DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 320

GEOLOGY AND WATER RESOURCES OF SULPHUR SPRING VALLEY, ARIZONA

BY

O. E. MEINZER AND F. C. KELTON

WITH

A SECTION ON AGRICULTURE

BY

R. H. FORBES

Prepared in cooperation with the
Arizona Agricultural Experiment Station

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GEOGRAPHIC SKETCH.

Sulphur Spring Valley lies in southeastern Arizona and is crossed by the thirty-second parallel and the one hundred and tenth meridian. From the international boundary, which is arbitrarily taken as its southern limit, it extends north-northwestward for 90 miles. Its average width is about 20 miles and its area is fully 1,800 square miles. (See fig. 1.)

The valley is bordered on each side by a chain of mountain ranges. The mountains on the west separate it from San Pedro Valley, which drains northward into Gila River; the mountains on the east separate it from San Simon Valley, which drains northward into the Gila, and from San Bernardino Valley, which drains southward into the Yaqui. Nearly 1,000 square miles of the bordering mountainous areas shed their storm waters into Sulphur Spring Valley. Thus the valley and the mountains whose drainage is tributary to it comprise an area of about 2,800 square miles. The southern two-fifths of this area is tributary to Whitewater Draw, which drains into the Yaqui; the northern three-fifths forms a depression with no drainage outlet but with a large barren alkali flat in the lowest part. North of this depression is Arivaipa Valley, which drains northwestward into the San Pedro.

Sulphur Spring Valley ranges in altitude from less than 3,900 feet where Whitewater Draw crosses the international boundary to more than 5,000 feet above sea level on the highest slopes near the mountains. Several of the loftiest mountain peaks in the bordering ranges rise more than 9,000 feet above the sea.

The climate is arid or semiarid and most of the rain falls in a few heavy storms between the middle of July and the middle of September. The average temperature at Willcox during a period of 25 years was 61.7° F.[1] The hottest part of the year is in June and July, preceding the rainy season. In the winter the temperature seldom falls below 10° F. above zero. The rare, dry, cloudless atmosphere allows the rays of the sun to penetrate to the earth readily but also permits the rapid escape of the heat. Hence, in both summer and winter it is warm while the sun shines and cold at night.

FIGURE 1.—Map showing physiographic provinces of Arizona and position of Sulphur Spring Valley.

On the highest mountains, especially the Chiricahua and Pinaleno ranges, the rainfall is sufficient to support a growth of tall yellow pine, but the low ranges receive so little rain that they carry only small timber or are quite bare. In the mountains there are many springs the largest of which give rise to small streams, but no permanent stream enters the valley.

[1] Summary of the climatological data for the United States, U. S. Weather Bur., 1908, sec. 3, p. 28.

HISTORICAL SKETCH.

Sulphur Spring Valley, together with the rest of that part of Arizona which lies south of the Gila, was acquired from Mexico by purchase in 1853. Up to that time and until about 20 years later it was occupied almost exclusively by the Chiricahua Indians, who were among the most warlike of the Apache tribe[1] and who, according to some authorities, were the fiercest Indians on the continent.[2] Consequently this region was avoided by the Spanish explorers and missionaries and later by Mexican and American prospectors and settlers.

In 1846 Gen. Kearny, in making his well-known military expedition from New Mexico to the Pacific coast, followed the Gila, and therefore went north of Sulphur Spring Valley; but Lieut. Cooke, with his "Mormon battalion," took a more southerly course and opened a wagon road by way of San Bernardino and Tucson. In the next few years the San Bernardino route was followed by numerous emigrant parties on their way to California. In 1855, two important exploring expeditions crossed Sulphur Spring Valley. One of these, in charge of William H. Emory, made the Mexican boundary survey; the other, in charge of Lieut. John G. Parke, made explorations for a transcontinental railroad route near the thirty-second parallel.

The boundary survey party stopped for some days at the springs in San Bernardino Valley to make astronomic observations, but after leaving the springs hurried westward across Sulphur Spring Valley because no watering place was known in its southern part.[3] Parry,[4] the geologist of the expedition, gives the following description of San Bernardino Valley:

> On the western edge is situated the deserted settlement of San Bernardino. Adjoining this rancho are numerous springs, spreading out into rushy ponds and giving issue to a small stream of running water * * *. Signs of previous cultivation are limited, this settlement having been engaged principally in stock raising. The numerous bodies of wild cattle now running at large over this section of country are the remains and offspring of domestic herds, now widely scattered and hunted by Indians.

Parry[4] describes Sulphur Spring Valley along the international boundary as follows:

> The descent to the alluvial bed of the Agua Prieta [Whitewater Draw] is over a long, tedious slope, the gravelly tableland giving place to extensive tracts of clay or loam, supporting a patchy growth of coarse grass. The "Black Water" Valley at its lowest depression at this point contains no constant running stream, its course being mainly occupied with low saline flats or rain-water pools. Extensive lagoons are said to occur in this valley a short distance south of where the road crosses.

