling lake add to the magnitude of the thermal phenomena presented. The total number of active geysers is probably not less than one hundred. Of these the *Beehive*, the *Giant*, *White Mountain* and *Old Reliable* are the most noteworthy. The first-named seldom experiences activity oftener than every third day; but is violent in action, and forces its mammoth fountain spray 140 feet high. The last-named is active at intervals of less than an hour, and throws its mighty column as high as its neighbor, but with less accompaniment of steam, spray and explosion.

THE ROCK DECOMPOSITION resulting from thermal action is of a nature identical with that recorded as resulting from volcanic eruptions, and needs no further comment.

The industrial importance of thermal waters as sources of heat and power is just beginning to receive recognition.

The city of Baden-Baden has long been supplied with hot water conducted from its famous springs to all parts of the town for domestic and economical use. And the capital of Hungary, Buda-Pesth, is even now successfully experimenting with the bold project of supplying its houses and factories with water, heat and power extracted from the Earth's interior in the form of thermal waters artificially confined, and brought into service.

III. CONTRACTION OF THE EARTH'S SURFACE.

Any force or natural phenomenon resulting in the changing of surface conditions, the rupture of strata or rearrangement of strata relations, becomes of direct importance as a producer or abettor of rock-transformation and disintegration.

Among the occurrences of this nature, and therefore demanding consideration, *changes of surface level*, *mountain formation*, and *earthquake action* are of chief significance, and the origin of all may be traced directly to the contraction of the Earth's surface resulting from the gradual reduction of temperture through radiation of heat and consequent cooling.

A. GRADUAL CHANGES OF SURFACE LEVEL.

Firm and inelastic as the solid Earth's surface may casually appear, many portions of it covering extensive areas are still gradually undergoing either elevation or depression of level.

The movement is usually so slight, or is extended over geological periods of time so great, that the fact of change of level would be difficult of determination, did not the sea-level offer a permanent standard or base for comparison.

The phenomena thus made apparent embrace occurrences of almost universal extent and significance.

--Sea cliffs and beaches buried beneath the waters of former times are found to-day high and dry above the tide. Harbors become useless through shallowing because of elevation of bottoms. Coast-lines creep gradually out to sea. Coral formations are laid bare; and shores of ocean and fresh water alike gradually disappear beneath the flood, bearing into the waters the relics of the time of sinking for the enlightenment of coming ages.

ELEVATION OF SURFACE finds its most striking and best-known illustration in the Scandinavian peninsula, the coast of which has not yet gained a final equilibrium since the disturbances to which it was subjected during the Cenozoic time.

Norway presents tide-water markings on the sides of cliffs, and deposits of marine fossils of recent origin from 400 to 500 feet above the present sea-level. The most vivid presentation of the phenomena existing in the neighborhood of Tronhdjem, while in the vicinity of Christiania, terraces and beaches of water-washed sand exist at an elevation of more than 600 feet. The force which thus reared a great expanse of territory several hundreds of feet above its former level is still at work, and its progress is recorded by the National Geological Survey of Sweden and Norway.

The occurrences in Scandinavia find corresponding phenomena in Scotland and Chili. In the former country the so-called "raised beaches" exist 30 feet above the sea, and extend often for many miles along the coast; presenting not only recent fossils, but well-preserved relics of man's existence in the form of canoes and implements of stone.*

In Chili the elevation of the coast region is still making appreciable progress, and is doubtless one of the causes resulting in the formation of the deposits of nitrate of soda (Chili saltpetre), to which, perhaps, more than to any other cause the country owes its prosperity.

DEPRESSION OF SURFACE is an occurrence of far greater difficulty in establishing, owing to the lack of standards of comparison of level through disappearance of surface beneath the sea. Yet though the rate of disappearance is hard to determine, abundant evidence of such action is brought to notice.

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* Lyell, "Antiquity of Man," p. 60.

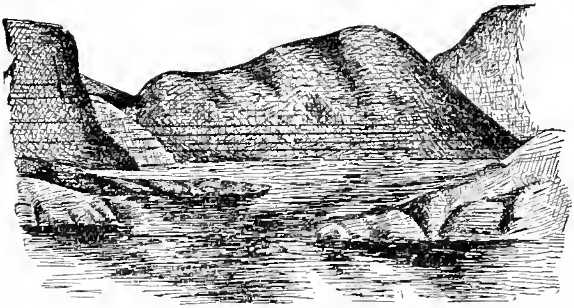

FIG. 9.—Sea-terraces of Norway, showing elevation of land. (After Geikie.)

(*To face page* 80.)

Beneath the waters of sea or lake, coral-banks, peat-beds, forests and human habitations, are either seen to disappear, or are discovered long years after they were engulfed by the waves. The amber-producing forests of the North Sea and the lake dwellings of Switzerland offering most forcible illustration of the fact.

Coast regions of England, of France, and of North America from New Jersey to the Gulf of Mexico, the southern part of Greenland, and the North Sea coast of Germany, are gradually, but constantly, being buried beneath the waters of the ocean.

The ruin of the temple of Jupiter Serapis on the Bay of Naples offers an example not only of sinking of surface level but of subsequent re-elevation. The once noble structure presents to present view a marble pile from which three superb pillars tower 37 feet above their base. The upper and lower sections of the columns retain their marble lustre and polish; but midway of their height a space about 4 feet in length possesses a surface water-worn and burrowed by boring mollusks whose remains still exist imbedded in the stone.

Evidence is thus furnished to establish the fact that, since the temple was reared, long since the era of authentic history began, the Italian coast in the vicinity of Vesuvius must have sunk some eight feet in level, and have thus remained while the mollusks retained in the Serapis columns did their historical work; after which a period of elevation set in, and continued till the pillars were raised to the position they to-day occupy.

THE CHANGES OF LEVEL DURING FORMER GEOLOGICAL TIMES accomplished results in comparison with which the occurrences of to-day are insignificant indeed; yet there is no evidence that the rate of activity was greater then than now; for the *duration* of our present observation is as infinitesimal, as compared with the whole lapse of time of even one age of geological history, as the phenomena we witness are unimportant when compared with similar disturbances of past times.

The greater part of all continents was once the bed of oceans, from the waters of which the sedimentary deposits were laid down, and above which they were afterwards forced by gradual elevation.

Not only is the origin of continents directly traceable to this lifting movement, but whole continents are supposed to have, by the reverse process, been engulfed in the waters, leaving archipelagoes to mark this former location of continents.

An explanation is here presented for the occurrence in certain islands, as for instance in New Zealand and Australia,* of animal and plant forms long since extinct on the continents from which they are separated by expanse of ocean, connection with foreign fauna and flora, with their modifying influences, being thus removed.

The frequent similarity of life existing in islands now far distant from each other also furnishes presumptive evidence, confirmed by geological features and ocean soundings, that the now isolated isles once formed the mountain summits of great continents at present covered by fathoms of water.

B. MOUNTAIN FORMATION.

The accepted belief as to the causes to which the great mountain chains of the Earth owe their origin has undergone a radical change during the present generation. Formerly the belief was universally held that mountains were the result of volcanic action, or of exertion of pressure from within the Earth, exerting itself upward and rearing the mountains by the force of its upheaval. But a new theory has become the accepted belief of the present day, owing to the unimpeachable evidence of facts irresistibly presented by Heim, Suess and Dana.

Fig. 10.—Mountain Formation. Profile through the Alleghanies. 1, Miocene; 2, Eocene; 3, Chalk; 4, NewRed Sandstone; 5, Carboniferous; 6, Devonian; 7, Silurian; 8, Primary Gneiss.

THE PROCESS OF MOUNTAIN FORMATION is simply the folding or wrinkling of the thin Earth-surface, following the continued cooling and resulting contraction of the same.

The rock-stratifications of the Earth are easily traced through

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* Though Australia is now considered a continent, its isolated position geographically and geologically favor the former designation, island.

all their convolutions; and when they form chains of mountains, their original extent when lying in flat level layers on the Earth's surface can be determined beyond hazard of doubt; and they are proved to have originally occupied an area far greater than that into which they have been forced or *shoved* by decrease in dimensions of the Earth-mass. The decrease of surface can only be explained by the fact of *contraction through cooling.*

THE FLEXIBILITY OF ROCK-MASSES which thus allowed themselves to be beset and folded with only occasional breaks or faults is traceable to two causes. *First,* the movement may not have extended through the entire mass as a unit, but the pressure applied may have reduced the rock affected to the finest compact particles which, forced from the position formerly occupied, assumed new *directions* of stratification, in which position they became again aggregated, and exist as the folds and convolutions of mountain strata.

Second, no solid is so dense that it is insensible to pressure, and cannot be bent or flexed, if the force be great and exerted through periods of sufficient duration. A result more readily accomplished with rocks, if, as claimed by Heim, the molecular condition of the rocks of mountain-making ages was different from that they to-day present—if they were, in fact, plastic in nature—a condition in which much of the deep rock-mass of the Earth must still exist, and to which either heat or pressure is capable of again reducing both rock and mineral.*

Though the force thus exerted through contraction caused the most lofty mountains to rear their peaks above the surrounding plain, and compelled the rocks to wrinkle and fold on themselves, the tension was often too great or the contraction too rapid to allow the strata to readjust themselves without parting. Faults and fractures thus resulted, by whose presence the disintegrating forces of nature are abetted and aided in their labor of rock-disintegration.

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* Prof. Spring succeeded in reducing filings of bismuth, tin, zinc, aluminium, copper, antimony and platinum to solid metallic blocks, microscopically identical with wrought metal, at a pressure of 2000–6000 atmospheres; and at 5000 atmospheres tin and aluminium flowed in liquid form from the apparatus. (Credner, p. 189; *Jahrbuch für Mineralogie,* 1882, p. 42.)

CONTINENT FORMATION is a grand and direct result of this surface contraction and mountain-formation phenomena.

The Earth-crust by contraction of mass through cooling became too large for its nucleus, and the superabundance of surface was absorbed in the folds of mountain-chains; but the wrinkles thus formed consisted of necessity of both elevations and depressions. Into the latter or lowest portions of the globe the waters collected on its surface became gathered into oceans, while the elevated land thus left dry forms the continents of to-day, the coasts of which are parallel with the great mountain-chains resulting from a continuation of the same universal contraction.

C. EARTHQUAKES.

Mountain formation as a result of surface contraction is, so far as visible or actual existence of present phenomena are concerned, an occurrence of past geologic times. A phenomenon of similar nature, however, resulting from identical causes, and followed by the same effects on the rock-strata of the surface, and very probably the present evidence of mountain growth whose complete results must be deferred for coming ages of geological activity, is presented in the earthquake action of such universal occurrence during this and former times.

True, no phenomena of nature present fewer definitely understood and generally accepted facts than the occurrences classed under the term "*Earthquake*;" and none have been surrounded by greater dread and superstition, or have been the subject of more futile attempts to reduce their causes to the limits of forces acting under and controlled by known natural laws.

True, also, that a large proportion of the earthquake action of modern times is directly traceable to a volcanic origin. With this latter form we are not concerned further than to repeat the brief statement made in connection with volcanic action. The occurrences of this nature are, however, but an insignificant portion of the great number of earthquakes to which the Earth has been subjected during each generation of the modern epoch.

Few geologists would hazard the assertion that all the laws of earthquake action are yet known, and that satisfactory causes based on natural law can be assigned for each and every earthquake experienced; still, a long stride towards so desirable an end has been made within the present half-century, through the labors of Mallet, Seebach, Fuchs, Heim, and the Seismological Society of Japan under the leadership of Prof. Milne.

As a result of the labors of these and other workers in the field, the vast majority of earthquake phenomena are to-day recognized as belonging to one or the other of two forms; and however much opinion may vary as to the origin of a given example of earthquake action, there is practical unanimity in the verdict that two, and only two, causes can be assigned for all the great earthquakes of modern times. These causes of earthquake phenomena may be designated as *Surface Contraction* and *Subterranean Explosion.*

Phenomena whose origin is referred to the former cause constitute the so-called DISLOCATION EARTHQUAKES, and are a mere continuation of the occurrences resulting in the mountain-ranges whose structure we have already reviewed.

In reality these earthquakes are simply the sensible effects of the breaking of rock strata, or the forward movement of one rock-formation over or on another. The shock is only the jar resulting from inertia or from friction, the magnitude of results depending on area or extent of rock moved and the distance of fall or forward movement.

The force or power exerted is simply the irresistible force of contraction through cooling by continued radiation of heat.

The nature of such phenomena will be most satisfactorily understood by reviewing a typical earthquake of such recent occurrence as still to be fresh in recollection. Such an example is furnished by the *Charleston Earthquake* of August 31, 1886.

Mention has already been made of the fact that the eastern coast of North America from New Jersey to the Gulf of Mexico is now undergoing a gradual sinking.

This depression of surface extends inland from one hundred to two hundred miles, and is bordered westward by the line of fracture of the continent. This region has, during former geological ages, undergone many changes of level, now moving up, now moving down. The present period of depression cannot, from the nature of the geological conditions, be permanent, but changes of level must continue to take place for ages to come.

The line of fracture, the interior limit of movement, may again become, as in former times it was, the continental coast-line, or the coast may continue to advance seawards a hundred miles beyond its present position.

While this condition of instability continues, the Atlantic coast region cannot escape surface agitation; and the movement may at long intervals attain the force of an earthquake.

This was doubtless the real event that was attended with such disastrous consequences in South Carolina; all the circumstances of the event, both local and extensive, point to this one solution, and the *shock* was a *geological dislocation.*

The second, or EXPLOSION EARTHQUAKE, through having origin in the sudden liberation of an explosive force within the subterranean depths, or beneath the surface formation of the earth, presents phenomena not so easily or satisfactorily accounted for. The *fact* of explosion is not doubted, but the immediate *cause* of the explosion is accounted for in various ways.

This class of earthquake action is practically confined to regions of volcanic origin; but the volcanoes are more probably another result of the same cause to which the earthquakes are due, than themselves being either directly or indirectly the actual cause.

Attention has already been drawn to the fact that the temperature of the Earth regularly increases with the depth from the surface, till at 3300 metres the boiling-point of water is supposed to exist. We have also seen that the waters of the surface permeate the rock-mass and through capillary action may descend to any depth, but the pressure exerted will prevent the evaporation of this water at 100° C., and a temperature sufficient to decompose water into its component elements, hydrogen and oxygen, might be attained. At a certain depth, also, the capillary attraction would be overcome by heat; and at this depth, when the waters could penetrate no farther, an equilibrium would be established between the waters as vapors and the heated rock,—a delicate equilibrium easily disturbed, either by movement in the mass or by addition of more water from the surface; and then an explosion occurs, either of vapors formed, or by the sudden transformation of water into vapor, and the shock of the explosion felt at the surface is called an earthquake.

Such is, doubtless, the origin of the earthquakes of volcanic regions, and particularly of the majority of the annual average of sixty earthquakes in Japan.

THE RELATION BETWEEN EARTHQUAKES AND THE GEOLOGICAL STRUCTURE OF THE AFFECTED REGION is most intimate; indeed earthquakes are distinctly geological phenomena, all depending on geological causes for the character of their action; and many, as we have seen, resulting from movements of rock-formations.

There are also local phenomena of a more distinctly geological character still, to which reference was made on page 25. But whatever may have been the cause of a given shock, its intensity and duration are chiefly controlled by the nature of the rock-formations beneath which the force is exerted.

The force of an individual shock varies with the density of the rock-mass against which it is exerted. It follows, therefore, that regions of massive unstratified rock are least affected; that in regions of sedimentary formation the movement does not proceed regularly in all directions, but follows the course or direction of stratification.

The greatest severity of shock is experienced with conjunction of loose porous deposits on a massive solid sub-formation; and the most effective geological protection against severity of shock is presented by fractures and faults interposed to break the continuity of the earthquake wave. Facts experimentally demonstrated on the largest and most significant scale by the great disaster whose centre fell in the vicinity of Charleston, a region of porous, often sandy, structure, bedded on massive and older rocks, and confined within the area bounded by the great fault of the "Piedmont Escarpment."

THE SYSTEMATIC OBSERVATION of earthquake action is chiefly based on accurate records of the time of arrival of individual shocks and the duration of the same, together with the direction and angle of the display of the force as exerted against different objects. The rate of motion and direction of movement, together with the angle at which the force was exerted against a given structure, being thus determined, data are at hand for establishing the "centrum" or place of origin of the shock; and the fact seems already established that earthquake origin is at a comparatively slight distance from the Earth's surface, being found at from 17,260 to 127,309 feet toward the Earth's interior.* The force thus exerted appears, therefore, in the vast majority of shocks of the explosive character, to be not greater than is compatible with the theory of origin. Chemical explosions often communicate shocks through areas several miles in extent, while it is hardly possible that the slightest movement or motion in a mass so enormous and of such weight as the rock-strata of the Earth, even to a depth of a single mile, should fail to be followed by shocks equal in severity to the greatest earthquake phenomena of history.

IV. ROCK-METAMORPHISM.

By the term *metamorphism* a very important fact as related to rock-decomposition is designated. The word implies any change either in the texture or composition of the rock. It, in reality, signifies a physical or chemical transformation either of the rock or of its constituent minerals. By the action thus described, the great geological class of metamorphic rocks, rocks of crystalline structure, was brought into existence. Sedimentary sandstones, shales, conglomerates and limestones have thus been transformed into slate, mica-schist, gneiss, granite and marble.

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* Milne, "Earthquakes" (London, 1886), p. 214.

The transition from one form to the other is, however, exceedingly gradual, and no definite line of demarcation can be drawn between the changed and unchanged rocks, the sedimentary passing insensibly into the metamorphic.

The transformation thus effected in the composition or characteristics of geological formations must assume high importance among the conditions indirectly influencing or. controlling the subsequent rock-transformation by decomposition or disintegration, as the results accomplished by the forces engaged in the latter processes are controlled no less by physical conditions than by chemical composition of the rock form against which they are compelled to act.

The causes chiefly responsible for this metamorphism or alteration of rocks are these: *Pressure*, *Heat*, *Moisture*, *Chemical Affinity*.

Metamorphism by Pressure alone has, doubtless, been a frequent consequence of geological activity, yet it is hardly probable that the transformation could have thus resulted were it not for the fact that the pressure exerted is the cause of an extraordinary elevation in temperature, followed by crystallization of the rock-mass affected.

The transformation thus produced is known as *Techtonic Metamorphism ;* and the fundamental cause seems to have been the mountain formation as a result of contraction, whereby the necessary pressure was exerted. This origin for the phenomena seems demonstrated both by natural events and by experimental facts.

The degree of crystallization in slate rocks is usually proportional to the amount of disturbance which the original stratification has undergone. In other words, the perfection of crystallization or metamorphismis determined by the degree of mountain-making *force* exerted. The experiments of Spring alluded to on page 83 further demonstrate that not only is crystallization a direct result of this pressure, but chemical combination, as well, is produced by the same means: copper filings and powdered sulphur uniting to form crystalline copper sulphide, as a result of extreme pressure experimentally applied.

HEAT either directly or indirectly is the chief cause of rock-metamorphism. As just demonstrated, however, heat is not the *fundamental* cause of the transformation, but is an accompaniment of the change; still, much of the transformation of sedimentary rocks was doubtless the direct consequence of increase in temperature unaccompanied by other cause.

The source of the temperature thus active must be sought in the internal heat of the Earth, radiating to the surface, and exerting its transforming influence on all the sedimentary accumulations through which it passed.

The temperature resulting in metamorphism was not of an extremely high degree, varying from 250° C. to 650° C. The transformation was thus produced at comparatively low temperatures, but by heat acting through long eras of geological time.

MOISTURE as an active agent in rock-metamorphism is established by the fact that rocks cannot become heated without the presence of moisture, and water is frequently found enclosed in crystals of quartz, garnet and other mineral constituents of metamorphic rock.

The moisture of metamorphism was for the most part derived from the sedimentary formation on which the transformation was performed, either filling the pores of the rocks, or existing between strata.

Here it served, first, to increase the heat-conductivity of the stone, which when dry is a most imperfect conductor of heat, thus furthering and increasing the activity of the heat engaged, and then by the action of the same heat being converted into vapor, and becoming of itself a dissolving and decomposing agent resulting in crystallinic transformation.

The amount of water usually present in sedimentary rocks is not far from 3 per cent of their total composition, an amount equalling about five pounds of water for each cubic foot of rock. The amount of vapor thus generated was, therefore, capable of producing all the transformation that ensued.

If, moreover, as was very generally the fact, these waters were sea-waters, they contained mineral matter, compounds of sodium and magnesium, with boracic, hydrochloric and phosphoric acids; which ingredients were added to the crystalline structure resulting from the metamorphic action.

THE HYDROCHEMICAL PROCESS of metamorphism produces its results by the combined action of water and heat exerted according to the laws of chemical affinity.

Bischoff, indeed, strongly advocates this as the chief or only cause of regional metamorphism. The transformation, as he traces it, resulted from the action of plutonic heat on the hydrostatic waters of the rocks. The atmospheric moisture precipitated as rain on the Earth's surface absorbs carbonic acid and oxygen, and permeates the surface rocks.

The oxygen becomes exhausted as an oxidizing agent, while the carbonic acid attacks the silicates and transforms them into carbonates; and at the same time the waters, penetrating deeper and deeper, become finally exhausted, and all decomposition through their agency must cease.

But the water thus saturating the rocks is a most powerful dissolving agent; and becomes laden with dissolved mineral matter, which in the deeper regions becomes active for rock-transformation by decomposition and recombination. The transformations thus occurring are chiefly the result of combination of the soluble alkaline and calcium silicates with aluminium and magnesian silicates, principally mica and feldspar, which, in time, become crystalline.

The principal obstacle to the extensive action of this process of metamorphism lies in the exceeding great lapse of geological time required for the completion of the process by water saturation of the rocks existing now in transformed strata.

The chemical decomposition and transformation produced was doubtless increased and hastened by a degree of heat capable of converting water present into superheated vapor, a most powerful solvent and destroyer of cohesion. All silicious minerals are by the decomposing action of such heated vapor themselves vaporized, and on condensation form crystals of quartz, feldspar, mica, zeolites, pyroxene, and other silicious minerals.

These are but constituents of the most abundant metamorphic rocks: granite, gneiss and crystallinic schists, with the vast series of transformed sedimentary formations thus being possible results of the presence and action of the heated vapors of water.

The degree of heat and amount of moisture present were doubtless the controlling factors in determining the character of the metamorphic change. For instance, excess of moisture would produce *hydrous* rocks, like chloritic schist, while a greater degree of heat, or less moisture, would have resulted in the formation of a hornblende schist, the only essential difference between the two being the content of moisture.

It is, therefore, apparent that sedimentary rocks, which are most closely allied in all characteristics, may by the process of metamorphism become transformed into varieties wholly dissimilar, both in chemical composition and physical structure.

PSEUDOMORPHISM, the change of constituents of a mineral without change of crystalline form, is a variety of metamorphism as important as it is remarkable. The pseudomorph possesses a crystalline form foreign to its present composition; and this change is, therefore, wholly in its constituents, that is, the change is chemical in nature; and has been produced by the dissolving power of water, whereby a mineral of comparative insolubility has, through the lapse of ages, been reduced to solution, and carried away, while in its place new material has been deposited, and occupies the old crystalline form; or, by the action of water, a slow but actual transformation in constituents has occurred.

This transformation may be the loss of certain constituents, the addition of new material, or the substitution of one substance for another; and their existence establishes the solubility of many compounds which are usually classed as insoluble in the presence of chemical reagents. In this connection, those products are most important which possess no chemical relation to the original minerals, illustrated by pseudomorphs of limonite and pyrites after quartz, and of quartz after fluorspar.

The phenomenon of pseudomorphism is most frequently a silicification, that is, the transformation usually results in either a silicious mineral, or in the transformation of silicates.

Though the chemical substitution or reaction occurring may be of various forms, the most abundant is a simple process of hydration, illustrated by the conversion of pyroxene, chlorite and other *anhydrous* magnesian silicates into serpentine, the *hydrous* magnesian silicate.

The transformation in chemical composition, and in the characteristics of minerals, through the process of pseudomorphism, often occurs on a most extensive scale, changing the geological formation over large areas of country, and thus furnishing an important means of rock-metamorphism.

Large deposits of doleryte are transformed chlorite; while a large part of the serpentine rocks are a pseudomorph of chrysolite and pyroxene. Serpentine is also a product of transformed apatite. But more remarkable yet is the recently-claimed transformation of quartz into serpentine, and the fact that the latter mineral so widely distributed is in large areas of the Pacific coast region a pseudomorph after quartz.* It also appears that, in the same formation, most metamorphic rocks "are subject to serpentinization."

Pseudomorphism must, therefore, be recognized as an important factor in the series of mineral transformations whereby rock-characteristics are modified, rock-decomposition influenced; and the products of their disintegration controlled.

CHAPTER III.

ROCK-DISINTEGRATION THROUGH EXTERNAL FORCES.

THE expression "firm as a rock," so commonly used as the superlative of stability, must, in the light of facts reviewed in the preceding chapter, lose all significance other than as a mere medium of comparison.

Acted on by the forces of nature, rocks are, in reality, any-

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* G. F. Becker, *American Journal of Science*, May 1886, p. 355.

thing but enduring; however much the process may be controlled or modified by the agencies already considered, the ultimate disintegration is inevitably the result of direct chemical decomposition and transformation, the course of which as occurring in rock, and the stages of soil-production, must next be systematically examined.

Rock-decomposition consists of two distinct processes: first, the mere destruction of form, or pulverization of the rock-mass; second, the erosion or washing away of the fragments.*

The former is chiefly effected through the chemical action of water and air, through change of temperature and action of organic life. The latter is accomplished through the action of the water descending as rain, and filling the rivers and streams; the waters of ocean beating against shore, and of congealed streams forming moving masses of ice.

The transformation by which soils succeed rocks in geological progression has, therefore, been produced by the direct action of four distinct factors, namely: *change of temperature*, *water and ice*, *air* and *organic life*.

I. CHANGE OF TEMPERATURE.

The rock-crust of the Earth itself resulted from the cooling of the rotating mass; and the gradual continuance of this cooling process must have been followed by a concentration of mass and contraction of surface and volume, resulting of necessity in the breaking and cracking of the crust. The elevation, subsidence, wrinkling and folding, resulting from this shrinkage, caused the formation of sea-basins, mountain-ranges and valleys.

The varying composition of crystalline rocks, with resulting irregularity in expansion and contraction through the influence of heat and cold, together with the unequal expansion and contraction of the same crystal around different axes, were important factors in the breaking up of rock-masses and the formation of soils. This separation of rocks into their com-

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* Heim, *Ueber die Verwitterung im Gebirge* (1879), p 6.

ponent crystals, and the subdivision of the crystals themselves, is, perhaps, the most important fundamental cause for the pulverization of the Earth's rock-mass.

The outer surfaces of rocks are very sensitive to the changes of temperature, not only with the seasons, but from day to night. The former is estimated to exert an influence at a depth of from 60 to 100 feet; though the influence of the latter does not extend deeper than from 3 to 10 feet.

This variation of temperature is followed of necessity by contraction and expansion of surface, resulting in fracturing the mass and rendering it more porous.

In desert lands, where the temperature from day to night not seldom varies 60° C., boulders are often broken in pieces from this cause alone.

But the most powerful and extensive action consequent upon change of temperature follows the influence exerted through the presence of moisture and a *decrease in temperature below the freezing-point of water.*

Water forms an exception to the rule that "bodies expand with heat and contract with cold." The law of expansion and contraction is, in this case, reversed when the liquid reaches 4° C., below which temperature it expands. Ice occupies, therefore, a greater space than the water from which it was formed. In the freezing of water, then, lies the source of irresistible power, the partial confining of which in the pores and crevices of rocks results in tearing, breaking, rending and crumbling of the same.

This expansion of volume through the freezing of water is equal to one fifteenth of its mass, and the power is manifested in the splitting of enormous blocks, tons in weight; in the tumultuous breaking down of whole cliff-ranges, or the silent disintegration of rock-surfaces; the gradual crumbling away of grain on grain, crystal from crystal, or particle by particle.

II. ACTION OF WATER.

Among all the agents of rock-disintegration, by far the most active is water. It is the great transforming force in nature, acting both as liquid and as solid; and with an influence and transforming power reacting from the tops of the highest mountains down through all the strata of the Earth's mass to the deepest geological structure yet aggregated from the interior magma.

The entire circulation of water from the uncondensed moisture floating in the atmosphere surrounding our earth, through the precipitation in drops of rain, and passage through the rocks and soil, or over their surface into the streams and back again to the ocean to become re-evaporated into the air, is a progression of geological changes, followed by constant modifications of surface, and transformations in composition of the material, against which water is made to exert its power.

Not only does water possess the advantage of being triple-armed for the accomplishment of its work, exerting its force as vapor, liquid or solid, but it is capable, under varying circumstances, of either mechanical or chemical action. Thus, through all the ages of geological activity, it is to water more than to all other agents combined that the physical and chemical features of the Earth have been due: rock-formation and rock-disintegration being alike the result of its action; mountain and valley, rock and soil, being but varying records of its perpetual activity and all-reaching power.

A. MECHANICAL ACTIVITY OF WATER.

The transformation wrought through the physical action of water may be described as resulting from two different properties, or really two different modes of action.

First, the effects produced by the direct abrasion or erosion caused by a moving mass of water, the result being in reality due to motion, water being but the agent.

Second, the action of water as a destroyer of cohesion, whereby, through its penetrating rock-masses, the particles become separated from each other, and the rock softened in consequence, and rendered more susceptible to the disintegrating influences to which it may be subsequently subjected.

This latter mode of action is universal in extent, and follows every instance of contact between water, either moving or stationary, and rock or soil. It is usually this action with which the influence of water as a rock-disintegrator begins; the subsequent reduction of mineral constituents to solution, or the results of chemical combination, being simply the final effects of a condition first produced by loss of cohesion in the rock attacked.

RUNNING WATERS or streams are chief among the direct means by which the erosive, or water-friction, results of the mechanical influence of water are produced.

The atmosphere is the medium through which the waters of the ocean, the great reservoir, become gathered into streams which become the chief sources of surface modification. Evaporated into the atmosphere, precipitated as rain or snow, gathered by gravity into streams, flowing back to the ocean,—thus the circulation of water through the universe goes on through the ages, performing in its course its offices of softening, abrading, disintegrating; consuming here, building there; tireless, resistless, ceaseless.

The amount of water thus kept in motion, and without rest laboring against the geological structures of the Earth, is inconceivably great. An annual rain-fall of three feet for all the world becomes in one thousand years an accumulation of three thousand feet over the surface of the globe; yet a thousand years are but a jot as compared with the lapse of a single geological age, and an age is but a fraction of all geological time. Still, through these periods of countless years, the activity of this constantly-moving, ever-replenished mass of water has not ceased. There is no wonder, then, that valleys are formed, that cañons are grooved in solid rock, that thousands of tons of sediment form the annual burden of innumerable streams ever gaining fresh accessions from rains, springs and percolations.

EROSION, the wearing away of rock and soil by the action of moving streams, has been the most active of the immediate causes of the results attributable to water action. The term, however, really includes chemical as well as mechanical action, inasmuch as the results are infinitely enhanced by the action of chemical solvents held in suspension in the waters of all moving streams.

The mechanical action on the solid mass of the Earth is but an illustration of the hidden force of moving water, ever exerting itself against all impediments in its course, and by continuous, persistent action overcoming and obliterating every obstacle.

The very changes of temperature resulting from modification of level send the atmospheric moisture from the heated valleys and plains to the cooler mountains and plateaus, where it becomes condensed, and, falling upon the surface, rills are formed, rivers rise, and mighty currents sweep to the sea, leaving evidences, through all the region they traverse, of water's erosive action. Whether the force be made manifest in the form of atmospheric moisture precipitated on rocky walls of mountain summits, or driven by the winds through valleys and over plains; whether it be by storm-beaten ocean rolling wave on wave against unprotected shore, or river current washing and undermining its overhanging banks, the result is the same, and the ultimate end is only gauged by duration, for the force is resistless.

The more marked the action, the greater the power for action, the erosive force constantly increasing in ever-ascending ratio; for every particle of sand and or stone detached from its mass becomes an instrument driven by water-power and worked for the grinding and pulverizing of every solid mass with which it comes in contact, or against which it is driven.

Every river-bed or valley, every sea-beach and every mountain-side present graphic proof of this never-ceasing activity of moving water.

Some of the most remarkable illustrations of such action are: the isle of Helgoland in the North Sea; the Elbe Valley near the Bastei in Saxony; the Simeto River in Sicily, which, in two hundred and fifty years, excavated a channel more than fifty feet deep and forty feet wide through solid basaltic rock; and the Colorado and Mississippi rivers, in each of which cases the action which has been proceeding for centuries still

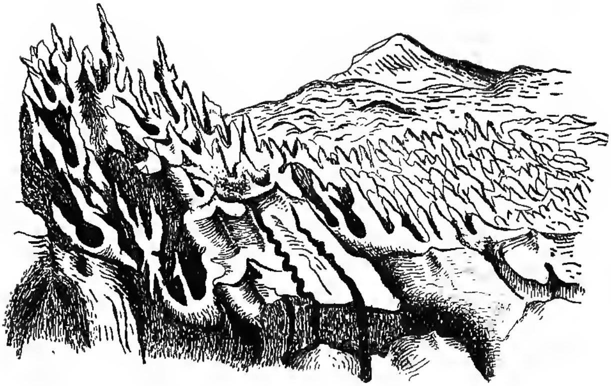

Fig. 11.—Karrenfelder of the Alps, resulting from water-erosion. (After Heim.)

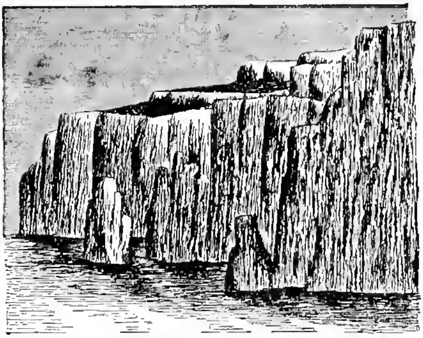

Fig. 12.—Water-erosion. The Yellow River, Shansi, China.

(*To face page* 98.)

continues to-day the work of surface modification, and conversion of rock into soil.

The quantity of solid matter detached from its mass and held in suspension or reduced to solution by the currents of streams can be approximately rendered in figures, and reaches an amount the aggregate of which is simply enormous.

Although the proportion of solid matter to water in streams may seldom be greater than one to six thousand, yet even this apparently slight amount reaches a quantity expressed by thousands of tons as the annual burden of solid matter transported by a single stream; and in a period of six thousand years the result is an amount equal to the annual weight of water flowing in the river indicated.

The Mississippi detaches and carries to the ocean annually 3,702,758,400 cubic feet of solid material, a quantity sufficient to cover an English square mile of surface 268 feet deep with alluvium. The Ganges transports to the sea 6,368,000,000 cubic feet of sediment yearly. Yet these rivers are not remarkable in their erosive effects, except through the magnitude of their currents.

Smaller rivers furnish facts of an identical nature. The Thames is estimated to flow on the average 100,000 cubic feet of water per day, bearing in suspension 1802 tons of mineral matter, equivalent to an annual burden of 657,595 tons of transported material.

Deposits made by Running Waters. The question next naturally presented by the facts just considered is, What ultimately becomes of this vast quantity of material removed from the rocks and soils of water-sheds?

The greater part of the suspended matter consists of fine sand and silt gathered from all the soils with which the waters come in contact, and of the finer particles of the rocks of the region traversed. Mountain-streams and the head-waters of most rivers, however, transport stones, even boulders, not infrequently long distances.

Since all common rocks vary only between 2 and 3 in specific gravity, they lose nearly one half their weight when suspended in river-water, the average specific gravity of which varies from 1.005 to 1.500; and their transportation becomes a matter requiring far less force than would be otherwise necessary. Whirled and rolled onward by the current, the fragments of broken rock become gradually transformed into smooth, water-worn pebbles, and the abraded matter is added to the fine sediment carried on by the stream.

The material thus gathered from rock and soil is largely deposited along the courses of the stream, forming the alluvial beds of their valleys, or becoming perennial accumulations of fertilizing matter brought and laid on the meadows with unfailing regularity with every succeeding overflow.

The distance of transportation may be either long or short, according to the amount of sediment or the rapidity of current; the Nile and the Mississippi often bearing their gathered burden thousands of miles, while in certain localities the transportation may be only from one bank of the stream to the other.*

DELTA-FORMATION is the ultimate end of most of the vast quantity of sediment not disposed of before the current gains the sea. The material transported becomes thus deposited at the mouths of the streams, forming regular strata of detached matter, the coarser particles being laid down directly at the river's mouth, the finer ones being carried farther out and forming the outer portion of the islands rising from the waters.

Deltas are often formed as the result of the emptying of mountain-streams into lakes, where the calm waters of the latter compel the precipitation of the earthy matter brought to them with the influx of rivers. But the chief delta-formation results from the emptying of sediment-laden streams into the

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* An aggravated case of this nature occurred in Hampshire County in Massachusetts some years ago. The county is divided by the Connecticut River, the towns of Hadley and Hatfield being thus separated; the elevation of the latter above the river being several feet greater than that of the former. After one of the annual spring freshets the current so changed as to abrade the high Hatfield bank and transport the sediment thus obtained to the Hadley shore, where in time an island of fertile alluvial soil grew, the ownership of which was decided after litigation to be vested in the Hadley owners of the adjacent land.

ocean, the principal cause of their origin lying in the existence of reefs or bars beyond the coast-line whereby lagoons are formed, in the quiet waters of which delta-deposition is greatly aided. The delta of the Nile furnishes a most perfect confirmation of this fact.

From the fact that delta-formation is not infrequently a phenomenon of regions subject to gradual elevation of surface, Credner* draws the inference that this elevation of surface is the important factor in furthering delta-formation. He further supports his conclusions by the fact that most great rivers free from such formations, like the Hudson, Delaware, Amazon and Elbe, empty where the coast at present is undergoing gradual depression of surface.

GLACIER ACTION† is simply aggravated water action, for glaciers are but streams frozen and moving slowly but irresistibly onwards, down well-defined valleys, grinding and pulverizing the rock-masses detached by the force and weight of the onslaught. The resulting amount of earthy matter transported by streams having their origin in the waters flowing from glaciers is not only enormous in quantity, but possesses the peculiarity of consisting of little but the finest rock-detritus free from organic matter and earth alluvium.

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FIG. 13. — Alluvial Islands, coast of North Carolina, formed by opposition between ocean and river action.

OCEANS may also not only be great sources of erosive action, but may be the direct cause of land-formation from the transported material brought to the sea by the influx of rivers. No better illustration of such formation exists than those offered by the coast structure of North Carolina, where the sand reefs and islands inclose Pamlico and Albemarle sounds; shallow stretches of brackish water into which numerous rivers empty their waters laden with detritus, which, meeting the tide, is flung up in reefs and islands, sometimes of sand, sometimes of mud, and then again building the rich alluvial soils producing the renowned "sea-island cotton."

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* *Petermann's Geologische Mittheilungen*, No. 56 (1878).

† See page 45.

B. CHEMICAL ACTION OF WATER.

No water precipitated upon the Earth's surface from the atmosphere, be it rain, hail or snow, is chemically pure hydrogen oxide. It invariably contains absorbed gaseous constituents of the air, chiefly carbonic-acid gas and oxygen; the former giving it a slightly acid reaction, the latter rendering it a weak oxydizing agent; while organic constituents absorbed lend it reducing properties; and the ammonia gathered and conducted to the soil forms a most important fertilizing ingredient.

Though the amount of foreign substances thus existing in the purest of waters is infinitely small, and to be detected only by chemical means, yet to their presence is chiefly due the chemical transformation wrought in the rock-masses of the Earth. However, the quantity of these active ingredients is immediately increased so soon as the water gains access to the rock and soil, where decomposing animal and vegetable matter constantly supply fresh accretions of each of these active ingredients of water.

Small as may be the total of these absorbed substances in even the most impure of running waters, their action being ceaseless and their supply exhaustless, the aggregate eventually exerting itself against a given formation is, in reality, large; the lapse of time abundantly compensating for the minuteness of the active agents and the slowness of the results accomplished.

To the chemist, minerals subjected to the action of water which on filtration give no trace of soluble matter, either in response to reagents or on evaporation, are held *insoluble*. But to the geologist, such minerals may not only be considered soluble, but even *very soluble*; for he takes into consideration not only the results of action continued through thousands of years, but under constant repletion of the dissolving medium.

Geologically speaking there is no insoluble mineral, and all rocks are, with greater or less rapidity, undergoing dissolution. The dissolving power of pure water is least when exerted against silicate of alumina; but even this is dissolved 1 part for every 200,000 parts of water acting.

The disintegrating power of water may be exerted in either of two distinct ways: *first*, by solution; and *second*, by combination. These two means, by which the results of water action are accomplished, operate so commonly together, exerting their united power against most rock-formations, that a practical separation is useless.

THE PENETRATION, SOLUTION AND DECOMPOSITION of rocks by the action of water are universal; no rock can escape, therefore, the water's action; for where one property fails another succeeds, and the combined action is resistless.

In the accomplishment of its ends, water is not compelled to follow the crevices or strata of the rocks, for every rock-mass consists of aggregations of minerals, and is permeated in all directions by microscopic pores, through which the water passes to the remotest recesses of the formation, extracting all soluble material, and reducing the mass gradually to a softer earthy material.

Even the natural silicates, the hardest and most insoluble of rocks, are, to an appreciable extent, acted upon by chemically pure water; and the hardest of flint-glass is dissolved slightly by the action of boiling water.

Insolubility and freedom from decomposition are unrecognized properties of rocks where the action of water is concerned; pseudomorphism (see p. 92) proving both the solubility and decomposition of quartz, the most intractable of all mineral forms; while experiment shows that mere pulverization reduces tourmaline, augite, hornblende and other equally resisting minerals to forms readily soluble in distilled water.

SOLUTION BY WATER ALONE occurs to but comparatively few rock-forms, and these are principally of simple composition; gypsum, rock-salt, limestone and dolomite forming the best examples of rocks thus affected

Gypsum being among the most abundant mineral forms, the solubility of 1 part in 400 parts of water becomes of great significance in moulding the surface aspect of the Earth; and as lime forms an essential ingredient of all vegetation, this extreme solubility is, from an agricultural standpoint, of inestimable value, as it renders the mineral not only an abundant natural source of plant-nutrition, but gives the substance great value as an artificial fertilizer.

The extreme solubility of rock-salt is also of vast industrial as well as geological importance, as to this property is due the origin of all saline springs.

Limestone, though far less soluble in water than the two preceding, is so extraordinarily abundant and wide-spread as a geological formation, that its subjection to the dissolving action of water is productive of the greatest change in the geological structure of the Earth. It is soluble in water to the extent of 1 part in 1000 parts, and much more soluble in carbonic-acid acidulated water, to the action of which it is so universally subjected. The distinction between the results as due to the dissolving power of pure water or of acidulated water cannot be drawn.

Nevertheless the dissolving of this rock and its removal by running waters are productive of all-important changes in the physical features of nature.

The caverns in which the earliest human remains are discovered resulted from this removal of calcium carbonate, while the enormous caves of Kentucky, Tennessee and Virginia are of similar origin.*

Where the limestone is not of a homogeneous character, the more readily soluble parts are washed away in the lapse of ages to depths of 3 to even 50 feet, in deep narrow grooves or channels, separated by rugged ridges of less soluble rock, forming the famous "Karrenfelder" of the Alps.

THE CONVERSION OF ANHYDROUS INTO HYDROUS MINERALS by the addition of water results by direct combination, the change in composition thus occurring chiefly affecting silicates and metallic oxides; orthoclase, albite, hornblende, augite, mica, magnetic iron and hematite being typical illustrations.

The transformation is simply a chemical combination with

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* N. S. Shaler in *Scribner's Magazine*, October 1887.

the elements of water, no other change in composition taking place, time being the only essential for the reaction.

A wide-spread and important hydration of a mineral form is the frequent change of iron oxide, hematite (red iron ore), Fe_2O_3, into iron oxyhydrate, limonite (brown iron-stone), $Fe_4H_6O_9$:

$$2Fe_2O_3 + 3H_2O = Fe_4H_6O_9.$$

By an identical process, anhydrite ($CaSO_4$) becomes, in time, gypsum ($CaSO_4 + 2H_2O$), a transformation quickly accomplished, and of very frequent occurrence in many geological formations.

THE OXIDATION OF MINERALS, resulting from the oxygen absorbed by waters, is a common change closely allied to the one just noticed.

Aside from carbonic acid, water contains free oxygen absorbed or held in suspension, and all substances which unite readily with this element undergo oxidation, therefore, when brought into contact with such waters.

Most frequent among the transformations thus wrought are the conversion of ferrous into ferric compounds; spathic iron (siderite), $FeOCO_2$, becoming $2Fe_2O_3 + 3H_2O$, the carbonic acid being displaced by water, and the protoxide by the attraction of oxygen becoming sesquioxide. By a similar process magnetic iron ($FeO + Fe_2O_3$) becomes hematite (Fe_2O_3).

$$2Fe_3O_4 + O = 3Fe_2O_3.$$

This transformation has affected many extensive iron-ore deposits, and accounts for the origin of important beds of iron sesquioxide (hematite) in Brazil and the Lake Superior region.