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[1] Hamilton, Patrick, The resources of Arizona, 1883, p. 235.

[2] Encyclopedia Americana, vol. 1, 1903. (See under "Apache.")

[3] Emory, W. H., Mexican Boundary Survey, vol. 1, 1857, p. 31.

[4] Parry, C. C., Mexican Boundary Survey, vol. 1, pt. 2, Geology and paleontology, 1857, p. 17.

The railroad expedition crossed the northern part of Sulphur Spring Valley and camped at Croton Springs, on the northwest margin of the alkali flat.[1] By the members of this expedition the name "Playa de las Pimas" was given to the alkali flat and was used in an indefinite sense for the entire Sulphur Spring Valley. In the report of the expedition comments are made on the strange aspect of the valley, whose topographic development is so strikingly different from that of the humid valleys with which the explorers were familiar. Thomas Antisell, the geologist of the expedition, was impressed by the springs at the margin of the flat and also by the amount of water that accumulated on the flat in wet seasons. He expressed the opinion[2] that from these two sources enough water could be obtained to operate a railroad, but he evidently had no conception of the great quantity of water that underlay the valley.

About 1859 the Chiricahua Indians held a council of war at which were present the two notorious Apache chiefs, Cochise and Geronimo. Cochise was the chief of the Chiricahua band and Geronimo, then a young man, represented a small band which ranged along the Gila north of Sulphur Spring Valley. As a result of this council, the Chiricahuas, together with other Apaches, went on the warpath.[3] From this time until about 1872 the Apaches made innumerable bloody raids, directed against Mexican settlements in Sonora and against United States soldiers and civilians wherever they were found. Several encounters took place in the vicinity of Apache Pass, where Camp Bowie was established about 1862.[4] Cochise took advantage of a natural fortress formed by the rugged crags and peaks of granite and quartzite in the Dragoon Mountains, a few miles west of the present village of Pearce; and this rugged mountain area, conspicuous from a large part of the valley because of its fantastic castellated appearance, is still known as the Cochise Stronghold.

In 1872 Gen. O. O. Howard made a treaty of peace with Cochise, as a result of which was established the Chiricahua Reservation which included most of Sulphur Spring Valley. The agency was successively at Sulphur Springs, the San Simon Ciénega, Pinery Canyon, and Apache Pass. From 1872 to 1874 Gen. George H. Crook made vigorous and effective war upon the Indians who were still hostile. Cochise, however, remained faithful to the treaty until his death in 1874. In 1876 further trouble arose, as a result of which the Chiricahua Indians were removed to the San Carlos Reser-

[1] Explorations and surveys for a railroad from Mississippi River to the Pacific Ocean, 1853–1856, vol. 7, 1857.

[2] Idem, pt. 2, p. 148.

[3] Barrett, S. M., Geronimo's story of his life, New York, 1906, p. 47.

[4] Bancroft, H. H., History of Arizona and New Mexico, 1889, p. 515.

vation, and Sulphur Spring Valley was restored to the public domain.[1]

About 1872 Fort Grant was moved to the west base of the Pinaleno Mountains (see Pl. I), and two ranches with over 10,000 head of cattle were established in Sulphur Spring Valley. One of these was Hooker's ranch (Sierra Bonita), located at the ciénega near the north end of the valley.[2]

In 1873 G. K. Gilbert and Oscar Loew, in connection with the Wheeler Survey, made a scientific expedition into the northeastern part of Sulphur Spring Valley. Gilbert ascended Mount Graham, in the Pinaleno Range, from the northeast, and then went to the vicinity of Dos Cabezos and Fort Bowie, whence he traveled northeastward across San Simon Valley. Loew reported that "water is reached almost everywhere on this plain at a depth of 10 feet," and expressed the belief that for this reason certain crops could be raised without irrigation. He analyzed two samples of soil, one taken in the vicinity of Fort Grant and the other on the alkali flat. He spoke with enthusiasm about the good quality of most of the soil but recognized the inferiority of that on the alkali flat. He announced that "crops will be raised this year for the first time."[2]

After 1876 bands of Apaches frequently escaped from the San Carlos Reservation and went forth on bloody raids. In 1883 a band of about 250 Indians led by Geronimo left the reservation and made a raid into Mexico. According to Geronimo's story, this band went through Apache Pass and had an encounter with United States soldiers in Sulphur Spring Valley.[3] In 1886 Geronimo and Naiche, the son and successor of Cochise, surrendered to Gen. N. O. Miles near Skeleton Canyon, about 10 miles north of the Mexican boundary. With their entire band they were taken to Fort Bowie and soon after deported from Arizona, first to Fort Pickens, Fla., and ultimately to Fort Sill, Okla., where Geronimo died in 1909.