Ores of manganese are subject to an identical process of higher oxidation.

A series of transformations perhaps yet more important is the oxidation of metallic sulphides into sulphates of the same metals.

Iron pyrites ($Fe S_2$) thus becomes ferrous sulphate ($FeSO_4$), which by further oxidation is transformed into brown iron-stone or limonite ($2Fe_2O_3 + 3H_2O$); and the sulphuric acid set free combines with other bases, as, for instance, it drives the

CO_2 from limestone, and forms calcium sulphate or gypsum. Zinc, lead, copper, cobalt and other sulphides undergo like transformation with similar products of oxidation.

Thus through the action of water not only the physical characteristics of rocks become changed, and physical results are accomplished; but the elements of water, or gases held dissolved therein, combine chemically with rock-constituents, changing the composition and character of the mass, and rendering it susceptible to influences before inactive.

ROCK-SOLUTION BY THE CARBONIC ACID OF WATER. In nature, rocks are never exposed to the action of pure water, and this power of solution is greatly aided by the CO_2 universally present in all spring and running waters. The oxygen and certain salts so frequently held in solution also greatly add to the solvent power, but in a degree far inferior to CO_2.

The amount of CO_2 thus absorbed by water at ordinary temperature and pressure reaches a bulk equal to that of the water holding the gas, while either at lower temperatures or greater pressures the volume of gas absorbed is largely increased.

This acidulated water acts most forcibly on the carbonates of lime and magnesia, and on the protoxides of iron and manganese; compounds practically insoluble in pure water, but found to a considerable extent in ordinary running waters. Silicious minerals, too, so slightly affected by pure water, become readily attacked and dissolved by carbonic-acid waters; the insoluble silicates being converted into soluble carbonates; lime, magnesia and iron being thus removed from the rocks, and carried into solution.

The ordinary carbonate constituents of rock-formations, for instance common limestone, are simple or mono-carbonates which by the action of the CO_2 dissolved in water become converted into bicarbonates, soluble in water, and held in solution. If, now, the solution be boiled, this additional CO_2 becomes disengaged, passes off, and the monocarbonate with which it was combined is precipitated; hence the efficacy of boiling hard waters, rendering them fit for domestic use.

Decomposition of silicates, the most insoluble of rock-forms, by the action of the carbonic acid of waters, is of incalculable importance, as the products are all comparatively soluble compounds; the recombinations resulting being, therefore, fraught with physical changes of structure as well as with changes in chemical composition of many rock-forms.

The bases from combination with which the silica is displaced are most commonly potassa, soda, lime, iron and manganese oxides. With these the carbonic acid combines to form carbonates, while the silicic acid is set free.

The Earth's rock-mass consists largely of hornblende, feldspar and augite. These minerals are silicates of alumina or magnesia combined with alkalis, with calcium, and with iron and manganese.

These rocks are, therefore, decomposed by the carbonic acid of the percolating waters, and carbonates take the place of silicates in this most important series of rocks; while the undecomposed silicates of alumina and magnesia attract water, and remain behind as hydrous silicates, minerals of which clay, kaolin, chlorite, serpentine and talc serve as types, produced by the transformation described.

Agriculturally considered, this dissolving power of carbonic acidulated water is of vast importance, not only by reason of the conversion of insoluble silicates into soluble compounds of elements of plant-nutrition, but this solvent property is exerted on a class of indispensable compounds, namely, the phosphates of different bases. Especially phosphates of lime, magnesia and iron, salts containing the essential ingredient of vegetation, phosphoric acid, but existing in an insoluble and comparatively worthless condition, are by the dissolving powers of the carbonic acid, however, rendered soluble and available as plant-food.

III. ACTION OF THE AIR.

As with water, so with air, the decomposition or weathering of rocks through its influence is due chiefly to the presence and activity of the two ingredients, carbonic acid and oxygen. The action of the former as a constituent of the air, is mainly a repetition of its influence as an ingredient of water. Oxygen produces its effects simply as an oxidizing agent, converting protoxides into the higher oxides; iron and manganese minerals being most frequently thus affected; and these minerals enter into the composition of a very large number of the more prevalent rock-formations: mica, amphibole, chlorite, talc, serpentine and feldspar being good instances of the occurrence of the protoxides of iron or manganese, convertible into higher oxides by the action of atmospheric oxygen.

Iron sulphide, so abundant in many rock-forms, is also affected by the presence of oxygen, the iron being converted into the sesquioxide; the sulphur combining with oxygen and water to form sulphuric acid, $2FeS_2 + 9O = Fe_2O_3 + 2SO_3$; $SO_3 + H_2O = H_2SO_4$. Rock-disintegration is materially hastened by this decomposition or oxidation, particularly as the higher oxides occupy more space than the metals or the lower oxides; thus the result is due to both chemical and physical changes.

The sulphate of the protoxide of iron, $FeSO_4$, illustrates the fact, by the oxidation of the clear green crystal of the protosulphate $FeSO_4 + 7H_2O$ to the more bulky, brown, opaque sulphate of the sesquioxide; a bottle filled with the former being made to overflow by the formation of the latter through attraction of oxygen.

These products are soluble in water, and enter readily into solution in spring and running waters; and by their presence still further chemical decomposition and combination result. Carbonate of lime becomes gypsum; dolomite becomes bitter salt, Epsom salts or magnesium sulphate and gypsum; sodium chloride, or rock-salt, is transformed into sodium sulphate, or Glauber's salt; and most important of all, the insoluble tribasic calcic phosphate, $Ca_3(PO_4)_2$, becomes soluble monobasic calcium phosphate, $CaH_4(PO_4)_2$, and gypsum ($2CaSO_4$).

This soluble calcium phosphate is the "superphosphate" of commerce, the most valuable form of agricultural phosphoric acid; and the reaction thus occurring in nature is identical with that performed in the fertilizer manufacture by treatment of bones or rock-phosphates with sulphuric acid.

MODIFYING INFLUENCES AFFECTING ROCK-SOLUTION. Aside from these chief causes of rock-decomposition, others of more or less significance as modifiers, or as producers, of rock-decomposition, exert themselves under varying circumstances. Every solution of a salt, indeed the solution of every material occurring naturally in the moving waters of soils, be the solutions of natural occurrence or the result of artificial fertilization, exerts itself on the insoluble soil silicates decomposing them, and forming therefrom soluble salts of bases which are essential ingredients of plant-food. This action is particularly noticeable in the case of salts of ammonia, lime, potash and soda, many of the compounds of which are among the most important sources of vegetable nutrition.

The form of the chemical combination, the degree of hardness, and the character of the individual rock-ingredients or mineral constituents, determine the degree to which the decomposition is effected by the factors of disintegration.

The mechanical nature of the rock attacked is likewise of no inconsiderable importance in determining the result; the fine-grained, compact basalt, for instance, being far less readily decomposed than the coarse-grained, more or less porous granite. Even a given rock may resist the disintegrating influences differently in its different constituents. Thus the feldspar of granite is often reduced to a fine white clay, while the mica and quartz exist as fine undecomposed particles, intact and unaffected by conditions destroying the more easily-disintegrated feldspar.

IV. ACTION OF ORGANIC LIFE.*

The modifying or transforming influences exerted on rocks by living organisms are not of an occasional or isolated nature, but are of almost universal occurrence, pursuing their ceaseless action as quietly and nearly as resistlessly as the ever-acting water.

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* In this connection only the action of life as a promoter of rock-disintegration will be considered; the incorporation of animal and vegetable matter with the decomposed materials of rocks, and the modifications in soil composition and characteristics resulting from the action of life, are considered in PART THIRD.

The variety of action exerted by animal and vegetable life is very great, but the means by which the results are accomplished are either physical or chemical, or a combination of the two.

ANIMALS EXERT THEIR DISINTEGRATING POWER always through chemical means, the result being actual chemical decomposition through the exertion of chemical affinity. Yet the geological activity of animal life is more distinctively *formative* than *destructive;* coral reefs, chalk and flint deposits, and the infusorial earth composed of diatomes so small as to contain 41,000 millions of distinct organisms to the square inch, being wholly of animal origin, while by far the largest portion of all limestone formations are composed chiefly of aggregations of calcareous lower organisms.

REDUCTION THROUGH ORGANIC DECOMPOSITION is a most frequent and important effect of animal or vegetable existence, since the death of these organisms furnishes through the products of their decay the hydro-carbons which are the chief natural reducing agents of mineral forms.

These products of organic decomposition act not only at the surface, but, passing into solution in the percolating waters, they penetrate the deepest depths of geological formations, exerting their reducing influences through all the regions penetrated.

By these means carbonic acid is evolved through the extraction of oxygen from higher oxides which become thereby reduced to lower oxides, with which the carbonic acid evolved combines to form carbonates of monoxides. These by the action of the atmosphere are transformed into hydrous oxides, and thus precipitated, iron being most frequently thus affected.

In similar manner, sulphates through loss of oxygen become sulphides through the action of decomposing organisms; and the sulphides may, by a continuation of the process, lose their sulphur by combination with oxygen, and metallic copper, zinc or lead may be the result, according to the base originally combined with the sulphuric acid reduced.

The presence of pyrites as the fossilizing material in numerous fossilized ammonites, brachiopods and gasteropods is thus explained through the reducing action of the decomposing animal on the mineral sulphates with which it was surrounded.* Sulphates of the metals are not alone thus affected; but also the compounds of sulphuric acid with the alkalies and alkaline earths, by the reduction of which hydrogen sulphide is evolved which, in turn, may combine with metals and form sulphides, or may by atmospheric oxidation result in the deposition of free sulphur.

PLANTS ACCOMPLISH THEIR DECOMPOSING EFFECTS perhaps fully as often through physical as through chemical means. Aside from the incorporation of organic matter with the mineral matter of the soil by extraction or absorption from the air through the vegetable organs, and conveyance to the soil through death and decomposition thereon, the organs of plants act directly as rock-disintegrators, both chemical and physical action being exerted. In both cases the roots are the chief factors by which the result is directly accomplished.

THE CHEMICAL ACTION OF THE ROOT as a rock-disintegrator is accomplished by means of the secretion and excretion, through the pores of the root, of an organic acid which possesses the property of decomposing and dissolving the rock-mass with which it comes in contact,† rendering it plant-food and directly assimilable; thus filling an office to the plant closely allied to that of the gastric juice in the animal organism.

THE PHYSICAL ACTION OF THE ROOT is in as great a degree allied to the action of frost as a rock-disintegrator. The roots permeate the rock-mass wherever the slightest crevice offers an entrance; and then, by the expansive force of the growing tissue, the most tenacious of rocks are rent and torn asun-

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* An exceedingly interesting phenomenon of this nature is known to have occurred in Tennessee during the American civil war. A copper mine near the village of Ducktown was closed because of the hostilities. The exposed ore of copper sulphide became converted by oxidation into copper sulphate, which became dissolved by the percolating waters gathered at the lower levels of the mine. When work was begun again after the close of the war it was found that whereever the timber supports of the galleries stood in the copper-sulphate-impregnated waters, reduction of the sulphate had resulted from the decomposing wood; and deposits of metallic copper adhered to the immersed pillars. Credner records similar occurrences in mines in Ireland, Spain and Germany.

† Meyer, *Lehrbuch der Agriculturchemie* (Heidelberg, 1876), p. 364; Pfeffer, *Pflanzenphysiologie* (Leipzig, 1881), Bd. I. pp. 78–80.

der, no power in nature being able to withstand the force of this slow-working but resistless expansive action.

The disintegrating power of different roots on various rock-formations was experimentally demonstrated by Dietrich with the following results:

Variety of Plant.	Mineral Matter Dissolved.	
	Variegated Sandstone.	Basalt.
Lupine	0.6080 grm.	0.7492 grm.
Peas	0.4807 "	0.7132 "
Buckwheat	0.2322 "	0.3274 "
Vetch	0.2212 "	0.2514 "
Wheat	0.0272 "	0.1958 "
Rye	0.0137 "	0.1316 "

From the above figures it appears that during the period of growth either the pea or the lupine will disintegrate more rock than will the weathering process during the same interval. The definite comparison is as follows:

	Mineral Matter Dissolved.			
	K	Ca	Mg	P_2O_5
Weathering process	0.0388	0.4516	0.0892	0.0356
Peas	0.0684	0.5218	0.1230	0.0868
Lupine	0.0920	0.4625	0.1332	0.0971

All roots and most other growing vegetable tissues possess a distinctly acid reaction,* and the presence of minute quantities of these vegetable acids in water renders the latter capable of reducing to solution salts not soluble, and therefore unnutritive substances, in pure water.

FIG. 14. — Illustrating gradual transformation of bed-rock (3) into subsoil (2) and cultivated soil (1). (After Geikie.)

Aside from this action of the living plant on rock-disintegration on soil formation and utilization, the death and decomposition of the plant is a most potent factor in the transformation of mere disintegrated mineral matter into soil capable of sustaining vegetation. The roots of all plants die either wholly or in part each year, and by decomposition become, in longer or shorter time, incorporated with the soil, giving it back not only the material originally taken from it, but also the 95%, or more, of organic matter of atmospheric origin. And where not reassimilated by subsequent vegetation, as, for

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* Liebig, *Die Chemie in ihrer Anwendung auf Agricultur und Physiologie* (1862), vol. i. p. 137. "Die Wurzeln scheiden hiernach eine Säure aus."

instance, in forests or under water, the mass of vegetable matter, roots, leaves, whole plants, results in time in the accumulation of vast stores of decomposed or decomposing vegetation: leaf-mould, muck, humus; material recognized as forming a distinct geological formation of the *Diluvial epoch.*

The transformation of the living plant-tissue into these products of decomposition is due to distinctly chemical causes resulting in chemical action. Decomposition is fundamentally oxidation; and here the decaying mass consists chiefly of carbon and hydrogen, which become by union with atmospheric oxygen oxidized into carbonic-acid gas (CO_2) and water, with marsh-gas (CH_4) and carbon monoxide; while the albuminoids, nitrogenous constituents of vegetation become transformed into ammonia (NH_3) and nitric acid (HNO_3). Further than this, the decomposition of vegetable matter results in the formation of geic, ulmic and humic acids; while the first by further oxidation gives rise to the stronger crenic and apocrenic acids.

The effects of the action of the products of this organic matter on the mineral ingredients of the soil are manifold.

1. By their hygroscopic properties they keep the soil in a moist condition.
2. Their decomposition is a fruitful source of carbonic-acid gas (CO_2), the results of the action of which have already been noticed.
3. The acids produced act as direct disintegrators of rocks and the mineral constituents of soils, reducing insoluble matter to soluble plant-food.
4. The nitric acid formed results by combination in *nitrates*, the most valuable form of nutritive nitrogen, while the ammonia and other salts formed are direct plant-food.

That humus itself can be assimilated, or is required by the plant, is wholly disproved. It simply yields material utilized by the plant, in lieu of other source, and acts as a producer of plant-food by action on insoluble ingredients of the soil.

This combination of organic and inorganic matter completes the formation of *soil* from disintegrated minerals.*

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* For further consideration of these products of organic decomposition, see PART THIRD.

CHAPTER IV.

PRODUCTS OF ROCK-DISINTEGRATION.

WEATHERING is the term applied to the combined action of the elements, or of all atmospheric action exerted against rock-forms.

THE TIME REQUIRED for the weathering, or disintegration, of various rocks has formed the subject of extensive experiment, the most reliable results of which demonstrate that the disintegration of Jurassic limestone to the depth of 1 metre would occur at the end of 72,800 years of atmospheric action; while the same depth of syenite would be similarly affected after a lapse of 731,400 years.

The exact results of rock-disintegration are most forcibly presented by Wolff's analyses of the progressive products obtained from two different rock-forms.

I. Composition of the products of the weathering of VARIEGATED SANDSTONE.

	Fine-grained Undecomposed Sandstone.	Rock of the Sub-soil.	Fine Earth of the Sub-soil.	Arable Soil.
	per cent.	per cent.	per cent.	per cent.
Water and organic matter	0.6236	2.6190	4.6637	10.9642
Silicic acid, SiO_2	91.7348	81.8343	78.8766	73.0505
Al_2O_3	3.7425	7.6152	9.6989	9.1640
FeO	1.4891	3.7450	3.0253	2.5463
MnO	0.0167	0.5078	0.1450	0.2083
$CaCO_3$	0.0854	0.0988	0.1050	0.2300
CaO	0.0949	0.0876	0.0745	0.1158
MgO	0.1114	0.2555	0.1616	0.2167
H_2SO_4	0.0095	0.0093	0.0080	0.0304
P_2O_5	0.0249	0.0457	0.0498	0.0940
K_2O	1.8925	2.7847	2.6499	2.7214
Na_2O	0.0825	0.4420	0.3728	0.3859
	99.9078	100.0569	99.8311	99.7275

II. Composition of the products of the weathering of SILICIOUS LIMESTONE.

	Unweathered but Crumbling Limestone.	Loose particles of Crumbling Rock.	Sub-soil.	Cultivated Soil.
	per cent.	per cent.	per cent.	per cent.
Water, and loss by ignition	1.2010	3.6580	7.6970	8.9362
SiO_2, insoluble	15.0913	40.1820	54.5304	55.4569
SiO_2, soluble	1.0439	1.6629	11.2359	11.7193
Al_2O_3, insoluble	0.1301	0.1026	0.8073	1.0710
Al_2O_3, soluble	0.6199	1.1633	7.2517	7.9043
Fe_2O_3	0.0920	8.7048	9.3935	8.1769
$FeCO_3$	2.8463	......	......	......
MnO	0.3633	0.6017	0.7600	0.6600
$CaCO_3$	77.1607	43.1071	6.2362	2.6400
$MgCO_3$	1.0437	0.7210	0.3717	0.3927
CaO	0.0134	0.0255	0.1027	0.1515
MgO	0.0148	0.0371	0.3884	0.3740
P_2O_5	0.1963	0.5304	0.4833	0.4650
H_2SO_4	0.0166	0.0475	0.0493	0.0583
K_2O	0.1487	0.1641	1.2151	1.5473
Na_2O	0.0632	0.0579	0.2408	0.3429
	100.0452	100.7660	100.7633	99.8963

The relative weathering susceptibility of different rocks has been experimentally demonstrated. One-half cubic foot of variegated sandstone, of shell limestone, of basalt, and of Röth,* were subjected to atmospheric influences for four years, under like conditions. The amount of disintegration was determined by passing successively through sieves of graduated fineness. The results were classed in three divisions, as fine earth, sand and rock physically unchanged, with the following percentage results:

	Variegated Sandstone.	Shell Limestone.	Basalt.	Röth.
1. Fine Earth	2.61	1.38	0.47	3.12
2. Sand	4.32	4.87	2.52	49.44
3. Unchanged	93.07	93.75	97.01	47.44

From these investigations it appears, as was to be expected, that Röth, typical of the shales, is of all common rocks most

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* A variety of argillaceous shale, usually existing in conjunction with variegated sandstone, and a distinctively German variety.

easily attacked by the weathering influences, and most rapidly converted into soil; while basalt remains the most obdurate.

For a more definite understanding of the actual results of rock-disintegration a consideration of the products of the weathering of each individual rock-form becomes necessary.

I. PRODUCTS OF THE WEATHERING OF SIMPLE CRYSTALLINE ROCKS.

QUARTZ is wholly unaffected by the weathering process, except by the action of freezing water whereby it becomes separated crystal from crystal. The particles thus formed may be ground to fine sand by the action of running waters, but the product of such action remains quartz, and quartz only, though it may be mixed with the products of the destruction of other rock-forms.

FELDSPAR may be transformed into various products of decomposition according to variety and composition. With the lapse of time the potash, soda, lime and a part of the silicic acid become disolved by the action of carbonic-acid-saturated waters, and, finally, silicate of alumina (clay) and carbonate of lime or their mixture remain behind, together with traces of the silicates of soda and of potash, forming either *kaolin, clay* or *marl.*

OLIGOCLASE weathers most readily among feldspars because of its content of lime, while *orthoclase* decomposes with far greater difficulty, its decomposibility being inversely proportional to its content of soda and iron protoxide.

ZEOLITE decomposes with great ease because of the presence of considerable quantities of the alkalies and alkaline earths. This fact is of considerable importance because of its bearing on the transformation of rocks containing zeolite, basalt for instance, into agricultural soils, because of the destructibility of the zeolite.

HORNBLENDE weathers easily or not, according to presence or absence of considerable quantities of lime and iron protoxide. Because of the comparative absence of aluminium oxide, its silicate, or clay, is not a product of hornblende or augite decomposition, but compounds of iron, carbonates of lime and magnesia and the silicate of the latter.

MICA is among the more indestructible rocks and possesses the peculiarity of decomposing from the interior outwards. The rapidity of the process depends on the quantity of sodium oxide present, the process being furthered by the presence or increase of soda. As a result the potash and magnesia micas remain intact long after the soda variety has become wholly decomposed. The presence of iron protoxide also increases the facility with which mica weathers.

Potash mica yields yellow clay (ochre-colored from the presence of iron) mixed with glistening particles of undecomposed mica. In the case of magnesia mica this product is mixed with the carbonates of magnesia and of lime.

TALC AND SERPENTINE seem to be wholly unaffected by atmospheric agencies. Wherever these rocks come to the surface, soil is wholly wanting, and no vegetation finds a habitat.

CALCITE not only becomes decomposed by weathering into calcareous sand, but is also attacked by carbonic acid present in water, and dissolved by the same and taken into solution.

DOLOMITE weathers with greatest difficulty, even when containing iron protoxide, and without this ingredient only the action of frost is able to reduce dolomite rocks, which become thus transformed into sand closely resembling quartz-sand in properties, and nearly as insoluble, though finally reduced to solution by carbonic-acid-acidulated waters.

GYPSUM is extremely soluble in the moving waters of the soil; a fact of inestimable importance agriculturally, as it becomes incorporated with the soil as a constituent part, thus readily furnishing the plant with the essential calcium.

MAGNESITE is readily weathered, becoming an asbestos-like compound capable of becoming a pseudomorph of talc.*

OLIVINE changes rapidly under atmospheric action. The first change results in the appearance of a dirty green color, which finally becomes brown through oxidation of the iron-protoxide. The final products of the decomposition are very

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* Roth, *Chemische Geologie*, Bd. I. p. 182.

numerous. Silica may be displaced by carbonic acid, or magnesian and iron silicates may be replaced by water, serpentine being the result.

LEUCITE decomposes by the weathering influences into a kaolin-like product; the transformation is, however, slow and but partial.

NEPHELINE becomes under atmospheric influences transformed into zeolith.

IRON MINERALS as affected by the weathering influences have been considered under the action of air and of water as decomposers of rock-forms.

II. PRODUCTS OF THE WEATHERING OF COMPOUND CRYSTALLINE ROCKS.

GRANITE decomposes into its constituent minerals, feldspar, quartz and mica, accompanied by a more or less important production of clay.

SYENYTE becomes by the weathering agencies transformed into clay, usually yellowish in color, and impregnated with bits of hornblende and chlorite undecomposed.

GNEISS forms on weathering a yellow-tinted clay-like product, with particles of mica and feldspar.

GRANULYTE decomposes with greater difficulty than either granite or gneiss, being not infrequently, however, converted into a nearly pure kaolin mixed with intact crystals of quartz.

PORPHYRY results through weathering in a considerable number of products, varying with the composition of the original rock. The product is, however, of a clay character, but may, if originating in a porphyry rich in potassium-oligoclase, contain from 2 to 6 per cent of calcium carbonate.

TRACHYTE becomes transformed into an impure kaolin, approaching nearer genuine kaolin in character with the increase in the amount of feldspar entering into its composition.

PHONOLYTE results in the formation of a marly product, whitish in color, very insoluble in water, and hardening from its solution or water-deposition into a very compact and hard mass. In localities, therefore, where subjected to drying or sun-hardening it forms a most unmanageable and sterile soil; where retaining a constant and considerable amount of water, on the contrary, it forms a fruitful soil, containing 2–5 per cent of calcium carbonate and 5–10 per cent of sodium compounds.*

MICA-SCHIST varies in the products of its decomposition, according as the mica entering into its composition be of the potash or of the magnesia variety. Quartz-sand is an accompaniment of the weathering, together with iron oxide and particles of chlorite and talc bedded undecomposed in the loam formed.

SLATE weathers to clay, impregnated with particles of mica, quartz, chlorite and hornblende.

DIORITE forms many and varied decomposition-products. Hornblende diorite, containing little lime but much magnesia, with oligoclase weathers with difficulty, producing, however, a fertile loam free from quartz-grains. Lime-diorite, containing hornblende and feldspar, decomposes faster, producing a clayey product, yellow-colored from the iron of the hornblende, containing 5–10 per cent of lime and considerable quantities of carbonate of magnesia.

BASALT weathers with greatest difficulty for the formation of a marly product, containing large quantities of iron oxide, imparting a brownish or greenish color, together with particles of chlorite and of augite.

DIABASE weathers with products more or less resembling diorite, augite or chlorite, as one or the other of these minerals predominates.

MELAPHYRE becomes after ages of weathering a red-brown clay, when dry an impalpable powder, when moist a most tenacious soil containing, however, 10 per cent or even more of calcium carbonate.

HYPERYTE is transformed into loam containing large quantities of calcium carbonate, even 5 per cent, but only traces of either soda or potassa.

GRANULAR LIMESTONE is readily transformed into calcium

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* Göhren, *Ackerbauchemie*, Bd. I. p. 27.

bicarbonate, thus passing into solution. The rapidity of the change is modified by the presence of magnesian carbonate, so prevalent an accompaniment of crystalline limestones.

III. PRODUCTS OF THE WEATHERING OF NON-CRYSTALLINE ROCKS.

All fragmental or sedimentary rocks, without doubt, once existed in the form of soil resulting from the weathering of crystalline rocks, precisely after the manner of transformation occurring at present. During this former existence they were surely the habitat of plants securing their sustenance from them.

These rocks are, therefore, not only transformable into such soils again, but all the soils of to-day, sand, clay or loam, are as certainly capable of re-formation into rocks, sandstone, slate, by subjection to the proper solidifying and metamorphic influences.

The entire series of non-crystalline rocks are liable to transformation into soils by the decomposing influences of water and frost, but the properties and composition of the products vary materially with the nature of the binding material of the rock acted on.

Clay, the most frequently occurring binding material, becomes, by the constant action of water, a clay-like mass containing particles of sand and undecomposed material, the fertility of the resulting soil depending on the composition of these more insoluble and enduring substances, without the presence of which the resulting soil can be little but the silicate of alumina with iron oxide and sand, or possibly some silicate of magnesia.

GRIT, consisting as it does chiefly of silicic acid, disintegrates with great difficulty, and forms finally a sandy soil somewhat more fertile than that resulting from quartz disintegration, because of the small amounts of iron-magnesia and of organic matter present.

TUFA is a term describing more particularly the manner of origin of a class of rocks than either the chemical or physical characteristics of the product. One fact, however, holds true of all varieties of tufa; they are all of volcanic origin, and therefore all possess properties similar to those of crystalline rocks of igneous origin resulting in products of disintegration similar to those of basalt, trachyte and phonolite; with the difference, however, of more rapid decomposition and a larger yield of fine earth, with increased content of carbonates and sodium salts.

The predominating constituent is, however, silica, lending an invariable sandy texture to the product. There are tufa-formations possessing a composition more nearly allied to that of wood-ash, containing considerable quantities of potash and of phosphoric acid, the decomposition of which results in the formation of soils of almost exhaustless fertility; illustrated by certain localities in Italy and the Black Sea region of Russia.

Other soils of tufa origin are so abounding in silica as to not only furnish little vegetable nutriment, but as to be almost unworkable with steel or iron implements because of the scouring to which they are subjected. Yet even these are finally capable of yielding a product of fertile productive soil.*

SAND AND GRAVEL are transformed by the weathering agencies only very slowly, producing widely-varying products with, however, silica as the ever-predominating constituent.

SANDSTONE, consisting chiefly of quartz particles held together by a more or less tenacious binding material, is very easily disintegrated. This binding material, being in general exceedingly soluble, is more frequently washed away, leaving only the pure sand behind. When this does not take place, however, but the sand remains mixed with a considerable quantity of both mineral and organic matter, the soil resulting is usually one of considerable fertility, and particularly adapted to certain uses because of the warmth resulting from the absorptive powers of quartz towards the sun's rays.

Because of the solubility of the unsilicious portion of the

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* Large areas in Yesso naturally fertile and covered with forests of maple and magnolia are of tufa origin, and unworkable and untillable because of the gritty nature of the soil, in which a steel plough will not endure twenty-four hours of steady use.

sandstone, the product of the disintegration of new sandstone is far less fertile than that resulting from the decomposition of sandstone of earlier date; as the latter has not passed through a second or third process of weathering, solution and re-solidification, but exists as the original sedimentary deposit of the disintegrated material of early crystalline rocks.

GREENSAND, though decomposing with difficulty, consists largely of the silicates of potash and of iron, soluble under the influence of carbonic-acid waters, and therefore yielding elements of fertility with comparative ease, phosphoric acid in the form of calcium phosphate from organic remains adding value to the product.

SHALES disintegrate with ease both under the action of water and of air; the product is clay of varying composition, but not infrequently containing considerable quantities of sodium, potassium, calcium and iron compounds.

CHALK undergoes little chemical change as the result of weathering, the change being chiefly of a physical nature whereby combination with organic matter is facilitated.

MARL, most closely resembling chalk in characteristics, is similarly affected by weathering influences. The product is, however, superior because of the presence of magnesia and of phosphate of lime from organic sources.

Having now reviewed and recorded the definite results of atmospheric action as applied to each individual variety of rock, we are prepared to intelligently and advantageously consider the ultimate products of this action—the combinations of these various disintegrated rocks when united with organic matter, and thus transformed into soil. The fact must, meanwhile, not be lost sight of that every soil thus formed must of necessity partake of the composition of the rock in whose disintegration it had origin.

PART THIRD.

CHAPTER I.

ORIGIN AND COMPOSITION OF SOILS.

THE disintegrated rock whose progress toward soil-formation we have thus far followed undergoes one further transformation before the final product capable of sustaining vegetable existence appears. Plants consist of both organic and inorganic matter, and, though the chief part of the former is of atmospheric origin. It must, to a certain extent, be obtained from the soil; therefore only with the presence of both classes of matter does the disintegrated rock arrive at the true condition of soil. This necessary incorporation of organic matter with the mineral constituents of rock origin results chiefly through the action of living organism, either animal or vegetable.* Nitrogen, however, so important a constituent of all living organism, becomes a soil-constituent largely by absorption from the atmosphere in the form of ammonia.

The action of plants and of animals toward soil-formation are, however, so essentially different that a separate consideration of each is rendered necessary.

I. PLANTS AS A SOURCE OF THE ORGANIC CONSTITUENTS OF SOILS.

Geological evidence all tends to establish the early existence of vegetable forms on the Earth; only the earliest Archaic rocks are known to have been formed previous to the appearance of the lowest forms of plant-life. The method employed by nature for the incorporation of vegetable organic matter with the inorganic mass of the Earth-crust, or the development

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* In this connection it should be borne in mind that, chemically considered, only that material is *organic* which contains the element *carbon*.

of organisms on a purely mineral soil, needs no hypothetical explanation, but is to-day practically illustrated by the transformation of solidified lava from recent volcanic eruption into a plant-supporting soil.

The eruptive mass, like the original Earth-crust, appears as a molten, glowing aggregation of different kinds of wholly inorganic matter. It cools by the radiation of heat and becomes igneous rock. Through time's metamorphosis it begins to disintegrate; and presently the simplest forms of microscopic vegetable life appear, finding the simple requirements of their existence on their rocky habitat, and, procuring organic matter from the atmosphere, finally die. The substance of their organisms becomes deposited on the rock-surface to which the lowly plant adhered.

Each generation of life adds to the accumulated organic matter thus covering the rock-mass. The process continues; the weathering influences play their part; and the deposited organic matter becomes mingled with the disintegrated mineral matter, a true soil, however minute may be the quantity, being the result. Gradually but ceaselessly the depth of soil increases as the action continues, and the character and nature of the vegetation advance apace, the plants themselves adding to the disintegrating forces engaged, till finally with the lapse of years the original rock-formation becomes completely buried beneath the accumulation of mineral and organic matter incorporated together; a perfect agricultural soil capable of supporting the highest organisms of the vegetable world is finally formed.

The rapidity of the increase in organic matter through the life-function of the plants finding a habitat on different soils is shown when we remember that of the entire weight of all plants not more than 5% in any case is of soil, or mineral, origin; the remainimg 95% is wholly of atmospheric origin; most of which becomes added to the soil-mass on the death and decomposition of the plants.

The amount of organic matter thus becoming incorporated with the soil is not ordinarily a large proportion of the entire soil-mass, though the limits of variation are great. Though the quantity of organic matter absolutely necessary as a constituent of soils for the production of plants is very small, the amount which may be present in soils consisting chiefly of decomposed vegetation is proportionally large. Peat may contain as high as 70% of organic matter in its dry mass, while some prairie and long-enriched garden soils not infrequently contain 25% under like conditions. The rich alluvial of the Mississippi Valley seldom contains more than 10% of organic matter, and few agricultural soils contain over 15%, while the average for good productive lands is not above 6%, clays seeming to contain the highest average amount among arable soils, presenting not seldom even 12%. Most common crops are, however, produced from soils containing far less than this proportion. Oats, rye and buckwheat thrive with the lowest amount of organic matter, requiring but from 1 to 2 per cent, while wheat and tobacco evidently require most among common agricultural products growing best in those soils containing from 5 to 8 per cent of dry organic matter. The process by which this organic matter becomes incorporated with the soil is simply the decay of the organism furnishing it. The organic constituents of the soil are, therefore, all products of decomposition; the character of which is important as bearing on the nature of the transformation wrought in the composition of the inorganic rock-mass by this accession.

The entire product of the decomposition process is collectively designated *Humus;* a term not defining a definite product, but embracing all the non-volatile solid products of a definite chemical action or decomposition. But decay or organic decomposition is a process identical with combustion; the products are ever the same, and the ultimate end is the formation of water and carbonic acid, with a residue of mineral matter or ash, if such existed in the burning or decaying body. Humus, therefore, is not the end of a process, but an intermediate stage of the transformation. Hence, were no addition of fresh humus from newly-decomposed organic matter constantly made, the soil must become devoid of this material through its gradual transformation, or the final completion of the process of decomposition.

Under ordinary conditions of decay, however, the accession of fresh material is more rapid than the loss occasioned through the ultimate completion of the combustion. It thus appears that the result of the decay of vegetation is not only the addition of organic matter, or humus, to the soil, but that *there is at the same time a constant accession of mineral matter from the same source.* And, moreover, that only by constant replenishing of the supply of the material undergoing decay, and the gradual passing of the material through the various stages of decomposition, is the organic content of the soil perpetuated.

THE CONDITIONS ESSENTIAL TO ORGANIC DECOMPOSITION are those most favorable to combustion or oxidation—access of air, presence of moisture and application of heat.

The air combines with the constituents of the decomposing body to form products of oxidation; and the diminishing of the supply of air immediately checks the rapidity or completeness of the decomposition, thus explaining the accumulation of peat under water, and of leaf-mould under the protecting upper strata of deposited material. The presence of moisture and of warmth aids the humus-forming process, inasmuch as all chemical action is increased or rendered more energetic by the action of one or both of these agencies.

Besides these abettors of decay, the chemical activity exerted may be increased by the action of any caustic alkali or alkaline carbonates. The latter by neutralization of acid products, the former by direct decomposition.

Should the decomposing organism contain albuminoid material, protein compounds, as is almost invariably the case, the decay assumes a different form, known as *putrefaction*, resulting from a process of fermentation the products of which are, in addition to those otherwise arising (water and carbonic acid), compounds of hydrogen with carbon, nitrogen, phosphorus or sulphur.

The carbonic acid formed through organic decomposition is of incalculable agricultural significance, since it not only exerts a most important influence on the mineral constituents of soils, as already noticed, but supplies plants with the carbon forming so large a part of their organic material.

But organic putrefaction results in the evolution of another gaseous compound of only less importance; namely, volatile ammonia-gas resulting from the union of nitrogen and hydrogen (NH_3). This gas combines most readily with acids for the formation of ammonium salts, among which the carbonate ($(NH_4)_2CO_3$) only is volatile and escapes to the atmosphere.

In the soil, however, only a comparatively small amount of the total product of ammonia is volatilized, both because of its combination with acids and its absorption by humus.

The ammonia thus resulting from putrid fermentation undergoes a further decomposition known as *nitrification*, resulting like the original putrefaction from the action of oxidizing microbes through the activity of which ammonia becomes transformed into nitric acid.*

The transformation is doubly important inasmuch as loss from volatilization is prevented; and moreover the new form in which the nitrogen exists is one furnishing this essential element of plant-nutrition in a form far more assimilable and readily available by the crop than in the previous or ammonia condition.

The most recent experiments at Rothamstead with reference to the relative value of nitrogen as plant-food in the two forms of ammonia and of nitric acid indicate that there exists a difference of 25% in favor of the latter combination.†

THE CONDITIONS FAVORABLE to this change of form are: presence of atmospheric air, moisture, heat above 12° and below 55° C. The activity increases with elevation of temperature till 37° C. is reached, at which point the maximum nitrification occurs; it then diminishes regularly till at 55° C. it ceases altogether, the microbes losing all nitrifying power.‡

The products of the phenomenon of putrefaction, like those of all organic decomposition, are identical with the process of combustion, with a difference only in time required and consequent energy of the chemical action. We have already seen

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* Warrington in *Journal of the Chemical Society*, Jan. 1878.

† Personal communication from Sir J. B. Lawes to the author.

‡ Wolff, *Düngerlehre* (Berlin, 1883), p. 12.

that in each case a residue of inorganic, non-combustible material or ash must be the result. But the accomplishing of this result through humification not only brings to the soil an accession of atmospheric matter, but, since the mineral constituents of plants are obtained often from great depths by the penetrating roots, and the decay of the plant thus built occurring comparatively near the surface, the process of necessity *results in the constant transfer of mineral matter from the subsoil, accessible to but few plants, directly to the surface-soil, where it becomes freely-soluble food awaiting the demands of all agricultural plants.*

Another feature of the process of humification worthy of note is the fact that the more rapid or complete the decomposition the greater is the resulting product of ash material, because of the large amounts of water and of carbonic acid formed; the same cause increases the product of nitrogen and carbon, while the quantity of hydrogen and oxygen is diminished.

In connection with this fact is the self-evident truth that the nearer the surface the more perfect must be the decomposition, because of the more free access of air. And atmospheric oxygen not only furthers the decomposition, but facilitates the transformation of nitrogen into ammonia and nitric acid.

It therefore follows that the deeper soil-strata and peat-deposits excluded from free atmospheric action contain vast stores of the all-essential nitrogen, not converted into assimilable form as ammonia or nitric acid, but remaining in an unutilizable form, awaiting the completion of its decomposition, through artificial subjection to atmospheric action and consequent conversion into plant-food.

Though ammonia salts and nitric acid are by far the chief nitrogen-furnishing compounds among all sources of nutrition, yet organic nitrogen cannot be asserted as being wholly inactive or dormant; the supply of food obtained from this source is, however, so small as to pass almost unnoticed.

II. ANIMALS AS A SOURCE OF THE ORGANIC CONSTITUENTS OF SOILS.

All that has been recorded concerning the action of plant-life and decomposition in supplying the organic matter present in all agricultural soils might be repeated, with equal force and applicability, in describing the function of animals in transforming broken-down rock into true soils; with this difference, however, that the organic matter thus conveyed to the soil by animal life and death was not extracted from the atmosphere through the life-function of the animal body, but passed first through the intermediate stage of plant existence; then entering the animal system as food, to finally pass to the soil, there to be subjected to the same influences acting on vegetable matter; to undergo like process of decay or decomposition with a final formation of identical products.

One difference, not of kind but of degree, should, however, be cited. Plants are characteristically carbonaceous in composition, while animals are as distinctively nitrogenous. Carbohydrates are the predominating constituents of the former, albuminoids of the latter. It therefore necessarily follows that although the decomposition of the two different classes of organisms results in the formation of the same class of compounds, and putrid fermentation is a characteristic phenomenon in both cases, it is a far more important occurrence with animal matter, because of the greater quantity of material subjected to its action, and the consequent greater yield of the typical products ammonia and nitric acid.

Another distinction should also be made between the methods by which plants and animals contribute to the organic matter of the soil. Although with the former the procuring of organic matter from the atmosphere as well as from the soil direct is a distinctive *life-function*, the return or conveyance of the material thus obtained to the soil is only accomplished through death and decomposition.

On the other hand, though animal death and decay are no less distinctive steps toward supplying the soil with its organic matter than is the case with the vegetable world, the animal possesses the further power of returning organic matter to the soil as a direct result of the life-functions themselves.

Animals return to the soil that part of the organic matter consumed as food but not assimilated by the system. This effete matter, or excreta, both solid and liquid, becomes incorporated with the surface-soil, undergoes the same decomposition, and furnishes the same resulting products as is the case with decaying animal or vegetable organisms.

Important as this excretion of organic matter by living animals has been, and continues to be, as a factor in supplying soil with its quota of organic constituents, other and even more important results are accomplished through the energy and activity of certain animal forms. Not by the addition to the soil of effete or exhausted material, but by the direct action of the animal on the soil itself in performing its life-functions and fulfilling the destiny of its existence.

THE BURROWING OR PLOUGHING OF CERTAIN ANIMALS is of a nature identical with the labors of the human ploughman, and with results on the organic constituents of the soil commensurate with the energy exerted. The importance of the labor thus performed during the lapse of long periods of time cannot appear small when it is recalled that thereby are secured the means of exposure to atmospheric action, resulting in oxidation of carbonaceous and albuminous material, as well as the mineral constituents of the soil.

Ants, moles, prairie-dogs and marmots are the animals whose activity in this work has been most noteworthy.

Concerning the labors of these last-named quadrupeds, interesting and important facts have just been brought to light.*

It is reported that on the Caspian Steppes the burrowing of these animals has brought to the surface within a few years one cubic metre of earth per square metre of surface. Or over large areas, not less than 30,000 cubic metres of earth have been brought to the surface for every square kilometre of area;

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* Mushketorf, *Nature*, Oct. 6, '87, p. 541.

hundreds of square miles having been thus subjected to literal upheaval and pulverization.

Considerable as has been the influence thus exerted on the ultimate organic content of the soil, it is but insignificant as compared with another class of animal action exerted in a far different way.

EARTH-WORMS have, through all geological time since their arrival on the Earth, been steadily engaged in the conversion of the inorganic soil into vegetable mould, as a life-function, through the addition to it of the organic matter required for the transformation.

The action of worms is of two kinds. First, chemical action on the mineral constituents of soils by conveying to them organic matter of a humus character in the form of digestive secretions; and second, physical action on the soil-particles by passing through the alimentary system of the animal.

THE SECRETION OF ORGANIC ACIDS IN THE DIGESTIVE ORGANS OF WORMS is thus described by Darwin:* "From the contents of the intestines of worms, and from their castings being acid, it seems probable that the process of digestion induces an analogous chemical change in the swallowed triturated and half-decayed leaves. The large quantity of carbonate of lime secreted by the calciferous glands apparently serves to neutralize the acids thus generated; for the digestive fluid of worms will not act unless it be alkaline. As the contents of the upper part of their intestines are acid, the acidity can hardly be due to the presence of uric acid. We may therefore conclude that the acids in the alimentary canal of worms are formed during the digestive process, and that probably they are nearly of the same nature as those in ordinary humus."

The best experimental demonstration of the transformation thus wrought in the composition and characteristics of the soil is by Von Hensen.†

A vessel eighteen inches in diameter was filled with sand, the

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* "The Formation of Vegetable Mould through the Action of Worms," p. 240.

† *Zeitschrift für Wissenschaftliche, Zoologie,* 1877, p. 360.

latter being strewn with leaves. Two worms were introduced; the leaves were quickly drawn into the burrows of the worms to a depth of some three inches, and were partly consumed and partly used as lining or as barriers at the entrance to the burrows. At the end of six weeks a uniform layer of sand one centimetre in depth was converted into humus by having passed through the alimentary canals of these two individuals.

Not only is organic matter conveyed to the soil as a product of the digestive systems of worms, but the leaves drawn into the burrows as food are, after being but partially digested, saturated with intestinal and urinary secretions and mingled with the soil. The latter thereupon becomes the dark, rich humus so universally covering the surface of the Earth with its well-defined protecting stratum.

The amount of organic matter thus directly or indirectly added to the soil may be inferred from the fact that Darwin estimates that the material annually brought to the surface by worms is two tenths of an inch per acre; equivalent to an average of 10.59 tons for each acre inhabited by worms.

No data exist for determining the exact difference in composition between the soil before and after subjection to this action. But Darwin states the ammonia content of worm-casting to be 0.018%, while the average amount of ammonia present in common surface-soils as determined by Knop and Wolff * is only 0.00056%. It therefore appears that the action of worms has increased the ammonia content of the soil acted on more than threefold (321%); and the total amount of ammonia added to the soil by this means would be represented by .01744% of 10.59 tons; equivalent to an accession of 36,936 lbs. of ammonia per acre. Yet ammonia is but one, and perhaps not the most important, of the constituents directly conveyed to the soil by the life-functions of worms. At present, however, we can only surmise that the accession of other material is proportional to the gain in ammonia.†

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* Johnson, "How Crops Grow," p. 250.

† The chemical changes resulting through the action of worms on the soil are at present being experimentally investigated under the direction of the author.

This, be it borne in mind, is but a change wrought in one year, and capable of yearly repetition. And, moreover, "the entire mass of the mould on every field passes in the course of a few years through their (the worms) alimentary canals." *

III. Composition of the Soil.

Having now reviewed the incorporation of organic matter with the mineral matter, the result of which is the production of a true agricultural soil, it becomes in order to consider more intimately the chemical constitution of the combined material; first examining more carefully

A. COMPOSITION OF THE ATMOSPHERIC INGREDIENTS OF THE SOIL.

As already noticed (page 125), humus, or the constituent of soils derived from organic decomposition or from the life-function of animals and plants, is a complex material consisting of a varying number of ingredients, all definite chemical compounds, chief among them being recognized ulmin and ulmic acid, humin and humic acid, crenic and apocrenic acid.

Ulmin and its acid compound are supposed to characterize brown humus, while humin and humic acid are obtained from dark or black humus. The composition of these bodies cannot be stated as determined beyond doubt, and Johnson ("How Crops Grow," p. 125) even doubts the existence of either humin or ulmin as distinct from the corresponding acid though later authorities † recognize the distinction.

The change from base to acid is, however, not a change in composition, and is wrought by the action of a solution of sodium carbonate in which the acid alone is soluble. These compounds are not only products of organic decomposition, but may be synthetically formed by the action of strong acids on sugar, starch or cellulose.

The most reliable results of analyses establish the composition of these different humus compounds as follows:

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* Darwin, p. 243.

† Mayer, *Agriculturchemie*, Bd. II. p. 67; Beilstein, *Handbuch d. Organ. Chem.* p. 608.

Ulmin and Ulmic Acid.

Carbon,	67.1%	Corresponding to $C_{40}H_{28}O_{12} + H_2O$.
Hydrogen,	4.2%	
Oxygen,	8.7%	

Humin and Humic Acid.

Carbon,	64.4%	Corresponding to $C_{21}H_{24}O_{12} + 3H_2O$.
Hydrogen,	4.3%	
Oxygen,	31.3%	

Crenic Acid.

Carbon,	44.0%	Corresponding to $C_{12}H_{12}O_8$?
Hydrogen,	5.5%	
Nitrogen,	3.9%	
Oxygen,	46.6%	

Apocrenic Acid.

Carbon,	34.4%	Corresponding to $C_{24}H_{24}O_{12}$?
Hydrogen,	3.5%	
Nitrogen,	3.0%	
Oxygen,	39.1%	

There are, aside from these humus compounds, others still less known and the action of which is not yet understood; among them xylic acid, $C_{24}H_{30}O_{17}$, saccharic acid, $C_{14}H_{18}O_{11}$, glucinic acid, $C_{12}H_{22}O_{12}$, besides a brown humus acid containing carbon, 65.8%, and hydrogen, 6.25%, and a black humus acid yielding carbon, 71.5%, and hydrogen, 5.8%.*

It is somewhat remarkable that the composition of these compounds still remains shrouded in uncertainty; the only explanation being the extreme difficulty in obtaining them sufficiently isolated and pure for analysis. It is perhaps pardonable in agricultural chemists to still accept and quote the authority of Mulder when the latest works on organic chemistry, including Roscoe and Schorlemmer and Beilstein, venture no formulæ for these long-ago-recognized compounds.

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* Beilstein, p. 609.

Yet Mulder's assertion, repeated by Johnson and others, that the nitrogen detected by all of his analyses of crenic and apocrenic acid was due to the presence of ammonia compounds, probably ammonia salts, is irrational in the extreme, though true no other explanation was then more tenable.

That any ammonia salt should have successfully withstood the action of caustic potash is not possible, since no known organic nitrogen compound fails to yield ammonia through this action; while with most organic compounds caustic potash acts rather with too great energy, so that the weaker alkali, magnesia, is more frequently used for the purpose.

It is therefore far more reasonable, as explained by Mayer,* to believe that the so-called crenic acid and apocrenic acid of humus are in reality organic nitrogen compounds. This being true, the excessive insolubility and resistance of many soils (peat, for instance, with a humus yielding as high as 4.7% of nitrogen) to the action of plants, and their worthlessness as sources of plant-food nitrogen, is explained. When caustic potash fails in reducing organic nitrogen to a soluble form, the efforts of the growing plant must be hopeless indeed.

THE ACTION OF THESE HUMUS COMPOUNDS ON THE INORGANIC CONSTITUENTS OF THE SOIL is of no inconsiderable importance. The ulmates, humates, crenates and apocrenates of the alkalies, potash, soda and ammonia, are freely soluble in water and must therefore serve as plant-food. A fact important in its bearing on the conversion of insoluble silicates into soluble compounds of the humus acids.†

THE NITROGEN OF THE SOIL may exist in three different and distinct forms; 1. As organic nitrogen combined with carbon, hydrogen and oxygen (sulphur, phosphorus and chlorine may also be present in the compounds). 2. As ammonia or ammonia salts; 3. In the form of nitric acid.

The total amount of nitrogen present in average agricultural soils is slight, varying from 0.1 to 0.3 per cent, although in peat and humus from 4 to 5 per cent is not unknown.

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* *Agriculturchemie* (Heidelberg, 1875). Bd. II. p. 69.

† Julien, Proceedings A. A. A. S. 1879, p. 311.

Of these three forms only the two latter can be considered as available nitrogen, and the former is of no value as plant-food except as converted by decomposition into one of the other forms mentioned. A transformation occurring but slowly at best. The extremely inaccessible organic nitrogen of soils is aptly described by Mayer as corresponding to the nitrogen of mineral coal, also resulting through a process of humification, and as being, so far as vegetation is concerned, similar to insoluble phosphoric acid and potash.*

THE AMMONIA OF THE SOIL exists, because of its affinity for acids, exclusively as ammonia salts, the carbonate being most prevalent. The entire quantity present at any one time is very slight, the extremes being 0.00014–0.001 per cent, with an average of 0.00057%. Ammonia salts are, however, all soluble in water, and therefore the quantity present is wholly available, while the amount receives constant replenishing through organic decomposition.

Much ammonia is doubtless received from the air, chiefly absorbed by rain and thus conducted to the soil as an aqueous solution, but either immediately combines with acids or is lost by volatilization. The formation of ammonia through the process of putrefaction, as already considered (page 127), remains the most interesting source of vegetable nitrogen, inasmuch as it supplies not only the ammonia assimilated by plants, but also is the greatest supplier of the nitric acid resulting from the process of nitrification.

THE CONVERSION OF INACCESSIBLE ORGANIC NITROGEN INTO AMMONIA has a most important bearing on vegetable nutrition, not so much through its occurrence in natural soil-constituents, but from the fact that the richest of all nitrogenous natural fertilizers, urine, contains nitrogen only in the form of urea, where it exists as combined organic nitrogen wholly inaccessible as plant-food; by decomposition, however, the urea, N_2H_4CO, becomes transformed into ammonium carbonate, $(NH_4)_2CO_3$, soluble plant-food.

$$N_2H_4CO + 2H_2O = (NH_4)_2CO_3.$$

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* *Agriculturchemie*, Bd. II. p. 70.

The transformation wrought is the result of the life function of a micro-organism living only in presence of oxygen; and Prof. Kellner of Komaba, Japan, has recently shown that the transformation occurs only comparatively near the surface, seldom deeper than 0.5 metre, since below this depth sufficient oxygen for supporting the life of the transforming organisms is not present. A most important fact when taken in consideration with the truth that the transformation is not of immediate but rather slow occurrence, and that the soluble urea must therefore often be carried by heavy rains far deeper in the soil than its transformation into ammonium carbonate is possible; therefore, being wholly insoluble, must be a total loss so far as a source of vegetable nitrogen is concerned.*

THE NITRIC ACID OF THE SOIL, as already recorded, is chiefly a product of organic decomposition existing in the soil, combined with potassium sodium, ammonium or calcium to form nitrates of these most common soil-bases, and resulting from the transformation of ammonia by the action of living organisms, through a process known as nitrification.

The total amount of nitric acid in agricultural soils is, according to Wolff, slight, and varies between the extremes 0.0006 and 0.03 per cent, with an average of .01502%. Small as the quantity is, however, it plays a most conspicuous part in the nutrition of all agricultural plants.

Since nitric acid, formed in the atmosphere through the action of electricity, is, therefore, always present in traces as a constituent of the air, and is most readily soluble in water, it follows as a matter of necessity that some nitric acid must find its way to the soil as a constituent of rain-water, usually, however, combined with the ammonia likewise extracted from the air. By far the greater quantity of soil nitric acid, however, is of organic origin, and formed directly in the earth by decomposition, passing through the intermediate stage of ammonia formation.

THIS PROCESS OF NITRIFICATION, already mentioned (page 127), resulting in the conversion of ammonia into nitric acid,

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* *Landwirthschaftliche Jahrbücher*, Bd. XV.

through the action of living microbes, occurs only in the upper strata of soil, where access of oxygen for supporting the existence of the acting organism is greatest; and is of necessity increased by the porosity of the soil and by exposing new surfaces to action.

The most recent Rothamstead experiments demonstrate that little or no nitrification occurs in the subsoil; 2–3 feet being evidently the extreme depth at which the phenomenon occurs.* The nitric acid of the soil below this depth is doubtless carried thither in the drainage or by diffusion.

The depth at which nitrification may occur, however, is capable of considerable variation, not only because of the physical condition of soil, and access of oxygen, but depends largely on the character of the crop grown; leguminous plants, like vetch and clover, seeming to possess the property of considerably increasing not only the depth at which the transformation may occur, but also the activity of the nitrifying organisms.

To refer the occurrence back from effect to cause since the leguminous plants are most fortunate in the amount of nitric acid furnished them by the micro-organisms, it is a reasonable inference to suppose that the leguminous plant in its turn furnishes the most favorable conditions for the growth of the microbes, or the proximity to the roots of legumes is their most congenial habitat.†

ATMOSPHERIC NITROGEN ITSELF MAY ALSO BE SUBJECTED TO THE NITRIFICATION PROCESS, there seems every reason to believe, although the author is aware of no assertion of the fact. But nitrification and action on urea are not the only functions of lower organisms effecting nitrogen compounds. Berthelot has recently shown ‡ that certain soils, both argillaceous and sandy, possess the property of absorbing and fixing atmospheric nitrogen, through the action of a living organism.

Five series of experiments were made with soils under as many different conditions. The first soil was preserved in a

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* Warrington, *Journal Chem. Soc.*, Feb. 1887.

† Miles, *Agricultural Science*, May 1887.

‡ *Bullétin de la Société Chimique*, Feb. 26; also *Am. Journ. of Science*, **May** 1886, p. 391.

room, the second in the open field, but under shelter, the third exposed on top of a tower 28 metres high, and the fourth was contained in hermetically closed flasks, while the fifth was sterilized. In the first four cases, or, in other words, with all soils not sterilized, there was a slow fixation of atmospheric nitrogen, independent of ammoniacal condensation, and of nitrification.

Each kind of soil was equally affected; and all locations or conditions chosen. The compounds formed were complex, insoluble amides, resembling those existing in living organisms; and must have resulted through the vital activity of the microorganisms present.

The reaction does not occur in cold weather, is manifest throughout the growing season, but is prevented at temperatures above 100° C.

The amount of nitrogen becoming thus fixed by each hectare of surface is equivalent, during one season, to 20 kg. for yellow sand, 20.5 kg. for second sand and 35 kg. for clayey soil.

The chief interest and importance attached to these facts seems to rest on the most reasonable supposition that nitrogen thus extracted from the atmosphere may become actual plant-food, and thus revolutionize previously-conceived ideas concerning the ability of the plant to assimilate nitrogen of atmospheric origin; and explain many before mysterious facts concerning vegetable nutrition. We have heretofore supposed atmospheric nitrogen to be inaccessible to plants, unless converted into nitric acid or ammonia and in these forms absorbed by the soil. But now, though we still possess no evidence that atmospheric nitrogen is direct food for plants, we find that it becomes, by the action of living organisms, transformed into organic nitrogen and is taken up by the soil in a form closely resembling the forms of organic nitrogen already considered; and must, like them. be subjected to the action of those forces or beings through the activity of which organic nitrogen becomes converted into ammonia and nitric acid and thus finally exists in accessible form for plant-assimilation.

The study of these organic nitrogen compounds of atmospheric origin through their metamorphosis from atmospheric nitrogen to nitrogenous compounds containing accessible nitrogen remains a field for further research.

THE REVERSE OF NITRIFICATION is likewise a well-recognized phenomenon. That is, the nitric acid formed by the action of certain organisms on ammonia may, under certain conditions, *become re-transformed into ammonia.* This process results from the affinity of nitric acid for soil-bases, chiefly alkalies and alkaline earths; it therefore never exists uncombined in the soil, but in the form of nitric-acid salts, particularly as nitrates of potash, soda, lime and ammonia. And these compounds by reduction lose their nitric acid, which again becomes ammonia, and the bases combining with the oxygen remain behind as oxides. The reaction occurs chiefly in the subsoil stratum, where atmospheric oxygen finds less ready access, and where, therefore, nitrification seldom occurs.

OTHER INGREDIENTS OF ATMOSPHERIC ORIGIN exist as occasional constituents of the soil, some of which are capable of indirectly furnishing plant-food; among them nitrous acid and carbohydrates, decomposable into carbonic acid and water. The carbonic acid thus formed is doubtless to a limited degree a source of vegetable carbon; but its chief action is through combining to form carbonates or bicarbonates, the importance and action of which have been fully considered in PART SECOND.

B. NON-ATMOSPHERIC CONSTITUENTS OF THE SOIL.

These are of course wholly mineral. Nitric acid and ammonia are equally mineral as distinguished from organic; but from the difficulty of separating them from organic compounds from which they are generated, they have been considered with their organic combinations under the classification of *atmospheric.*

The soil must of necessity contain, in addition to the constituents already considered, all the elements composing the rocks through whose disintegration they were first formed and on which they find a basis. As a matter of fact, therefore, soils, or some soils, must contain the more than threescore of elemental bodies existing in different rock-forms. But agriculturally considered, the soil is of a much simpler organization, and in addition to those constituents already enumerated contains but twelve substances recognized as entering into the composition of plants, and therefore important and essential compounds of all agricultural soils.

These are, as they exist in the soil and are found in the plant, mostly compound in nature, being either oxides or acids as follows: potasa, soda, magnesia, lime, alumina, iron and manganese oxides, sulphuric acid, phosphoric acid, silica, carbonic acid, and chlorine.

The occurrence and characteristics of each require separate discussion.

POTASA AND SODA exist in the soil only combined with acids, never in free condition. Most frequently the combination is with silicic acid to form silicates; the sodium exists combined with chlorine to form the very abundant and widely-distributed sodium chloride, common salt. With the exception of silicates, the potash and soda, and all alkali compounds, of the soil are all readily soluble in water. The soil content of these alkalies seldom rises above 3–4 per cent, of which total by far the greater part is included among the insoluble silicates.

LIME is among the most variable of soil-constituents existing in all proportions from barely detectable traces, to even 30% in certain soils of limestone regions. Uncombined calcium oxide is of rare occurrence in the soil, it is more frequently combined with carbonic acid, phosphoric acid, or sulphuric acid, forming carbonates, phosphates or sulphates. With the exception of the crenate, nitrate and sulphate, the salts of calcium are wholly insoluble in pure water, and the latter even with much difficulty.

Carbonates and phosphates are, however, soluble in waters containing free carbonic acid, as is always the case with the running and hygroscopic water of soils.

Lime is of unusual importance as a soil-constituent, inasmuch as it is not only a necessary ingredient of all plants, but exerts a peculiar activity on the physical properties of the soil.

MAGNESIA is an invariable companion of lime as a soil-constituent, since rocks containing the one as a rule contain the other. The most frequent form of occurrence is combined as carbonate, which is wholly insoluble in pure water but dissolved by carbonic-acid waters, though to a less degree than is the case with calcium carbonate.

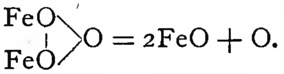
ALUMINA is among the most abundant of soil-constituents, particularly combined with silica to form silicate of alumina, or common clay; alumina is estimated as embracing 16.66% of the entire Earth-crust. The silicate (clay) exerts its influence chiefly on the physical properties of soils, and forms about 20% of the total soil-mass, wholly insoluble in water. Combined with water to form the hydrate, and with sulphuric acid as sulphate, alumina forms slight quantities of soluble compounds, the total amount of which is, however, hardly recognizable except as traces.

IRON occurs not only in widely-varying proportions, but also in greatly-diversified form as a soil-constituent. The total quantity present as iron oxide is commonly not greater than 5% nor less than 0.5%, though soils exist with as high as 30%; these, however, are barren through excess, just as those containing less than 0.5% are sterile for lack of iron; the latter are chiefly marls, the former ochres.

The two forms in which iron fundamentally exists in the soil are as the protoxide FeO and the sesquioxide Fe_2O_3; and the entire character and value of a soil may be dependent on the question of the existence of one or of the other of these two iron oxides.

The affinity of iron for oxygen is such (iron oxidizes so readily) that the protoxide can exist only in the absence of sufficient oxygen to form the higher oxide. Wherever access of abundance of atmospheric air exists, there the sesquioxide is found; but where this sufficiency is lacking, in the deeper soil-strata, there the lower oxide is found; seldom, however, in a free condition, but combined with acids to form salt of the protoxide.

A most important fact, however, is the frequent reduction of the higher to the lower oxide in the soil. Organic compounds decomposing in presence of oxygen-containing compounds possess the property of attracting the oxygen from the metallic oxide, or reducing the same. This is the principle in the use of charcoal in the smelting of metals. An identical process occurs in the soil, where organic decomposition is constantly taking place. The oxygen of the iron sesquioxide is attracted to combine with carbon or other constituent organic matter to form carbonic acid or other product of combustion or decomposition, and instead of Fe_2O_3. 2FeO is found, thus:



$$\left.\begin{matrix}\mathrm{FeO}\\ |\\ \mathrm{FeO}\end{matrix}\right\rangle \mathrm{O} = 2\mathrm{FeO} + \mathrm{O}.$$

The product, however, iron protoxide, immediately attracts oxygen again from the air if this is present and re-forms the sesquioxide, so that the process may go on indefinitely repeating itself.

The higher oxide combines readily with water to form hydrated iron oxide, or the red iron-rust so common, and noticed so universally as a red deposit on soils or on the bottom of pools or streams of water in iron-impregnated regions.

Agriculturally considered, the process of reduction is of great importance, inasmuch as the lower oxide is poisonous to plant-life and often renders large areas sterile and unproductive. The remedy for which misfortune is, however, simply to hasten the oxidation process by increasing the supply of accessible oxygen, by ploughing, by burning or by the application of caustic lime; the result being the rapid conversion of the poisonous protoxide into the harmless sesquioxide.

This difficulty is most frequently met with after the first ploughing of peat lands, or former swamps, or any land so compact as to have enjoyed but slight access of air, and remedies itself with thorough pulverization.

The iron compounds of the soil are chiefly sulphates, carbonates, crenates or phosphates of the protoxide. Of these the sulphate alone is soluble in water, but the carbonate is also dissolved by soil-waters containing, as they do, absorbed carbonic acid.

MANGANESE in properties and compounds closely resembling iron is a much more rare constituent of the soil, and plays a far less considerable *rôle*. Its hydrate, the chief soil-compound of manganese, is soluble only in carbonic-acid waters.

SILICIC ACID (Silica) is, so far as abundance is concerned, the chief constituent of all soils. The entire Earth-crust is estimated as containing 66% of silica. It exists not only as free silicic acid in the form of quartz and sand, but combines freely with numerous bases to form silicates. These latter compounds, with the exception of silicates of potash and soda, are wholly insoluble in water, as is the free silica itself. The latter is, however, soluble to a certain extent at the moment of displacement from combination. The quantity of soluble silicic acid present in the soil is never more than a mere trace, though the total silica content of many sandy soils may be 90%.

PHOSPHORIC ACID is present as a rule only in minute quantities, although it forms one of the most important and valuable among all the soil-constituents; it seldom forms more than 0.5% of the total soil-mass. It exists only combined; phosphates of lime, magnesia, iron and alumina being the most prevalent forms, all of which are insoluble in water; but, with the exception of the alumina compound, all are reduced to solution by the action of carbonic-acid water.

SULPHURIC ACID occurs as a constituent of all soils, but only in most minute quantities, and usually combined with lime as calcium sulphate.

CARBONIC ACID may exist in three different forms as a soil-constituent. Combined with bases it forms the abundant carbonates; in gaseous form as a part of the air of the soil, which may be either of atmospheric origin, or result from organic decomposition in the soil itself; or again, as a constituent of the water in which it is so freely soluble, and in which form its action as a solvent is so important.

CHLORINE is a most wide-spread constituent of soils, combined with bases to form chlorides. Sodium, magnesium and potassium chlorides being the most prevalent forms, and all of which are freely soluble in water. The total amount of chlorine thus occurring in the soil is exceedingly slight, seldom exceeding 0.01% of the entire mass.

In addition to the chemical constituents of the soil here enumerated, other substances are more or less generally present, namely, the water of soil and gases. But these are not actual integral parts, but rather extraneous material, however universal or important may be their occurrence and functions. They are therefore considered not as soil-constituents, but rather in the next chapter, among properties or characteristics of soil.

The composition of the soil, the aggregation of facts here discussed, are graphically collated and presented by the table of soil-analyses included at the close of the volume.

One fact must, however, be forcibly presented through the perusal of the material collected in this chapter, namely: The constant and great variation in the composition not only of different soils but of the same soil at different times and under varying circumstances; variations even from day to day, through constant change; through decomposition and re-combination the results of which tend to make the chemical composition of a given soil at a given time a most uncertain factor in determining its treatment for different crops—so uncertain, indeed, as to utterly overthrow Liebig's proposition to make the chemical composition of soils, as determined by analysis, the basis of rational culture.

Therefore, important as the composition of soils must be, and dependent as successful husbandry must remain on a correct knowledge of the properties and uses of soil-constituents, and the transformations and reactions occurring in the soil, the greatest good is not to be derived through the mere study of soil-composition, but through a knowledge of the ultimate relations existing between *soil and plant.*

Study of the composition and methods of deriving and assimilating nutriment from air and soil, must offer the only solution to the true and rational utilization of the substances known to constitute the material cultivated as soil.

CHAPTER II.

CLASSIFICATION AND CHARACTERISTICS OF THE SOIL.

As demonstrated by the facts recorded in the preceding chapter, the varieties of soil, so far as composition and properties are concerned, are almost innumerable. Yet we are deficient in terms by which these differences may be expressed except by actually describing the individual soil itself. Certain terms are, however, used to designate soils of similar properties, and the various classifications thus devised are numerous. Two, however, are more commonly resorted to, and describe with considerable definiteness the peculiarities of the different soils thus grouped together. These two different classifications are based on distinct properties possessed by the soils embraced within the divisions made. The basis for the first system being *method of formation*, and for the second *physical characteristics;* and both must be briefly considered.

I. DISTINCTIONS BASED ON ORIGIN OR METHOD OF FORMATION.

Among the soils thus designated, two varieties are recognized: SEDENTARY or soils in place, and TRANSPORTED soils, the latter being subdivided into *Drift* and *Alluvial.*

SEDENTARY SOILS remain in place or in close proximity to the rocks from which they were formed. Such soils, as a rule, are comparatively shallow, and partake, of necessity, of the character of the underlying rock-mass, an examination of which is the truest criterion for determining their composition and value.

TRANSPORTED SOILS have been subjected to geological agencies, by whose action they have been removed from the beds where they were originally formed, and deposited in new localities, usually a sediment from flowing water, though glaciers were a prevalent cause of the transportation, in which case suspension in water was not an inevitable prelude to final deposition.

DRIFT SOILS, in Europe commonly designated as "Diluvial," consist of small stones mixed with more or less finer material resulting from disintegration and water-erosion, the pieces of rock composing which have invariably been rounded by water or erosive action. They are most commonly unstratified, and may be composed of the most widely-diversified materials, consisting of parts of all the rocks over the entire region traversed by the transporting glacier.

ALLUVIAL SOILS embrace all soils of water-deposition, fresh or salt, consisting of finely-abraded material resulting from erosive action. They are usually more or less stratified because of difference in density, the larger and heavier particles being at the bottom of the deposit. They are the most fertile of soils because of the fineness of division or pulverization, and the fact of precipitation from waters containing the more soluble constituents of the soil and rock areas over which they have passed or through which they have permeated. They embrace river "bottoms" and delta formations, and are in constant process of deposition to-day.

Soils are of course not necessarily composed of either of these particular varieties, but frequently consist of mixtures of any or all of them; or more commonly all the kinds may exist quite distinct but in close proximity to each other; this being particularly the case in the Connecticut Valley, where the sedentary soils are of easily disintegrated New Red Sandstone origin.

II. SOIL-DISTINCTION BASED ON PHYSICAL CHARACTERISTICS.

GRAVEL consists of unweathered bits of rock, smoothed and more or less worn by water-action, and including varying quantities of fine earth not usually exceeding 30% of the entire mass.

The larger the proportion of stone the less the agricultural value, both through difficulty of working and absence of nutriment; the latter may, however, not be wanting if the rock is of an easily-weathering variety; and the disadvantage of cultivation may be surmounted by utilization for grazing, vineyard or forestry purposes.

SANDY SOIL embraces those soils containing 80% or over of pure sand. The origin of this variety of soil is usually traceable to the weathering of sandstone or conglomerate. The older rock-formations, as gray wacke and variegated sandstone, furnish a product richer in alkalies, while the younger rocks yield more quartz-sand. The latter with calcareous sand increase the barrenness of the soil not only through absence of plant-food, but through the absence of the necessary physical properties of cohesion and absorption of water.

But sandy soil may consist of a variety of materials besides quartz-sand. Lime-sand, consisting of calcium carbonate, greensand containing considerable quantities of silicate of potash and phosphate of lime, as well as more or less important amounts of iron oxide, may be present in sandy soil and give it an enviable fertility.

CLAY SOIL is that containing at least 60% of clay together with varying proportions of sand, of amorphous silica, and products of weathering. It may originate in the disintegration of a vast number of different rocks; feldspar-oligoclase slates and micaceous rocks being the chief clay-formers.

It exists in the finest possible state of division, is cohesive, and often in wet localities exceedingly tenacious, being capable of drying to an almost rock-like and unworkable consistency; and through the contraction necessarily following, clay areas are often traversed and intersected by deep and wide cracks or clefts causing considerable damage to vegetation through tearing and destruction of roots.

Clays are exceedingly impermeable to water, and therefore, unless lying on a porous subsoil, are apt to dry slowly and be wet and cold. Clay soils containing from 60–80 per cent of clay form as a rule most valuable and productive soils, yield good crops of all the more common agricultural plants, particularly wheat, roots, clover and grass. Those soils containing between 80 and 90 per cent of clay have a diminished utility, but yield profitable returns of wheat, clover, buckwheat and horse-beans. While more than 90% of clay reduces the limits of successful cultivation because of the difficulty of working and danger from excess of water.

LOAM SOILS comprise those soils ranging between sand and clay, and possessing more or less of each of these two constituents. The amount of finest weathering product or loam varies from 30 to 50 per cent in addition to which sand, clay, lime and the different products of rock-decomposition are present.

The properties of loam soils partake to a greater or less degree of the characteristics of sand and of clay as the proportion of these constituents is much or little. These variations are designated Heavy clay loam with 10 to 25 per cent of sand; clay loam with 25 to 40 per cent of sand; loam with 40 to 60 per cent of sand; sandy loam with 60 to 75 per cent of sand; light sandy loam with 75 to 90 per cent of sand; while soils with less than 10 per cent of loam are either sand or clay as the case may be. The term loam is therefore a most indefinite characterization of a soil without the qualifying prefix ‘sandy" or "clayey."

MARL as a distinct variety of soil, is a much more definite term, and applies to all *calcareous clays;* the proportion of carbonate of lime, however, may not fall below 15%, nor the quantity of clay rise above 75%. The name is commonly applied to certain formations containing much shell-lime and considerable quantities of greensand, in which case the material is extensively used as a fertilizer, but is, however, incorrectly designated.

LIME SOILS contain, as the name implies, calcium carbonate as a predominating ingredient, the proportion of which may rise above 75%, although the usual quantity is under 50%. Indeed the soil is more frequently designated as "calcareous" *clay loam* or *sand.*

SALT SOIL is a term applied to soil containing considerable quantities of soluble salts, usually of lime or of soda, and embraces soils of little or no fertility like the alkaline plains of Arizona. They are not infrequently, however, rendered fertile by artificial application of water.

PEAT, MUCK, or HUMUS SOILS, all characterized by the presence of humus of vegetable origin, are, however, distinguished according to conditions of formation. *Peat* includes soils resulting from partial decay of vegetable matter under water, the product being compact but fibrous and forming fuel. *Muck* results under like conditions, but is less compact, not fibrous, and is easily pulverized on drying.

Humus soil, or *vegetable mould*, is the product of vegetable decomposition without inundation. The amount of humus in these soils may amount to 70% of their dry matter.

OTHER DISTINCTIONS OF SOIL, more or less generally recognized, exist, made with reference to location as regards tillings: *Arable soil* or *tilth*, being the upper stratum or portion to which fertilizers are applied, in which the seed is planted and which forms the theatre of most farm operations. Beneath this comes the *Subsoil* into which the roots of many crops penetrate, and which possesses usually the character of the tilth before subjected to cultivation. Most soils rest or repose on a stratum of dense tenacious clay, being gradually reconverted to rock by pressure and the action of alkaline silicates and humates penetrating from above; a formation appropriately termed *Hardpan*.

III. SOIL-ESTIMATION.

These distinctions drawn between different soils because of various characteristics or physical peculiarities are based not alone on mere obvious differences, these being wholly insufficient. The distinctions are made because of actual and demonstrable differences, either chemical or physical, determined by definite examination or subjection to fixed methods of inquiry yielding exact results. As all differences among soils are necessarily either chemical or physical, so the methods of inquiry or estimation may be directed toward detecting either chemical or physical proportions.

Our methods of analysis are therefore either chemical or physical. For the distinctions forming the basis of soil-classification, however, only

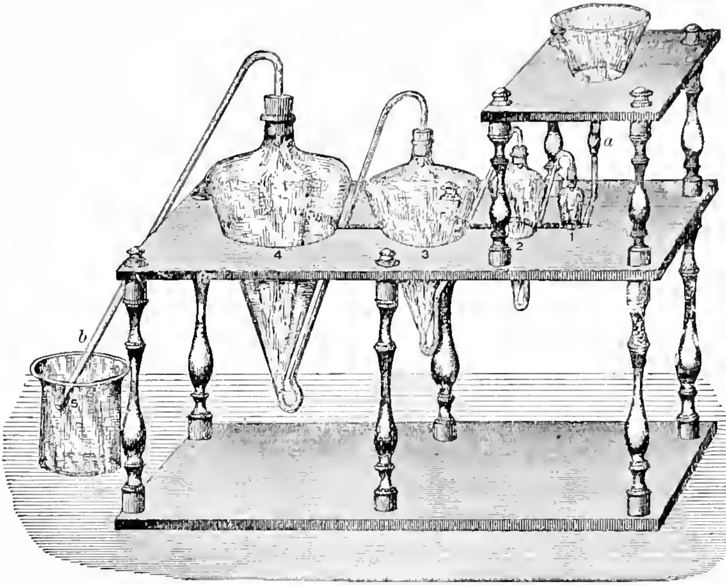


FIG. 15.—Noebel's Analysis-of-soil Apparatus. (*To face page* 151.)

PHYSICAL ANALYSIS OF THE SOIL is required or resorted to. The method is based on difference in specific gravity, detected by suspension in water.

Solid substances of different specific gravities agitated in water become stratified, on being allowed to settle; the heavier at the bottom. In like manner soil or gravel subjected to the action of the currents of running streams becomes gradually deposited, the heavier first, or up stream, from the finer and lighter particles.

Nöbel's apparatus, most frequently used for the mechanical analysis of soils, is simply an apparatus consisting of a series of vessels graduated in size and all connected, through which a known volume of water containing a definite weight of soil is allowed to pass and become deposited in the successive vessels for a fixed length of time.

The accompanying illustration from a photograph graphically presents the process as conducted in most agricultural chemical laboratories.

The volumes of the four different conical vessels in the series maintain definite proportions to each other as follows:

$$1^3 : 2^3 : 3^3 : 4^3 = 1 : 8 : 27 : 64$$

The apparatus is so graduated that in 20 minutes 9 litres of water, in which a known weight of soil has been thoroughly suspended by boiling, will pass. At the expiration of the specified time the current is stopped and the finest or most buoyant portion of soil has passed entirely through the apparatus into a vessel intended for its reception, and standing several hours until wholly precipitated, is dried, weighed, and designated as No 5; the contents of the four conical vessels are treated in like manner, the smallest being known as No. 1.

The result of the process will be the separation of the original sample of soil into five different kinds or degrees of fineness:

No. 1. Gravel, rock-fragments.
" 2. Coarse sand.
" 3. Sand.
" 4. Fine sand.
" 5. Silt or impalpable matter.

The separation thus effected is in many respects faulty, but serves the general purpose of determining the relative proportions of the different conditions of the soil-making material of any given locality.

CHAPTER II.

CHARACTERISTICS OF SOILS.

Soil *characteristics* or *properties* must of necessity be of two kinds; either chemical or physical. The former, dealing with the internal composition of the soil, have been already considered in that connection; the latter in contradistinction may be described as relating to the external or visible properties of the soil, including its position, porosity, cohesiveness, its temperature, and its wetness or dryness. Characteristics of the utmost importance as related to the growth of plants, and far less under the control of the farmer than the mere chemical composition of the soil, which can be easily changed at will. The amount of actual plant-food present in a soil is of secondary consideration as compared with the facts of natural wetness, cold or density, on which conditions the growth of plants, the cost of working and the action of fertilizers so largely depend.

These physical properties will be reviewed in their relations to the growth and nutrition of plants and influence on soil management under the following division:

1. Weight and Specific Gravity.
2. Color and Structure.
3. Behavior toward Water.

1\. " " Heat.
2\. The Soil and Electricity.
3\. Behavior toward Gases.

I. WEIGHT AND SPECIFIC GRAVITY OF SOILS.

Both the absolute weight and specific gravity of a soil obviously depend on the density of the same, an exceedingly variable quantity; and as a matter of fact neither property furnishes anything like a definite factor for determining the nutritive content of the mass.

THE ABSOLUTE WEIGHT OF THE SOIL varies of course materially with the porosity and with the character of its mineral constituents and amount of organic matter present. The average absolute weight of natural soil of the field is about 75 lbs. per cubic foot.

The results of Schübler's investigations are as follows:

WEIGHT, IN POUNDS, OF 1 CUBIC FOOT OF DRY SOIL.

Sand,	110	Heavy clay,	75
Sand and clay,	96	Vegetable mould,	78
Common arable soil,	80–90	Peat,	30–50

THE SPECIFIC GRAVITY of most soils existing in the porous condition of cultivated soil will be represented by an average of 1.2, though few soils not lying at the surface of cultivated fields will fall below 2. Schöne's experiments with soils reckoned as solid masses give the following results:

SOIL SPECIFIC GRAVITIES.

Humus soil from Orenburg,	2.53
Clay soil,	2.65
Sand soil,	2.67
Lime soil from Jena,	2.71

These results correspond with the specific gravities of the predominating minerals constituting the soils, as follows:

Specific gravity of Quartz,	2.66
" " Orthoclase,	2.55
" " Oligoclase	2.65
" " Labradorite,	2.70
" " Mica,	2.8–3.1
" " Augite,	2.9–3.5
" " Calc Spar,	2.7
" " Hornblende,	2.9–3.4
" " Dolomite.	2.0

Specific gravity of	Dry Clay,	2.5
" "	Kaolin,	2.2
" "	Gypsum,	2.26–2.4

From these facts it will be instantly recognized that the so-called "light soils" are the heaviest of all, while the commonly designated "heavy" clay is lighter than any but soils of chiefly organic origin. The terms then are not applied because of actual weight, and simply imply "easy" or "hard" to work.

II. STRUCTURE AND COLOR.

THE COLOR OF THE SOIL depends exclusively on its composition; humus, for instance, forming a nearly black soil, while sand or silica gives a very light yellow, and iron oxide produces a red color. The matter of color is therefore of some importance as indicating the composition of the soil. But its chief influence is through the action of different colors as absorbers of heat, the darker soils having, other things being equal, the highest absorptive power toward solar heat as demonstrated through the earlier disappearance of the winter's snows from these soils, and the efficacy of applying muck to the surface of the snow in the spring whereby an earlier preparation of the soil for cultivation is gained.

SOIL-STRUCTURE, under which term is implied the porosity or state of division of the soil, is of the greatest importance in influencing the results of cultivation. Indeed the fertility of the soil is largely due to its porosity and thus thorough subjection to the action of atmosphere and moisture. The chief difference between bare quartz rock and sand being the difference in pulverization whereby cultivation and growth of plants in presence of abundance of water is rendered possible. And it is a fully accepted fact that, other things being equal, that soil is *invariably* most fertile which exists in the finest state of division, whose particles are the smallest.

Plants assimilate food *only from solution*, and the rapidity of solution in the soil or elsewhere is in direct ratio to the surface exposed to the action of the dissolving medium; a fact resting on the simple truth that the greater the surface exposed to any action, the greater must be the product of that action.

It must be borne in mind, however, that this very fineness of the soil-particles renders it more susceptible to the impacting influences of nature, or to cohesion, against which, however, the process of cultivation is aimed, greatly abetted by the action of frost, which tends to loosen the soil-particles and render the mass more porous. And with the increase in porosity the activity of the atmospheric influences exerting themselves against the soil is increased.

The structure of the soil should also obviously be such as to allow of self-drainage, or freeing from a superabundance of surface-water.

III. Behavior of the Soil toward Water.

No property possessed by soils can be of greater direct influence on the growth of plants than the relations existing between the soil and the water which permeates it. For not only is the water essential to the production of assimilable plant-food, but the circulation of fluids in the plant itself is directly and wholly dependent on the supply of water extracted from the soil through the roots.

IMBIBITION, OR THE WATER CAPACITY OF THE SOIL, varies greatly with different soils and determines to a great degree their capability of supporting vegetation. The water capacity of a soil is its ability to retain a definite quantity of water by absorption without losing it or becoming super-saturated. Saturation being indicated by the dropping or draining away of the excess not held by the soil. This property of necessity depends on the volume of air-space in the soil into which the water can enter and exclude the air. The water capacity of different soils as determined by Melster is as follows:

Clay soil	imbibes	50.0	per cent	of water.
Loam soil	"	60.1	"	"
Humus soil	"	70.3	"	"
Peat soil	"	63.7	"	"
Garden soil	"	69.0	"	"

Lime soil	imbibes	54.9	per cent	of water.
Chalk soil	"	49.5	"	"
Gypsum soil	"	52.4	"	"
Sand soil imbibes	(82% sand)	45.4	"	"
" " "	(64% sand)	65.2	"	"
Quartz-sand imbibes		46.4	"	"

It therefore appears that the pure mineral soils vary but slightly, while the water capacity of soils seems to depend on the proportion of organic matter present, and to vary with an approximately fixed ratio.

So far as matter of practical value is concerned, however, these results are of little value, inasmuch as they were obtained under such conditions as cultivated soil in nature is never subjected to. Soils are seldom if ever actually *saturated* with water, because there is usually an outlet at the bottom for all that is added at the surface; and, moreover, the estimations were made with so shallow portions of soil that the height of the column of water was very slight, and gravity therefore reduced to a minimum never actually existing in the soil.

Mayer first pointed out this inaccuracy, and undertook its remedy.* He subjected columns of soil one metre in height to experiment, and obtained what he designates the *absolute water capacity*, in contradistinction to the former or *full* or *greatest water capacity.* A noteworthy difference was thus demonstrated. His results were expressed as follows:

WATER CAPACITY.

	Quartz.	Clay.	Sawdust.	Heavy spar.
"Full"............per cent	49.0	46.0	76.4	39.2
"Absolute"........ "	13.7	24.5	45.6	11.7

By these experiments it became at once apparent that the absolute water capacity of the soil is far smaller than had formerly been considered its capacity; and it was further demonstrated that the capacity varied greatly with the structure of the soil, increasing in a fixed ratio with the porosity.

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* *Agriculturchemie*, Bd. II. p. 143.

THE PERMEABILITY OF THE SOIL is its property of allowing the passage or percolation of water; a property of greatest importance agriculturally, and varying widely with different soils. The percolation must of necessity be proportional to the porosity of the soil, and therefore is governed by the proportion of fine earth humus or clay substance present, while as a natural consequence sand ranks as the most permeable of soils.

The chemical composition of the soil is also not without influence on the water percolation since it is known that the property is decreased by addition of lime. Either excess of activity of soil toward percolation is equally objectionable. Too great a porosity allows the passage of waters and nutriment through the soil so rapidly that much of the benefit for the plant is lost; while, on the other hand, insufficient percolation is followed by excess of surface-water and consequent damage to the growing crop.

THE CAPILLARY WATER OF THE SOIL is most closely allied to its percolating power, since all waters in the soil are governed in their movements by what is known as capillary force, which, however, only manifests itself between bodies of different degrees of moisture, the movement being as a rule from the more moist to the more dry substance. The movement of oil in a lamp wick is the most apt illustration of the principle; and the soil answers the purpose of the wick, the waters of the lower strata corresponding to the oil, and the surface evaporation into the dryer atmosphere being the motive power which keeps the force in action. Liebenberg has shown, however, that the action in the soil may be either upwards or downwards according as the atmosphere is dry or supplies soil-saturating rain.

The force is but a manifestation of surface attraction, the same as witnessed in the rising of liquids against the sides of narrow tubes in which they are confined; and the movement, wherever it occurs, is but the passage of the fluid through infinitely small or *capillary tubes.* Meisner* has experimentally

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* Meisner, *Jahresbericht für Agriculturchemie*, 1859–60, p. 42; also Mayer, Bd. II. p. 150.

demonstrated the relative capillary attraction of different soils under like conditions; the height to which water rose in narrow glass tubes filled with various soils and dipped at the lower end in water being measured in mm. and compared side by side.

	½ hour.	5½ hours.	6½ hours.	21½ hours.
Clay soil	340	1100	1150	2000
Humus	400	1100	1140	1770
Garden earth	290	950	900	1610
Quartz sand	440	920	970	1170
Peat	260	500	570	1140
Sand soil	450	620	660	900
Gypsum.	120	400	400	820
Chalk soil	60	330	540	700

These results show that clay soil is most freely subjected to capillary action, closely followed by humus, while the purely mineral soils possess of all the least capillary power. The fineness of division seems to control the soil capillarity; and, moreover, great difference is noticed in the rapidity of action and as a rule the more rapid the force manifests itself, the less is the ultimate capillarity of the soil. The definite relation between rapidity of capillary action on the fineness of the soil acted on is graphically shown by the researches of Haberlan,* who subjected soils of different degrees of fineness to capillary action for varying lengths of time with results as follows:

Time Allowed.	Height of Water Column in mm.	
	Coarse soil.	Fine soil.
½ hour	50	135
1 hour	62	174
3 hours	71	223
4 hours	83	279
8 hours	114	409
1 day	130	453
2 days	146	506
3 days	150	524
6 days	159	543

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* Gohren, *Agriculturchemie* (Leipzig, 1877), Bd. I. p. 89.

The amount of capillarity, or height above the water source, thus measured would indicate that when the force depends wholly on subterranean waters the height of its manifestation is not sufficient to be of great service to those plants whose roots do not penetrate to the near vicinity of the permanent or hydrostatic waters of the soil. This condition is, however, rarely attained since the capillary waters are receiving constant accessions from the atmosphere in the form of rain, which, notwithstanding the percolating power of the soil and the action of gravity, is kept moving upwards towards the surface by capillary power, which thus serves directly to supply the growing plant with this all-essential substance, but moreover brings to the surface-soil, and within reach of the roots, constant accessions of soluble plant-food, dissolved and brought upwards, by the moving waters, from deeper strata.

On this capillary water, then, the plant must chiefly rely for the moisture on which its life and growth depend, for rain-water *as such* plays but an inferior part, inasmuch as there are weeks during every growing season when no rain falls and the crop is wholly dependent on the stored-up capillary water within the soil. And not infrequently during periods of protracted drouth the growth of the plant is directly proportional to the supply of capillary water to which it has access.

The water absorbed by the roots passes into the plant-circulation, and by far the greater part is evaporated from the leaves, which have little power of re-absorbing. Where the supply of water is insufficient the plant wilts, and if the evaporation long continues in excess of the supply obtained from the soil death must ensue.

The quantity of water thus required and evaporated by different agricultural plants during the period of growth has been found to be as follows:

1 acre of Wheat	exhales	409,832	lbs.	of water.
1 " " Clover	"	1,096,234	"	" "
1 " " Sunflowers	"	12,585,994	"	" "
1 " " Cabbage	"	5,049,194	"	" "
1 " " Grape-vines	"	730,733	"	" "
1 " " Hops	"	4,445,021	"	" "

Or for one million plants of different field grains (per hectare *):

Rye	83.4890 kg.	Barley	123.6710 kg.
Wheat	117.9920 "	Oats	227.7760 "

Dietrich estimates the amount of water thus exhaled by the foliage of plants to vary from 250 to 400 times the weight of dry organic matter formed during the same time, at which rates one ton of green clover would during its growth and maturity have extracted from the soil and exhaled into the atmosphere from 25,000–40,000 lbs. of water; and clover is no exception among foliaceous plants.

Davy concludes, as the result of experiment, that 100 lbs. of harvested wheat is obtained as the result of the exhalation of 90,000 pounds of water.

Knop found that Indian corn exhaled during its period of growth 36 times its total weight of water. It therefore appears, from all the evidence deducible, that the volume of water required by the plant for its maturity is enormous; yet, as we have seen, the capillary water of the soil is the direct source of supply; and when this fails, detriment or total failure must result to the crop.

It therefore becomes of the greatest moment to the farmer to so conduct his operations that this water may be conserved for time of need.

A most radical change has been brought about in the methods of farm practice in this respect, as the results of the investigations of Prof. Levi Stockbridge at the Massachusetts Agricultural College Experiment Station in 1878, by which the amount of evaporation from the soil itself, without the action of plants, was determined, and also the effects of different modes of treating the soil according to the quantity of water evaporated.

Six boxes, of one cubic foot capacity each, were filled with soil, by being *driven into place*, without disturbing its strata, immediately after a rainfall of .78 of an inch. The soil was from cultivated fields, two specimens each of sand, loam, heavy

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* 1 hectare = approximately 2.47 acres; 1 kg. = 2.2 lbs.

loam and clay. The boxes having received water-tight bottoms were placed in a trench with the surfaces of contents level with the ground.

One specimen of each variety of soil was then thoroughly hoed and turned over each morning to a depth of four inches. The experiment covered seven days, during which the weather was warm, and the sky free from clouds. The average day temperature of the soil was 36° C., and of the air 35° C., while the night temperature of the soil was 21.5°, and of the air 19.4°; the atmospheric humidity averaged 70.

At the expiration of seven days all specimens were reweighed and the loss by evaporation recorded, together with the difference in weight between the cultivated and uncultivated specimens, with these results.

KIND OF SOIL.	Tilled.		Untilled.		Actual difference.		Difference per acre.
	lbs.	oz.	lbs.	oz.	lbs.	oz.	barrels.
Clay	5	5	6	14	1	9	256
Sandy loam	3	3	7	8	4	2	734
Heavy loam	6	13	7	13	1		223

The average diurnal loss per acre was as follows:

	Barrels per Acre	
	Tilled	Untilled
Clay	129	167
Sandy Loam	77	182
Heavy Loam	158	189

The average daily evaporation for all three soils was, therefore, for the tilled soils 121⅛ bbls. per acre and for the untilled 179⅛ bbls. per acre, or an average daily difference for the three soils of 58 bbls. per acre saved to the soil by cultivation to a depth of 4 inches.

Considerable as this quantity is, and important as is its bearing on the management of growing crops, it should be borne in mind that in nature the amount of total evaporation must be far in excess of that demonstrated by the experiment, inasmuch as the soils treated were but one foot in depth and were boxed in against all possibility of any access of capillary water from the lower strata to take the place of that evaporated, which would otherwise have been the case.

But another important fact is demonstrated by this experiment. If cultivation prevents loss of water by evaporation, absence of cultivation must aid the soil in freeing itself from superabundance of surface-water. The experiment was therefore repeated to demonstrate this fact, the following results being obtained from the same specimens of soil wet to saturation:

Clay soil tilled	lost	4 lbs.	4 oz.
“ “ untilled	“	5 “	15 “
Heavy Loam tilled	“	6 “	15 “
“ “ untilled	“	4 “	11 “
Sandy Loam tilled	“	5 “	13 “
“ “ untilled	“	4 “	

Drought and excess of moisture are the two extremes against which the farmer has to contend, and against which his battle is so often hopeless; and they are very apt to follow each other in the same season. These experiments demonstrate the means of relief from both extremes.

Cultivation conserves soil-moisture. Lack of cultivation hastens evaporation of soil-moisture. So obvious were the benefits obtained that the facts demonstrated immediately found wide application, and are to-day most successfully followed in practice.

The reason of the facts as deduced by experiment are simple. Cultivation of the surface destroys the density, makes the soil porous or breaks the capillary tubes through which the water moves, and its passage is of necessity thus retarded. The more perfect the capillarity the greater the surface evaporation, and *vice versa.* And capillarity is always inversely proportional to the porosity of the body subjected to its action.

THE DRYING PROPENSITY OF SOILS is most intimately connected with imbibition and capillary powers, but the rapidity or susceptibility of soils to part with their hygroscopic water varies greatly with different soils irrespective of capillarity, and the changes resulting to the soil through this drying process are very various and multiform.

Sand is known to be the most readily dryable among soils, that is, gives off the most water, in a given time, through evaporation, while clay and humus retain the absorbed water a much longer time.

The rapidity of evaporation is proportional to the surface exposed to action; consequently the more porous the soil the faster the evaporation *provided that only the surface, or portion actually exposed to atmospheric action, is concerned;* as a matter of fact, however, all soils contain *capillary water which is not, for reasons already explained,* thus affected. But of two varieties of soil exposed to the same conditions, that soil containing most fine earth or humus, possessing an absorptive power for water, gives off that water most rapidly and readily.

Since the evaporation of water is at the expense of heat, the soil becomes cooled by the evaporation of much water. Because of this reduction of temperature, and more especially through the loss of mass by exudation of water, evaporation results in a condensation or contraction of mass or volume of soil. The contraction is of course proportional to the volume of water lost, and therefore affects the more retentive humus soils most. This condensation is often very noteworthy. A remarkable example of such a phenomenon on a large scale has just occurred in the vicinity of Sapporo, Japan, where a large marsh has been partially dried through the opening of an outlet into the Ishikari River. The entire affected area, many square miles in extent, has in the course of six months sunken an average of two feet below its former level, and the trees with which it was covered now stand with roots exposed and bare which previously were often more than three feet beneath the surface.

ABSORPTION OF VAPOR OF WATER is a property possessed to a certain degree by all soils, and is known as their hygroscopic power. But the power is not only possessed to a comparatively limited degree, but even the slight amount of moisture thus gained by the soil is of little practical use to the plant. Indeed a radical change has occurred in the opinion of agriculturists concerning this matter during the last decade. And though no less an authority than Johnson claims that "this property of the soil is of the utmost agricultural importance,"* the experiments of Schübler on which Johnson supports his assertion were as long ago as 1876 pronounced "antiquated"† by Prof. Mayer of Heidelberg, perhaps the highest authority, as he has been the most tireless investigator, of the subject; and the same statement is later accepted and quoted by Dr. Gohren, director of the Franz-Joseph Agricultural Institute at Vienna.‡ The facts in the case seem to be these. Absorption only occurs between bodies of different hygroscopic conditions: the drier absorbs from the more moist, except in the case of bodies possessing a *chemical affinity for water;* it therefore follows that *soil only absorbs moisture from the air when it is drier than the air.*

"Only dry soil is capable of utilizing its hygroscopic property for the absorption of atmospheric moisture;"§ and the experiments of Mayer, undertaken to ascertain whether natural and artificial soils exhausted of water by plant exhalation possess the power of condensation of atmospheric vapor, give conclusively negative results. "These experiments," says the investigator, "all show that the actually occurring condensation is of no avail to the plant, because this is far too much reduced for lack of water before the condensation actually sets in."‖

Moreover, all recent experiments show that the condensing property of the soil is but slight, not greater than that of other similar porous bodies, and has been held in much too high esteem. The famous experiments of Schübler, on which much erroneous teaching has been based, are to be honored for the initiative they made, and not for their correctness in the light of subsequent development. They were made under entirely artificial conditions wholly impossible in nature, and leading to most erroneous deductions. The soils treated were dried at the boiling-point of water till the last trace of liquid had been vaporized, then they were cooled and exposed to an atmosphere artificially saturated with moisture. *Of course* they immediately absorbed large quantities of vapor of water and re-

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* "How Crops Feed," page 161.

† l. c. Bd. II. p. 142.

‡ *Agriculturchemie*, Bd. I. p. 92.

§ l. c. Bd. II. p. 134.

‖ l. c. Bd. II. p. 134.

tained the same condensed as hygroscopic water. *Any* substance would have done the same; even a cut diamond would have increased in weight under like conditions. Yet the carbon of the latter is just as accessible for plant-food, as the moisture absorbed under such conditions is a natural resource for the plant in time of need.

THE WATER SOLUTIONS OF THE SOIL contain all of the soil material existing in an immediately assimilable condition for the plant; their composition and amount, in other words the action of soil waters on the plant-food constituents present, become, therefore, of the greatest value in determining the agricultural characteristics and value of the soil.

Indeed, most cultivated soils yield water solutions containing more of each of the elements of fertility than would suffice to supply the necessities of one crop of any agricultural plant or more than analysis shows to be present in any crop grown* on the same soil.

A fact utterly at variance with and overthrowing Liebig's once widely accepted theory that water dissolved none of the potash, silica, ammonia or phosphoric acid of the soil; and that none of the elements of plant-nutrition was taken from the soil by the action of water; but rather all these substances were extracted or absorbed by the soil from solution.†

The present knowledge of the action of soil-waters toward soluble elements of nutrition is the result of the use of the lysimeter in investigating the question in place of "*funnels full* of soil" employed by Liebig.

As the result of twenty experiments with as many different specimens of soil, Hoffmann concluded that the quantity of matter dissolved from the soil by water varied between 0.242 and 0.0205 per cent of the dry earth; of which, however, from 0.194 to 0.0137 per cent was organic matter. These results, however, are but partially correct as indicators of the real action of water on the nutritive soil-constituents, inasmuch as no soil gives up all its soluble plant-food at one time, and moreover the presence

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* Gohren, *Hoffmann's Jahrb. über die Fortschritte der Ag. Chem.*, Bd. VI. p. 7.

† *Chem Briefen*, 6te Ausg. p. 350.

and action of carbonic acid in the water varies and cannot be definitely determined in a given case; also the presence of other acids and their salts makes the actual phenomena occurring naturally in the soil quite different from the results attained experimentally by the use of pure or even running water.

Far more impossible yet is it to determine by this means the actual amount of plant-food accessible during an entire growing season. The action of plant-roots, of temperature, and of rainfall, all most inconstant factors, must seriously vitiate any attempted calculation of the possibilities of a given soil for a definite period.*

CHAPTER III.

CHARACTERISTICS OF SOILS—(*Continued.*)

I. THE RELATIONS BETWEEN THE SOIL AND HEAT.

THE warmth of the soil is necessarily of the greatest influence and importance in its bearings on the production of crops; the entire growth of the plant, from the germination of the seed to the ripening of the fruit and the gathering of the harvest, being to a very great degree dependent on temperature.

THE SOURCES OF THE HEAT OF THE SOIL are three; namely, solar heat, as the sun's rays; heat of chemical decomposition within the soil; and the original or plutonic heat of the Earth, proceeding from the still molten Earth interior.

The latter source though great in itself yet is so removed from the surface, and the radiation there is so rapid, that this heat is of no considerable value to the plant. The heat of decomposition, though considerable, in soils rich in organic matter, occurs only in the presence of comparatively high temperatures, and is therefore not manifest except in soils not needing its action to influence their behavior toward vegetation. The sun, therefore, remains the only source of heat of

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* For composition of soil solutions see Appendix, Tables I, II and III.

material importance as related to the production of plants from the soil. The soil-temperature, however, whatever its origin, is, to a greater or less degree, modified by numerous conditions.

THE COLOR OF THE SOIL is among the chief of these modifying influences. Since the solar heat influences the soil-temperature in proportion to its absorption and radiation, that soil absorbing most and radiating fewest rays must, other things being equal, attain the highest temperature. Black being the color possessing this property in the highest degree, it follows that the darker the color of a given soil the warmer it must be.

Humboldt records the temperature of a white and of a black sand situated side by side as respectively 40° C. and 54.2° C. The illustrations of the same fact are numerous and explain the reason why snow always disappears first where sprinkled with soot; fruit ripens earliest on dark-colored hillsides. As a matter of practical importance the difference thus often manifested is of no little moment, a difference of from 8 to 14 days in the ripening of potatoes, melons, grapes, and other crops having been secured by a difference in the color of soils otherwise equally suited to the needs of the crop cultivated.

Oemler has compared the temperatures of different soils with these results:

		Ratio to moor peat.
Moor peat	30.5° C.	
Humus	29.0° C.	95.3 : 100
Sandy humus	28.4° C.	93.2 : 100
Soil colored with Fe_2O_3	28.3° C.	92.9 : 100
Humus loam	26.2° C.	90.6 : 100
Humus clay	26.6° C.	87.7 : 100
Loam	26.2° C.	86.1 : 100
Clay	25.0° C.	82.0 : 100
Sand	25.9° C.	85.0 : 100
Chalk	23.8° C.	77.9 : 100

The most graphic presentation of the exact influence of color on soil-temperature is furnished by Schübler, who treated the surface of different soils alternately with a coating of lamp-black and of magnesia, whereby black and white surfaces were respectively obtained for each variety of soil, and the temperature then recorded, as follows:

Kind of Soil.	White.	Black.	Difference.
Quartz sand, 1	43.3° C.	50.9° C.	7.6° C.
Quartz sand, 2	43.3° C.	51.1° C.	7.8° C.
Gypsum	43.5° C.	51.3° C.	7.8° C.
Fine lime soil	42.9° C.	50.5° C.	7.6° C.
Humus	42.6° C.	49.4° C.	6.8° C.
Clay	41.3° C.	48.9° C.	7.6° C.
Field-soil (Jena)	42.9° C.	50.5° C.	7.6° C.

It therefore appears that a mere difference in color is capable of producing an average difference of over 7° in soil-temperature.

THE SPECIFIC HEAT OF THE SOIL is a most important factor in determining the ease with which a soil receives and retains solar heat. The less the specific heat, the greater the susceptibility of the soil to the accession of heat from external sources. The specific heat of the soil is usually between 0.20° and 0.25°; while that of water is 1°, or four to five times as high. It therefore follows that

THE MOISTURE OF THE SOIL POSSESSES GREAT INFLUENCE ON THE SOIL-TEMPERATURE: So much influence, indeed, that a dry light-colored soil may attain a greater degree of warmth than a moist dark-colored one.

Liebenberg experimented on the specific heat of many different soils with the following results; the soils all being dried at 100° C.:

Coarse Tertiary sand	1.268	Loess loam	0.259
Fine " "	0.275	Loess marl	0.284
Coarse Diluvial "	0.191	Humus loess loam	0.310
Fine " "	0.160	Weathered porphyry	0.209
Lime sand	0.188	" granite	0.301
Diluvial loam	0.220	Shell-lime soil	0.339
" marl	0.249	Tertiary clay	0.160

Taken in connection with the fact that the experiments of Plattner, made at Innsbruck in Tyrol, demonstrate that, in that region at least, no soils with a specific heat below 0.22 are fruitful, these results are of much value, and prove how great is the influence of specific heat on the productiveness of the soil. The action of water in reducing soil-temperatures is easily explained. The physical condition of water is the direct result of temperature; with sufficient variation in which it may assume either a solid, liquid or gaseous form.

Evaporation of water, or its transformation into the form of vapor, is due simply to the action of heat; the transformation is performed at the expense of heat; the more water evaporated from the soil the more heat must be extracted from the soil for the evaporation. Therefore, the more water contained in a soil the lower must be its temperature because of the greater evaporation and consequent exhaustion of heat. The amount of heat required for this evaporation depends naturally on the temperature of the water subjected to the action. Consequently the soil-temperature in cold seasons or in cool climates is much lower, proportionally, than the air-temperature, and not seldom may fall actually below the latter. The experiments of Park show that at a depth of 30 inches the difference in temperature between soil wet and dry is immaterial, being on the average for an entire year 6.25° C. and 6.62° C. respectively, but the difference increased proportionally with approach to the surface; at 13 inches the wet soil still remaining at 6.25° C., while the dry-soil temperature stood at an average of 9.75° C.*

Schübler, as the result of investigations made with twelve different soils the temperatures of which were taken both wet and dry, came to the conclusion that the average temperature of the former was 38.15° C. and of the latter 44.88° C., or an average difference of 6.73° C.

Somewhat different but more reliable are the more recent results of the investigations of Stockbridge, whose trials embraced daily records for four months with both cultivated soil and grass land identical except in the degree of moisture present.†

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* V. Gohren, *Agriculturchemie*, p. 97.

† Report Massachusetts Agricultural College Experiment Station, 1878.

AVERAGE TEMPERATURE AT 4 A.M.

Month.	Dry Cultivated Soil.		Wet Cultivated Soil.		Dry Grassland.		Wet Grassland.	
	Air.	Soil.	Air.	Soil.	Air.	Soil.	Air.	Soil.
	C.	C.	C.	C.	C.	C.	C.	C.
August....	14.1	16.5	13.2	16.6	11.2	17.3	12.4	17.7
September	8.1	12.7	2.	8.	6.8	14.6	5.8	14.3
October...	7.7	11.4	6.	11.	6.1	12.7	5.6	11.7
November	−4.9	1.	−6.6	1.4	−5.3	1.9	−4.9	3.
Aver. for 4 months		10.4°C		9.2°C.		12.6°C.		12.6°C.

From these observations it appears that no appreciable difference exists between the temperatures of grassland wet or dry; while, on the other hand, cultivated soils appear to be on the average 1.2° C. warmer when dry than when wet; the difference in the results of observation on the two kinds of soil being doubtless due to the action of growing vegetation.

Though the reduction of soil-temperatures through the presence of moisture is thus shown to be less than is usually claimed by other investigators, these results are doubtless more nearly correct for American conditions than are those of European observers.

The actual amount of heat taken from the soil by the evaporation of its water as estimated by Dickinson in Herts, England, after eight years' observation with drained land, was equal to the evaporation of 90% of all the water entering the soil, only the remaining 10% penetrating to the depth of three feet. He estimated that during the time of observation the total amount of water thus evaporated was 2,600,000 lbs., requiring the expenditure of heat equal to that produced by the combustion of 75 tons of coal.

The usual claim, however, that this evaporation is the direct result of the action of the absorbed heat of the soil is obviously erroneous; the actual expense of *soil-heat* being in reality considerably less than at first apparent from these misleading figures, inasmuch as the evaporation of *surface*-water must result to a certain extent, not only from the action of atmospheric heat, but moreover from heat-rays incapable of absorption by certain soils which can suffer no reduction of temperature thereby.

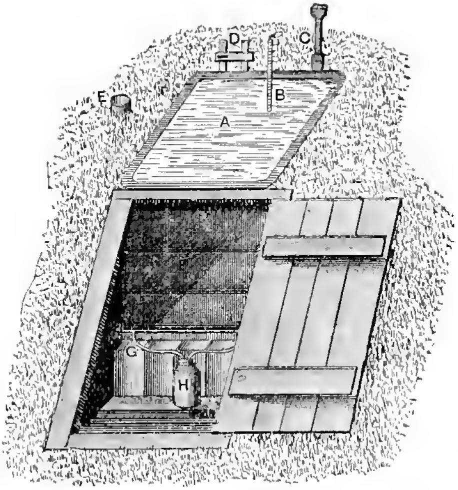

Fig. 16.—**Lysimeter.** A, soil; B, thermometer for soil-temperature; C, thermometer for air-temperature; D, maximum and minimum thermometer; E, rain-gauge; F, side of lysimeter, 3 feet deep; G, outlet-tube; H, percolation-receiver. (*To face page* 171.)

This fact of the evaporation of soil-waters before their penetration of the deeper sub-soil is of interest not only as related to soil-temperatures, but as disproving the once agricultural *bête noir* of soil leaching, since we here have ocular proof that but 10% of the soil-water descends even to a depth of 3 feet, while many agricultural plants send roots to a far greater depth, clover roots, for instance, penetrating often more than 6 feet beneath the surface.

Experience with the lysimeter here in Sapporo is of interest in this connection. The instrument has now been in place one year, and yet thus far not a drop of water has been obtained from it, showing that none of the rainfall for the year has penetrated 3 feet, but has all been either absorbed, or has evaporated from the surface.

The total amount of rainfall recorded here during the growing season of this interval, from May 1 to November 1, 1887, was 400.7 mm., equivalent to 15.76 inches. The lysimeter therefore received 142.628 gallons of water, equal to 426,840 gallons per acre, all of which was available for the crop, and not a drop of which carried soil-nutriment beyond the reach of any common crop.

In the light of these facts, established by observations in Europe, America and Asia, drainage-waters are not only of slight moment as compared with the total quantity of soil-solution, but their action on, or relations to, actual soil-nutriment is of comparatively slight significance.*

THE SOIL-CONDUCTIVITY OF HEAT is comparatively slight, so that the sun's heat as influencing the atmosphere is but slightly felt by the soil. The heat not only penetrates the soil to but a short distance, but the changes of temperature as affecting the air are of little import to the soil, its temperature being far less variable, and but slightly modified by change from day to night, or from summer to winter. The limit at which diurnal changes of temperature are felt is between 2 and 3 feet, while in temperate climates the annual changes of season are without influence on soil-temperature at a depth of 70

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* For composition of drainage waters, see Appendix.

feet.* These conditions of conductivity vary of course to a certain extent with the physical character and chemical composition of the soil. Rocks and minerals are all better conductors of heat than is either water, air, or organic matter; therefore, the more humus a soil contains, the more slowly does it respond to the influences of solar heat; likewise, the coarser the soil, the better a conductor is it; while the finer soil, enclosing more non-conductive air, is slow in warming through the influence of the sun's rays.

Though the soil is a much better conductor of heat than is water, the latter is superior to air as a conductor; as a result moist soils, the interstices of which are partly filled with water, are better conductors, and warm faster and deeper, than dry soils in which air, in considerable quantities, is present.

THE RADIATION OF HEAT FROM THE SOIL, and the consequent cooling propensity of the latter, are directly proportional to the absorptive power of the soil. Two soils of like absorptive power toward heat possess equal radiating power. It does not follow, however, that soils most rapidly warmed are likewise most rapidly cooled again. Because the sun's rays are of two kinds, illuminating-rays and heating-rays, and substances absorbing or radiating one kind of ray may be inactive toward the other. For instance, lampblack absorbs heat-rays of all degrees, while white lead absorbs all illuminating-rays, but only heat-rays of 100° C.

It therefore follows that a soil may be very passive toward the sun's rays, but at night be very active in radiating non-luminous heat-rays.

In general, however, the greater the heating capacity and conductivity of a soil, the more readily and rapidly does it give off its heat and become cooled, clay being the most slowly affected and sand the most readily influenced.

The absorption and radiation of heat by the soil are modified by numerous influences; chiefly by the properties of the atmosphere and protective covering of various kinds, snow, vege-

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* Approximately the average annual atmospheric temperature for the given locality.

tation, and clouds, all of which act like non-conducting clothing to moderate the intensity or rapidity of the sun's action, and retard subsequent radiation of the heat absorbed.

THE FORMATION OF DEW is, however, by far the most important result attending the phenomena of the absorption and radiation of heat by the soil.

And concerning the origin, method of formation, and office of dew, a wholly new belief has been adopted during the last decade, and has supplanted the previously accepted theory.*

Dew is simply aqueous vapor condensed by contact with a colder substance and deposited as drops of water on the surface of the soil or on vegetation. The theory of formation until recently universally accepted is that proposed by Dr. Wells in 1814. It explained the origin as the result of the contact of warm atmospheric vapor with the surface of the colder earth, and a consequent condensation and deposition of water which becomes absorbed by the soil, or drunk by the thirsty plant thus furnished with a never-failing source of water of atmospheric origin, by which the soil at night more than regains the loss through evaporation during the day. Identity between the formation of dew and the deposition of water on the surface of an ice-pitcher in a warm room was thus established.

This identity remains unassailed, but the error in deduction was one resulting from false premises. The old theory presupposed the coldness of the soil and the warmth of the atmosphere: conditions the essential falsity of which are easily demonstrated with the simplest thermometer on any summer evening. The condensation must, of course, result from cooling. The only question is as to the medium. Experiment shows the soil at the place of dew-deposition to be invariably warmer than the surrounding vapor-containing atmosphere. The soil, or warmer surface, cannot condense the colder vapor. The process is reversed, and the condensation is the result of contact of warm soil-vapor with the colder overlying atmosphere. The ice-pitcher explains the fact completely, but the relations

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* Müller, Pouillet, Pfaundler, *Lehrbuch der Physik und Meteorologie* (1881). Bd. II. p. 635.

of the two factors are reversed; the soil is the warm vapor-furnishing material, and the night atmosphere becomes the cold condensing medium.

This new theory is the conception of Prof. Levi Stockbridge; and the ingenious and important experiments by which the facts became conclusively demonstrated are of his devising, as are most of the important deductions drawn from the premises. The results of his labors were published as a report of the experimental work of the Massachusetts Agricultural College Experiment Station for 1878; and were issued as a State publication among the "Senate Documents" for 1879, and afterwards made public in pamphlet form.*

Notwithstanding the revolutionary character of the theory advanced, the facts adduced in its support were so incontestably supported by experiment so conclusive that it became immediately accepted by many of the most eminent physicists of America; and was at once adopted by the leading specialists of Europe, including Profs. Pfaundler and Wollny; and was supported by such scientific journals as *Der Naturforscher; Forschungen auf d. G. d. Agricul. Physik; Nature;* and the *Journal of Science.*

The investigations of the originator of the new theory have been repeated by many investigators with identical results; and little has been added to the facts as represented by the first advocate. The only similar investigations requiring note are those of Aitken, recorded in the Transactions of the Royal Society of Edinburgh for 1885, whose conclusions are identical with those of Prof. Stockbridge, and were reached as the result of independent experiment similar to those of the American investigator made seven years previously, but of which the Scotch scientist was ignorant.†

The experiments conducted at Amherst, Mass. were of such importance, both through their scientific value and practical application, that they will be recorded at length, as opposed to the facts still currently accepted by many agriculturists.

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* Investigations on Rainfall, Percolation and Evaporation of Water from the Soil; Temperature of Soil and Air; Deposition of Dew on Soil and Plant. Boston, 1879. Rand, Avery & Co., printers to the State.

† *Chambers' Journal,* 1886. p. 351.

The language used is occasionally that of the originator of the experiments described and the best qualified demonstrator of the facts enunciated.[*]

The Difference between the Temperature of Soil and Air is the direct cause of the deposition of dew; the origin of the moisture being of necessity in the warmer substance, from which it is with equal certainty condensed. The old theory of dew-formation accepted as for granted that as the ice-pitcher was cooler than the atmosphere, the temperature of the soil on which a similar deposition of moisture occurred must likewise be lower than that of the surrounding atmosphere. The experiments made to fix this identity were superficial and of necessity led to erroneous generalization. One of them was a comparison of the temperature of snow with that of the atmosphere, and as the latter was frequently warmer than the former it was concluded that dew was condensed from the atmosphere by the soil, a supposed cooler body.[†]

The Exact Relation between Soil and Atmospheric Temperatures was exhaustively studied by Prof. Stockbridge with these results:

Month.	Daily Average.			
	Temperature of Air.		Temperature of Soil.	
	Day.	Night.	Day.	Night.
May	21.7	12.1	17.1	12.5
June	26.5	14.7	28.1	18.
July	31.3	17.1	32.6	19.5
August	26.8	13.7	27.8	17.
September	27.	9.6	26.2	14.9
October	17.6	4.7	18.4	9.7
November	8.2	2.5	—5.8	2.9

By this table it is shown that the average temperature for the entire season was for air 22.7° C. by day, and for the soil

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[*] Having been conversant with these experiments during their progress, and possessing opinions in the premises much the same as those of the investigator, the author has, by special permission, occasionally resorted to the language of the latter without quotation or other reference.

[†] Müller, Pouillet, Pfaundler, l.c. II. p. 635.

22.2°; while at night the air average was 9.6°, and for the soil 13.5°.

It therefore appears that so far from the night temperature of the atmosphere being higher than that of the soil, the latter is on the average of an entire season of daily record 3.9° warmer than the air. This being the case, no dew could possibly have been deposited by the condensing action of the soil.

These temperatures were, however, recorded at the time supposed to give the maximum and minimum diurnal temperatures, varying somewhat with the season but being approximately 2 P.M. for day and 4 A.M. for night.

The results thus obtained were thought to possibly furnish an incorrect criterion for the average difference between the temperature of soil and air for the entire night. Observations were therefore made every evening during the month of June, at 10 o'clock P.M. The average of these observations gave the temperature of the soil as 18°, and of the air as 14.5°. The difference being 3.5°, against 3.9° as obtained for the entire season by the first recorded experiment. Results very nearly coinciding, *and the soil, again being shown the warmer at the time of dew-deposition, could not have been the precipitating medium.*

These observations having all been made in one locality and with but one variety of soil, observations were next instituted on thirty-four different kinds of soils, or soils under as many different conditions, and all in different localities. The results thus obtained showed the average night temperature of all the various soils and numerous localities to be 18.9° C., and for the air 16°, showing a difference of 2.9°. In no case was the soil found to be colder than the surrounding atmosphere, and only once was the air found as warm as the soil, and then in the middle of a dense wood on the night of a day on which the thermometer indicated 38.9° at 2.30 P.M., in the shade, and the night was remarkably sultry and still. *Again, the soil, being warm, was proved to be incapable of dew-precipitation.*

The writer is here able to offer the results of observations of his own, identical in nature and in result, but covering a very extended area, with every variation of soil and of altitude between 300 feet and 9000 feet above sea-level.

Indeed, the thermometer and aneroid have been his almost constant companions for several years, during which the relative temperatures of soil and air have been observed in Europe, America and Asia with never a variation of the fact that *when and where dew is being deposited the atmosphere is invariably* colder than *the surface on which the deposition is made.*

One such series of observations only is offered in detail.

LOCALITY.	6 A.M.		2 P.M.		Elevation.
	Soil.	Air.	Soil.	Air.	
Frankfort	13° C.	9° C.	......	......	200
Heidelberg	15° C.	14° C.	......	......	400
Darmstadt	16° C.	15° C.	......	......	340
Odenwald	15° C.	12° C.	......	......	400
Waedenschye	18° C.	15° C.	......	......	1,500
Rigi Kulm	.....	......	21° C.	16° C.	5.906
Interlaken	......	......	19° C.	26° C.	1,863
Lauterbrunnen	14° C.	12° C.	......	......	2,700
Faulhorn	......	......	17° C.	13° C.	7,800
"	......	......	14° C.	8° C.	8,200
"	......	......	10° C.	6° C.	8,803
Scheideck	9° C.	9° C.	......	......	6,500
"	......	......	10° C.	6° C.	5,800
"	......	......	12° C.	6° C.	6,200
Rhone Glacier	2° C.	1° C.	......	......	5,160
"	3° C.	1° C.	......	......	5,155
Lindeu	......	......	21° C.	19° C.	1,310
Innsbruck	14° C.	6° C.	20° C.	21° C.	1,812
Dölnach, Tyrol	......	......	14° C.	11° C.	3.370
Heiligenblut	10° C.	6° C.	......	......	4,600
Salzberg	......	......	22° C.	25° C.	1,352
Munich	......	......	20° C.	20° C.	1.703
"	14° C.	10° C.	......	......	1.703

These observations were all made during the months of August and September; yet even at 2 P.M., the warmest time of the day, only three localities out of twelve recorded show atmospheric temperature as high as that of the soil one inch beneath the surface. And if the temperature of the air is not warmer than that of the soil during the time of the sun's greatest intensity, it is of course impossible that the case should be reversed after sun-down when the dew begins to form.

The record made at 6 A.M. with one exception was made with soil wet with dew; and this one exception was a morning when vegetation was free from moisture, and is the only case where the soil was not found to be warmer than the overlying air. *The dew of these mornings and numerous widely separated localities was certainly not precipitated by a cold soil from a warmer atmosphere, as such conditions did not exist.*

The facts thus deduced were put to the test of observations with soils under five different conditions and at two different depths for a period of four months, with results as follows :*

AVERAGE TEMPERATURE AT 4 A. M.

MONTH.	CULTIVATED SOIL.						GRASSLAND.						FOREST SOIL.		
	Dry.			Wet.			Dry.			Wet.					
	Air.	Surface Soil.	5 inches deep.	Air.	Surface Soil.	5 inches deep.	Air.	Surface Soil.	5 inches deep.	Air.	Surface Soil.	5 inches deep.	Air.	Surface Soil.	5 inches deep.
	C.			C.											
August	14.1	16.5	19.	13.2	16.6	18.8	11.2	17.3	19.1	12.4	17.7	19.2	14.1	16.7	17.3
September.........	8.1	12.7	14.4	2.	8.	13.4	6.8	14.6	16.7	5.8	14.3	15.9	10.2	15.1	15.8
October.	7.7	11.4	12.5	6.	11.	12.3	6.1	12.7	13.2	5.6	11.7	12.7	7.6	12.5	13.1
November.	−4.9	1.	2.	−6.6	1.4	3.9	−5.3	1.9	3.6	−4.9	3.	4.8	−4.6	4.4	5.1
Av. for 4 months.	6.	10.4	11.9	3.6	9.2	12.1	4.7	11.6	13.1	4.7	11.7	13.1	6.5	12.2	12.8

These observations were made in localities long distances apart and under varying conditions of exposure and soil characteristics, and are believed to show with accuracy the soil and atmospheric temperatures of the region and period they cover. The average night temperature of the air during the season of observation was 5.1° C.; the surface of dry cultivated soil 10.1° C., and at 5 inches depth 11.9°; wet cultivated soil averaged at the surface 9.2° C., and at 5 inches depth 12.1° C.

Dry grassland had an average temperature of 11.6°, and at 5 inches depth 13.1°; wet grassland showed respectively 11.7° and 13.1°; while forest land averaged 12.2° at the surface, and 12.8° at the lower depth.

The average night temperature of the soil at 5 inches depth, for the entire period between August 1st and December 1st, was 12.6° C., or 7.5° higher than the nightly atmospheric temperature for the same period.

The result of all observations on the relative temperatures of soil and air at night admit of but one conclusion ; namely, that all soils on which dew is actually being deposited are on the

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* Report Mass. Agric'l Coll. Experiment Station, 1878; pamphlet reprint, p. 15.

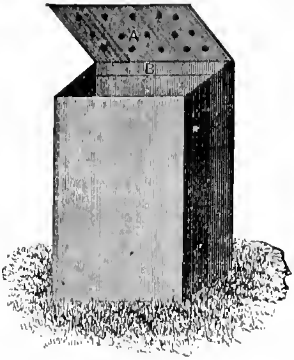

FIG. 17.—Illustrating Experiment No. 1. A, dew formed on cover of box; B, soil free from dew.

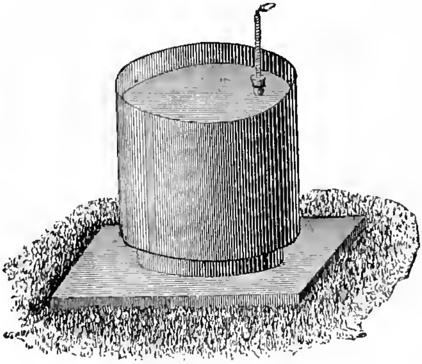

FIG. 18.—Experiment 2. (*To face page* 179.)

average 3.7° warmer than the overlying air, and that therefore the moisture precipitated is not the result of condensation by the soil; and that the latter cannot bear the same relation to the atmospheric moisture that is borne by the ice-pitcher, and that a new explanation of the phenomenon of dew-formation must be sought.

If the soil as the condensing medium plays the part of the ice-pitcher, the pitcher if filled with soil on which dew was being deposited must inevitably become covered with its customary beaded moisture.

The truth of this supposition was put to the test in

EXPERIMENT I.—A can of thin tin was prepared, which was three inches square, five inches deep, and without top or bottom. At eight o'clock of the evening of July 20th it was filled with soil from a cultivated field, in the same manner as the soil is taken into a lysimeter. It was placed on a grass-plot, and there remained until the morning of the 21st, and, though the surrounding grass was loaded with dew, there was not the slightest trace of it on the box. At 4 A.M. of the 21st the temperature of the soil in the box was 18.8° C.; that of the air was 15.5°. The experiment was repeated many times, with identical results. The soil does not bear the same relation to the air as the "ice-pitcher." On the night of July 25th a loose cover was placed on the top of the box: on the succeeding morning the top of this cover was dry; but the under side, next to the soil, was thickly studded with drops of water.

The principle illustrated by the "ice-pitcher" is a natural one; but it does not apply to the soil: in this case the soil becomes the warm, moist substance, performing the office of the air, and the air the cold substance, condensing its evaporating water. If the soil of the field gathers water from the air at night, then a given portion of it in natural position will be heavier in the morning than at night; if it evaporates water, it will be lighter.

EXPERIMENT 2.—Two boxes were prepared with capacity of a cubic foot. They were filled with soil in the same manner that soil is taken into a lysimeter, and without disturbing its particles or disarranging its strata. One was filled with absorbent, retentive loam, the other with peat; and these soils were taken because it was supposed that evaporation from them would be less rapid than from gravel or sand. Tight bottoms were nailed upon them, and they were placed in a trench in the open field, level with the surrounding ground, and exposed to all the vicissitudes of the weather. The experiment commenced the 1st of June, and was continued through the month, except when interrupted by rain or fog, the boxes being weighed night and morning. It will be noticed that the increase and decrease of the weight was not uniform, which was due to varying amounts of rainfall; but the results were as follows:

DATE.	LOAM.						PEAT.					
	Evening Weight.		Morning Weight.		Gain	Loss	Evening Weight.		Morning Weight.		Gain	Loss
	lbs.	oz.	lbs.	oz.	oz.	oz.	lbs.	oz.	lbs.	oz.	oz.	oz.
June 1....	110	4	110	1	0	3	112	0	111	8	0	4
2...	109	2	109	2	0	0	110	2	110	0	0	2
3....	108	9	108	8	0	1	108	12	108	12	0	0
4....	108	0	108	0	0	0	107	6	107	7	1	0
5....	107	1	106	15	0	2	105	1	105	2	1	0
6....	106	6	106	5	0	1	103	13	103	10	0	3
7....	105	14	105	11	0	3	102	5	102	1	0	4
9....	115	8	115	5	0	3	109	0	108	13	0	3
14....	115	12	115	9	0	3	109	4	109	0	0	4
15...	114	9	114	8	0	1	107	9	107	8	0	1
17....	113	13	113	13	0	0	106	9	106	7	0	2
19....	112	4	112	2	0	2	104	4	104	2	0	2
20....	109	4	109	3	0	1	103	14	103	12	0	2
21....	110	6	110	6	0	0	101	13	101	12	0	1
23...	116	12	116	12	0	0	107	7	107	6	0	1
28....	115	15	115	13	0	2	106	14	106	14	0	0
29....	114	6	114	4	0	2	105	2	105	1	0	1

This experiment, though not conclusive, indicates that the soil at night evaporates water, and that it is possible that the little moisture we find on the surface of a field in the morning may have been received from deeper soil rather than from the air. But the experiment was crude, the weights taken large, and the danger of mistake in exact weighing imminent; therefore the fact was sought by a different method.

EXPERIMENT 3.—A tin cup or can was prepared, 7 inches in diameter and 8 inches high, and holding 308.67 cubic inches of air. The sides were made double, but with the tin plates

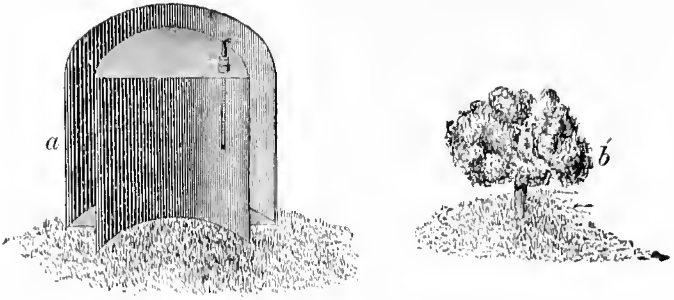

FIG. 19.—Experiment 3. *a*, double walled box (section); *b*, sponge for absorbing dew.

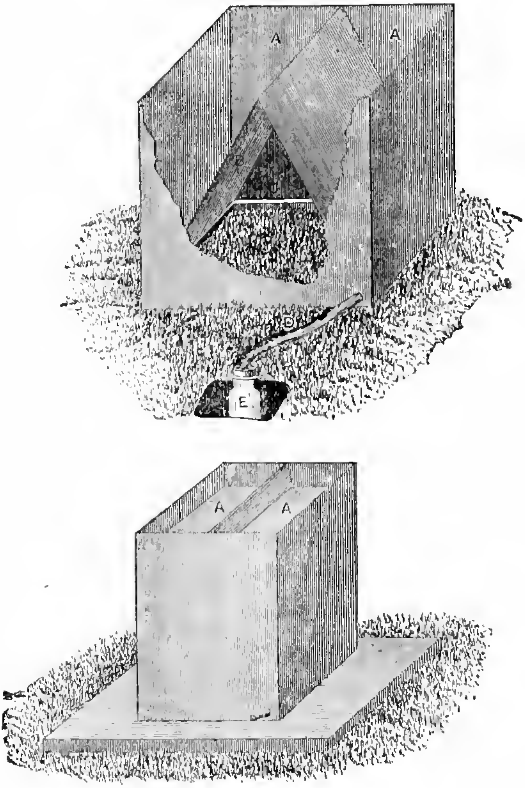

FIG. 20.—Experiment 4. (*To face page* 181.)

an inch and a half apart to contain water to reduce the temperature within the can to the same degree as the air outside: it was without bottom, but had a top through which was an orifice made tight by a cork, but in which was an aperture to insert a thermometer. It was well soldered, so that when it was put down upon, and its lower edge cut into, the soil, it was practically air-tight. For the purpose of absorbing moisture a piece of fine sponge was taken of twenty grains' weight. The sponge was placed under the can on a wooden peg two inches above the ground or board on which the cup was alternately placed, and was weighed night and morning. It was assumed that if the water absorbed by the sponge came from the air, there would be a marked uniformity in the weight of the sponge, whether the can stood on the board or the ground; but if it came from the soil, its weight would be greatest when the board was removed. When the can stood on the board, the outside air was excluded by banking around the bottom with dry soil.

The following table exhibits the result of the trial:

DATE.	Per cent of Humidity of Air.	Inside Temperature.	Outside Temperature.	Cup on Board, Moisture on Sponge	Cup on Ground, Moisture on Sponge	Temperature of soil.	REMARKS.
				grams.	grams.		
June 7..	67	12.2° C.	11.1° C.	....	3.00	20.0° C.	Rain on previous day; soil wet.
9..	86	10.5	9.4	....	2.35	13.3	
10..	92	10.5	9.4	....	3.10	11.1	
12..	88	10.0	8.9	0.030	....	11.6	
13..	88	14.4	11.6	0.431	....	15.5	
14..	72	11.1	10.0	0.620	....	20.0	
15..	88	14.4	14.4	0.550	....	18.3	
16..	62	14.4	15.0	....	1.76	18.3	
17..	74	15.5	14.4	....	1.43	17.7	
19..	70	11.1	10.0	0.245	....	17.7	
20..	88	15.0	14.4	....	2.76	21.1	
21..	70	12.7	12.2	0.250	....	19.4	
23..	83	14.4	13.3	....	1.94	18.8	
24..	87	15.0	15.0	....	4.50	18.8	
25..	87	12.2	13.8	0.740	....	16.6	
28..	95	16.6	15.5	....	2.88	20.5	Ground not hard after rain.
29..	96	18.3	17.7	....	4.16	25.0	Ground just hoed and very moist.

The rapidity of evaporation from any object is supposed to depend on its temperature and the amount of water it contains, modified by the motion of the air, its temperature, and its per cent of humidity. But the table does not show by the amount of water collected over the ground or board any special uniformity in this respect. It is noticeable that when the air under the can was comparatively dry, as on the nights of the 16th, 17th, 19th and 21st, the least water was collected; but no attempt was made to ascertain if, during that time, its humidity was increased by the soil-evaporation, or decreased by sponge-absorption on the nights of the 10th, 20th, 28th, and 29th, when it had a high per cent of moisture and the sponge contained the most water. It is quite possible, however, that, when the humidity of the air was near the point of saturation, the sponge received all the water evaporated by the soil, making its quantity large; and, on the other hand, when the air was dry, *that* received and held a portion of the evaporation, making the sponge collection small. As a rule, the amount of moisture taken by the sponge was largest after rain, when the soil was wet, and at a high temperature. The result, as a whole, corroborates the conclusions drawn from the second experiment. The amount of water collected, though small, must have been derived principally from soil-evaporation; but it does not determine what the maximum evaporation would be if the soil had not been covered by the can; for, as the enclosed air approached saturation, the sponge would not fully relieve it, and there must be a diminution in the soil-evaporation. Therefore, the more completely to determine the whole truth, the investigations were continued in the following manner.

EXPERIMENT 4.—A double vessel of thin tin was prepared which, within, would cover one square foot of soil and contain half a cubic foot of air, and of the same holding-capacity in the outside receptacle. On the inside, one inch above the bottom edge, a gutter was soldered on the four sides, slightly inclining to one point, and connected with a tube which passed through the side of the vessel; a tight-fitting rubber hose was drawn over this, and its outer end inserted in a flask. When in use, the lower edge of the vessel was cut into the soil to the depth of one inch, or as deep as the gutter would allow, to exclude the external air, and the outside receptacle was filled with ice and water to act as a condenser of the water vapor within. The results of the use of the can on cultivated and sod land, and on a board, were as follows:

DATE.	Per cent of Humidity of Air enclosed.	Actual Water in Air enclosed.	Actual Water obtained.	Gain over that contained in the Air enclosed.	Am't of water obtained per acre	Temperature of the Outside Air.	Temperature of the Soil.	REMARKS.
Night of		grams.	grams.	grams.	barrels.			
July 8...	82	0.1555	2.550	2.3945	8.950	70°	75°	A leak at the tube.
9...	96	0.3045	19.220	18.9155	70.941	76°	79°	Vessel on garden soil recently hoed.
10...	95	0.2786	33.060	32.7814	122.216	76°	79°	Soil wet by heavy rain previous day.
13...	92	0.2267	0.445	0.2183	0.818	70°	74°	Vessel on a board.
15...	82	0.1555	13.050	12.8945	48.364	68°	74°	Vessel on dry sandy land.
16...	86	0.1684	17.430	17.2616	64.745	65°	72°	Vessel on grass-land, and grass under it, loaded with dew, but little on grass outside.

The water collected in this experiment was the evaporation from a square foot of surface, and, though so small as to be hardly appreciable for that area, yet in nature it is a vast movement, as can be seen by noticing the collection of the night of July 10th, when it was at the rate of more than a hundred and twenty-two barrels per acre. This may or may not be the maximum of soil-evaporation at night; but it conclusively proves that the law of evaporation is not suspended or contravened, but is in active operation, at night, modified, of course, in degree by those influences which affect it during the day. The trend of the four separate investigations is clearly in one direction, and teaches that in the open field, with soil and air in natural condition,—the general soil, the upper stratum or film of air-dry soil,—lifeless substances lying on the ground or near it do not absorb water from the comparatively cold, dry air, but obtain it directly from the water which is evaporated by the warmer and more moist soil. On this principle, and this alone, can the phenomena to which allusion has been made be understood or explained, or that more striking natural appearance commonly known as "ground-fog." This is seen during the night, when there is no perceptible motion to the air, as a compact sheet of mist of one or two feet in thickness, and resembling a covering of snow, and always over water or very wet land. The surface-soil beneath the fog is many degrees warmer than the air, and contains hundreds of times more water in an equal space. Its abundance and warmth cause rapid evaporation, which is immediately condensed and made visible by the colder air. The principle which these observations appear to establish as governing the natural relations which exist between the soil and water, in both the liquid and vapor forms, and its movement thence to the air, may have a more extended influence and application than has yet been given it, and exhibit the cause and process of "dew-fall" in the case of the living plant; which phase of the subject should here receive our careful examination.

Allusion has already been made to the principle of "dew-fall" as illustrated by the "ice-pitcher;" and dew is described as "moisture from the atmosphere condensed by cool bodies on their surface at night." With the principle and the fact as stated, the belief appears to be and is in harmony, if no mistake is made in the application. It is, however, pertinent to inquire if this heretofore universally-accepted and time-honored theory of *dew-fall* is consistent with many well-established laws of plant-life and many well-known natural phenomena. And, first, the plant is endowed with a most wonderful and elaborate system of roots extending deep, far and wide into the soil, which has a temperature at night many degrees warmer than the air, and saturated with water of its own temperature. The most important function of this root-system is to gather soil-water, and force it upward, through every part of the structure of the plant, to the leaves. This power is so great, that when the plant is in rapid growth, and there is a full water-supply in the soil, it is subjected to great pressure. The root-force of plants has been frequently investigated, but never more completely, or with a clearer or more decided record, than by the experiments at the Massachusetts Agricultural College in the years 1874 and 1875. It is recorded in those experiments that the pressure exerted by a birch-root severed from its connection with the tree was equal to a column of water 85 feet in height; and that of a squash-plant eight weeks old, soft, open in its texture, and very tender, exerted a force equal to a column of water 45.5 feet high. Such plants as corn, tobacco, and the dahlia exhibited a similar power. The leaves, acting in conjunction with the roots, pass nearly all the water thus forced into their tissues, through their stomata, into the air. A rapidly-growing calla in the college conservatory has been noticed to exude water from its leaf-pores in such quantity as to stand upon the surface or fall to the ground in large drops. An Indian-corn plant, during its season of growth, has been found to evaporate thirty-six times its own weight of water. It has been stated, after careful investigation, that the leaves on an average acre of forest exhale many thousand tons of water during their summer growth, and a sun-flower-plant has evaporated three pounds in twenty-four hours. There is no natural reason why this evaporation should not be constant during growth, modified only in quantity by the supply of water in the soil, its temperature as affecting the activity of the roots, the rapidity of the motion of the air, and by its content of water. Second, young, succulent, rapidly-growing plants standing in the field by the side of those nearly ripe and comparatively dry always exhibit much the most dew. Third, other things being equal, those leaves and plants nearest to the ground "collect" the most dew. Fourth, other things being equal, plants growing on soils fully supplied with water show more dew than those on dry land. The Colorado wheat-grower, producing his crop by irrigation, determines when his lands are dry, and need watering, not by examining the *soil*, but by viewing the growing *crop* early in the morning. If this is well covered with water, he knows the soil is moist; if it has little or none upon it, it is the reverse, and the irrigating-sluices are at once opened. Fifth, some plants, at certain stages of their existence, have dew upon them, if the direct rays of the sun do not strike them, although it is several hours above the horizon and the temperature several degrees above the "dew-point." These phenomena may not prove that plants do not receive their dew from the air; but they give occasion for serious doubts, and indicate the possibility that it may come from the plant itself, or be a deposit of moisture rising from the soil as in the case of the "ground-fog."

A consideration of the mutual relations of root-action and leaf-evaporation leads to the conviction that it is hardly possible that the force or the result is one of diurnal periods, as in the case of the opening and closing of certain flowers, but rather the cause is active day and night, unintermitted during the period of growth. But the positive fact could be proved only by investigation, and was, therefore, attempted in the following manner:

Do plants evaporate water at night?

EXPERIMENT 5.—Two petunias and a cabbage-plant were selected, of convenient size for the experiment, and in thrifty, growing condition. A tin pot was prepared for each, in which they were potted and soldered in. Tubes were inserted in the top and bottom to admit water, and for drainage. The orifice around the stem was closed perfectly with grafting-wax, and, when on trial, the apertures for water and drainage were stoppered with rubber-lined corks, so that it was impossible for anything to escape from the pots except through the stem and leaves of the plants. In this condition the plants, with their pots, were weighed night and morning. The corks were removed during the day, and the plants watered as their health required. Fig. 21 represents one of these plants as potted for use. Plants show no dew when kept at night in a sitting-room, in a conservatory, or under a roof; and to know if, during that time, evaporation was taking place, one of the petunia-plants was kept under cover, and weighed evening and morning, with the following result:

DATE.	Evening Weight.	Morning Weight.	Loss.	Gain.	REMARKS.
	grams.	grams.	grams.	grams.	
June 10...	240.040	238.260	1.78	0	Temp. of room, 11.6° C. Humidity of Air, 88.
11...	231.050	229.850	1.20	0	Temp. of room, 12.7° C. Humidity of Air, 70.
20...	224.130	222.910	1.22	0	
21...	233.065	231.855	1.21	0	
23...	229.595	228.335	1.26	0	
24...	233.635	232.445	1.19	0	
25...	230.575	229.145	1.43	0	
26...	220.605	219.395	1.21	0	
28...	228.355	226.975	1.38	0	
29...	214.785	213.325	1.46	0	
30...	233.825	232.295	1.53	0	

Though the result shows no regularity of loss in proportion to the whole weight, yet the unvarying decrease proves conclusively that one plant evaporated water at night, and indicates clearly that this may be the law of all, whether situated in the open air or in a room. But to prove or disprove this supposition, one of the potted petunias and the cabbage plant were nightly placed in the open air in the garden, with the pots thoroughly wrapped in cloth to prevent their collecting water from the soil, and with results as follows:

PETUNIA-PLANT.

DATE.	Evening Weight.	Morning Weight.	Loss.	Gain.	Temperature of the Air.	Per cent of Humidity.	Water on the Plant.
	grams.	grams.	grams.	grams.	degrees.		grams.
June 13	221.700	218.370	3.33	0.00	52	88	....
14	246.800	246.550	0.25	0.00	60	72	....
15	252.900	251.460	0.44	0.00	61	88	....
17	242.880	242.160	0.76	0.00	62	74	....
20	148.060	148.240	0.00	0.14	64	88	....
21	169.125	169.165	0.00	0.35	61	70	....
25	167.905	167.605	0.30	0.00	56	66	0.52
26	165.305	165.105	0.20	0.00	57	87	0.93
29	158.955	158.925	0.43	0.00	72	96	0.38
July 6	158.395	158.155	0.24	0.00	83	65	0.46

CABBAGE-PLANT.

DATE.	Evening Weight.	Morning Weight.	Loss.	Gain.	Temperature of the Air.	Per cent of Humidity.	Water on the Plant.
	grams.	grams.	grams.	grams.	degrees.		grams.
June 26	234.685	232.725	1.96	0.00	57	87	1.80
27	259.005	254.775	4.23	0.00	63	91	2.77
28	250.720	250.805	0.00	0.85	64	93	4.87
29	238.255	237.705	0.55	0.00	72	96	4.15

CABBAGE-PLANT PLACED UNDER TIN CAN ON A BOARD, AND THE TEMPERATURE REDUCED.

DATE.	Evening Weight.	Morning Weight.	Loss.	Gain.	Temperature of the Air.	Per cent of Humidity.	Water on the Plant.
	grams.	grams.	grams.	grams.	degrees.		grams.
June 30	253.145	248.925	4.22	0.00	73	....	1.32
July 5	203.745	198.955	4.79	0.00	66	....	0.90
6	173.875	173.405	0.47	0.00	51	....	0.47

No attempt was made to determine the amount of water on the plants as dew until the 25th, when, after the morning weighing the leaves were wiped with a soft sponge as dry as possible, and the plant re-weighed. It will be noticed that, on nights when the plants lost weight materially, they at the same time had dew upon them. This is explained by the fact that frequently the plants stood in the garden several hours before they gathered moisture; at other times it commenced gathering very soon after they were carried out. It may be that in the former case the loss was occasioned by evaporation which was not condensed. It was assumed that if the plants in the morning, with the dew upon them, weighed more than at night, it would be proof that the dew came from the general air, or moisture arising immediately from the ground; if they weighed the same, or less, it must have exhaled from and accumulated on the leaves. The result is not an absolute demonstration; but it furnishes the missing link in the chain of evidence which will enable us to deduce conclusions having all the force of principles; and, that the evidence may be distinctly seen in its proper relations, we recapitulate.

The declaration is made "that dew on plants is water of vapor of the air, which is deposited on cold objects at night, it being condensed thereby." Proof: The exhibit of the "ice-pitcher." *Answer 1st:* The pitcher is at least twelve degrees colder than the surrounding air. and on the outside hygroscopically much drier: and plants at night are, on the average, at least as warm as the air, and therefore could not condense moisture. *Answer 2d:* The natural office of the leaves under force and pressure of the roots is to exhale water into the air, and they do it at night, nearly regardless of temperature. *Answer 3d:* Some plants exhibit dew in the day-time, if removed from the evaporating influence of the direct rays of the sun, and when the temperature of the air which surrounds them is many degrees warmer than what is technically termed the "dew-point." *Answer 4th:* Plants abundantly supplied with, and containing the largest per cent of water, and whose roots and leaves are the most active, exhibit the most dew. *Answer 5th:* In time of severe drought plants have little dew, though there is a high per cent of moisture in the air, and the nights are cold. Is it probable, then, that living, growing plants are under the control of the law exhibited by the "ice-pitcher," or has a mistake been made in the application of the principle?

But, again: *the declaration is made that dew on plants is caused by condensation, by the air, of warm vapor as it rises from the soil, and which therefore collects on plant-leaves.* Proofs—1st: The vapor of the soil is much warmer at night than the air, and would be condensed by it. 2d: Vapor from the soil is soon diffused and equalized in the whole atmosphere, but is in largest proportion when evaporation is taking place near the surface of the soil; and, other things being equal, leaves and plants near the earth have the most dew. 3d: Dew under boards, hay-cocks, and like objects on the ground, could receive it from no other source. Answers—1st: Admitting the facts, can they annul or make inoperative the law of evaporation from the surface of leaves at night, and its condensation there? 2d: Living organisms in the performance of their functions are superior to, supersede, and in a measure control, the laws of dead substance; and the subject-matter of dew relates more specifically to the living herbage of the fields. 3d: Water on the leaves of a plant on a board under a can could not have been received from the ground. *The declaration is here made that dew is the condensed exhalation of the plant.* Proofs—1st: Plants evaporate water at night. 2d: The air is colder than the plant and its exhaled vapor, and would condense it at the surface. 3d: The great preponderance of testimony is that, other things being equal, plants with the dew on them weigh less in the morning than on the previous evening, which could not be possible if it was received from any foreign source. 4th: A plant confined at night or during the day from the general air and the ground will, if the temperature is reduced, have more dew upon it after eight hours' seclusion than all the water in the air with which it is confined.

Though of the greatest importance to the cultivation of the soil, the natural phenomena we have thus investigated are so extremely subtle and delicate in their nature as to make absolute demonstration a matter of the greatest difficulty. But the facts obtained harmonize quite perfectly with the known natural laws of the absorption, retention and radiation of heat by different kinds of matter, and the movement and change of form of liquid water in the soil and plant. They give a rational and consistent explanation of many facts and phenomena which have been enveloped in more or less of mystery, and may direct to better or more intelligent methods in the treatment of soil and crops.

CONDITIONS MODIFYING THE TEMPERATURE OF SOILS are of the greatest importance as of necessity modifying the relations between soil and plant. Vegetation must rank first among natural modifiers of temperature conditions of the soil. In summer the earth covered with vegetation is colder than one offering free access to the sun's rays; the result being intensified by the relations between plant and soil water, and the transpiration or evaporation of the latter by which means soil-heat is necessarily reduced. In winter, on the contrary, the vegetation-protected soil is much the warmer because of the hindrance to heat-radiation offered by the covering of vegetation, turf possessing this property in a most marked degree, and proved by Becquerel to be capable of ameliorating soil-temperature as much as 5° C.

The relations of forest to soil temperatures have been exhaustively studied by Ebermeyer, whose observations show an average difference, between the soil of forest and field, of 2.55° for spring, 4.02° for summer, 1.55° C. for fall, while to the depth of 1.3 m. both soils possess the same temperature during the winter months. Forest soils naturally present least change of temperature with differences of depth, and also slighter daily modifications which seem to exert no influence below 0.6 of a metre from the surface.

THE CONDITION OF THE ATMOSPHERE, as already explained in considering the deposition of dew, exerts a modifying influence on soil-temperature, as the latter is modified by the amount of radiation, which is greatest with a clear unobscured atmosphere.

THE ANGLE OF CONTACT BETWEEN SUN'S RAYS AND SOIL SURFACE, naturally modifies the temperature of the latter; the more direct the contact, the more nearly perpendicular the descent of the rays, or the nearer the approach to a right angle formed by the earth's surface and the sun's ray, the warmer the soil, because the greater the amount of heat received.

Consequently in north latitudes locations with a southern inclination, and in south latitudes with a northern inclination, may be many degrees warmer than localities of opposite aspect or with surfaces more nearly level. Facts abundantly utilized in the locating of vineyards and other crops requiring the maximum of sunshine for maturity or perfection.

II. THE SOIL AND ELECTRICITY.

That the soil is a highly electrified body need not be repeated; but the use or relation of this soil-electricity to the production of plants is not so generally recognized. This electricity is largely, if not wholly, of frictional origin, resulting chiefly from the friction of soil-particles, but also to a great extent from the friction between atmosphere and soil as the wind moves over the surface. The atmospheric water entering the soil as rain is also an important source of electricity. The action of electricity on vegetation is doubtless of two kinds. *First*, experiments made by Fischer directly establish the fact that the electric current possesses the property of acting upon the soil-constituents, rendering the insoluble ingredients more soluble and, therefore, assimilable. *Second*, electricity is the most active ozone-former in nature, acting on atmospheric oxygen to convert it into the more active and energetic form of ozone, the invigorating and vivifying effects of which on vegetation and animal life are witnessed with every recurring thunder-shower.

III. THE RELATION BETWEEN SOILS AND GASES.

Certain gaseous substances are, with comparative invariability, present in most soils, not as an actual constituent part, but as bodies external, of intimate connection, however, with the various processes taking place in the soil, and thus properly considered among properties of physical influence on soil-characteristics. The gases thus demanding consideration are more especially oxygen, carbonic acid, nitrogen, ammonia and vapor of water.

These gases are present in the soil-interstices either as ingredients of the atmosphere through which they have been diffused, or are the result of decomposition, or of direct root-excretion.

The composition of the air confined in agricultural soils was first investigated by Boussingault and Levy with these results:

KIND OF SOIL.	Cubic Feet Air in 1 Acre, to Depth of 14 Inches.	Cubic Feet Carbonic Acid per Acre.	COMPOSITION OF THIS AIR IN VOLUME PER CENT.		
			CO_2.	Oxygen.	Nitrogen.
Sandy subsoil of forest.........	4,416	14	0.24	.....	.....
Loamy forest sub-soil..........	3,530	28	0.79	19.66	79.55
Forest surface-soil............	5,891	57	0.87	19.61	79.52
Clay soil......................	10,310	71	0.66	19.99	79.35
Unfertilized soil..............	11,182	86	0.74	19.02	80.24
Asparagus bed fertilized.......	11,182	172	1.54	18.80	79.66
Sand soil fertilized and wet.....	11,783	257	2.21	.....	.....
Sand 4 days later.............	11,783	1,144	9.74	10.35	79.91
Vegetable compost heap.......	21,049	712	3.64	16.45	79.91
Air 14 in. above 1 surface acre..	50,820	12	0.025	20.945	79.030

These results are chiefly valuable as having been obtained with a considerable number of agricultural soils; and as having been the first systematic efforts at investigating the composition of soil-air and its relations to the atmosphere and the growth of plants.

But our knowledge of the composition and properties of soil-gases has recently been largely increased, chiefly through the labors of Fleck, Pettenkofer, Nichols and Fodor. The last-named investigator, as the result of thirteen analyses, gives the average composition of soil-air drawn from a depth of 1 metre as follows:*

	Maximum.	Minimum.	Average.
O........................	21.335	18.797	20.031
CO_2......................	0.899	1.039	1.019
	22.234	19.836	21.050

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* *Boden und Wasser; und ihre Beziehungen zu den epidemischen Krankheiten. Hygienischen Untersuchungen von Dr. Josef Fodor.* Braunschweig, 1882. pp. 99–142.

From 4 metres depth:

	Maximum.	Minimum.	Average.
O	18 532	17.290	17.906
CO_2	5.445	2.631	3.761
	23.977	19.921	21.667

The differences between soil-air and the atmosphere were demonstrated by subjecting the latter to analysis by the same methods and with the same apparatus, resulting in an average detection of 21.029 volume per cent of oxygen and 21.068% CO_2.

Through these observations the investigator arrives at the conclusion that: "In the soil one of the constituents of the air, oxygen, is in truth used, and then in its place commonly nearly the same volume of CO_2 is formed. In the soil therefore occurs an oxidation of carbonaceous substances whose product is the carbonic acid of the soil."

The relative proportions of the three chief soil-gases is found to be exceedingly variable; the oxygen and carbonic acid being sometimes present in greater, sometimes in smaller, quantities than this proportion in the atmosphere. A fact demonstrating the activity of numerous processes in the soil more complicated than the simple oxidation just noticed.

The varying proportion of oxygen and of carbonic acid is doubtless due to the constant chemical decomposition and recombination. A part of the oxygen is utilized in the combustion of organic hydrogen, part becomes combined with nitrogenous matter during the process of nitrification, and still another part combines with protoxides to form sesquioxides, or to form oxides of lower combinations. And the carbonic acid undergoes as many recombinations whereby its relative proportion in the soil is constantly unstable; as already recorded in considering the action of carbonic acid on soil-ingredients.

Ammonia and nitrogen as existing in the soil have been considered under the composition of the soil. Water vapor exists only in the upper soil-strata, seldom below a depth of 2 metres from the surface.

The relations between soil-gases and plant-nutrition are of considerable moment and will be reviewed in Chapter IV.

CHAPTER IV.

THE SOIL AS RELATED TO THE PRODUCTION OF PLANTS.

THE soil was obviously designed for a special office in the economy of nature, for the conduction of which the transformations and properties already considered are but the progressive and systematic preparation necessary for the ultimate end. This end or final office for the assumption of which so many preliminary stages were passed is not other than the supporting of plants with which the earth is decked, on the presence of which animal existence depends.

Though water and air are likewise each the habitat of a flora peculiar to itself, the soil alone under normal conditions is the home of plants of agricultural significance, and is, thus, alone concerned in our consideration.

True, the soil is both home and nourisher of the plant-forms occupying it. But neither as source of vegetable nutrition nor as magazine or laboratory for the reception or preparation of atmospheric matter for plant-nutrition does it occupy first place in a consideration of the relations existing between soil and plant. The office performed by the soil as *bearer and habitation* of plants must be accorded position as of chief importance in this connection, since all other properties must be subservient to this on which alone their activity depends.

THE SOIL AS BEARER AND HABITATION OF PLANTS must be considered as of first significance in governing or controlling the other relations existing between the soil and the vegetable product grown upon it. The influence thus exerted is of the kind existing between all organic life and environment or habitat, and thus controls or modifies not only individual and race characteristics, but also development, health and maturity.

The ultimate amount of nutriment supplied the plant even indirectly by the soil is but a fraction of the entire material entering into its composition, and even this portion depends on no characteristic quality or action of the soil as an actual essential to assimilation; but it can, should circumstances allow, derive this food directly from water solutions, without soil-interposition, as is abundantly demonstrated by the numerous experiments in water culture.*

THE SOIL IS THE HABITAT OF THE PLANT, THE PLACE OR MEDIUM FOR GROWTH, a material furnishing the necessary support or foothold for the roots which, penetrating the mass, hold the plant in that position in which the life-functions can be best performed.

The soil is, therefore, primarily simply the physical bearer of the plant, and on the performance of this office all other properties, and each other relation existing between them, depend.

The function of the soil as the habitation of the plant is important and far-reaching; character, variety and perfection of vegetable growth being dependent upon this condition of habitat to a greater degree than to any other influencing factor, with perhaps the single exception of character of climate.

Races of men and of most other animals are far more independent of environment than is the case with vegetable forms; facts fully recognized on all sides. Animals are easily acclimated in any region to which they may be moved or compelled to emigrate within certain limits of temperature.

Plants, on the contrary, however perfectly may be preserved the climatic conditions of an artificial or new habitat, demand certain physical and chemical conditions, in the absence of which thrifty growth is impossible.

Though white birch and willow may grow in close proximity, surrounded by the same atmosphere, bathed in the same sunlight, and warmed to the same degree, no art of man can force them to an interchange of habitat. Where the golden-rod thrives, only sickly violets can be made to bloom; and no farmer would attempt to grow cranberries and rye in the same field. The question of habitat, then, or adaptability of crop to soil, becomes a factor of the greatest moment, and occupies a

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* Pfeffer, *Planzenphysiologie* (Leipzig, 1881), Bd. I. p. 70.

most significant place in any system of culture. So universal is the manifestation of this natural relation between soil and plant, and dependence of plant on character of habitation, that nature draws the most rigid lines of demarcation in field and forest, and offers proof of the natural selection of habitat so strong that the surest criterion for the determination of soil-characteristics is furnished by the kind of vegetation with which a soil is naturally covered.

THE SOIL AS FEEDER AND STOREHOUSE FOR THE PLANT, and the relation thus maintained between them, follows naturally the facts thus recorded, and on which this function of the soil so directly depends.

All vegetation contains compounds of both organic and inorganic matter, of which two classes of material plant-nutriment must, therefore, consist. But whatever may be the nature of the material entering into the composition of plants, or to whichever division of matter it may belong, no vegetable growth possesses the power of assimilating simple or elementary material, with the single exception of the element oxygen. With this one exception, therefore, no elementary body, however important a position it may hold in the plant organism, can be considered as direct plant-food, or can under any condition be, in a free state, assimilated by the plant, or even assume the form of vegetable nutriment.

Only combined material is capable of furnishing the plant with sustenance, and, hence, soil compounds alone bear any direct relation to the growth of plants.

Of the compounds more or less generally entering into the composition of plants, two groups, an atmospheric and a soil, are recognized; and of these the following are considered as essential constituents of all vegetable forms:

I. Water, carbonic acid, ammonia.

II. Phosphoric acid, potash, soda, silica, lime, magnesia, iron oxide, sulphuric acid, and hydrochloric acid.

Though other materials exist as constant constituents of individual plants or classes of vegetable growths, these two groups of compounds are the invariable essentials of all vegetation. No agricultural plant grows without their presence in sufficient quantity and soluble assimilable form in the habitat wherein its life-functions are to be performed; and in case either sufficiency or assimilability fail, plant-life also fails.

The first of these two groups of substances, though wholly inorganic in nature, is distinguished from the members of the second group as consisting of products of organic decomposition or combustion, and existing in gaseous form as constituents of the atmosphere, and hence designated "atmospheric" in contradistinction to organic and inorganic or mineral matter. Though distinctly atmospheric in character, these three compounds are unfailing constituents of the soil air, and enter the plant-organism in solution through the root in a manner identical with that characteristic of mineral plant-food.

The second group consists wholly of mineral matter originally of rock origin. By the processes of combustion or of decomposition these substances become separated from the organic bodies with which they may have been combined; and are reduced to the form of solid, non-volatile *ash* or salts.

These facts render clear a circumstance not at first recognized in considering the composition of plants or of vegetable nutriment, namely, that though all living bodies consist of two distinct classes of matter, organic and inorganic, combustible and non-combustible, plants feed only on inorganic matter *as such*, possessing the power of transforming inorganic matter, carbonic acid, water, ammonia, nitric acid, into organic matter, or combustible carbon compounds, by recombination, as the result of the life-function of the vegetable organism.

As the inevitable result of this relation between these two different classes of matter, their mutual dependence, each is absolutely essential to the growth of the plant, one as necessary as the other, and, without the presence of both in sufficiency and assimilable form, plant-growth is impossible. Growth is essentially the formation of new material, and the new material of vegetable organisms consists of compounds of organic and inorganic matter, only to be formed by recombination of the constituents of these groups of atmospheric and ash materials. Hence, should either fail, the combination must fail, and the formation of new material must cease.

Neither atmospheric nutriment nor the soil-constituents can alone exert any influence on the growth of plants. The atmospheric ingredients are the indispensable means for the transformation of soil-material into organic compounds; and the soil-constituents are, in like manner, the necessary means by which is effected the change of atmospheric foods into vegetable and animal organisms.*

The fact is also as incontrovertibly established that unless each and every one of the members of these two nutritive groups is accessible to the plant in sufficient quantity and assimilable form, thrifty development is impossible, and that the absence of either of these constituents immediately manifests itself in an abnormal development, or the death of the plant thus deprived. Moreover, though other materials are often essential ingredients of individual plants, and must exist in the soils from which the plant feeds, and though other matter not naturally a constituent of the given plant may be forced into its organism by artificial conditions, the essential or normal constituents of the plant must invariably and under all conditions exist accessible to the plant, and for this material no substitute matter can be consumed, *exchange* of food-constituents being wholly impossible.†

The inevitable result of these facts is the now established truth that not one of the indispensable constituents of the nutriment of a given plant possesses greater importance for that plant than any other such ingredient; for, without them all, the action of each is impossible, and the absence of one renders all the others ineffective as producers of normal or healthy plant-growth.

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* "Da weder die atmosphärischen Nahrungsmittel *für sich allein*, noch die Bodenbestandtheile *für sich allein* auf die Entwickelung der Pflanze irgend eine Wirkung äussern können, so sind die atmosphärischen Nahrungsmittel die unentbehrlichen Vermittler des Uebergangs der Bodenbestandtheile in organische Verbindungen; und die Bodenbestandtheile die unentbehrlichen Vermittler des Uebergangs der atmosphärischen Nahrungsmittel in Korn und Fleisch."—*Ueber Theorie und Praxis in der Landwirthschaft*, von Justus von Liebig (Braunschweig, 1865).

† Rosenberg-Lipinsky, *Praktische Ackerbau*, Bd. I. p. 304. Breslau, 1879. The experiments of Knop would nevertheless indicate that a slight substitution of soda for potash *might be possible*.

FIG. 21.—Potted plant used in Experiment 5.

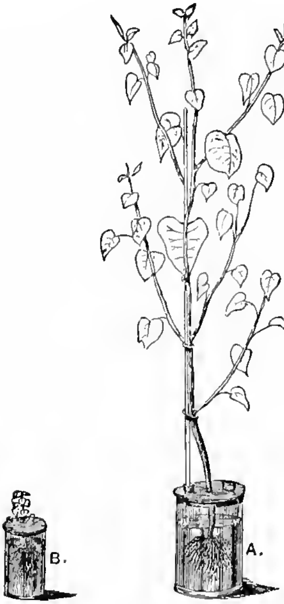

FIG. 22.—Water-culture. Illustrating the necessity for a sufficiency of each plant constituent. A grows in a perfect nutritive solution; B in the same solution, except potash, which is absent. (Pfeffer.) (*To face page* 199.)

The relations thus existing between the plant and the materials from which its organism is formed were first enunciated by Liebig, who affirms that "not one of the enumerated vegetable nutrients possesses greater importance than any other; *all are equally indispensable to plant-growth.*" *

THE EXTRACTION AND ASSIMILATION OF PLANT-FOOD.—Having reviewed the nature and varieties of plant-food, it next becomes necessary to follow the relations existing between plant and soil a step farther, and inquire into the means adopted by the plant for procuring the essentials to its growth from the soil, and follow the stages of subsequent assimilation.

Though not an actual part of the subject of the relations between plant and soil, the life-history, growth and functions of the plant form a series so complete and intimately related, that before considering the fixed relations existing between plant and soil, a glance at the fundamental facts of vegetable assimilation of atmospheric foods seems necessary.

THE ASSIMILATION OF ATMOSPHERIC FOOD BY PLANTS involves two distinct processes, inasmuch as these ingredients of the plant enter its organism through two different and unlike organs, the leaves and the roots. Oxygen and carbonic acid are, however, the only constituents entering the plant through the leaves; all other food being absorbed by the roots from solutions existing in the soil.

THE ORGANIC INGREDIENTS OF VEGETATION are chiefly the five compounds, starch, sugar, cellulose, fats, and albuminoids. The composition of the four first, or non-nitrogenous, compounds, consists of some modification of combination of the elements carbon, hydrogen, and oxygen, whence they derive their designation "carbohydrates;" while the albuminoid material contains nitrogen as well. These materials all result from the combination within the plant of the inorganic compounds carbonic acid and water, with the addition of nitrogen in the case of albuminoids, in which phosphorus and sulphur may also be present in minute quantities.

The process of organic synthesis thus conducted by the plant

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* Liebig, *Ueber die Moderne Landwirthschaft* (Leipzig, 1859), p. 24.

is briefly this: The carbonic acid of the atmosphere constantly surrounds and bathes every part of the exposed plant. Coming into contact with the green leaves, it enters the pores or stomata with which the under surface of the leaf is covered. Here, by the action of sunlight, a process of reduction follows, resulting in the liberation of the oxygen of the decomposed acid which passes out of the pores to again become mingled with the atmosphere, thus purified, while the carbon remains behind, and, combining with the water of the plant-circulation, forms the carbohydrates of which the plant so largely consists.

Not only does sunlight prove to be indispensable to the process of assimilation, but the green coloring matter of the growing tissue, known as chlorophyl, is even requisite to the transformation; and is evidently the direct means for the combination of the carbon extracted from the atmosphere with the inorganic constituents of water.

The first and direct product of this combination is generally starch, though possibly sugar may be the first actual product of the union, remaining invisible, however, because of its solubility in water or cell-juice; and in certain plants, the onion for instance, being the final product as well, starch remaining wholly absent. Whichever of these carbohydrates, even though it be fat,[*] may be the first and direct product of this union of inorganic matter with atmospheric carbon, the entire series may be formed by subsequent oxidation, whereby variations in the relative proportions of the three factors, carbon, hydrogen, and oxygen, are produced.[†]

The actual chemical transformation wrought may be expressed as follows:

Water. Carbonic Acid. Cellulose or Gum. Oxygen.

$$5H_2O + 6CO_2 = C_6H_{10}O_5 + 12O \text{ liberated.}$$

Starch.

$$15H_2O + 18CO_2 = (C_6H_{10}O_5)_3 + 36O \text{ liberated.}$$

Glucose.

$$6H_2O + 6CO_2 = C_6H_{12}O_6 + 12O \text{ liberated.}$$

Sucrose.

$$11H_2O + 12CO_2 = C_{12}H_{22}O_{11} + 24O \text{ liberated.}$$

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[*] Discredited by Pfeffer.

[†] Pfeffer, loc. cit., Bd. I. pp. 182–211.

Not only is it thus apparent that any one of these carbohydrate bodies is capable of construction by the union of carbon with water, but the closeness of their relations one to the other is graphically presented; the difference between any two members of the series being but slight, and transformation of one compound of the group into another is readily effected.

It becomes evident, therefore, that from the starch resulting from the assimilation of carbon, sugar, gum, oils, and cellulose, the entire organic mass of the plant is produced as the result of the life-function of the organism.

Moreover, though the conversion of starch into other carbohydrates, for instance glucose, may be artificially accomplished, the plant is endowed with powers not successfully imitated by man, namely, the conversion of sugar into starch, cellulose, or fats.

Not only is growth or the formation of new cells thus accomplished, but the plant elaborates material not required or utilized as building material, but elaborates reserve material deposited within the plant-cells. This reserved material is destined as the prepared food of the plant when first beginning the next season's growth. It may consist of any one of the carbohydrate products of carbon assimilation, and be deposited in any part of the plant; as starch in the potato-tubers, sugar in the maple or beet, or oil in many seeds.

Having fixed the principles of carbohydrate formation, we must next consider the remaining group of organic compounds, and answer the question, HOW ARE THE ALBUMINOIDS FORMED?

Briefly, albuminaceous or protein nitrogenous plant-constituents are the result of the action of nitric acid on non-nitrogenous compounds, probably sugar with the elimination of carbonic acid and perhaps water, though direct combination for albuminoid formation is not probable; intermediate or amido compounds being the direct product of the decomposition. The definite method of combination still remains in doubt, and is best summed up with the statement that "the synthesis of organic nitrogenous substances within the plant is a function of the living protoplasm in which material the entire process occurs." *

Chlorophyll and light, however, seem inactive as agents of protein formation. A singular property of the albuminoid constituents of plants is the fact of their inability to penetrate the cell-wall, and, therefore, move from the place in which they were formed to the place in which their final office in the plant is to be performed. For the accomplishment of this change of position, the protein body becomes decomposed into asparagine or some other amide compound, which penetrates the cell-wall and enters the plant-circulation: a final change into the ultimate protein body being again effected by the action of carbohydrates, and the incorporation of the product with the new cell-material, or its reservation as nutriment for the next generation.

Though we have discussed only the assimilation of carbon and exhalation of oxygen by the plant, as, by far, the chief life process of vegetation, it must not be forgotten that the plant, nevertheless, possesses to a limited degree the ability to absorb oxygen, chiefly through the growing buds, and exhaling carbonic acid, particularly in the dark, thus actually completing a process of respiration identical with that of animals, although this must be considered as an exceptional rather than indispensable life-process of the organism.

THE ASSIMILATION OF SOIL-FOOD.

The extraction of nutriment from the soil and the assimilation of this nutriment depend directly on the processes involved in the utilizing of atmospheric constituents, since plant-growth results only from the combination of the two for the formation of new cell-matter. The office of actual absorption of soil-matter devolves upon the mesh-work of roots penetrating the mass, and is accomplished through the cell-walls of the root. And this food must exist in the form of solution, since material only in this form is capable of entering the plant, and

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* Pfeffer, l. c. p. 245.

combining to become a constituent of its organism. It is apparent from this fact that but an infinitely small portion of the soil-mass exists at any time in the form of actual plant-food, or immediately assimilable material. The greater portion of this plant-food is combined in comparatively insoluble form to constitute the soil-mass itself.

THE METHODS OF SOLUTION, whereby the root is enabled to procure material from the inorganic soil-constituents, have already been reviewed in considering the subject of rock-disintegration.

The process is nearly always the result of chemical action; the various acids which exist, or are formed, within the soil by combination with different soil-elements transform insoluble, or mineral, salts into more soluble compounds. But the solubility of plant-food is not gauged by its susceptibility to water action; the carbonic acid, ammonia, and nitric acid present in most soil-waters by combination directly influencing the solubility of soil-constituents; every other material dissolved in the soil-waters being directly engaged in accomplishing the same results.

Moreover, as already recorded (p. 111), the root itself is its own best servant in dissolving mineral soil-matter, excreting, or at least elaborating, an acid which, by direct contact with mineral matter surrounding the root, dissolves the same, which thus becomes, by the root's own action, directly assimilable plant-food.

Not only does the root possess the property of dissolving its own food from the intact rock-mass, but it is capable of seeking out that nourishment demanded by its organism, and travelling long distances, surmounting every obstacle in its indefatigable search for the craved material. The distance thus traversed by roots is frequently a radius greater than the height of the plant itself; the direction of nearly all of the roots of many plants being toward the most abundant source of required nutriment; instances of roots extending long distances for the sake of reaching and feeding on an accidental dung-dropping are of constant occurrence. If a plant be grown on a soil made up of strata of nutritious and non-nutritious material, the former will be found filled with a mesh-work of rootlets, while the latter remains nearly devoid of roots.*

Although the plant thus seeks the food essential to its growth, it does not follow that it possesses the property of selecting and absorbing only such material as is indispensable to its development. On the contrary, the roots must take up whatever is offered them in solution, even though, as is not seldom the case, the material thus absorbed is injurious to the organism. Plants no more possess the power of rejecting soluble mineral matter, or of excreting non-essential material, than the animal can reject a poisonous body present in its food: essential and non-essential alike enter the system if presented in a soluble or digestible form.

Plant-development, however, by assimilation of nutriment is subjected to the law of diffusion of fluids, or, better, the cell-wall possesses osmose properties, as the result of which, although the root takes up material in the proportions and relations in which it is presented in the soil-waters, or nutritive solution, a given constituent of the solution is drawn into the plant through its roots only until the solution within the cell becomes saturated with this one substance. That is, till the strength of the solution is the same on both sides of the cell-wall or osmose membrane.

When, however, the mineral substance within the cell becomes assimilated, or becomes an integral part of the organism, and, therefore, assumes insoluble form, the solution within the cell becomes more dilute than that without, and the absorption begins again to continue till equilibrium is once more gained. It, therefore, appears that though the plant is endowed with no power of selection of food, still the actual amount of material and composition of the cell-fluids depend on the actual quantity of soluble mineral matter used by the plant, and the character of the same or essential nutriment varying with every family

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* The power of roots to overcome obstacles in their search for nutriment was forcibly illustrated by a large elm on the college farm at Amherst, the roots of which travelled underneath a hard gravel road and filled a manured flower-bed fifty feet beyond with such a mesh-work of rootlets that its cultivation was rendered impossible.

of plants, each taking from the soil and assimilating food after the demands of its own kind.*

In this manner it happens that different plants of varying requirements growing side by side, on the same soil, and extending their roots into the same nutritive solution, derive unlike materials from that nutriment, and develop systems of widely varying composition.

But the plant, in its assimilation of nutriment from soil-solutions, is not limited to supplying the actual demands, or positively essential materials, but often takes up substances in quantities far in excess of the necessities of its existence. This fact is naturally inferred from the statement that whatever mineral matter was offered the root in solution entered into the circulation of the plant. In case any element of plant-growth is present in a given soil in predominating quantity, more of this material, conditions of solubility being equal, enters into solution than of any other soil-constituent present, and quantities in excess of the actual necessities for thrifty development are taken into the plant-system, and become a constituent part of the ash ingredients of its organism.†

The variations in the composition of the ash of most plants, within certain limits, though each may have reached normal development and attained an equal degree of thrift, are thus accounted for. This superabundance of certain constituents has led to the application of the term "nutritive luxuries" to these mineral matters.

THE DETERMINATION OF THE CHARACTER AND QUANTITY OF MINERAL INGREDIENTS INDISPENSABLE TO THE THRIFTY DEVELOPMENT OF A GIVEN PLANT is attended with no little difficulty because of this variation in the composition of healthy, normal plants of a given variety. Yet tireless experiment has determined with remarkable accuracy the indispensable constituents of all agricultural plants.

Moreover, analysis of plant-ash demonstrates that the variation in mineral constituents oscillates only between certain

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* Wildt, *Katechismus der Agriculturchemie* (Leipzig, 1884), p. 62.

† Johnson, "How Crops Grow," p. 186.

limits, beyond which in either direction the variation cannot pass, without resulting in symptoms of abnormal development.

Chemical analysis, therefore, offers a reasonably reliable criterion for determining not only the nature but the quantity of mineral matter required for the production of any definite quantity of every known plant or crop. As the result of countless investigations, the fact has now become universally accepted, and adopted as a rule of practice, that average normal agricultural soils contain sufficient of all the inorganic constituents of plant-food to withstand the depletion of constant cropping for ages to come; the gradual disintegration and reduction to soluble form keeping pace with the demands of plant-growth—*the elements potassium, phosphorus and nitrogen alone excepted.* These indispensable constituents of all vegetation must be supplied by artificial means, if the fertility of the soil is to be maintained; the quantity required being obviously the same removed in the crop produced. This amount is accurately determined by analysis; and if the demands of the crop are thus met, sterility *through deficiency of plant-food* is impossible; and if the material thus artificially supplied to the soil is in excess of the immediate demands of the crop, then increase in soil fertility or available nutriment is the result.*

THE PROPER CONCENTRATION OF NUTRITIVE SOLUTIONS IN THE SOIL naturally presents itself here for consideration; and the limits within which the most satisfactory results are to be expected have been shown by repeated demonstration to be capable of but slight variation.

The solubility of soil-matter is so slight under the most favorable conditions in nature, that solution is accomplished not only exceedingly slowly, but only with the action of repeated and large quantities of water. The results derived from the researches of numerous investigators demonstrate that the average concentration most favorable to plant-development is 1 part of mineral matter per 1000 parts of water. The maximum and minimum quantities of solid matters per

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* See Appendix, tables of Ash Constituents of Plants.

1000 parts of water beyond which deterioration in vegetable product results were found by Nobbe to be respectively 2 and 0.5 parts.* These figures refer only to the entire or total mineral content of the solution, the variation with individual ingredients being far greater, and depending obviously upon the relative proportion of each constituent demanded for the normal development of any given plant. Indeed, since, as already mentioned, all mineral matters presented to the root in solution are of necessity taken up by diffusion, too dilute a solution for utilization is impossible; and the actual concentration of many non-essential or occasional constituents of plants as actually utilized by the plant must be almost inconceivably dilute, 1 part of mineral matter to 100,000,000 parts of water being not impossible as a matter of actual plant-assimilation.

The amount of water positively acting on a given soil to furnish the large amount of ash found in the plant from so extremely dilute a solution is far less than appears at first essential. The nutritive solution of proper strength, as presented to the roots, loses a part of its dissolved mineral matter through absorption by the plant, and the water thus set free acts again on the soil to reduce new portions to solution. So that in reality the same water may act again and again on the soil-constituents, to reduce them to solution, and convey them to the plant.

These facts of the concentration of nutritive soil-solutions offer an explanation of an occasional occurrence in practice of serious import to the production of crops, namely, the wilting and possible death of plants through the application of plant-food in a form too concentrated. This is particularly observed in Japan, where human excrement is the almost exclusive artificial application to the soil; and is elsewhere noticed through the injudicious use of concentrated chemical fertilizers. In either case the material is wholly and immediately soluble in

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* *Versuch Stat.* vi. pp. 40 and 343, viii. p. 337; Johnson, "How Crops Feed," p. 320; Pfeffer, l. c., Bd. I. p. 254.

soil-waters, and the resulting solution becomes so concentrated as to prevent, or check, the process of water-diffusion in the root. The plant wilts, and if dilution of the solution does not soon come to the relief, and effect a renewal of the water-circulation, loss of the crop must follow.

THE ABSORPTION OF NUTRITIVE MATTER BY THE SOIL is a phenomenon of universal occurrence and widest significance, as influencing the conditions of vegetable growth. Its manifestation is among the most common processes of nature; yet not till within the present half-century was it fully recognized or appreciated in its bearings on plant-nutrition. Solutions of either organic or inorganic matter are universally known to lose a part of their solid constituents on passing through any considerable quantity of soil. So great is this absorptive power, and so well recognized is its efficacy, that wells are dug in close proximity to foul waters with little fear of contamination;* and sand is often resorted to as a filter for removing organic impurities from potable waters.†

The nature or cause of this characteristic of the soil is clearly of two kinds. First, as the result of physical action or surface-attraction between particles. Second, and far more important and far-reaching, is the exertion of chemical affinity between soil-constituents and ingredients of the solution acted on, whereby new combinations are the result, and a transfer of acids and bases occurs between soil and solution.

Though every soil, even quartz-sand, is known to possess this absorptive property in greater or less degree, the power is limited, and ceases altogether in time, showing that *saturation* occurs. This condition is naturally reached sooner with some materials than with others; hence the absorptive power of soils is exceedingly variable, depending on composition of soil and of solution acted upon, and consequent possibility of chemical transformation and recombination.

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* The author is not discussing *hygiene*, but *soil-chemistry*.

† The extent of this absorptive property is readily manifest by passing a solution of some organic coloring matter through a funnel of soil, when a colorless liquid will be obtained.

The actual absorptive power of the soil for different nutrients is evidenced by the experiment of Voelcker, who subjected 4000 parts of manure diluted with an equal weight of water to the action of 300 parts of arable soil. The results show the total absorption of different ingredients in 1 gallon (7000 grains) of solution.

	Before mixing with earth.		After mixing with earth.	
Ammonia	19.68	grains.	6.91	grains.
Organic matter	184.05	"	118.50	"
Silica	0.75	"	2.38	"
Phosphates of lime and iron	7.90	"	1.54	"
Calcium carbonate	17.46	"	79.72	"
Calcium sulphate	2.18	"	7.92	"
Carbonate of magnesia	12.83	"	6.16	"
Sodium chloride	22.85	"	18.90	"
Potassium chloride	35.25	"	26.44	"
Potassium carbonate	85.27	"	4.29	"
	338.22	"	282.76	"

It therefore appears that the soil experimented with absorbed 105.46 grains from 1 gallon of the solution; equivalent to 27.16% of the total of solid matter present.

The results of the most recent and comprehensive investigations of soil-absorption may be summarized as follows:*

The nutrients ammonia, potash, soda, lime and magnesia are absorbed; while silica, phosphoric, hydrochloric, sulphuric and nitric acids are not to any considerable degree absorbed. The absorptive power as related to the nutrients potash, ammonia and phosphoric acid is especially important inasmuch as these supply the plant with the three indispensable elements nitrogen, potassium and phosphorus; and, moreover, each of them is not only acted upon in a different way, but in each case the cause of the action differs.

PHOSPHORIC ACID becomes absorbed simply because it combines with soil bases to form phosphates of alkaline earths and

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* Complete reviews of the subject of soil-absorption, with the literature of the subject, may be found in Knop's *Die Bonitirung d. Akererde* (Leipzig, 1872), and in Mayer's *Agricultur Chem.*, Bd. II. pp. 73–113.

metals; compounds insoluble in water, and, therefore, not taken from the soil by the percolating waters. Superphosphate applied to the soil as fertilizer soon combines with soil bases to form calcium, magnesium, iron and aluminium phosphates. And in time the acid leaves its lime and magnesia combinations, and unites wholly with the iron and alumina, perfectly insoluble, and consequently totally absorbed or retained by the soil. The carbonate constituents of the soil increase phosphoric-acid absorption by transposition and conversion into phosphates, chiefly of lime and magnesia, whereby the acid becomes absorbed as a soil-constituent. Gypsum, in like manner, gives up its lime for combination with the phosphoric acid, the sulphuric acid being set free. In each case, the absorption is the result of definite chemical action.

POTASSIUM, without doubt, passes from either the hydrate or carbonate form directly into the soil as a component part of the latter; and although the strongest mineral acids exist in most soils, their combination with potash seems a secondary occurrence; and Knop consequently ascribes to the soil a "power of dissociation," resulting in the separation of bases from acids, followed by new combinations. The maximum quantity of potassium compounds appears to be absorbed in the presence of hydrous silicates, with hydrated iron and aluminium oxides, amorphous silica, sand, and iron and alumi-phosphates. On the other hand, little or no potash seems absorbed by hydrous iron or alumina oxides when existing alone, nor by the salts of the humus acids, and carbonates of lime and magnesia.

AMMONIA combines with, or is absorbed by, phosphate of magnesia, hydrated magnesia and iron oxides; while the humus acids unite with great readiness with ammonia, to hold it combined in the soil.

It will thus be noticed that potassium and ammonia are acted on by nearly the same factors, and become absorbed by approximately identical soil-constituents.

The practical developments of the phenomena of soil-absorption as recorded by Knop are these:

Soils possessing absorptive powers from

0 — 1 are wholly sterile;
8 — 10 are poor;
15 are good;
20 — 25 are fruitful;
50 — 100 are fertile.

The figures indicate the volume of nitrogen gas obtained from the absorbed ammonia; and some soils yield even a higher ratio than here recorded, 135 being the proportion for Nile mud.

THE ABSORPTION OF GASES has already been mentioned (pp. 191–193), where we found that the air of the soil varies materially in composition from the atmospheric air; a condition due, in considerable extent, to the fact of condensation within the soil. The amount of average condensation as determined for different soils being as follows:*

	Sand.	Clay.
100 grammes of soil yield cubic centimetres of gas....	29.4	32.2
The gas consists of—		
Carbonic acid..	16.5	26.4
Oxygen..	15	13.3
Nitrogen..	68.5	60.3
Ratio of oxygen to nitrogen =	1 : 4.61	: 4.5

The results here presented may be thus generalized: carbonic acid, though occasionally absent, is, as a rule, present in large quantities in the absorbed gases. Oxygen exists in small quantities, or is wholly absent. Nitrogen is absorbed in greater proportion than it exists in the atmosphere, and in certain soils, particularly peat, is greatly condensed. Moisture increases the ratio of nitrogen and oxygen in the absorbed gases. Decomposing organic matter in the soil tends to reduce carbonic acid to carbon monoxide. The carbonic-acid content of the soil is increased by the presence of iron oxyhydrate; sunshine and elevation of temperature expel it; consequently the quantity present is greater at night than during the day. Moisture tends to retain soil carbonic acid.

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* Gohren, loc. cit. p. 117.

Especially important among the phenomena of gas-absorption is the fact that iron oxide exerts an absorptive influence upon atmospheric ammonia, absorbing it in considerable quantities, as evidenced by the following comparison of the absorptive properties of different soils toward atmospheric ammonia:

Kind of Soil.	Lbs. of Nitrogen in form of ammonia per acre.
Quartz and 5% ulmin	46.041
Quartz and 3% ulmin	24.300
Quartz and 1% ulmin	7.008
Ulmin	6.494
Iron oxide	12.495
Carbonate of lime	3.286
Gypsum	0.295
Quartz	1.619

It therefore appears that the absorptive power of soils for gases results not only in the retention of chemically active agents in the soil, but in the actual absorption of plant-nutriment from the air.

THE ULTIMATE RESULTS OF THE ABSORPTIVE PROPERTY OF SOILS as demonstrated by the facts reviewed are these: The fixation is neither absolute nor lasting from any soil-solution; a portion of the bases absorbed by the soil remains still soluble in water, and enters into the soil-solutions, passing into the drainage-water, or being utilized by the plant.

The composition of soil-waters is regulated or determined by the absorptive property.

Essential constituents of plant-food are retained in the soil in forms accessible to the plant.

Numerous important nutritive substances are converted into comparatively insoluble, but chemically and mechanically accessible, forms.

The two least abundant and therefore most important mineral ingredients of soils, potash and phosphoric acid, if set free from rock-compounds, and entering the soil as phosphate of potash, would, being soluble, be rapidly removed from the agricultural soil by percolating waters, were they not recombined with other soil-constituents, and fixed in forms available as plant-food, yet not soluble in rain-waters and removed; neither being so soluble as to accumulate to the detriment of the plant.

It appears, therefore, that the soil not only contains exhaustless stores of most vegetable nutrients, but is, moreover, endowed with a property which counteracts the wasting tendencies of disintegration and nitrification, thus conserving its own resources, and husbanding the soluble materials of artificial nutriment as permanent supplies of plant-food.

SOIL-EXHAUSTION.

The soil, consisting, as it does, of the elements of plant-growth, however diverse and manifold may be the relations existing between it and the plant grown upon it, is, so far as the farmer is concerned, the raw material which it is the end of his endeavor and labor to convert into either plant or animal organisms. Husbandry is in reality, then, merely the husbanding of the soil resources, and converting them at least expense into the most valuable ultimate or marketable form. Could this end be continuously attained from soil-ingredients, the acme of agricultural success is gained. The exhaustion of the soil is, therefore, simply the exhaustion or loss of resources; and the prevention of this deterioration is the aim of all scientific or intelligent agriculture.

Though the soil as consisting of plant-food may be disregarded, and may be considered as merely the receptacle of so much fertilizer which as raw material is by natural force to be converted into manufactured products or crops, agricultural methods conducted on such principles are subjected to the disadvantage of neglect of the natural conditions or resources of the soil; and, therefore, fail of securing the desideratum of agriculture, as of every industry, the most economical utilization of the cheapest or naturally available materials.

Soil-exhaustion is, moreover, a relative term, being applicable to a given soil for a certain crop, though a change of crops would develop latent or unexhausted soil-resources, and an available reserve of fertility; a principle forming the basis of all the numerous systems of rotation.

THE MAINTENANCE OF SOIL-FERTILITY, though a most intricate and involved subject as related to farm economy, is fundamentally based on the simple fact already stated, that the exhaustion process begins when the crop removes a greater quantity of nutriment than is returned to it before the growth of the succeeding crop begins. Maintenance of fertility continues just so long as the annual depletion through plant-growth is returned in available form.

Chemical analysis of the crop offers the most rational basis for the maintenance of this fertility, by showing the actual quantity of nutriment removed from the soil, and thus showing the actual material necessarily returned to prevent deterioration.

The once much-lauded soil-analysis proposed by Liebig as furnishing the data for successfully withstanding the effects of cropping, and for maintaining the fertility, is no longer of even theoretical value, offering the insurmountable difficulties of constant variation in composition, and never showing the *ultimate available fertility* present in any given soil.

In considering the needs of a given crop under any circumstances of growth, and the maintenance of the soil in a state of fertility equal to the demands of the plant, the fact must be constantly recalled that the fertility of the soil, its ability to nourish and sustain plant-life, extends just so far as does the minimum quantity of any food-essential present.

When the resources of the soil have been exhausted toward any one ingredient of the crop, the ability of the soil to produce that crop is at an end; and further development of the plant is impossible however abundant may be the other resources of the soil.

The plant can make no substance from nothing, or without a sufficient supply of each and every one of all the essential ingredients of its composition.

This fact applied in practice, and not only does the maintenance of soil-fertility necessarily follow, but, as a natural and inevitable result, the cultivator is enriched by increase in soil-productiveness, and the conversion of inert mineral matter and free atmospheric material into organic matter endowed with life, as the result of his husbanding of soil-resources.

CHAPTER V.

USE OF THE SOIL.

THE foregoing chapters are devoted primarily to a consideration of the properties of soils. Origin, composition, and the various characteristics discussed are but the elaboration essential to a presentation of the conditions influencing or controlling soil-properties.

Knowledge of these principles leads to an increased facility in their application and their more successful utilization. Intelligent use of the soil is not only based on the action of the laws involved, but is also the object of their consideration.

The use of the soil, therefore, involves the application of the principles heretofore presented. Cultivation, or the production of crops, is the use for which the soil was intended, and is the natural subject of this chapter.

The special treatment of any particular crop or crops cannot be attempted; but cultivation in general, as a practice based on theory, offers a natural and important field for consideration.

Though the soil is the natural habitat or place of growth for the plant, besides being the great storehouse for the elaboration and conservation for plant-food, it is, more than all else, from the practical standpoint of farm-management the investment or material to be utilized for the production of crops, or raw material to be so utilized or manipulated by the cultivator as to be most quickly and economically transformed into finished products. In the care and management of this investment, as with any other, success is to be achieved only by conserving, husbanding, and intelligently utilizing. All systems of rotation, fertilizing, fallowing, draining, or in other way ameliorating soil-condition, are but systems for conserving the investment, means based on the laws involved in using the soil to the best advantage by increasing or perpetuating its productiveness.

Maximum production without diminishing future productiveness, the largest possible crops without exhaustion of soil-fertility, is the object aimed at. The application of the principles tending toward that end will now be considered, the familiar processes followed in crop-production being discussed in their relations to the scientific facts on which rational soil-cultivation rests.

PREPARING THE SOIL FOR THE CROP.

If preparation of the soil is the first step toward crop-growing, the old adage is nowhere more applicable than here, for certainly with soil well prepared for the crop efforts toward production are "well begun," and thus more than "half done." Irrespective of what crop may be contemplated, thorough preparation is the first and most essential element toward success; too much care or attention on this point is hardly possible, and thorough pulverization is the prerequisite for proper preparation.

Among implements of tillage the plow of course stands first, both in importance and historical interest, and has been appropriately accepted as the emblem of agriculture. The degree of perfection in the plow is an unfailing indicator of the condition of the agriculture of the locality or nation using it.

Strictly speaking, this implement is not a pulverizer, but prepares the soil for the pulverizing to follow. The plow is so devised as to utilize the principle of both the screw and the wedge for lifting and inverting a strip of the surface-soil without materially disturbing its particles. Not that the latter condition is sought or desired, but the force exerted in separating the furrow-slice and inverting it necessarily results in more or less compacting both it and the plow-pan underneath. The degree to which this effect is produced depends naturally on the ease with which the furrow is turned: the less the force necessarily exerted the greater the degree of pulverization produced by turning the furrow; and with soils already in a mellow condition the plow itself becomes a real and effective pulverizer.

For the reasons stated, and others to be considered, the plow does not perform the duty frequently expected of it, and certainly not all that has long been hoped for. So far as the character of the work done is concerned, the spade is a far more effective implement, though its slowness and cost of use preclude recourse to the hand implement, and all attempts at the production of a spading-machine as generally applicable as the hand tool or the plow have been unsuccessful.

An inevitable result of the construction of the plow renders its use on many soils conducive toward a condition eventually serious. The pressure exerted in lifting the furrow-slice necessarily impacts the bottom of the furrow. If nearly the same depth of furrow is turned through several successive years, a hard, nearly solid, and impervious "plow-pan" or stratum results, frequently to the detriment of the crop. This hard layer is not only sometimes impassable to roots, and the crop is thus cut off from its supply of food and moisture, but the hard stratum is so nearly impervious to moisture that excess of rain is prevented from freely draining away, and the surface-soil becomes so surcharged with moisture as to seriously injure the crop. On the other hand, in times of drought, this same impassable layer prevents the natural free movement of subterranean waters to the surface by capillary action; the surface soil, above the interposed impeding layer, becomes dried by evaporation and transpiration, and serious consequences follow.

These conditions explain what have frequently been grave puzzles in crop-puoduction. The remedy is self-suggesting. By changing the depth of plowing, especially by a constant though gradual deepening of the arable soil, the formation of this "plow-pan" is prevented. If once formed, however, subsoiling by breaking the compact layer removes the difficulty. The occasional exceptionally satisfactory results of subsoiling are thus explained. The growing of root-crops tends toward accomplishing the same result.

The pulverization is at best only begun with the plow, and must be continued with harrow, drag, roll, and other implements adapted to the soil and the particular crop to be grown thereon. With any and all subsequent implements of tillage there may occur a difficulty similar, though less in degree, to that described as to be guarded against with the plow. The weight of the implement tends to press down and impact the lower stratum while pulverizing the surface actually in contact with the implement. So long as mere pulverization of the soil is the end in view, this effect is doubtless occasionally injurious; but it probably is not infrequently without compensating results, inasmuch as a moderate solidification of the under stratum facilitates the upward movement of soil-waters, while thorough pulverizing of the very surface conserves the moisture and retains accessible to the crop most of that finding its way upwards.

This matter will be discussed more fully farther on.

There is no question but that all cultivated crops thrive in proportion to the fineness of the soil on which they grow, so that so far as mere crop-growth is concerned the degree of pulverization can never be excessive. It is obvious, however, that the increased productiveness of a given soil resulting from its special degree of pulverization may not suffice to justify the expense of the exceptional state of fineness attained. There is therefore a practical limit beyond which artificial pulverization of a given soil for any one crop may not reasonably extend. This point varies with every given field and the particular crop to be grown thereon.

The object of pulverization must here be recalled. Though, fundamentally, the soil is broken or the stubble turned that the crop may be more readily introduced to the soil, still without a certain degree of mellowness the crop, even could it once gain a footing, would show but meagre and unsatisfactory growth.

The reasons are chiefly two: First, the compactness of the soil would admit of but slight root-development, and consequently deficient food-absorption. Second, crop-production being dependent on life-function, and all life dependent on air or its essential oxygen, a compact soil, which is an *unaerated* soil, is but imperfectly able to sustain life and its attendant crop-growth.

This second condition is more far-reaching and important than the first, because all food-formation or assimilation in the soil is the result of, and depends on, chemical action, the prime factors with which are atmospheric oxygen and soil-moisture. All chemical action, or mere solution, is *proportional to the surface exposed to action.* The finer the state of division of the soil-particles the greater the surface exposed to action ; consequently the greater the amount of air permeating the soil the greater the quantity of water acting on it, the greater the amount of plant-food prepared in the soil and the greater the quantity actually assimilated by the plant, and the larger the yield of crop.

The fineness of division here considered must be understood as referring simply to the mellowness or separation of soil-particles and not to the fineness of, or size of, the individual particles themselves, which is a wholly different matter. There seems to be a definite relation between soil-productiveness and the fineness of the particles composing the soil-mass. Prof. Whitney of Maryland has attempted to arrange soils into definite types based on this fact, referring each type to the crop to which practice shows it to be specially adapted. He fixes the minimum and maximum degrees of fineness, or number of soil-particles per gram of soil, at one billion seven hundred thousand and twenty-four billion grains or particles, respectively, and designates these two soils as "pine-barrens" and "mountain pasture," referring to the typical natural products of the soils thus characterized.*

The gradations based on this principle of fineness or number or particles per gram of soil would be as follows:

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* Maryland Experiment Station Report, 1891.

1,700,000,000 grains, minimum fineness of agricultural soils;
6,800,000,000 grains, sandy soils, garden-truck soils;
8,000,000,000 grains, tobacco soils;
10,000,000,000 grains, wheat soils;
24,000,000,000 grains, maximum fineness for agricultural soils.

THE SUPPLY OF PLANT-FOOD is essentially part of the process of preparing the soil for the crop it is to grow, and a most important element in determining the results of the entire undertaking, since without a sufficient supply of available nutriment all other advantages must prove of little avail. The food-requirements of a given soil depend almost entirely on the particular crop to be grown thereon, since both soils and crops vary so materially in composition, that a soil wholly deficient in the requisites for the growth on a certain crop may be abundantly supplied with the necessities for the production of a different crop.

It must therefore be remembered that, strictly speaking, *soils* have no food requirements, but the requirements of the *crop* in question form the all-important problem on the solution of which successful production chiefly depends.

Most soils are in a sufficiently fertile condition, that is, contain a sufficient quantity of available plant-food, to render the growth and maturity of a fair crop of any kind reasonably sure under normal climatic conditions.

The fertilizer or plant-food question is therefore seldom one of *assuring* productiveness, but rather of *increasing* productiveness—the securing of larger crops on a given area. The end may be achieved through two different means: either by increasing the total quantity of available plant-food, or by correcting the composition of the soil by changing the relative proportions of food-ingredients required by the crop to be grown, and thus securing a *properly-balanced* food-supply to best meet the conditions of growth for any given crop. Barnyard manure and complete chemical fertilizers are the best illustrations of the former procedure and the plowing under of leguminous crops, supplying excess of nitrogen, and the application of phosphates to make good the depletion in phosphoric acid caused by successive grain-cropping, are common practices illustrating the latter method.

The problem of maintaining or restoring soil fertility will be considered later; only the questions *what* and *when* plant-food should be supplied to the soil as a step in its preparation for the crop demand attention here.

Two elements enter into the rational solution of this question—the crop to be grown and the soil which is to produce the same. Only such principles as may be of general use will be discussed, and the inter-relations between the *what* and the *when* are so close that both considerations naturally unite to form a single problem. For instance, if nitrate of soda, furnishing nitrogen in soluble, easily elusive form, be the *what*, the time of application as near the time when actually required by the growing crop is the *when;* and if Fall application is the *when*, nitrogen in comparatively insoluble form, tankage or cotton-seed meal is the *what*. There are no sufficiently unvarying data or facts on which application to all soils for all crops may be based, nor even with invariable results for any particular crop. These are, however, principles sufficiently well established to offer basis for general practice. In this matter the crop to be grown should be the controlling factor rather than the soil on which it is to be raised. *In the problem of the rational application of plant-food the soil has received relatively too much and the plant too little consideration.*

We know the normal food-requirements of every agricultural plant, while it is doubtful if a half-century of study has yet positively determined the food-requirements of the Rothamstead soils for the most economical production of any particular crop. *How much less can any one claim to have established the actual and invariable food-requirements or nutritive idiosyncrasies of any other soil!*

Soil-analysis is still clung to by some cultivators, and others who should be better informed, as offering the longed-for missing knowledge. All other obstacles aside, however, the inability of the soil-analysis to show the amount or character of the food-constituents of any soil except at the time the sample is taken, and thus the kind and quantity of nutriment available to the plant during its entire period of growth, remain hopelessly enigmatical.

For several years many of our experiment-stations, largely under the instigation of the Department of Agriculture, have been indulging in "soil-tests," "plat experiments," and "co-operative experiments," with little actual benefit so far as the enunciation of any law or principle furnishing reasonable basis for a solution of the problem of rational fertilization, or even means for definitely solving the problem for any particular locality.

The fact still remains that the plant or crop to be grown on a given soil furnishes the most satisfactory basis for settling the question of the plant-food to be applied; and scientific workers as well as farmers are recognizing the significance of the fact, and not only shaping their investigations but their farm practice, also, in harmony with this principle.

The composition and habits of growth form the most nearly fixed factors for determination of the food-requirements of any given crop, and analysis of the crop in question, or rather the average composition established by numerous analyses, the basis for rational fertilization. By this means the crop, being supplied with the materials of which it is composed and in the proportion found in the crop itself, must of necessity be provided with food-essentials required for its growth. True there may be cases where one or more elements of fertility are present in available form in excess of the requirements of a given crop, and the artificial supply of such material as fertilizers seems uncalled-for and wasteful; still, if the food is supplied as fertilizer it is not extracted from the reserve supply in the soil, and thus soil-exhaustion is rendered impossible. On the other hand, the moment the crop begins to draw upon the elaborated food-supply of the soil in excess of the annual recuperative force of the soil itself or the additions of fertility artificially made, soil deterioration and exhaustion begin. A material step forward in the predetermination of the fertilizing requirements of crops and soils has been made in Helmkampf's suggestion.*

Plant-analysis is the basis of the method proposed, but under new conditions. Crops grown with additions of the different elements of fertility are subjected to analysis, and these analyses compared with those of the same crop grown without such treatment. If the proportion of any ingredient in the plant is found to have been increased by the addition of that ingredient to the soil, the fact is accepted as evidence of the necessity for such artificial fertilizing. On the other hand, whenever analysis shows no increase in any crop constituent through the addition of such constituent to the soil, the crop-requirements toward that element are satisfied, and its use as fertilizer not required.

As a method for guidance in regular farm practice, however, the average composition of the crop in question as established by analyses, modified by the known habits of growth of the crop to be grown, remain the most definite and satisfactory basis for controlling the practice of fertilizer-supply. The point of habits of growth and the modifying influence thus exerted on the matter of food-supply as indicated by analysis is best illustrated by the well-known relation existing between leguminous plants and nitrogen-assimilation. *Analysis* shows a certain amount of nitrogen present, and thus indicated as required by a given crop; its *habit of growth*, however, enables it to extract much of this nitrogen from the atmosphere, and the quantity required to be artificially supplied is therefore reduced below the analytical quantity indicated. Of similar importance is the fact that in normal soils the elaboration of plant-food is a constant process; so that however low a state of fertility or productiveness a soil may have reached, it is capable of supplying some plant-food, and thus growing some kind of crop.

It is never necessary, therefore, to supply by application all the fertility or food required by any crop. The application

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* Centralblatt für Agriculturchemie, 20, p. 826.

should be based on the amount or degree of fertility possessed by the soil; and the artificial supply be made in the proportion that the available supply of fertility in the soil bears to the amount of such material contained in a normal crop, or such a crop as it is desired to produce.

To illustrate: If the soil has shown its capacity to produce, unaided by fertilizers, one half of a normal crop, or such a crop as is reasonably desired, the application of fertilizer should be in the proportion the natural crop is to the desired crop, namely, one half the material shown by analysis to be contained in the normal crop, or quantity of crop desired, when unmodified by peculiarities of growth, as already explained.

The tables in the Appendix, giving the quantities of fertilizing materials removed from the soil by all the different farm crops, and the composition of the important American fertilizing materials, furnish the data, enabling any one to determine these matters with scientific accuracy. It must not be forgotten that in this discussion though the terms "composition" and "ingredients" are used they refer to the essentials of fertility known to require artificial replenishing in all normal soils after continuous cropping, namely, nitrogen, potash, and phosphoric acid.

THE FORM OF MATERIAL IN WHICH PLANT-FOOD IS SUPPLIED is a matter of comparatively little importance, provided only that it is, within reasonable limits, *available;* that is, accessible to the crop when required. The important consideration, after availability has been disposed of, in determining the question of form of supply, is *market value* of the raw material to furnish the nutriment required; and locality will be the controlling factor in determining this point. To illustrate: In the Southern States cotton-seed meal will furnish a given quantity of nitrogen cheaper than any other form of supply, and for many crops equally available with other sources.

In this connection it is perhaps well to notice a prejudice quite commonly prevalent against certain forms of food-supply as against others, this being particularly marked in the case of phosphoric acid. Farmers naturally became familiar with bone as a source of this essential before other forms of supply were known, and now commonly entertain the belief that Thomas' slag and Carolina rock are only substitutes or even adulterants of less actual plant-food value than the original bone. Unquestionably raw bone or bone-meal furnishes insoluble phosphoric acid more readily converted into plant-food than is the case with either other raw material. But all Carolina phosphate and other mineral phosphates are sold on their content of *available* phosphoric acid; the greater part of all manurial bone products are similarly placed on the market. *Available* phosphoric acid is *available* irrespective of its source. A given quantity or percentage of *soluble* or *available* plant-food is equally valuable whether it was obtained from bones, Carolina rock, Thomas' slag, or apatite.

The determining factor, therefore, in selecting a given food-supply is not *origin*, but *cost* of the actual food contained therein. To illustrate: Dissolved bone-black and dissolved South Carolina rock-phosphate are two common forms of manurial phosphoric acid. The *quality* of the actual plant-food furnished by the two forms is identical, yet at recent market prices the available phosphoric acid in the bone-black cost 8 cents per pound, while the Carolina rock furnished the same material at 6 cents per pound. What is true of phosphoric acid is equally applicable to other plant-foods, particularly potash, where the difference in market value between sulphate and muriate is frequently great, even with the same proportions of actual potash present, which for most crops is equally valuable as plant-food irrespective of source.

The price per ton of fertilizing materials and the origin of the same are no indication of the economy of purchase. *The cost per pound of the available plant-food known to be present should be the basis for determining the real or relative value of fertilizing materials.*

FARM MANURES are subject to the same principles applying to chemical fertilizers, but with the very material practical difference that they are most commonly made on the farm where used instead of being procured from an outside source. Stable manure is the natural restorer of lost fertility, being the very material removed from the soil whose loss must be replaced if deterioration is to be prevented. As such its production is the corner-stone of all successful farming; and other sources of plant-food are simply substitutes for manure, the production of which should be fostered and increased by all the means at hand or available. Modern farming, however, renders the sale of a large part of the products of the farm without the intervention of animal feeding imperative, and thus causes an inevitable loss of fertility removed as crop, but not returned to the soil as manure. Even when the crops grown on the farm are all fed there and the manure so produced returned to the soil, the sale of the animals themselves or their products necessarily removes from the farm fertility not retained as manure; and to maintain the soil without deterioration this abstracted material or lost fertility must be returned in the form of plant-food obtained from outside sources. The purchase of manure or fertilizers direct, or the feeding of materials not produced on the farm, but grown on some one else' soil, are the two most effective methods for the maintenance of soil-fertility. Fallowing, which is self-recuperation, and green manuring are also means toward the same end, but will be considered elsewhere as not directly related to the subject of preparation of the soil for the crop.

After all rational means have been adopted, there is in our farming, as a whole, an enormous discrepancy between farm supply and farm demand for fertilizing materials. The question of whence shall this demand be supplied is a vital one. Two available solutions to the problem present themselves in most communities, with relative merits varying with localities. These are *commercial fertilizers* and purchased *stable or stock-yard manure.* The latter could not begin to meet the demand were it our sole source of supply of fertilizing materials. When available, however, the extent to which it may be economically utilized in face of commercial-fertilizer competition is a most important problem.

Plant-food is what we seek to replenish our soils. *The cost* *of the actual fertility obtained must be the basis on which the final selection* should be made, though modifying conditions will call for consideration.

In the manufacture of sugar saccharine matter is the substance sought. *Sugar is sugar*, and the refiner cares little whether the beet or the cane elaborated his raw material. The proportion of crystallizable sucrose or *available sugar* present determines the economy of use. The farmer requires available nitrogen, potash, and phosphoric acid. The proportion of available plant-food present in the raw material offered for selection should determine his action; it matters little whether stock-yard manure, cotton-seed meal, or a commercial fertilizer chances to be the raw material used.

The following proportions and value of the actual elements of fertility contained in the excrement of various farm animals will furnish data for comparisons necessary to the solution of this problem:

VALUE OF MANURE PRODUCED BY FARM ANIMALS.*

Animals.	Food.	Amount of manure daily.	Value of Manure.		
			Per ton.	Per animal, daily.	Per 1000 lbs. live weight, value per yr.
Cows	Hay, silage, beets, bran, corn, cotton-seed meal	81.5	$2.37	$0.093	$19.12
Work-horses	Hay, oats	52.5	2.79	0.073	29.82
Sheep	Grain, beets, hay	7.2	4.19	0.015	38.55
Swine	Corn-meal, flesh	3.5	3.18	0.006	17.11

The value placed on the manure in the table is, of course, estimated and not necessarily its actual value as plant-food. This is, however, invariably the case with the so-called "commercial values" given fertilizing materials. These trade values of course vary somewhat with the condition of the market. They are, however, definite, inasmuch as they show the *actual cost* of the materials if purchased in the market. So in the table the comparisons are accurate, and the different fertilizing

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* Cornell Experiment Station Bulletin 27. These values make no allowance for loss by waste.

constituents of manures would have cost the amounts stated had the same materials been purchased in the form of commercial fertilizers instead of being furnished in the manures made.

Reference to the table shows that the average value of mixed horse and cow manure, which may be taken as a fair basis for comparison, is $2.58 per ton. The weight of manures made and kept under different conditions varies far more widely even than its composition, so that no standard can be satisfactorily adopted. But the weight per cord or load of any manure in question can be readily determined at any time, and this factor, with the data in the above table, also by reference to the complete tables in the Appendix, will enable any one interested to determine for himself the probable actual fertilizing value of any particular lot of manure in question.

Facts, however, justify the assertion that it is extremely doubtful economy to purchase common stable or yard manure at its usual market price and then haul the same any considerable distance for application, when the actual plant-food contained in the manure is the only reason for its use or value. This statement, it must be borne in mind, is based on the comparative average cost of manure and of other fertilizing materials. The relative cost of plant-food in the form of manure is still more enhanced by the materially greater expense for handling and applying.

In this connection, however, a complete presentation of the subject cannot fail to take cognizance of the fact that manure is not always used solely for the actual fertility contained therein, but that it possesses other features sometimes equally important and desirable.

THE PHYSICAL ACTION OF MANURE on the soil is not infrequently of vital importance; indeed, on many soils its value is chiefly the result of such action. The case is well stated as follows:

" The value of barn-yard manure depends not so much upon the actual amounts of the essential elements of plant-food, since analysis shows these to be comparatively small, as upon its effect upon the physical qualities of the soil. It not only improves the mechanical conditions of both light and heavy soil, but it induces fermentative changes in the soil which render available latent plant-food and promotes the capillary flow of soil-water toward the surface, thus augmenting both the supply of water and plant-food."*

It is unquestionably the humus content of manure which exerts this action, since humus is not only a powerful absorbent of both water and gases, but its decomposition liberates humic and ulmic acids, combining with insoluble soil constituents to make soluble ones. This absorptive power renders dry soils more moist; and the opposite effect is produced on wet, heavy soils, which are made more light and porous by the coarse, fibrous parts of the manure.

Admitting these properties of manure and giving them their full importance, the question naturally arises: to how great an extent does manure thus become indispensable? A positive and definite reply is impossible; but it must be remembered that these properties of manure are not peculiarities of manure alone, but pertain to all animal and vegetable substances undergoing decomposition.

It is admitted by all that the actual plant-food contained in manure does not render it an economical fertilizer when purchased in competition with commercial fertilizers. Most soils are sufficiently equipped with humus to keep the soil "in heart" and withstand all legitimate drafts upon it for an indefinite period under any rational system of care and cropping, even though the drain on its resources be maintained by applications of mineral fertilizers exclusively. This assertion will be more readily accepted when it is recalled that humus is not itself plant-food and is transformed into plant-food by nitrification only very slowly, so that there is little drain on it as a feeder for the crop. It must also be remembered that the very process of crop production is necessarily a humus former, the roots and other unremoved portions of the plants being important sources of humification with some crops, clover particularly,

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* Wisconsin Experiment Station Report, 1891, p. 111.

the humus content of the soil being increased even by the *growth and removal* of the crop.

In addition to these considerations is the fact that a very large proportion of our commercial fertilizers consist of or contain ingredients little if any less important or potent as humus formers than manure itself, cotton-seed meal, tankage, dried blood, and fish pomace being good illustrations.

When it is further considered that most present systems of rotation include the occasional plowing under of a green crop equal in humifying action to a heavy dressing of manure, it must be admitted that applications of manure need not be made simply because of their humus content or action, and that the same end can be attained whenever desired in conjunction with a more economical source of actual plant-food.

This matter has been considered at length, because of the prevalent belief among many farmers that though fertilizers are cheaper than manure so far as the supply of fertility is concerned, manure must be occasionally resorted to, even if necessarily purchased at above its plant-food value, for its needed physical action or humus supply required to keep the soil in heart. Sand and clay soils are most in need of this action, and with these manure is not indispensable to the highest success. With other soils and rational cropping it is doubtful if humus need ever be artificially looked after if the available supply of *fertility* is maintained.

THE TIME AND METHOD OF APPLYING MANURES AND FERTILIZERS are of vital significance in their influence on results.

The character and composition of the material to be applied must control the practice. Nitrogen is the ingredient offering opportunity for error, especially in the time of applying, its solubility and volatility in all manurial forms rendering it extremely unstable. Manure as such is not available to the crop; it must first undergo decomposition that its fertilizing constituents may become available. Decomposition, however, is inevitably accompanied by loss; this change should, whenever possible, be made to occur in the soil after application, not in the pile before. Reason and successful practice therefore dictate that manure be applied to the soil as soon as possible after being made, and incorporated with the soil as soon as practicable, although certain experiments indicate that this latter consideration is of minor importance.* When immediate application is impossible, storage under cover and composting with muck, or sprinkling with plaster or kainit to prevent the escape of ammonia, should be insisted on. Exclusion of air by treading and moistening also aid in preventing waste. Superphosphate also acts like the other two preservers, its sulphuric acid combining with the escaping ammonia to form non-volatile sulphate of ammonia.

The loss in fertilizing value by allowing the manure to remain unprotected in the common pile during the summer frequently amounts to more than *one half* the actual plant-food originally present. This fact must be remembered in connection with any estimation of the real value of the manure from any animals based on the total manurial content of all the excrement made.

Fertilizers of organic origin, animal or vegetable waste, may be applied like manure with little fear of loss, even though the total nitrogenous matter present be in excess of the immediate requirements or assimilative power of the crop. Indeed some such materials showing a high analytical content of nitrogen are practically worthless as plant-food, the nitrogen being present as *combined* nitrogen and *not available,*—leather, hair, horn, and hoof-parings being good illustrations of such worthless materials, not infrequently incorporated with low-priced fertilizers to give them an apparent value in excess of their real worth, and incapable of positive detection by any method of analysis.

Plants utilize nitrogen almost exclusively in the form of nitric acid present as nitrates. Organic nitrogen first undergoes decomposition, or putrefaction, resulting in ammonia formation. This process is comparatively slow, and the ammonia produced is either absorbed by the soil, "which has a wonder-

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* New Hampshire Experiment Station Bulletin No. 6.

fully retentive power for ammonia,"[*] or combined with acids to form salts of ammonia. In either form ammonia is rarely found in drainage-waters, but the loss is almost wholly of nitrates.[†]

The nitric acid of these nitrates is the final product actually utilized by the plant as food. It is formed by the process of nitrification acting on the ammonia compound.[‡] These facts make it apparent that nitrogenous fertilizers applied to the soil at such time or in such quantity that nitrogen formation is not in excess of the immediate assimilative power of the crop is practically free from the possibility of waste through leaching; and since nitrogen formation is practically at a standstill except during warm weather, fall, winter, or early spring, applications of any nitrogenous manures except such as actually contain nitrates may be made with impunity. Nitrates, of which nitrate of soda (Chile saltpetre) is the only one commercially important as a fertilizer, being already available as plant-food without further transformation, and for which the soil possesses little absorptive power,[§] are removed from soils in drainage-waters and lost to the crops if present in excess of their immediate needs, and should not be applied in excess of the actual requirements of the growing crop nor long before the crop can utilize the same. The presence of vegetation very greatly increases the retention of nitrates,[‖] and the time of most active growth is the period of greatest nitrogen assimilation and least danger of loss. It is therefore well to make the application of the total intended or required nitrogen at two different times—one when the crop is put in, or in the spring, and the other at the time of maximum growth of the crop in question. The possibilities of loss of this most expensive ingredient of all manures are thus reduced to the minimum.

The conditions here enumerated make one further fact

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[*] Fream, Soils and their Properties, p. 69.

[†] Ann. Agron. 1890, No. 6, p. 250.

[‡] See p. 127

[§] Indiana Experiment Station Bulletin 33.

[‖] Ann. Agron. l. c.

apparent: When nitrates or ammonia salts readily converted into nitrates, sulphate of ammonia being the chief commercial illustration, are applied as fertilizers, most surplus of nitrogen left in the soil in excess of that actually assimilated by the crop during the growing season will pass into the drainage-waters and become lost before the succeeding crop can utilize it, except such as remains behind as combined nitrogen in the roots and other crop residues. With many crops, however, this may be a material addition to the nitrogenous content of the soil.

All soils should be fertilized "broadcast," irrespective of the material used or the crop to be grown. Coarse manures should be plowed under, fine ones and commercial fertilizers harrowed, drilled, or cultivated in, the latter method being to all intents a "broadcast" application in so far as the object is a thorough incorporation of the fertilizer with *all* the surface-soil. Hill and furrow manuring are obsolete, though for a quick start small applications of manure or fertilizer may be made to the drill, row, hill, or furrow in *addition* to the general fertilizing of the entire soil of the field.

AMELIORATION OF THE SOIL, when necessary, must of course precede the application of plant-food for any particular crop, but is, comparatively speaking, so seldom necessary as an actual condition toward crop production that its later consideration seems advisable. The actual reclamation of soils, that is, the creation of arable soils from formations incapable of crop production, should be considered as a distinct subject; and drainage and irrigation, though frequently followed from choice and betterment rather than absolute necessity, will be classed under methods of reclaiming soils.

There are, however, other materials beside fertilizers producing chemical and physical effects on certain soils sufficiently important to demand attention. Lime, chalk, marl, plaster, sand and muck, are the materials resorted to for this purpose. Lime, either caustic or air-slacked, decomposes the organic matter in peat soils and converts combined nitrogen into ammonia available as nutriment; it also neutralizes the organic acids often extremely injurious to vegetation. Chalk, marl, and plaster perform the latter office either directly or indirectly, besides absorbing and fixing ammonia ; they also tend to lighten heavy soils and render them more workable and productive. Sand and muck each improves the physical condition of the other, and also of clay. They are best used as stable absorbents, and applied with the manure.

THE CROP.

The selection and putting in of the crop necessarily depend first on the market to be supplied, since it is useless to grow any crop, however well adapted to its production the soil may be, if the crop when produced cannot be disposed of at a profit.*

The relations between market and crop having been disposed of, those between the soil and the crop demand consideration.

The chemical or nutritive conditions of the soil as related to the crops to be grown are of little importance as compared to physical characteristics, because the former, consisting simply of the state of fertility of the soil or adequacy of available plant-food, are easily controlled at will. Over the physical properties of the soil, however, its lightness, heaviness, wetness, dryness, heat, or cold, the conditions determining natural plant habits and the adaptation of a crop to any given soil are far less susceptible to modification or control. For these reasons the chemical relations of different crops to certain soils may be passed lightly over. It must be borne in mind, nevertheless, that every cultivated plant has its special food requirements based on its own composition ; and these natural relations between the composition of the soil and the composition of the plant to grow thereon should be taken advantage of in the matter of determining crop adaptations when ever possible, even though the maintenance of the necessary relations between the materials existing in the soil and those entering into the formation of the plant and derived

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* Unless the indirect benefits from cultivation are equivalent to the cost of the same.

from the soil may be artificially maintained by rational fertilization.

The special adaptations of blue-grass to lime soils, of celery to muck soils, and of rye to sand are illustrations of the relations existing between many plants and the composition of the soils on which they thrive. Yet even with these crops the typical physical characteristics of such soils are not without bearing on their crop adaptations.

On the other hand, the proverbial preferences of cranberries for peat, melons for sand, and cabbage for loam are evidences of the intimacy existing between crops and the physical character of the soils they prefer.

THE PHYSICAL PROPERTIES OF SOILS AS AFFECTING CROP ADAPTATIONS demand special consideration, since, whatever may be the relations between plant and composition of the soil which produces it, crops possess but little ability to overcome physical disadvantages; and the adaptation of soils to the physical requirements of crops is one of the great problems of modern agriculture, involving as it does the most vital matter of controlling the relations between crop and moisture, and heat.

THE RELATIONS BETWEEN CROP AND MOISTURE are unquestionably the most important factors in controlling results, and over which the farmer exercises least control. Indeed over a large section of our country the problem of water-supply to meet the demands of the growing crop is the one obstacle in the pathway of success. Most farmers would gladly take all chances of frost, insects, disease, and poor markets could they only be assured of an adequate but not excessive supply of moisture during the growing season.

Modern methods of cultivation are increasing the independence of the cultivator on the sufficiency of natural moisture through rainfall. The success of irrigation over large areas where formerly deemed unfeasible is now subject for common recognition, and requires no comment. *Artesian irrigation*, however, is now receiving added attention, and success has been sufficiently frequent to justify great expectations. In the great James River artesian basin of the Dakotas success in securing abundant flow of water at depths from 150 to 1500 feet, with an average of about 600 feet, has been almost invariable. The only question is the adaptability of the water to irrigation purposes, there being wells flowing enormous quantities of water, so strongly saline, however, as to be unfitted for application to crops.

In California, Colorado, and Utah artesian irrigation has proved a success, and in Western Kansas the past season has seen the introduction of secondary artesian irrigation, the water being lifted from 130 to 190 feet by windmills, and with every promise of eventually reclaiming the drought-stricken portions of the State. The number of artesian wells now existing west of the 97th meridian is 13,750, not all of which, however, are or can be utilized for irrigation. The number of acres under ditch in 1891 was 8,026,526.

Sub-irrigation, though possessing certain advantages, particularly in removing alkali from the so-called " alkali soils " and for greenhouse use instead of surface sprinkling, is too expensive to justify general introduction for farm use.

Removal of surplus water is as essential in case of excessive wetness as conservation of moisture is under reverse circumstances, but the details of drainage and its value are too well known to demand detailed consideration here. CONSERVATION OF SOIL WATERS is, however, of such moment and the principles involved still generally so little understood, that their *résumé* here seems appropriate.*

The investigations of Levi Stockbridge in 1878–9 have since then been repeated and amplified by the experiment stations of New York, Missouri, Storrs, Maryland, and Wisconsin, and practically with only confirmatory results.

Soil-moisture is derived practically exclusively from the rainfall, and crops are incapable of absorption of water except by root-action in the soil. The amount of soil-condensation of atmospheric moisture, even when it can occur at all, is slight,

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* See pp. 155–156.

estimated at one fortieth of an inch of water.* Yet soils by evaporation and crops by transpiration are sending enormous quantities of moisture upwards into the dry air constantly all through the growing season.†

It is of importance in this connection to recall that poor soil or imperfectly nourished plants require more moisture and evaporate larger quantities than estimated as pertaining to normal soils and crops, because of the more dilute solution, smaller proportion of plant-food present in such waters, and consequently a larger amount of water is required to convey a given amount of food to the crop.‡

Any and all methods for conserving this moisture during periods of scarcity are therefore of the utmost importance on every farm.

Mulching, or protecting the surface-soil by covering with straw, grass, and similar materials, is a well-established practice, particularly adapted to tree and garden culture, but incapable of application to large farm proceedings. For cultivated-farm crops, however, there is an effective method whereby soil-evaporation may be materially controlled, and hastened or retarded as the necessities of the crop require. The movement of waters within the soil is controlled by two forces—gravity and surface-tension, and the passage is by means of capillary force or through capillary tubes.§ Gravity exerts itself chiefly in the downward passage of rain-water. Surface-tension is the contractive power of the exposed surface, and does not depend so much on the *amount* of surface as on the *kind* of surface acted on. Therefore the porosity or compactness of the soil determined by the mechanical analysis of the soil, which shows the number of soil-particles contained in a given weight of soil, does not offer a definite basis for estimating the rate or relative degree of water movement in the soil. Not the *number* of particles, but the *arrangement* of particles, determines the rapidity of movement. Thus nearly impervious pottery-clay and a good limestone subsoil may show identical results of mechani-

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* New York Station Report, 1888, p. 196.

† See pp. 159, 160.

‡ From "Soils of the Farm," p. 76.

§ See p. 162.

cal analysis—the same amount of clay and number of particles per gram of soil, yet the latter would allow the passage of any given quantity of water many times more rapidly than would the former.*

The condition of the capillary tubes through which soil-water passes, therefore, fixes the rapidity and amount of movement. The conditions by which this end is to be attained to the advantage of the farmer have been recorded; now, however, the details of repeated experiment and widely distributed farm-practice are available in support of the theory.†

It is an old and accepted principle, that tillage or soil cultivation has for its chief object the improvement of the physical condition of the soil as related to the crop growing thereon; other advantages, such as increase in fertility through chemical action, being but secondary. Among the physical conditions of importance to the crop, those affecting the circulation of water and food solutions are most important. The relations between tillage and plant-growth are therefore most intimate. The problem is, How can tillage be made to exert the most benefit upon the growing plant? On this point the evidence of the past few years is conclusive.

Soil-waters are in constant motion. During rainfall the water sinks by gravity, and if the amount of water supplied is sufficient, penetrates to the permanent water-table, and the entire soil is moist. When the rain ceases or the air becomes drier then soil-evaporation begins, the water rising by capillarity. Certain crops, like corn and clover, are able to draw a portion of the moisture required directly from the permanent supply or water-table.‡ Most crops, however, are dependent entirely upon the water either falling on the surface and taken up by the roots before it penetrates beyond their reach, or on the supply brought up within available depth by capillarity.

From the point of actual saturation or permanent water upwards the soil is always moist; but at a certain height,

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* Experiment-station Record, May, 1892, p. 668. † See pp. 161–2.

‡ Wisconsin Experiment Report, 1889, p. 193.

except when the surface-soil is wet from recent rain, this moisture disappears, and a dry stratum of soil exists. An important question, bearing on this problem is, Why does this soil become dry when there is permanent moisture at some point beneath, in the porous soil? Rapid evaporation from the surface, removing water more rapidly than the loss can be made good by capillary action, is the reason; but the lack of greater capillary power adequate to maintain the supply and prevent the surface from drying through excessive evaporation still needs explanation.

The capillary tubes, as a result of this very evaporation, have become partly dried, and therefore crumbled and broken, forming wider tubes or more coarse structure of the surface-soil, and water finds passage through the wide open spaces impossible; surface-tension or pulling-up power of the soil not being equal to the task, evaporation gains on capillary action, more water evaporates from the surface than can be drawn up through the coarse soil, and the surface-soil dries out while the crop begins to suffer for want of water.

How to obviate this condition is the practical issue. The cause offers means for prevention. If the surface-soil be maintained in so fine a condition that the capillary tubes remain active, water will pass upwards and the necessities of the crop be supplied. To what extent and depth must the cultivation be followed to attain the best results are the important considerations.

The experiments of Prof. Levi Stockbridge in 1879 demonstrated that surface-cultivation to a depth of 4 inches increased the water-content of the soil to its maximum.* More recent investigations in many localities have simply confirmed these conclusions.

"The deeper the tillage up to the depth of four inches the greater is the increase in water content." †

Recent investigations have shown that on clay-loam soil 143 lbs. of water per square foot of surface was gained to the soil

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* See p. 161,

† N. Y. Station Report, 1888, p. 186.

by cultivation to a depth of four inches. This was independent of the moisture brought up from below through increased capillary action, but not evaporated; the figures showing simply the difference in evaporation between tilled and untilled surfaces side by side.*

Although, therefore, four inches seems to be the maximum depth of cultivation for conservation of moisture, there are two practical considerations which may modify the procedure.

In case of very shallow ploughing for small grains on prairie soils in windy localities, like the spring-wheat area of the Northwest, four inches of tillage to conserve soil-moisture would turn the entire arrable soil into a dry mulch to retain moisture in the unploughed depths when the crops do not feed. A safe rule would be: cultivate not to exceed one half the depth of the furrow turned, up to a maximum of four inches of cultivation for water-conservation.

It must also be considered that four inches of tilling with the object of preventing evaporation may result in injury to roots in excess of benefits from increase in water-supply; the rule under such circumstances should be, till to four inches depth, or to the depth where serious root-laceration begins, beyond which harm would follow.

Soils should be cultivated as soon after rain as possible, that excessive evaporation through the compacted soil may be prevented, there being danger otherwise that this rapid evaporation may diminish the supply of available water below its amount previous to the rainfall. The disk-harrow is the best implement for drying soils when excess of surface-moisture is objectionable.

The smoothing-harrow or spring-toothed cultivators, finely pulverizing the entire surface-soil, are best adapted to preventing evaporation. Rolling the soil increases evaporation, but tends to draw water from the lower strata. The surface-temperature is increased by the same means from 1° to 9° F. at 1 to 3 inches depth, and germination is hastened.†

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* Wisconsin Station Report, 1891, p. 105.

† Handbook of Experiment-Station Work, 1893, p. 323.

THE CHEMICAL CONDITIONS INFLUENCING SOIL-WATERS require little consideration. Composition necessarily exerts a material influence on the water capacity of all soils, their humus content being the important factor from its marked absorptive power. This, taken in conjunction with extreme fineness of soil-grains, produces the greatest known water-holding power in soils, the Red River Valley loam of North Dakota holding as high as 84% of water. Certain chemical compounds retard the capillary flow of soil-waters, while others, chief among which stands sodium chloride (common salt) in dilute solutions, materially increase the rapidity of the upward flow. This fact seems to be thoroughly demonstrated and accepted, yet its actual bearing on farm practice seems to have escaped notice.

There is among many farmers a well-established belief in the manurial value of salt, while both they and scientific investigators occasionally meet with apparent beneficial results from the use of salt or fertilizers like kainit, containing salt, or like combinations of Chili saltpetre and muriate of potash ($NaNO_3 + KCl$) capable of salt-formation, wholly inexplicable on the basis of actual manurial value through supply of available plant-food furnished. Scientists when called upon to explain this discrepancy between cause and effect have always resorted to two favorite arguments, neither of which has satisfied them or their interlocutors, but they have been accepted in lieu of better.

The hygroscopic property of salt has been used on the supposition of the "absorption of atmospheric moisture," and holding the same accessible to the plant. The well-known decompositions and recombinations taking place in presence of salt have been resorted to as evidence of "chemical action" on soil-constituents, and consequent increase in amount of available plant-food. Both explanations are based on facts, but wholly insufficient to explain occasionally observed conditions. The beneficial results following applications of salt are usually noticed either on dry soils or during times of drought. It seems to be reasonable, therefore, that the effects are due to the fact stated—*the increased capillary movement in soil-waters containing salt in small quantities.* Salt by increasing capillary action increases the quantity of water accessible to the crop, and in times of water scarcity this additional amount of water is sufficient to account for the improved condition of the salt-manured crop over that grown under the same conditions, except for the salt furnished.

There seems no flaw in the hypothesis, which is capable of being put to experimental demonstration. A rational deduction from the premises would be the use of material like kainit, capable of furnishing plant-food, as well as the capillary water-increasing action of salt.

ALKALI SOILS owe their characteristic properties so largely to their relations toward water-supply, that a few words of consideration seem called for.

These soils exist in localities in most States west of the Alleghanies, there being instances of such occurrence in Ohio and Indiana as typical as any in Wyoming or California. More commonly, however, they exist in regions of limited rainfall or of periodical rainfall, under which circumstances their mineral-salt ingredients are brought to the surface by capillary action, and these deposited by evaporation accumulate in the absence of dissolving rain, leaving a bloom or incrustation on the surface often crystalline and several inches in thickness. The deposit is generally nearly white in color, and consists of mixtures of sulphate, chloride, and carbonate of soda, the first named predominating, with potash and other alkaline salts. The California alkali possesses the following composition:*

Sodium sulphate	82.96%
" chloride	.48
" carbonate	.40
Magnesium sulphate	.50
" carbonate	.13
Calcium phosphate	.20
" sulphate	.10
Iron and alumina oxide	.30
Potassium sulphate	9.52
Silica	1.34
Organic matter and combined water	4.07
	100.00

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* California Station Report, 1890, p. 97.

There is little abnormal in the composition of these salts; they are much such as the water extraction of any fertile soil would contain. In arid regions or where swamps have been reclaimed, with lack of rainfall or lack of drainage the soluble salts accumulate and excess renders plant-growth impossible. Besides the white alkali, which is not corrosive, a black corrosive alkali is occasionally met with, more serious in its effects.

Neutralization of the alkali by chemical means, reducing surface-evaporation and consequent deposition, and supplementing the deficient rainfall by artificial water-supply, are the effective means for overcoming the difficulty. Sulphate of lime, gypsum (land plaster), is the most effective chemical neutralizer, converting the black alkali into the comparatively harmless white form, 500 lbs. to 1 ton per acre being the application required.

The conservation of moisture-supply or increasing access of water for overcoming the effects of alkali are identical with those described for general farm practice. The object is to keep the alkali in solution, or by excess of water wash the salts out of the soil into the drainage.

THE INFLUENCE OF SOIL-MOISTURE ON SOIL-TEMPERATURE results from the simple fact that evaporation of water requires heat, and if the water is in the soil the heat is taken from the same source, and thus in the soil evaporation becomes a cooling process and, other things being equal, a wet soil is cooler than a dry one.* It therefore follows that crop-methods tending to dry the soil at the same time warm it, lengthen its growing season, increase its adaptation to warmth-needing crops and hasten maturity. On the other hand, increasing the supply of available moisture produces opposite results. The dry mulch of fine soil resulting from surface cultivation transmits less heat to the lower moist layer, and the latter thus remains cooler as well as more moist. Cultivation, or pulverizing of the surface, therefore, acts in two ways. Since soils in crop are subjected to loss of moisture both by evaporation and

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* See pp. 169–71.

by transpiration through the plant, the destruction of weeds acts directly on the questions of moisture and heat as well as on the waste of plant-food. This exhaustion of moisture by action of the crop and its influence on temperature are frequently wrongly interpreted.

Soil covered by crop, other conditions being equal, is not kept moist by the presence, or shading effect, of the crop, but is drier and therefore warmer than the bare soil, independent of the heat resulting from organic decomposition—a fact of no little importance in practice. The interpretation is that the presence of a covering of vegetation, growing or as mulch, renders the soil wetter and cooler, and important as furnishing additional control over soil-temperatures.

THE EFFECTS OF CROPPING.

The mere production of crops under natural conditions is nature's way of increasing soil fertility, the death and decomposition of the plant where it grew enriching the surface-soil by addition of all the mineral food brought up from lower depths and all the nutriment derived from the air. Farming is not nature, however; and removal of crops is necessarily an exhausting process, the prevention of which or recuperation from which are the chief aims of modern agriculture.

The removal of the crop grown from the farm which produced it is the secret of the difficulty presented, and its magnitude is in proportion to the degree with which this practice is followed. To illustrate: Selling milk produced from the crops of the farm is the removal of the very basis of the soil itself, and calls for large returns of fertilizers in addition to the manure produced to maintain the fertility of the farm. Butter, however, consisting so nearly entirely of organic matter, air materials, carries little fertility away, and its sale will be followed with slight exhaustive effects.

In like manner the removal of only the flour constituents of wheat while the straw and bran remain as feed is comparatively harmless, while the selling of wheat to the miller and straw to the paper-manufacturer can only result in soil-exhaustion unless the removed material is restored in purchased plant-food.

The principles involved in the prevention of soil-exhaustion are identical with those already discussed under other subjects.*

SOIL-RENOVATION, or the restoring of lost fertility, however, offers a phase of the problem for further consideration. Each plant possesses its individual food-requirements, removing from the soil the materials required by its own nature; and except within very narrow limits man possesses no control over the food-preferences of crops. Each assimilates the constituents required for its special making up, and approximately no change in food-kind can be effected by artificial means, however similar may be the material *offered* to the material *sought.* One alkali cannot be replaced by another any more than ammonia can be replaced by carbonic acid, though both may be of organic origin. It therefore follows that a given crop always removes certain constituents from the soil, and that if this loss is not made good the soil may become deficient in certain ingredients while yet rich in other food-materials essential to other crops. CROP ROTATION is based on this truth and its practice. The following of a given crop by one of unlike food-requirements, like tobacco with wheat, in a regular system not only tends to diminish the possibilities of *soil-exhaustion,* but is practically a form of *soil-renovation,* since by it apparent unproductiveness may be turned into decided productiveness.

Renovation depends on restoring the soil to a state of fertility, but fertility is not solely accessibility of plant-food. The physical condition of the soil, as for instance impaction, may exert material influence on results, not, however, to the extent claimed by Prof. Whitney, who affirms that "soil-exhaustion is due to a change in the arrangement of the soil-grains, changing the relation of the soil to moisture and heat." †

The plowing under of green crops is the simplest step

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* See "Assimilation of Soil-food," "Soil-exhaustion," and "Supply of Plant-food."

† Experiment-station Record, May, 1892, p. 666.

toward renovation on many soils. Clover is by far the best crop for the purpose, and if the first crop is cut, the second still remains as green manure. Its use is particularly effective on clay and sand soils, where organic matter is particularly required. It must be remembered that though the clover-plant is deep rooted, and brings up considerable mineral matter from the subsoil to enrich the surface, complete renovation without addition of manurial food in some form is not possible. The time required, moreover, and consequent loss of use of land and resulting idle investment, will in case of valuable land make applications of purchased fertility expedient.

The bare fallow is now scarcely to be considered in this connection. Other leguminous crops, like alfalfa, field peas, and crimson clover, offer certain advantages, and rye and buckwheat may be utilized when clover will not thrive. It must not be forgotten that pulverization is itself a fertilizer, and access of air a potent soil-renovator. Plowing and cultivation to excess is therefore impossible, and *tillage* is often not only the secret of the maintenance of fertility, but of its restoration as well.

SOIL INOCULATION as a method of renovation or of increase in crop growing power is attracting merited attention, and is likely to become a justifiable method in practice. Not only are leguminous plants best adapted to purposes of green-manuring, but every soil is capable of growing every legume, particularly clovers and lupines. Red clover is not a natural prairie crop, and will not thrive on new prairie soil; even now its cultivation is not a success on the prairies of the spring-wheat region of the Northwest. Its habitat has moved westward from Ohio at the rate of about six miles per year—a fact indicative of the bacterial theory of adaptation, namely, that its growth is only successful in the presence of certain micro-organisms in the soil, the activity of which is evidenced by the "nodules" appearing on the roots of legumes.*

It is through the action of these organisms, or the presence

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* North Dakota Experiment Station Bulletin, September, 1894, p. 53.

of the nodules, that the nitrifying action of the clover is believed to be due. It has therefore been supposed that soils incapable of growing clover could be inoculated with the germs by being sown with soil from clover-fields containing the bacteria and nodules. Success has attended the attempt in many instances, and the field opened offers promise of practical utility.* In this same connection it is well to note the probability of the action of similar organisms on rock-disintegration, and therefore on soil-minerals, and the conversion of the same into available plant-food.

RENOVATION BY FERTILIZATION possesses no features differing from the principles applying to the fertilizing of special crops. It must be clearly understood that however depleted in fertility a soil may have become, if deficiency in available food for the requirements of the crop is its only lack, supplying of food adequate to the growth of the crop desired is effective renovation. The crop-producing power of any soil is limited to its *ability* to supply *all* of the constituents required by the plant, and the productiveness extends only to the limit of the *smallest* required constituent of the crop. In building a brick building it matters little how many brick may be available if the *mortar* runs short, for then the construction must cease. In plant building it avails little how abundant all other constituents may be if *one* is lacking, for *then crop-formation ceases or an abnormal crop is the result.* Should one or more mineral constituents fail, then nitrogen is present in excess and the abnormal crop is evidenced by its inability to stand alone.

Therefore, in practice it does not suffice that "phosphate" be liberally applied, and thus be present in abundance, if potash falls short of the requirements of a good crop. The crop will consume the potash and other ingredients in proportion, and go no further. If by any means it is known that any single element of fertility is present in sufficient quantity to meet the requirements of the crop to be grown, this constituent may be proportionally reduced in the applications

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* Experiment Station Record, February, 1892, p. 491.

made. For instance, on swamp-lands sown to onions nitrogen may be largely omitted in fertilizing applications for a time.

Where, however, as is the rule in practice, this knowledge is not available, but one safeguard exists. Apply the three elements of fertility shown by analysis to enter into the composition of the crop intended in the *proportion found in the crop*, modified by known habits of growth of the plant in question, *or manure with the equivalent of the crops removed.*

Such rational treatment will prevent soil-exhaustion, or insure restoration of crop-producing power.

APPENDIX.

PHYSICAL AND CHEMICAL PERCENTAGE

		Sterile, river sand deposit.	Quartz sand.	Gray-wacke.	Loess (Rhine).	Tertiary soil.	Sandy loam.	Good wheat and clover soil.	Gneiss soil.
Physical Analysis........No.*	1	The numbers refer to the grades determined by means of the Noebel s Apparatus.				1.15	......	....	9.87
	2					5.20	......	....	7.81
	3					33.10	......	....	35.44
	4					56.34	......	......	32.20
	5					4.12	......	....	11.08
$CaCO_3$ and $MgCO_3$........						0.09			0.60
						100.			100.
Loss by Ignition.	Hydroscopic Water..	0.79	1.20	1.50	0.78	0.84	1.38	1.80	0.26
	Combined Water.....	0.24	0.50	0.10	3.09	2.04	1.52	3.47	4.08
	Humus...	0.93	2.10	2.40	0.16	1.24	1.41	1.35	1.06
	$MgCO_3CaCO_3$.......	0.05	0.40	0.10	29.94	0.13	0.62	0.69	1.12
	Silica............. ...	92.18	95.30	79.90	57.00	89.15	91.35	82.17	80.63
	$Fe_2O_3Al_2O_3$..........	6.26	3.50	16.40	12.05	8.59	7.21	14.6	15.42
	Lime.................	1.51	0.80	3.60	0.41	0.49	0.82	3.08	0.14
	Magnesia............					0.75			0.23
	Soda..................					0.89			0.45
	Potash................								2.01

ABSORPTION OF THE

1	8	8	24	30	31	36	46

* See Physical

COMPOSITION OF TWENTY DIFFERENT SOILS.

Forest soil.	Gneiss weathering product.	Russian black earth.	Slate soil.	Best wheat and clover soil.	Diluvial soil.	New red sandstone soil.	Bohemian wheat soil.	Alluvial.	Sterile serpentine soil.	Alluvial.	Basalt soil.
.....	......	......	......	....	1.12	2.20	....	1.27	....	0.27	7.24
......	......	......	......	....	1.85	4.07	....	2.03	....	0.44	2.98
......	......	......	......	... .	3.57	10.73	....	4.15	....	0.76	4.40
......	.....	......	......	....	76.23	69.79	....	54.36	....	41.83	59.91
......	.....	......	......	....	15.66	12.40	....	27.51	....	35.07	22.23
......	......	.... .	......	....	1.57	0.81	....	10.68	....	21.63	3.24
......	......	......	......	....	100.	100.	.. ..	100.	....	100.	100.
1.40	3.12	6.80	5.80	3.91	2.52	2.40	4.06	3.21	0.40	4.03	4.37
0.60	4.54	1.00	2.00	4.74	4.75	4.92	7.81	8.31	12.43	8.64	5.72
1.20	3.82	6 80	6.20	1.75	1.96	1.44	1.92	2.25	0.77	2.13	1.71
0.16	1.35	5.30	1.40	2.07	1.86	1.07	19.70	13 17	1.70	24.68	3.91
87.10	72.45	79.30	69.30	68.32	76.47	77.65	63.57	55.46	46.00	46.82	61.91
9.00	20.79	14.00	28.00	22 99	19.47	18.29	16.61	23.94	19.60	19.71	27.09
3.70	5.41	1.30	1.30	6.62	0.25	0.74	0.12	3.74	3.32	4.90	2.81
					0.66	0.84		1.18		1.23	1.78
											0.65
					1.23	1.13		0.48		2.32	1.80
								2.42			

FINE EARTH (No. 5).

46	49	75	78	80	80	84	88	98	104	112	118

Analysis of Soil.

PERCENTAGE COMPOSITION OF CERTAIN AGRICULTURAL PRODUCTS REMOVED FROM THE SOIL.

	Water.	Nitrogen.	Ash.	Potash.	Soda.	Lime.	Magnesia.	Phosphoric Acid.	Sulphuric Acid.	Silica.
Live ox	59.7	2.66	4.66	0.17	0.14	2.08	0.06	1.86	....	0.01
Beef	77.0	3.60	1.26	0.52	....	0.02	0.04	0.43	0.04	0.03
Calf	66.2	2.50	3.80	0.24	0.06	1.63	0.05	1.38	....	0.01
Veal	78.0	3.49	1.20	0 41	0.10	0.02	0.02	0.58	....	0.01
Sheep	59.1	2.24	3.17	0.15	0.14	1.32	0.04	1.23	....	0.02
Mutton	75.99	17.11	0.85	....	....	....	....	....	....	....
Hog	52.8	2.00	2.16	0.18	0.02	0.92	0.04	0.88	....	....
Pork	7.40	3.47	1.04	0.39	0.05	0.08	0.05	0.46	....	....
Growth of young cattle	....	2.47	3.88	0.19	....	....	....	1.49	....	....
Growth of stall cattle	....	1.16	0.29	0.12	....	....	....	0.13	....	....
Milk	87.5	0.51	0.62	0.15	0.06	0.13	0.02	0.17	....	....
Butter	14.49	0.11	0.95	....	....	....	....	....	....	....
Cheese	45.0	4.53	6.74	0.25	2.66	0.69	0.02	1.15	....	....
Eggs	67.2	2.18	6.18	0.15	0.14	5.40	0.10	0.37	0.01	0.01
Wool	15.0	5.40	9.88	7.46	0.19	0.42	0.16	0.11	0.40	0.30
Raw sugar	....	....	1.00	0.55	0.17	0.06	....	....	0.12	....
Flax	....	....	0.76	0.04	0.04	0.40	0.03	0.08	0.03	0.09
Wine	86.6	....	0.21	0.13	....	0.01	0.01	0.04	0.01	....
English hay	14.4	8.20	6.60	1.70	0.47	0.77	0.33	0.41	0.34	1.97
Leaf tobacco	13.04	2.48	20.10	11.92	3.70	....	....	....	....	....
Shelled corn	13.12	9.85	1.51	27.0	1.50	2.70	14.60	44.7	1.10	2.20
Wheat	14.30	13.00	2.07	31.10	3.50	3.10	12.20	46.20	2.40	1.70
Oats	14.30	9.50	3 07	15.90	3.80	3.80	7.30	20.70	1.60	46.40
Potatoes	95.00	2.00	3.74	59.80	1.60	2.30	4.50	19.10	6.60	2.30

Per cent. of total ash.

AVERAGE PERCENTAGE COMPOSITION OF THE PRINCIPAL MINERAL FERTILIZERS.

	Water.	Organic Matter.	Nitrogen.	Phosphoric Acid.	Potash.	Soda.	Lime.	Magnesia.	Sulphuric Acid.	Chlorine. Fluorine.	Silica, Sand.	Iron and Aluminium Oxides.
Chili saltpetre	2.6	....	15.5	....	....	35.0	0.2	....	0.7	1.7	1.5	....
K or Na saltpetre	0.9	....	14.9	....	16.1	22.2	0.1	....	0.3	1.5	....	....
Sulphate of ammonia	4.0	....	20.0	....	....	....	0.5	....	58.0	1.4	3.0	....
Gypsum	20.0	....	....	....	....	....	31.0	1.0	44.0	....	4.0	....
Gaslime	7.0	1.3	0.4	....	0.2	....	64.5	1.5	12.5	....	3.0	....
Hard-wood ashes	5.0	5.0	....	3.5	10.0	2.5	30.0	5.0	1.6	0.3	18.0	....
Soft-wood ashes	5.0	5.0	....	2.5	6.0	2.0	35.0	6.0	1.6	0.3	18.0	....
Leached ashes	2.0	5.0	....	2.0	1.5	0.3	28.5	2.5	0.3	....	30.0	....
Peat-ash	5.0	....	....	1.2	0.5	0.4	45.7	0.5	4.4	0.6	13.1	7.8
Brown-coal ashes	....	....	....	0.6	0.7	0.4	16.0	1.9	10.4	....	57.6	9.5
Hard-coal ashes	....	....	....	0.8	0.5	....	8.5	1.6	6.1	....	62.0	19.8
STASSFURTH SALTS.												
Polyhalite	7.2	....	....	....	14.9	....	18.2	6.8	52.1	0.3	....	....
Carnellite	39.2	....	....	....	15.1	0.5	0.7	14.7	1.4	36.5	0.3	....
Kainite	20.8	....	....	....	16.9	....	....	18.5	34.6	12.9	....	....
Kieserite	16.4	....	....	....	0.6	....	....	27.8	53.0	2.4	....	....
Tachydrite	42.5	....	....	....	....	....	10.1	16.7	....	40.9	....	....
Kainite (prepared)	12.8	....	....	....	13.8	17.1	1.1	10.1	22.2	28.8	1.0	....
Potash salt, 3 concentrated	13.4	....	....	....	29.6	14.6	0.5	3.9	4.1	42.3	1.3	....
Potash salt, 5 concentrated	4.6	....	....	....	47.5	8.6	0.2	0.9	0.6	47.2	0.4	....
Raw K-Mg salt	8.5	....	....	....	16.9	18.3	1.3	8.6	19.8	30.8	1.9	....

ASH AND NITROGEN CONSTITUENTS OF AGRICULTURAL PRODUCTS.

THE following table is taken from "Mentzel und von Lengerke's landwirthschaftlicher Kalender für 1888."

Compare "Aschen-Analysen von land- und forstwirthschaftlichen Producten, Fabrik-Abfällen und wildwachsenden Pflanzen," von E. Wolff (Berlin, P. Parey, 1871); also "Zweiter Theil, Untersuchungen aus den Jahren 1870 bis 1880" (Berlin, 1880).

In the two latter publications are given, beside statements of single analyses and explanatory notes, tables showing the ash composition per thousand parts of the materials in dry state.

In the first-named work, however, and in the following table, these results of E. Wolff have been adjusted to represent the ash composition of air-dry or, in certain cases, fresh or green products. At the same time the average nitrogen content per mille has been added.

This has been done in order to exhibit a more convenient table for service in reckoning in connection with fertilization and cropping of land.

The quantities named are, of course, to be modified to correspond with the quantity of water present in any particular case. The latter varies greatly, especially in green and root crops.

It must also be borne in mind that the composition of the ash of all plants and parts of plants ranges widely with varying conditions of growth. Calculations, therefore, based on these averages have in the solution of agricultural problems only a relative value, and primarily as foundation for further reckoning.

EXPLANATORY NOTES.

3 Manured with liquid manure.
6 From Baltic sea.
7 Poa maritima (Huds), or
Glyceria maritima (Wahl).
9 Meadow hay from regions where the disease Osteocele in cows, abounds.
10 Norway.
12 Lolium perenne.
13 Phleum pratense.
14 Dactylis glomerata.
16 Trifolium pratense.
21 " repens.
22 " hybridum.
23 " incarnatum.

24 Medicago lupulina.
25 " sativa.
26 Onobrychis sativa.
28 Ornithopus sativus.
29 Vicia (sativa ?).
32 Spergula arvensis.
35 Urtica.
36 Elodea canadensis.
40 Lolium perenne.
48 Sorghum vulgare.
49 Panicum.
50 Trifolium pratense.
56 Trifolium incarnatum.
60 Ornithopus sativus.

64 Spergula arvensis.
67 Urtica.
68 Elodea canadensis.
75 Brassica napus esculenta.
81 Helianthus tuberosus.
86 Brassica napus esculenta.
88 " oleracea capitata.
89 Pastinaca sativa.
92 Convolvulus batatas.
93 Brassica oleracea gonglyoides.
94 Raphanus sativus radicula.
95 Apium graveolens.
98 Cynara scolymus.
99 Brassica oleracea capitata.
100 " " sabauda.
101 " " botrytis.
102 Lactuca sativa.
103 " " capitata.
104 " " (var.?).
106 Allium schœnoprasum.
107 Young
109 Old.
121 Panicum miliaceum.
126 Vicia faba.
127 Phaseolus vulgaris.
128 Soja hispida.
130 Vicia sativa.
139 Brassica rapa (varieties).
141 " " oleifera.
143 Papaver (var. ?).
144 Linum usitatissimum.
148 Coriandrum sativum.
149 Fœniculum officinale.
150 Anethum graveoleus.
174 Vicia faba.
175 Phaseolus vulgaris.
176 Soja hispida.
177 Vicia sativa.
192 Camelina sativa.
210 Phragmites communis.
211 Carex.
212 Scirpus species.
213 Zostera.
214 Erica.
221 Pinus.
222 Larix.
223 Picea.
224 Abies.
245 Residue from spirit manufacture.
246 Residue from starch manufacture.
247 From beet-sugar manufacture, in which the roots are pressed.
248 From beet-sugar manufacture, in which the sliced roots are extracted by "diffusion process."
250 Residue separated from sugar-beet molasses.
259 From Helianthus annuus.
260 From sesamum orientale.
261 Myrica cerifera (?).
273 Holstein.
286 Melolontha vulgaris.

ASH AND NITROGEN CONSTITUENTS OF AGRICULTURAL PRODUCTS,

By E. Wolff, Hohenheim.

Average Amounts in 1000 Parts, by Weight, of the Green or Air-dry Substance.

No.	Substance.	Water.	Nitrogen.	Ash.	Potassa.	Soda.	Lime.	Magnesia.	Phosphoric Acid.	Sulphuric Acid	Silica.	Chlorine.
	I. HAY.											
1	Meadow hay	143	15.5	59.8	16.0	2.2	9.5	4.1	4.3	3.1	17.2	3.7
2	Young grass and rowen	160	19.1	76.0	22.3	3.0	10.4	5.1	5.9	4.1	19.4	4.5
3	Grass, manured	160	28.7	80.1	35.0	2.5	9.5	3.2	9.3	4.6	6.9	9.9
4	Rich pasture grass	150	25.5	82.4	31.6	1.3	10.1	4.6	7.4	2.7	15.9	8.4
5	Best marsh hay	150	....	72.9	27.2	0.8	7.2	5.9	5.3	2.3	15.6	10.5
6	Salt meadow hay	150	....	65.5	19.1	7.6	8.5	2.8	4.7	4.1	12.6	7.1
7	Sea spear-grass	150	....	57.9	6.6	5.8	2.5	1.7	2.6	1.0	27.5	6.4
8	Alpine hay	150	18.5	29.7	7.7	0.4	7.1	2.4	2.7	1.4	7.2	0.7
9	Unhealthy hay	140	14.4	44.5	12.0	0.6	5.4	2.7	2.3	1.8	17.0	2.1
10	Forest hay	150	13.6	26.7	7.7	0.4	2.5	2.1	1.4	1.4	9.9	1.1
11	Sour grass	140	....	37.2	8.8		7.0	1.8	1.4	3.7	13.8	....
12	Rye grass	143	16.3	58.2	20.2	2.0	4.3	1.3	6.2	2.3	18.5	6.1
13	Timothy	143	13.5	58.5	20.3	1.1	4.7	1.9	6.9	1.7	18.8	3.0
14	Orchard grass	143		50.8	16.7	2.2	3.1	1.4	3.6	1.3	16.7	3.6
15	Cereals in flower	150	....	59.4	19.3	1.0	3.4	1.7	5.6	1.5	24.7	2.3
16	Red clover, quite young	167	35.5	82.3	29.7	1.9	23.5	7.6	10.0	1.8	2.5	3.3
17	" " in bud	165	24.5	68.4	25.3	1.4	20.7	7.6	6.9	1.7	1.8	2.4
18	" " in flower	160	19.7	57.6	18.6	1.1	20.1	6.3	5.6	1.9	1.6	2.2
19	" " ripe	150	12.5	44.7	10.0	1.4	15.8	6.9	4.4	1.4	3.0	1.3
20	Clover grass	160	17.8	54.9	25.6	0.9	5.6	2.3	5.3	2.8	11.1	1.2
21	White clover in flower	165	23.2	61.1	13.1	4.4	18.4	5.8	7.8	4.5	2.7	2.6
22	Bastard clover	160	24.0	40.0	11.1	1.2	13.6	5.0	4.1	1.6	1.6	2.2
23	Incarnate clover	167	19.5	50.7	11.7	4.3	16.0	3.1	3.6	1.3	8.2	1.8
24	Nonesuch	167	23.3	53.7	16.8	4.4	14.9	4.5	4.4	2.2	1.9	4.8
25	Lucerne	160	23.0	62.0	14.6	1.1	25.2	3.1	5.3	3.6	5.9	1.9
26	Esparsette	167	22.1	45.8	13.0	1.5	16.8	3.0	4.6	1.4	3.7	1.8
27	Anthyllis vulneraria	167	22.1	53.2	14.5	0.7	27.7	2.5	4.7	0.7	1.7	0.6
28	Seradella	167	21.6	81.6	31.9	1.7	18.2	2.8	9.1	3.1	7.0	2.1
29	Green vetches in flower	167	22.7	56.0	19.7	2.4	16.3	4.6	6.2	3.4	1.1	1.4
30	Green peas	167	22.9	62.4	23.2	2.3	15.6	6.3	6.8	5.1	0.8	2.0
31	Lupine hay	167	27.4	34.2	8.0	2.5	8.8	3.3	5.8	1.9	2.4	0.6
32	Corn spurry	167	19.2	56.3	19.7	4.5	10.8	6.8	8.3	1.9	0.8	4.4
33	Buckwheat in flower	160	21.4	69.1	21.4	1.6	27.9	9.2	4.2	2.5	0.8	0.5
34	Green rape beginning to flower	160	29.9	68.0	22.6	2.3	15.0	2.7	7.6	9.5	3.2	5.0
35	Nettles	114	29.3	120.0	38.5	2.9	33.9	8.6	9.4	10.0	4.8	8.0
36	Water weed	169	24.3	166.2	23.6	16.1	52.3	9.4	16.0	6.8	24.0	6.1

ASH AND NITROGEN CONSTITUENTS OF AGRICULTURAL PRODUCTS.

No.	Substance.	Water.	Nitrogen.	Ash.	Potassa.	Soda.	Lime.	Magneisa.	Phosphoric Acid.	Sulphuric Acid.	Silica.	Chlorine.
	II. GREEN FODDER.											
37	Meadow grass in flower..........	750	4.8	17.5	4.7	0.7	2.8	1.2	1.2	0.9	5.0	1.1
38	Young grass and rowen..........	800	5.6	18.1	5.3	0.7	2.5	1.2	1.4	1.0	4.6	1.1
39	Rich pasture......................	782	7.2	21.1	8.1	0.3	2.6	1.2	1.9	0.7	4.1	2.1
40	Rye grass........................	700	5.7	20.4	7.1	0.7	1.5	0.4	2.2	0.8	6.5	2.1
41	Timothy.........................	700	5.4	20.5	7.1	0.4	1.7	0.7	2.4	0.6	6.6	1.1
42	Orchard grass.....................	700	....	17.8	5.9	0.8	1.1	0.5	1.3	0.5	5.9	1.3
43	Sweet grasses in general.........	700	5.4	22.1	7.1	0.6	1.7	0.7	1.8	0.9	8.1	1.3
44	Rye fodder.	760	5.3	16.3	6.3	0.1	1.2	0.5	2.4	0.2	5.2	0.6
45	Green oats......................	810	3.7	14.2	5.6	0.5	0.9	0.4	1.3	0.5	4.4	0.6
46	Cereals in flower................	785	4.5	15.0	4.4	0.3	0.9	0.4	1.4	0.4	6.2	0.6
47	Corn fodder.....................	829	1.0	10.4	3.7	0.5	1.4	1.1	1.0	0.3	1.9	0.5
48	Sorghum in flower...............	773	4.0	14.0	3.9	1.9	1.3	0.6	0.8	0.5	4.0	1.1
49	Panic grass.....................	750	5.0	17.4	6.3	0.4	1.8	1.6	1.0	0.6	4.9	0.9
50	Red clover, quite young.........	860	6.0	14.0	5.1	0.3	3.9	1.3	1.7	0.3	0.4	0.6
51	" " in bud..............	820	5.3	14.7	5.5	0.3	4.5	1.6	1.5	0.4	0.4	0.5
52	" " in flower...........	800	4.8	13.7	4.4	0.3	4.8	1.5	1.3	0.4	0.4	0.5
53	Clover grass.	750	5.3	16.4	7.6	0.3	1.7	0.7	1.6	0.8	3.3	0.3
54	White clover in flower...........	805	5.6	14.3	3.1	1.0	4.3	1.4	1.8	1.1	0.6	0.6
55	Bastard clover..................	820	5.3	8.6	2.4	0.3	2.9	1.1	0.9	0.4	0.3	0.5
56	Incarnate clover.................	815	4.3	11.3	2.6	1.0	3.6	0.7	0.8	0.3	1.8	0.4
57	Lucerne beginning to flower.....	740	7.2	19.2	4.5	0.3	8.5	0.9	1.6	1.1	1.8	0.6
58	Esparsette in flower.............	800	5.1	11.0	3.1	0.4	4.0	0.7	1.1	0.3	0.9	0.4
59	Anthyllis vulneraria in flower...	830	4.5	10.9	3.0	0.1	5.7	0.5	1.0	0.2	0.4	0.1
60	Seradella.	800	4.8	19.6	7.7	0.4	4.3	0.7	2.2	0.8	1.7	0.5
61	Green vetches.	820	5.6	12.1	4.3	0.5	3.5	1.0	1.3	0.7	0.2	0.3
62	Green peas......................	815	5.1	13.9	5.2	0.5	3.5	1.4	1.5	1.1	0.2	0.4
63	Green lupine....................	850	5.0	6.2	1.5	0.5	1.6	0.6	1.1	0.4	0.4	0.1
64	Corn spurry.....................	800	3.7	13.5	4.7	1.1	2.6	1.6	2.0	0.5	0.2	1.1
65	Buckwheat in flower.	850	3.9	12.4	3.8	0.3	5.0	1.6	0.8	0.5	0.1	0.1
66	Green rape beginning to flower..	870	4.6	10.5	3.5	0.4	2.3	0.4	1.2	1.5	0.5	0.8
67	Nettles.........................	830	5.6	23.0	7.4	0.6	6.5	1.6	1.8	1.9	0.9	1.5
68	Water weed.	880	3.5	24.0	3.4	2.3	7.6	1.4	2.3	1.0	3.5	0.9
69	Hop refuse from brewery........	856	4.3	4.6	0.4	0.1	1.2	0.6	1.1	0.2	0.7	0.0
	III. ROOT CROPS.											
70	Potatoes	750	3.4	9.5	5.8	0.3	0.3	0.5	1.6	0.6	0.2	0.3
71	Artichokes......................	800	3.2	9.8	4.7	1.0	0.3	0.3	1.4	0.6	0.2	0.4
72	Beets	880	1.8	9.1	4.8	1.5	0.3	0.4	0.8	0.3	0.2	0.9
73	Sugar beets...	815	1.6	7.1	3.8	0.6	0.4	0.6	0.9	0.3	0.2	0.3
74	Turnips.........................	920	1.8	6.4	2.9	0.6	0.7	0.2	0.8	0.7	0.1	0.3
75	Rutabagas	870	2.1	7.5	3.5	0.4	0.9	0.3	1.1	0.7	0.1	0.5

ASH AND NITROGEN CONSTITUENTS OF AGRICULTURAL PRODUCTS.

No.	SUBSTANCE.	Water.	Nitrogen.	Ash.	Potassa.	Soda.	Lime.	Magnesia.	Phosphoric Acid.	Sulphuric Acid.	Silica.	Chlorine.
76	Carrots	850	2.2	8.2	3.0	1.7	0.9	0.4	1.1	0.5	0.2	0.4
77	Chicory	800	2.5	6.7	2.6	1.0	0.5	0.3	0.8	0.5	0.3	0.5
78	Sugar-beet heads	840	2.0	9.6	2.8	2.3	0.9	1.1	1.2	0.7	0.2	0.3
	IV. LEAVES AND STEMS OF ROOT CROPS.											
79	Potatoes, nearly ripe	770	4.9	19.7	4.3	0.4	6.4	3.3	1.6	1.3	0.9	1.1
80	Potatoes, unripe	825	6.3	16.5	4.4	0.3	5.1	2.4	1.2	0.8	1.2	0.9
81	Jerusalem artichokes	800	5.3	14 5	3.1	0.2	5.0	1.3	0.7	0.2	3.6	0.4
82	Fodder beets	905	3.0	14.6	4.5	2.8	1.6	1.4	1.0	0.8	0.5	2.3
83	Sugar beets	897	3.0	15.3	4.0	2.0	3.1	1.7	0.7	0.8	1.6	1.3
84	Turnips	898	3.0	11.9	2.8	1.1	3.9	0.5	0.9	1.1	0.5	1.2
85	Carrots	822	5.1	23.9	2.9	4.7	7.9	0.8	1.0	1.8	2.4	2.4
86	Rutabagas	884	3.4	19.6	2.8	0.8	6.5	0.8	2.0	2.3	2.1	1.5
87	Chicory	850	3.5	16.5	4.3	2.9	3.3	0.4	1.0	1.4	0.6	2.7
88	Cabbage	890	2.4	15.6	5.8	1.5	2.8	0.6	1 4	2.4	0.1	1.3
	V. GARDEN VEGETABLES.											
89	Parsnip	793	5 4	10.0	5.4	0.2	1.1	0.6	1.9	0.5	0.2	0.4
90	Asparagus shoots	933	3.2	5.0	1.2	0.9	0.6	0.2	0.9	0.3	0.5	0.3
91	Horse radish	767	4.3	19.7	7.7	0.4	2.0	0.4	2.0	4.9	1.5	0.3
92	Sweet potatoes	758	2.4	7.4	3.7	0.5	0.7	0.3	0.8	0.4	0.3	0.9
93	Kohlrabi roots	850	4.8	12 3	4.3	0.8	1.4	0.8	2.7	1.1	0.3	0.6
94	Garden radish	933	1.9	4.9	1.6	1.0	0.7	0.2	0.5	0.3	......	0.5
95	Celery tubers	841	2.4	17.6	7.6	....	2.3	1.0	2.2	1.0	0.7	2.8
96	Cucumber fruit, entire	956	1.6	5.8	2.4	0.6	0.4	0.2	1.2	0.4	0.5	0.4
97	Squash fruit, entire	900	1.1	4.4	0.9	0.9	0.3	0.2	1.6	0.1	0 3	...
98	Artichoke	811	....	10.1	2.4	0.7	1.0	0.4	3.9	0.5	0.7	0.2
99	Cabbage, heart	900	3.0	9.6	4.3	0.8	1.2	0.4	1.1	1.3	0.1	0.5
100	Savoy cabbage	871	5.3	14.0	3.9	1.4	3.0	0.5	2.1	1.2	0.7	1.1
101	Cauliflower, heart	904	4.0	8.0	3.6	0.5	0.5	0.3	1.6	1.0	0.3	0 3
102	Lettuce	940	....	8.1	3.7	0.8	0.5	0.2	0.7	0.3	1.3	0.4
103	Head lettuce	943	2.2	10.3	3.9	0.8	1 5	0.6	1.0	0.4	0.8	0.8
104	Roman salad	925	2.0	9.8	2.5	3.5	1.2	0.4	1.1	0.4	0.3	0.4
105	Squash	903	4.9	16.0	2.7	5.7	1.9	1.0	1.6	1.1	0.7	1.0
106	Chives	820	6.2	9.9	3.3	0.4	2.1	0.5	1.5	1.2	0.3	0.4
107	Onions, bulbs	876	4.5	8.4	2.6	1.2	0.9	0.3	1.4	0.6	0.6	0.3
108	Onions, leaves	908	3.4	7.6	3.1	0.5	1.7	0.3	0.6	0.3	0.6	0.5
109	Onions	860	2.7	7.4	2.5	0.2	1.6	0.3	1.3	0.4	0.7	0.2
110	Edible mushrooms	888	4.7	10.0	5.1	0 2	0.1	0.3	3.4	0.4	0.1	0.1

ASH AND NITROGEN CONSTITUENTS OF AGRICULTURAL PRODUCTS.

No.	Substance.	Water.	Nitrogen.	Ash.	Potassa.	Soda.	Lime.	Magnesia.	Phosphoric Acid.	Sulphuric Acid.	Silica.	Chlorine.
	VI. SEEDS AND FRUITS.											
111	Winter wheat	144	20.8	16.8	5.2	0.3	0.5	2.0	7.9	0.1	0.3	0.1
112	Summer wheat	143	20.5	18.3	5.6	0.3	0.5	2.2	9.0	0.2	0.3	0.1
113	Spelt, without husks	143	22.0	14.4	4.3	0.7	0.6	1.8	6.5	....	0.1	....
114	Spelt, with husks	148	16.0	36.6	5.7	0.4	1.0	2.6	7.6	1.1	17.1	0.2
115	Winter rye	143	17.6	17.9	5.8	0.3	0.5	2.0	8.5	0.2	0.3	0.1
116	Summer rye	143	....	18.0	6.2	0.3	....	2.2	9.2	....	0.2	....
117	Summer barley	143	16.0	22.3	4.7	0.5	0.6	2.0	7.8	0.4	5.8	0.2
118	Winter barley	145	16.0	17.0	2.8	0.7	0.1	2.1	5.6	0.5	4.9	....
119	Oats	143	19.2	26.7	4.8	0.4	1.0	1.9	6.8	0.5	10.5	0.3
120	Indian corn	144	16.0	12.4	3.7	0.1	0.3	1.9	5.7	0.1	0.3	0.2
121	Millet	140	20.3	29.5	3.3	0.4	0.2	2.8	6.5	0.1	15.6	0.1
122	Sugar millet	140	..	23.4	3.5	2.0	0.2	3.1	5.8	0.2	8.6	....
123	Sorghum	140	...	16.0	3.3	0.5	0.2	2.4	8.1	....	1.2	....
124	Buckwheat	140	14.4	11.8	2.7	0.7	0.5	1.5	5.7	0.2	......	0.2
125	Peas	143	35.8	23.4	10.1	0.2	1.1	1.9	8.4	0.8	0.2	0.4
126	Horse bean	145	40.8	31.0	12.9	0.3	1.5	2.2	12.1	1.1	0.2	0.5
127	Field bean	150	39.0	27.4	12.1	0.4	1.5	2.1	9.7	1.1	0.2	0.3
128	Soja bean	100	53.4	28.3	12.6	0.3	1.7	2.5	10.4	0.8	......	0.1
129	Lupine	130	56.6	37.0	11.4	0.3	2.8	4.5	14.2	3.2	0.1	0.3
130	Common vetch	143	44.0	26.6	8.0	2.1	2.2	2.4	9.9	1.0	0.3	0.7
131	Red clover	150	30.5	38.3	13.5	0.4	2.5	4.9	14.5	0.9	0.5	0.5
132	White clover	150	....	33.8	12.3	0.2	2.5	3.9	11.6	1.6	0.8	0.5
133	Esparsette	160	....	38.4	11.0	1.1	12.3	2.6	9.2	1.2	0.3	0.5
134	Seradella	120	34.9	28.4	8.2	2.2	5.5	2.7	7.8	....	0.6	1.7
135	Beets	140	....	48.8	9.1	8.5	7.6	8.6	7.6	2.1	1.1	5.3
136	Sugar beets	146	....	45.3	11.1	4.2	10.2	7.3	7.5	2.0	0.8	1.9
137	Carrots	120	...	74.8	14.3	3.5	29.1	5.0	11.8	4.2	4.0	2.8
138	Chicory	130	....	54.6	6.5	4.6	17.3	5.9	16.5	2.4	0.6	0.5
139	Turnips	125	....	34.6	7.6	0.4	6.1	3.1	14.0	2.5	0.2	....
140	Rape	118	31.2	39.2	9.6	0.6	5.5	4.6	16.6	0.9	0.5	0.1
141	Summer rape	120	36.8	34.9	7.7	....	5.2	4.7	14.9	2.3	.....	....
142	Mustard	130	....	36.5	5.9	2.0	7.0	3.7	14.6	1.8	0.9	0.2
143	Poppy	147	28.0	51.5	7.0	0.5	18.2	4.9	16.2	1.0	1.7	2.4
144	Flax	118	32.8	32.6	10.0	0.7	2.6	4.7	13.5	0.8	0.4	....
145	Cotton	77	36.5	33.8	10.9	2.3	1.9	5.6	10.5	0.7	0.1	0.5
146	Hemp	122	26.1	46.3	9.4	0.4	10.9	2.6	16.9	0.1	5.5	....
147	Caraway	130	....	46.4	12.2	3.0	8.4	3.8	11.3	2.5	2.3	1.4
148	Coriander	135	....	41.2	14.5	0.5	9.1	5.0	7.6	2.8	0.4	1.0
149	Fennel	134	....	61.4	19.6	1.5	12.1	8.6	10.1	0.5	0.2	2.1
150	Dill	133	....	54.7	17.3	1.3	14.5	4.1	9.5	3.7	1.4	2.7
151	Madder root	144	....	62.5	17.4	3.8	15.5	1.7	5.1	2.3	6.8	3.9

ASH AND NITROGEN CONSTITUENTS OF AGRICULTURAL PRODUCTS.

No.	Substance.	Water.	Nitrogen.	Ash.	Potassa.	Soda.	Lime.	Magnesia.	Phosphoric Acid.	Sulphuric Acid.	Silica.	Chlorine.
152	Grape seeds	110	19.0	22.7	6.9	0.5	5.6	1.4	7.0	0.8	0.2	0.1
153	Cocoanut, endosperm	466	8.8	9.7	4.3	0.8	0.5	0.9	1.7	0.5	0.1	1.3
154	Walnut, cotyledons	450	....	11.7	3.6	0.3	1.0	1.5	5.1	....	....	...
155	Horse chestnut, fresh	493	6.9	12.0	7.1	....	1.4	0.1	2.7	0.3	0.3	0.8
156	Acorns, fresh	553	4.0	9.8	6.3	0.1	0.7	0.5	1.5	0.4	0.1	0.2
157	Grapes	830	1.7	8.8	5.0	0.1	1.0	0.4	1.4	0.5	0.3	0.1
158	Apples, entire fruit.	831	0.6	2.2	0.8	0.6	0.1	0.2	0.3	0.1	0.1	....
159	Pears, entire fruit.	831	0.6	3.3	1.8	0.3	0.3	0.2	0.5	0.2	0.1	....
160	Cherries, entire fruit...	825	....	3.9	2.0	0.1	0.3	0.2	0.6	0.2	0.4	0.1
161	Plums, entire fruit	838	....	2.9	1.7	....	0.3	0.2	0.4	0.1	0.1	....
162	Gooseberries	903	..	3.3	1.3	0.3	0.4	0.2	0.7	0.2	0.1	....
163	Strawberries	902	...	3.3	0.7	0.9	0.5	...	0.5	0.1	0.4	0.1
	VI. STRAW.											
164	Winter wheat	143	4.8	46.0	6.3	0.6	2.7	1.1	2.2	1.1	31.0	0.8
165	Summer wheat	143	5.6	38.1	11.0	1.0	2.6	0.9	2.0	1.2	18.2	0.8
166	Winter spelt	143	4.0	50.1	5.2	0.3	2.9	1.2	2.6	1.2	36.0	0.5
167	Winter rye	143	4.0	38.2	8.6	0.7	3.1	1.2	2.5	1.6	18.8	0.8
168	Summer rye	143	5.6	46.7	11.7	....	4.0	1.2	2.8	1.5	25.2	....
169	Barley	143	6.4	45.9	10.7	1.6	3.3	1.2	1.9	1.8	23.4	1.5
170	Oats	143	5.6	61.6	16.3	2.0	4.3	2.3	2.8	2.0	28.8	2.7
171	Indian corn	150	4.8	45.3	16.4	0.5	4.9	2.6	3.8	2.4	13.1	0.6
172	Buckwheat	160	13.0	51.7	24.2	1.1	9.5	1.9	6.1	2.7	2.9	4.1
173	Peas	160	10.4	43.1	9.9	1.8	15.9	3.5	3.5	2.7	2.9	2.3
174	Horse bean	160	16.3	44.9	19.4	0.8	12.0	2.6	2.9	1.8	3.2	2.0
175	Field bean	160		40.2	12.8	3.2	11.1	2.5	3.9	1.7	1.9	3.1
176	Soja bean	140	13.1	32.7	5.0	0.7	14.6	5.0	3.1	2.1	1.8	....
177	Common vetch	160	12.0	44.1	6.3	6.9	15.6	3.7	2.7	3.3	3.6	2.2
178	Lupine	160	9.4	42.6	17.7	1.3	9.7	3.4	2.5	3.4	1.2	1.4
179	Rape	160	5.6	41.3	11.3	3.9	11.7	2.5	2.5	3.1	2.6	3.5
180	Poppy	160	....	48.6	18.4	0.6	14.7	3.1	1.6	2.5	5.5	1.3
	VIII. CHAFF AND PODS.											
181	Winter wheat	143	7.2	92.0	8.4	1.7	1.7	1.2	4.0	....	74.7	....
182	Winter spelt.	143	5.6	81.4	1.7	0.3	2.0	2.0	5.9	1.9	60.4	....
183	Winter rye	143	5.8	82.7	5.2	0.3	3.5	1.1	5.6	0.1	66.4	0.4
184	Barley	143	4.8	118.6	9.3	1.1	12.5	1.5	2.4	3.6	85.6	0.8
185	Oats	143	6.4	71.2	4.5	2.9	4.0	1.5	1.3	3.5	50.4	0.8
186	Rice husks	100	5.0	90.0	1.4	1.4	0.9	1.8	1.7	0.8	80.7	....
187	Indian corn cobs..	140	2.3	4.5	2.3	0.1	0.2	0.2	0.2	0.1	1.3	0.2
188	Bean pods	150	16.8	54.7	35.5	1.3	6.8	6.0	2.7	1.2	0.3	1.0
189	Lupine pods	143	7.2	19.1	9.4	1.3	4.4	0.8	1.0	0.4	0.9	0.3

ASH AND NITROGEN CONSTITUENTS OF AGRICULTURAL PRODUCTS.

No.	SUBSTANCE.	Water.	Nitrogen.	Ash.	Potassa.	Soda.	Lime.	Magnesia.	Phosphoric Acid.	Sulphuric Acid.	Silica.	Chlorine.
190	Rape pods	140	6.4	70.1	9.5	3.0	35.1	5.8	3.7	6.4	0 8	3.5
191	Flaxseed capsules	116	5.6	53.9	15.0	3.0	15.6	3.[illegible]	4.5	3.8	4.5	4.1
192	False flaxseed capsules	112	4.3	43.3	12.7	1.3	16.0	2.3	1.5	4.6	3.6	0.7
	IX. COMMERCIAL PLANTS.											
193	Flax stems	120	....	31.1	9.7	2.5	6.9	2.0	4.2	2.0	1.7	1.3
194	Flax stems, roasted	100	....	7.0	0.3	0.2	3.6	0.2	0.8	0.2	1.3	....
195	Flax fibre	100	....	6.8	0.3	0.3	3.6	0.3	0.7	0.3	0.8	....
196	Hemp stems	108	....	31.7	5.5	0.6	16.8	2.1	2.1	0.6	3.1	0.6
197	Hops	120	32.2	66.3	23.0	1.5	11.0	3.6	11.1	2.4	10.9	2.1
198	Hop stems	160	15.7	38.3	11.2	1.4	12.5	2 7	3.9	1.2	2.9	3.1
199	Hop, entire plant	140	25.0	72.9	17.9	1.9	19.7	7.0	5.8	2.9	13.3	3.7
200	Tobacco leaves	180	34.8	140.7	40.9	4.5	50.7	10.4	6.6	8.5	8.1	9.4
201	Tobacco stems	180	24.6	64.7	28.2	6.6	12.4	0.5	9.2	2.2	1.6	2.4
202	Madder root	450	..	32.6	14.0	1.9	8.9	2.2	2.4	0.8	1.1	1.8
203	Grape stalks	630	5.6	21.2	10.9	0.8	2.7	0.7	1.8	1.7	0.8	0.3
204	Pressed grapes	650	....	36.7	17.2	0.2	4.0	1.5	4.6	1.8	3.8	0.2
205	Wine dregs	536	13 1	47.6	33.4	0.1	4.0	0.4	3.6	1.3	3.2	....
206	Grape juice	840	1.8	4.7	3.1	0.1	0.3	0.2	0.6	0.2	0.1	0.1
207	Grape stalks and branches	550	4.1	12.7	4.1	1.3	4.0	0.7	1.4	0.5	0.3	0.1
208	Tea leaves	80	35.6	47.6	16.4	4.9	7.1	2.4	7.2	3.4	2.4	0.9
209	Mulberry leaves	720	14.0	30.1	7.3	0.5	9.6	3.9	2.4	0.7	7.2	0.3
	X. LITTER.											
210	Reeds	180	....	33.5	6.0	0.2	2.7	0.9	1.8	0.8	20.0	1.2
211	Sedges	140	....	60.0	20.2	4.4	3.6	2.6	4.2	2.0	18.8	3.8
212	Bulrushes	140	....	56.0	16.9	4.7	4.2	3.0	4.3	2.0	11.8	7.3
213	Eel grass	150	16.4	146.7	17.7	31.0	20 9	12.5	4.2	34.7	2.9	24.2
214	Heath	200	10.0	16.6	2.1	1.1	3.6	1 6	1.1	0.7	4.3	0.4
215	Moss	250	10.5	20.6	3.4	1.4	2.9	1.3	1.6	1.1	5.5	0.7
216	Ferns	250	....	48.7	18.6	1.8	5.6	3.1	3.7	1.7	10.0	3.7
217	Broom-corn tops	250	....	13.6	4.8	0.3	2.2	1.6	1.1	0.4	1.3	0.2
218	Beech leaves in August	560	13.0	21.6	4.4	0.4	6.3	1.6	1.8	0.5	6.2	....
219	Beech leaf	140	10.0	46.7	2.3	0.5	21 2	3.1	2.4	1.0	14.5	...
220	Oak leaf	140	10.0	46.1	3.5	1.3	17.1	4.3	2.0	0.9	15.4	....
221	Pine leaf	135	8.0	12.2	1.3	0.5	4.6	1.2	1.0	0.5	1.8	....
222	Larch leaf	140	....	34.3	1.6	0.5	7.5	2.4	1.3	0.6	19.6	....
223	Fir leaf	126	9.0	40.3	1.3	0.4	16.0	1.8	2.0	0.6	18.1	....
224	Spruce leaf	132	....	32.8	2.7	0.5	19.5	2.3	2.7	0.8	2.5	....
225	Pruning litter	150	....	28.1	7.4	1.8	10.8	2.0	3.0	1.4	0.8	....

ASH AND NITROGEN CONSTITUENTS OF AGRICULTURAL PRODUCTS.

No.	SUBSTANCE.	Water.	Nitrogen.	Ash.	Potassa.	Soda.	Lime.	Magnesia.	Phosphoric Acid.	Sulphuric Acid.	Silica.	Chlorine.
	XI. BY-PRODUCTS AND RESIDUES.											
226	Wheat bran	131	22.4	53.5	15.3	0.3	1.5	9.0	26.9	...	0.2	....
227	Rye bran	125	23.2	71.9	19.4	0.5	2.1	11.4	34.4	...	1.4	....
228	Barley-meal fodder	130	....	21.1	5.5	0.4	0.7	2.8	10.8	0.3	0.3	....
229	Barley bran	120	17.6	49.5	8.3	0.7	1.9	3.1	9.1	0.9	24.1	0.6
230	Oat husks	140	4.3	34.7	4.9	0.3	1.4	1.0	1.6	1.3	23.2	0.5
231	Buckwheat bran	140	27.2	29.8	9.7	0.6	2.9	4.0	10.7	0.9	0.6	....
232	Rice-meal fodder	100	19.1	54.7	6.1	1.2	1.2	9.5	23 8	0.2	10.3	....
233	Rice husks	100	4.9	153.9	2.4	0.5	0.8	0.1	4.1	0.7	143.5	0 2
234	Fine wheat flour	136	18.9	4.4	1.5	....	0.3	0.4	2.2	....	.....	...
235	Wheat-bread flour	120	21.6	11.2	3.5	0.1	0.6	1.4	5.6	..	......	....
236	Wheat mill-waste	92	24.4	26.5	8.4	0.6	2.2	3.5	11.7	...	..	....
237	Rye flour	142	16.8	16.9	6.5	0.3	0.2	1.4	8.2	...	.....	....
238	Indian-corn meal	140	16.0	5.9	1.7	0.2	0.4	0.9	2.7	...	.....	....
239	Barley flour	140	16.0	20.0	5.8	0.5	0.6	2.7	9.5	0.6	.....	....
240	Dried malt	75	16.0	25.6	4.4	....	1.0	2.2	9.3	...	8.5	....
241	Fresh malt	475	10.4	14.6	2.5	....	0.5	1.2	5.3	....	4.8	....
242	Malt sprouts	80	36.8	67.6	20.8	1.2	1.9	1.9	18.2	2.7	14.9	4.7
243	Brewer's grains	766	7.8	10.6	0 4	0.1	1.5	1.1	3.9	....	3.5	....
244	Beer	900	0.5	3.1	1.1	0.3	0.1	0.2	1.0	0.1	0.3	0.1
245	Potato slump	930	2.1	6.6	3.0	0.5	0.3	0.6	1.3	0.5	0.2	0.2
246	Potato fibre	850	1.3	1.1	0.2	...	0.5	0.1	0.3	....	... ..	....
247	Beet press-cake	700	2.9	11.1	3.8	0 9	2.5	0.7	1.1	0.4	0.9	0.4
248	Diffusion waste	948	0.8	3.3	0.3	0.1	1.1	0.2	0.2	0.1	0.7	0.1
249	Sugar-beet molasses	172	12.8	82.6	58.7	10.1	4.1	0 3	0.5	1.6	0.3	8.2
250	Molasses slump	920	3.2	12.1	9.5	1.3	0.1	....	0.1	0.2	......	0.5
251	Flax refuse	100	...	6.1	0.8	0.3	3.5	0.2	0.4	0.4	0.3	....
252	Hemp refuse	100	....	6.5	0.7	0.1	4.2	0.3	0.3	0.1	0.7	0.1
253	Rape-seed cake	113	50.5	57.0	13.0	1.9	7.1	7.3	20.0	3.4	2.9	0.4
254	Flax-seed cake	122	47.2	51.3	12.5	0.8	4.3	8.1	16.2	1.7	6.4	0.4
255	Poppy-seed cake	115	51.0	77.4	2.3	2.3	27.1	6.2	31.7	1 9	5.6	0.5
256	Walnut cake	137	55 3	46.2	15.3	....	3.1	5.6	20.2	0.6	0.7	0.1
257	Beech-nut cake	160	29.1	40.4	6.1	4.3	12.4	3.3	9.1	0.6	3.9	0 4
258	Olive cake	138	9.6	27.8	7.9	1.9	6 1	0.3	2.5	1.2	5.6	0.2
259	Sunflower-seed cake	103	59.7	49.7	11.7	....	5.4	8.1	21.5	1.0	0.3	0.3
260	Sesamum-seed cake	111	58.6	93.8	14.5	3.5	25.1	12.8	32.7	1.7	0.9	0.6
261	Candlenut cake	77	84.5	78.5	17.5	0.3	4.2	13.5	40.1	0.3	0.1	0.8
262	Peanut cake	104	75.6	39.7	15.0	0.9	1.6	5.2	13.1	0.9	1.2	0.9
263	Palm-oil cake	100	25.9	26.1	5.0	0.2	3.1	4.5	11.0	0.5	0.8	....
264	Cocoanut cake	127	37.4	53.3	19.6	1.5	5.5	3.0	13.0	1.8	1.8	6.2
265	Cotton-seed cake	112	62.1	66.4	15.8	....	2.9	10.1	30.5	0.8	5.5	...

ASH AND NITROGEN CONSTITUENTS OF AGRICULTURAL PRODUCTS.

No.	SUBSTANCE.	Water.	Nitrogen.	Ash.	Potassa.	Soda.	Lime.	Magnesia.	Phosphoric Acid.	Sulphuric Acid.	Silica.	Chlorine.
	XII. ANIMAL PRODUCTS.											
266	Cow's milk.	875	5.4	7.2	1.7	0.4	1.7	0.2	2.0	0.1	......	1.0
267	Sour milk	911	4.6	7.9	2.1	0.5	1.7	0.2	2.2	0.3	......	0.9
268	Colostrum	730	30.7	11.8	0.9	0.7	4.1	0.2	3.3	....	......	1.3
269	Cow's milk whey	933	0.9	5.4	1.7	0.7	1.0	....	0.9	0.2	......	0.8
270	Goat's milk whey	920	1.5	5.9	2.3	0.6	0.4	0.3	0.8	0.2	......	1.7
271	Sheep's milk	816	11.2	7.3	1.6	0.3	2.1	....	2.6	0.1	0.2	0.6
272	Parmesan cheese	322	37.0	39.8	1.1	5.8	14.8	0.5	14.4	0.4	......	0.5
273	Common cheese	513	51.2	50.1	6.6	0.7	17.7	1.2	19.2	0.1	......	3.7
274	Hand-made cheese	480	52.3	68.4	3.3	31.3	1.7	....	9.4	....	......	30.1
275	Gruyere cheese	358	43.5	72.9	1.8	24.1	13.0	0.6	14.9	....	0.1	24.5
276	Ox blood	790	32.0	7.9	0.6	3.6	0.1	....	0.4	0.2	0.1	2.7
277	Mammal's meat	763	35.2	10.2	3.8	1.0	0.3	0.3	4.2	0.1	0.1	0.5
278	Meat-meal fodder	115	116.5	15.9	0.9	0.5	3.6	0.6	6.9	0.2	0.1	0.3
279	Hen's eggs, without shells	737	20.0	9.2	1.6	2.1	1.0	0.1	3.5	....	....	0.8
280	Live ox	597	26.6	46.6	1.7	1.4	20.8	0.6	18.6	....	0.1	2.8
281	Live calf	662	25.0	38.0	2.4	0.6	16.3	0.5	13.8	....	0.1	3.0
282	Live sheep	591	22.4	31.7	1.5	1.4	13.2	0.4	12.3	....	0.2	2.2
283	Live hog	128	20.0	21.6	1.8	0.2	9.2	0.4	8.8		......	1.2
284	Washed wool	520	94.4	9.8	1.9	0.3	2.4	0.6	1.8	....	2.5	0.8
285	Unwashed wool	150	54.0	70.8	56.2	3.0	1.8	0.4	0.7	3.4	2.0	3.2
286	Fresh May-bugs	704	30.1	13.4	5.0	0.8	0.4	1.1	5.6	0.2	0.2	....

I.

FERTILIZING CONTENT OF AMERICAN FEEDING-STUFFS.

Substance.	Moisture.	Ash.	Nitrogen.	Phosphoric Acid.	Potash.
GREEN FODDERS.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Alfalfa	70.25	2.30	0.72	0.13	0.56
Apple-pomace silage	75.00	1.05	0.32	0.15	0.40
Clover (alsike)	81.80	1.47	0.44	0.11	0.20
Clover (red)	80.00		0.53	0.13	0.46
Clover (scarlet)	82.50		0.43	0.13	0.49
Clover (white)	81.00		0.56	0.20	0.24
Corn fodder	78.61	4.84	0.41	0.15	0.33
Corn silage	77.95		0.28	0.11	0.37
Cow pea	78.81	1.47	0.27	0.10	0.31
Flat pea (*Lathyrus sylvestris*)	71.60	1.93	1.13	0.18	0.58
Horse bean (*Viscia faba*)	74.71		0.68	0.33	1.37
Hungarian grass (German millet)	74.31		0.39	0.16	0.55
Italian rye grass	74.85	2.84	0.54	0.29	1.14
Lupine (white)	85.35		0.44	0.35	1.73
Lupine (yellow)	83.15	0.96	0.51	0.11	0.15
Millet (common)	62.58		0.61	0.19	0.41
Millet (Japanese)	71.05		0.53	0.20	0.34
Perennial rye grass	75.20	2.60	0.47	0.28	1.10
Oat fodder	83.36	1.31	0.49	0.13	0.38
Orchard grass	73.14	2.09	0.43	0.16	0.76
Prickly comfrey	84.36	2.45	0.42	0.11	0.75
Rye fodder	62.11		0.33	0.15	0.73
Serradella	82.59	1.82	0.41	0.14	0.42
Soja bean	73.20		0.29	0.15	0.53
Sorghum fodder	82.19		0.23	0.09	0.23
Timothy	66.90	2.15	0.48	0.26	0.76
HAY AND COARSE FODDERS.					
Alfalfa	6.55	7.07	2.19	0.51	1.68
Barley straw	11.44	5.30	1.31	0.30	2.09
Buckwheat hulls	11.90		0.49	0.07	0.52
Carrot tops (dry)	9.76	12.52	3.13	0.61	4.88
Clover (alsike)	9.94	11.11	2.34	0.67	2.23
Clover (red)	11.33	6.93	2.07	0.38	2.20
Clover (scarlet)	18.30	7.70	2.05	0.40	1.31
Clover (white)			2.75	0.52	1.89
Corn fodder (with ears)	7.85	4.91	1.76	0.54	0.89
Corn stover (without ears)	9.12	3.74	1.04	0.29	1.40
Cow pea (entire plant)	10.95	8.40	1.95	0.52	1.47
Hay (mixed)	11.99	6.34	1.41	0.27	1.55
Hungarian grass	7.69	6.18	1.20	0.35	1.30
Japanese buckwheat	5.72		1.63	0.85	3.32

FERTILIZING CONTENT OF AMERICAN FEEDING-STUFFS.

Substance.	Moisture.	Ash.	Nitrogen.	Phosphoric Acid.	Potash.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Kentucky blue grass	10.35	4.16	1.19	0.40	1.57
Meadow fescue (*Festuca pratensis*)	8.89	8.08	0.99	0.40	2.10
Meadow fox tail (*Alopecurus pratensis*)	15.35	5.24	1.54	0.44	1.99
Meadow oatgrass (*Arrhenatærum avenaceum*)	15.35	4.92	1.16	0.32	1.72
Millet (common)	9.75		1.28	0.49	1.69
Millet (Japanese)	10.45	5.80	1.11	0.40	1.22
Oat straw	9.09	4.76	0.62	0.20	1.24
Orchard grass	8.84	6.42	1.31	0.41	1.88
Red top	7.71	4.59	1.15	0.36	1.02
Rowen (mixed grasses)	18.52	9.57	1.61	0.43	1.49
Rye grass, Italian	8.71		1.19	0.56	1.27
Rye straw	7.61	3.25	0.46	0.28	0.79
Rye grass, perennial	9.13	6.79	1.23	0.56	1.55
Salt-marsh bay	5.36		1.18	0.25	0.72
Sainfoin	12.17	7.55	2.63	0.76	2.02
Serradella	7.39	10.60	2.70	0.78	0.65
Scotch tares	15.80		2.96	0.82	3.00
Soja bean (straw)	13.00		1.75	0.40	1.32
Soja bean (whole plant)	6.30	6.47	2.32	0.67	1.08
Timothy	7.52	4.93	1.26	0.53	0.90
Wheat chaff	8.05	7.18	0.79	0.70	0.42
Wheat straw	12.56	3.81	0.59	0.12	0.51
GRAINS AND SEEDS.					
Corn	10.88	1.53	1.82	0.70	0.40
Barley	14.		1.48	0.81	0.42
Buckwheat	14.10		1.44	0.44	0.21
Millet (common)	12.68		2.04	0.85	0.36
Millet (Japanese)	13.68		1.73	0.69	0.38
Oats	18.17	2.98	2.06	0.82	0.62
Rice	12.60	0.82	1.08	0.18	0.09
Rye	14.90		1.76	0.82	0.54
Soja beans	18.33	4.99	5.30	1.87	1.99
Sorghum seed	14.00		1.48	0.81	0.42
Wheat (spring)	14.35	1.57	2.36	0.70	0.39
Wheat (winter)	14.75		2.36	0.89	0.61
MILL PRODUCTS.					
Barley (ground)	13.43	2.06	1.55	0.66	0.34
Corn meal	12.95	1.41	1.58	0.63	0.40
Corn and cob meal	8.96		1.41	0.57	0.47
Oats (ground)	11.17	3.37	1.86	0.77	0.59
Pea meal	8.85	2.68	3.08	0.82	0.99

FERTILIZING CONTENT OF AMERICAN FEEDING-STUFFS.

Substance.	Moisture.	Ash.	Nitrogen.	Phosphoric Acid.	Potash.
BY-PRODUCTS.	Per cent.	Per cent.	Per cent	Per cent.	Per cent.
Apple pomace	80.50	0.27	0.23	0.02	0.13
Brewers' grains (dry)	6.98	6.15	3.05	1.26	1.55
Brewers' Grains (wet)	75.01		0.89	0.31	0.05
Buckwheat middlings	14.70	1.40	1.38	0.68	0.34
Corn cobs	12.09	0.82	0.50	0.06	0.60
Cotton-seed hulls	10.63	2.61	0.75	0.18	1.08
Cotton-seed meal	9.90	6.82	6.64	2.68	1.79
Gluten meal	8.59	0.73	5.03	0.33	0.05
Hominy feed	8.93	2.21	1.63	0.98	0.49
Linseed meal (old process)	8.88	6.08	5.43	1.66	1.37
Linseed meal (new process)	7.77	5.37	5.78	1.83	1.39
Malt sprouts	10.38	12.48	3.55	1.43	1.63
Rice bran	10.20	12.94	0.71	0.29	0.24
Rice hulls (screenings)	10.30	9.00	1.97	2.67	0.71
Rye bran	12.50	4.60	2.32	2.28	1.40
Rye middlings	12.40	3.52	1.84	1.26	0.81
Starch feed (glucose refuse)	8.10		2.62	0.29	0.15
Wheat bran	11.74	6.25	2.67	2.89	1.61
Wheat middlings	9.18	2.30	2.63	0.95	0.63
Wheat screenings	8.41	6.27			
ROOTS AND TUBERS.					
Carrots	89.79	9.22	0.15	0.09	0.51
Beets (yellow fodder)	90.60	0.95	0.19	0.09	0.46
Beets (red)	87.73	1.13	0.24	0.09	0.44
Beets (sugar)	86.95	1.04	0.22	0.10	0.48
Mangel-wurzels	87.29	1.22	0.19	0.09	0.38
Potatoes	79.75	0.99	0.21	0.07	0.29
Ruta-bagas	89.13	1.06	0.19	0.12	0.49
Turnips	89.49	1.01	0.18	0.10	0.39
FRUITS AND NUTS.					
Apples	85.30	0.39	0.13	0.01	0.19
Chestnuts	40.00	1.32	1.18	0.39	0.63
Grapes	83.00	0.50	0.16	0.09	0.27
Peanut vines	10.00	12.36		0.29	0.90
Peanuts	10.00	2.21	4.01	0.82	0.88

II.

PERCENTAGE COMPOSITION OF FERTILIZING MATERIALS.

Substance.	Moisture.	Nitrogen.	Potash.	Phosphoric Acid.			Lime.	Magnesia.	Sulphuric Acid.	Chlorine.
				Soluble	Reverted.	Total.				
Ammonite	5.88	11.33	.....	.....	.....	3.43	.....	.....	.....	.....
Ashes (hard-coal)	.....	.....	0.10	.....	.....	0.10	.....	.....	.....	.....
Ashes (soft-coal)	.....	.....	0.40	.....	.....	0 40	.....	.....	.....	.....
Ashes (lime-kiln)	15.45	.....	1.20	.....	.....	1.14	48.50	2.60	.....	.....
Ashes (wood-leached)	30.22	.....	1.27	.....	.....	1.51	28.08	2.66	0.14	.....
Ashes (wood-unleached)	12.50	.....	5.25	.....	.....	1.70	34.00	3.40	.....	.....
Bone-ash	7.00	.....	.....	.....	.....	35.89	44.89	.....	.....	.....
Bone-black	4.60	.....	.....	.....	.....	28.28	.....	.....	.....	.....
Bone-black (dissolved)	.....	.....	.....	15.40	1.30	17.00	.....	.....	.....	.....
Bone-meal	7.50	4.05	.....	0.40	7.60	23.25	.....	.....	.....	.....
Bone-meal (dissolved)	.....	2.60	.....	13.53		17.60	.....	.....	.....	.....
Carbonate of pot. and mag.	.....	.....	18.50	.....	.....	.....	.....	16.50	.....	.....
Carnallite	.....	.....	13.68	.....	.....	.....	.....	13.19	0.56	41.56
Castor pomace	9.50	5.50	1.10	.....	.....	1.75	.....	.....	.....	.....
Cotton-hull ashes	7.80	.....	22.75	1.25	6.50	8.85	9.60	10.75	.....	.....
Cotton-seed meal*	7.75	7.10	1.80	.....	.....	3.10	.....	.....	.....	.....
Cotton-seed meal	.....	4.30	1.50	.....	.....	3.10	.....	.....	.....	.....
Dried blood	12.50	10.52	.....	.....	.....	1.91	.....	.....	.....	.....
Dried fish	12.75	7.25	.....	0.55	2.60	8.25	.....	.....	.....	.....
Guano, Bat	40.09	8.20	1.31	2.37	1.24	3.80	.....	.....	.....	.....
Guano, Caribbean	7.31	.....	.....	.....	.....	26.77	39.95	3.25	2.68	.....
Guano, Peruvian	14.81	7.35	2.65	3.20	4.10	15.00	.....	.....	.....	.....
Horn and hoof waste	10.17	13.25	.....	.....	.....	1.83	.....	.....	.....	.....
Kainit	3.20	.....	13.54	.....	.....	.....	1.15	9.80	20.25	33.25
Kelp	87.75	0.20	0.24	.....	.....	0.06	0.40	0.20	.....	.....
Krugite	4.82	.....	8.42	.....	.....	.....	12.45	8.79	31.94	6.63
Marl (Kentucky)	1.50	.....	0.15	.....	.....	.4	34.00	.....	.....	.....
Marl, N. J. green sand	1.50	.....	3.5	.....	.....	2.5	5.00	.....	.....	.....
Meat scrap	12.09	10.44	.....	.....	.....	2.07	.....	.....	.....	.....
Muck	50.00	1.10	0.15	.....	.....	0.10	.....	.....	.....	.....
Muriate of potash	2.00	.....	51.48	.....	.....	.....	.....	.....	.....	48 80
Navassa phosphate	7.60	.....	.....	.....	.....	34.27	37.45	.....	.....	.....
Nitrate of pot. (saltpetre)	1.93	13.09	45.19	.....	.....	.....	.....	.....	.....	.....
Nit. of soda (Chili saltpetre)	1.40	15.70	.....	.....	.....	.....	.....	.....	.....	.....
Oyster-shell lime	15.00	.....	0.05	.....	.....	0.18	55	0.35	0.60	.....
Peat	61.50	0.85	0.18	.....	.....	0.08	.....	.....	.....	.....
Phosphate-rock (Florida)	2.25	.....	.....	.....	.....	24.50	28.50	.....	.....	.....
Phosphate-rock (S. Carolina)	1.50	.....	.....	0.27	0.07	28.13	41.87	3.03	.....	.....
Phos.-rock (S.C., dissolved)				11.60		15.20				

* Without hulls.

PERCENTAGE COMPOSITION OF FERTILIZING MATERIALS.

Substance.	Moisture.	Nitrogen.	Potash.	Phosphoric Acid.			Lime.	Magnesia.	Sulphuric Acid.	Chlorine.
				Soluble	Reverted.	Total.				
Plaster	.....	.....	.....	.....	.....	.....	20.93	.....	46.51	..
Sewage-sludge, precipitated	88.49	0.05	0.05	.....	.....	0.10	1.58	0.39	.....	.....
Tan-bark ashes	3.61	.....	2.04	.....	.....	1.61	33.46	3.55	.....	.....
Sumac waste	63.06	1.19	3.25	.....	.....	1.14	3.25	....	...	.....
Sulphate of ammonia	1.00	20.50	...	.....	.....	.....	.....	.....	60.00	....
Sulph. potash & magnesia	4.75	.....	25.50	.....	.....	.....	2.57	.....	44.25	2.60
Ammonite	5.88	11.33	.....	.....	.....	3.00	.....	.....	....	.....
Sulphate of potash	2.54	.....	33.40	.....	.....	.....	.....	.....	45.72	.....
Sulph. potash (high-grade)	.....	.....	51.50	.....	.....	.....	.....	.....	.....	.....
Sylvanite	7.25	.....	16.65	.....	.....	.....	.....	.....	.....	.....
Tankage	10.00	6.70	.....	0.30	5.10	11.80	.....	.....	.....	.....
Thomas' slag	1.45	.....	.....	.....	3.06	23.49	48.66	3.42	.....	.....
Tobacco-stalks	6.18	3.71	5.02	.....	.....	0.65	2.22	0.59	.....	.....
Tobacco-stems	10.00	2.35	8.20	.....	.....	0.70	4.20	0.80	0.65	0.65
Wool-washings	.....	.....	3.92	.....	.....	.....	.....	.....	.....	.....
Wool-waste	15.80	6.50	1.20	.....	.....	03.5	0.11	0.06	.....	.....

III.

COMPOSITION OF FARM MANURES.

Substance.	Moisture.	Nitrogen.	Potash.	Phosphoric Acid.	Lime.	Magnesia.	Sulphuric Acid.	Chlorine.
Barnyard manure, average	68.87	0.49	0.43	.32	.....	.....	.....	.....
Cattle excrement, fresh	.....	.29	.10	.17	.....	.....	.....	.....
Cattle urine, fresh	.....	.58	.49	....	.....	.....	.....	.....
Hen manure, fresh	60.00	1.10	0.56	0.85	.....	.....	.....	.....
Horse excrement, fresh	.....	0.44	0.35	0.17	.....	.....	.....	.....
Horse urine, fresh	.....	1.55	1.50	....	....	.....	.....	.....
Human excrement	77.20	1.00	.25	1.09	.....	.....	.....	.....
Human urine	95.90	0.60	0.20	0.17	.....	.....	.....	.....
Pigeon manure, dry	10.00	3.20	1.00	1.90	2.10	0.80	0.60	0.50
Poudrette (night-soil)	50.00	0.80	0.30	1.40	0.80	0.60	0.40	0.08
Sheep excrement, fresh	.....	0.55	0.15	0.31	.....	.....	....	.....
Sheep urine, fresh	.....	1.95	2.26	0.01	.....	.....	....	.....
Stable manure, mixed	73.27	0.50	0.60	0.30	.....	.....	.....	.....
Swine excrement, fresh	.....	0.60	0.13	0.41	.....	.....	..	..
Swine urine, fresh	.....	0.43	0.83	0.07	.....	.....	..	.....

IV.

MANURIAL VALUE OF FARM PRODUCTS.*

Substance.	Pounds Per Ton.			Value Per Ton.				Manurial Value of $10 Worth.
	Nitrogen.	Phosphoric Acid.	Potash.	Nitrogen.	Phosphoric Acid.	Potash.	Total.	
Alfalfa	40.2	9.3	27.8	....	....	....	....	....
Barley	39.65	9.0	15.4	$6.74	$0.63	$0.62	$ 7 99	$2.96
Cheese	90.60	23.0	5.0	15.40	1.61	0.20	17.21	0.69
Clover hay	40.16	11.2	36.6	6.83	0.78	1.46	9.07	9.07
Corn	33.06	11.8	7.4	5.62	0.83	0.30	6.75	3.70
Cotton-seed meal	135.65	29.2	56.2	23 06	2.04	2.25	28.35	10.12
Kentucky blue-grass	21.1	7.3	29.2	....	....	....	....	....
Linseed meal	105.12	32.2	24.8	17.87	2.25	0.99	21.11	7.54
Live cattle	53.2	37.2	3.4	9.04	2.60	0.14	11.78	1.18
Meadow hay	20.42	8.2	26.4	3.47	0.57	1.06	5.10	5.10
Milk	10.20	3.4	3.0	1.73	0.24	0.12	2.09	0.88
Oats	36.42	12.4	8.8	6.21	0.87	0.35	7.43	3.86
Potatoes	7.01	3.2	11.4	1.19	0.22	0.46	1.87	0.12
Sugar-beets	4.40	2.00	9.60	....	....	....	....	....
	25.6	9.80	33.80	....	....	....	....	....
Timothy hay	21.0	5.0	27.5	....	....	....	....	....
Wheat	37.53	10.6	15.8	6.38	0.74	0.63	7.75	2.58
Wheat bran	49.15	28.6	54.6	8.35	2.00	2.10	12.45	7.78
Wheat straw	11.80	2.40	10.2	....	....	....	....	....

* These figures indicate *commercial*, not *agricultural*, values; what the fertilizing ingredients would *cost* in the market at the time the table was arranged. This basis constantly varies, and the table does not indicate *actual* value to the farmer, but the *relative* value of the different products.

V.

FERTILIZING INGREDIENTS IN DAIRY-PRODUCTS.

Substance.	Nitrogen.	Phosphoric Acid.	Potash.	Substance.	Nitrogen.	Phosphoric Acid.	Potash.
Butter	0.12%	0.04%	0.036%	Skim-milk	0.56%	0.20%	0.185%
Buttermilk	0.48	0.17	0.158	Whey	0.15	0.14	0.181
Cheese	3.93	0.60	0.120	Whole-milk	0.53	0.19	0.175
Cream	0.40	0.15	0.130				

VI.

AVERAGE COMPOSITION OF AMERICAN SOILS.

Constituents.	Loam.	Sandy Loam.	Sandy Soil.	Clay.	Red Clay.	Alluvial-bottom Land.	Peat.	Gumbo.	Salt Marsh.	Drift.	Unbroken Prairie.	Cultivated Prairie.†
Fine earth....	97.00%	92.50%	86.60%	99.00%	99.64%	100. %	65.00%	.....	95.00%	67.96%	97.00%	94.00%
Total nitrogen	.34	.19	.05	.17	.17	.16	.80	.38%	......	.15	.23	.16
Insoluble silica.	55.63	76.21	88.20	52.02	48.01	74.12	25.27	60.21	51.33	78.19	74.01	73.90
Combined silica	17.21	7.36	3.48	15.46	21.81	9.22	6.78	9.00	7.16	3 99	10.72	7.68
Potash.......	.41	.55	.25	.75	1.70	.67	.29	.90	.34	.32	.65	.38
Soda...........	.32	.19	.44	.30	.84	.64	.27	.61	.32	.16	.73	.28
Lime...........	1.13	1.03	1.20	5.27	.99	.56	6.58	1.07	2.06	.35	1.07	1.18
Magnesia......	.91	.50	.47	2.40	2.35	.89	.45	.84	4.39	.38	.69	.45
Iron oxide......	3 02	3.07	2.52	5.39	4.46	.67	.69	3.49	9.56	3.43	4.43	3.22
Alumina........	5.44	2.94	2.58	10.98	10.15	5.82	3.57	9.15	6.04	4.01	4.62	4.44
Phosphoric acid	.17	.10	.10	.15	.17	.12	.46	.13	.13	.02	.21	.18
Sulphuric acid.	.26	.05	.04	.06	.06	.41	.24	.11	.38	.17	.08	.10
Carbonic acid	.50	.57	.01	.....	1.12	.51	7.24	.13	.....	.65	.16	.30
Volatile matter	10.41	4.81	1.80	3.19	......	4.78	44.49	14.29	17.98	*5.62	5.02	6.33

* Water and organic matter.
† Average of 12 years' cultivation to wheat, corn, and oats, without fallow.

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