After 1872, when the Indians came to be at least partly under the control of the United States troops, Sulphur Spring Valley became attractive as a cattle range and many ranches were established, most of which were situated either near the axis of the valley, where shallow water was discovered, or near the mountains, where springs or shallow wells were located. In the prospecting for water that resulted from the establishment of the ranches, the position of the ground-water table throughout the valley was approximately determined. In 1880 the main line of the Southern Pacific Railroad was built across the northern part of the valley,[4] and the village of Will-

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[1] Bancroft, H. H., History of Arizona and New Mexico, 1889, p. 566.
[2] Loew, Oscar, U. S. Geog. Surveys W. 100th Mer., vol. 3, 1875, pp. 591–593.
[3] Barrett, S. M., Geronimo's story of his life, 1906, p. 134.
[4] Bancroft, H. H., op. cit., p. 604.

cox grew to be the supply station for a large surrounding area. In recent years the cattle ranches have tended to become consolidated into a few large establishments, among the most important of which are Hooker's ranch and the J. H. ranch in the northern part, the Riggs ranches and the Chiricahua Cattle Co.'s ranch in the central part, and the Four Bar and Double Rod ranches in the southern part.

The first important mining district of the region was at Tombstone, situated just west of the Sulphur Spring drainage basin. It enjoyed great fame and prosperity in the early eighties. Later this camp was eclipsed by the Bisbee district, which has had a steady growth up to the present time. Since the early days of Tombstone, prospecting and mining have also been carried on at Dos Cabezos and at Johnson and other parts of the Dragoon and Little Dragoon mountains. The following statements are abbreviated from Hamilton's account[1] of the early history of Tombstone:

The discovery of mineral in the vicinity of Tombstone dates from 1877. When A. E. Shieffelin, a persistent prospector, announced his intention of exploring the country beyond the San Pedro, he was warned that he would find a tombstone instead of a fortune in Cochise's domain. Nothing daunted, he left late in 1877 for the region east of the San Pedro and in February, 1878, discovered rich silver deposits. In remembrance of the doleful prognostications he named the district Tombstone. The report of his rich discoveries spread like wildfire. Thousands of locations were staked out and many valuable discoveries made and a city sprang into existence as if by magic.

The following facts in regard to the history of the Bisbee district are taken chiefly from an account by Ransome:[2]

The presence of ore in the southern part of the Mule Mountains was probably known as early as 1876, but it was not until four years later that there was discovered the first of the great bodies of copper ore whose subsequent exploitation has caused the steady development of the Warren mining district and the growth of the towns of Bisbee and Douglas. In 1880 active operations were begun in the Copper Queen mine, and in 1881 two furnaces were erected in which wood was used for fuel. Benson, on the Southern Pacific Railroad, was at first the nearest railway station. Between this point and Bisbee supplies and bullion were transported by teams. After the completion of the railroad between Benson and Nogales, the Copper Queen Co. built a toll road over Mule Pass to the railroad at Fairbanks, and in 1884 freight was hauled over this road by 18-mule teams. Later a traction engine was used for a short time. In 1887

[1] Hamilton, Patrick, The resources of Arizona, 1883, p. 74.

[2] Ransome, F. L., Geology and ore deposits of the Bisbee quadrangle, Ariz.: Prof. Paper U. S. Geol. Survey No. 21, 1904, pp. 13-15.

grading was begun for a railroad to connect Bisbee with the Southern Pacific system at Fairbanks. The El Paso & Southwestern Railroad east from Bisbee was completed in 1902. As soon as it was built Douglas sprang into existence, and, owing to the location of the large smelters at this point, it grew within a few years to be one of the largest and most enterprising cities of Arizona.

INDUSTRIAL DEVELOPMENT.

As nearly as can be estimated from the 1910 census returns, the drainage basin of Sulphur Spring Valley contains about 29,000 inhabitants. Of this number somewhat over 15,000 live in mining towns in the mountains and nearly 14,000 live in the valley itself. Of the mountain population, over 13,000 reside in the Bisbee mining district and the rest chiefly in Courtland, Gleeson, Dos Cabezos, and Johnson. Of the valley population, 6,437 live in Douglas and the rest in Willcox, Pearce, and Cochise, and on the ranches and farms throughout the valley. From 1900 to 1910 the population of Cochise County increased 274 per cent, which is a higher rate of increase than in any other county in the State. This increase is due primarily to mining developments in the vicinity of Bisbee and secondarily to agricultural developments in Sulphur Spring Valley. The percentage of increase was no doubt even greater in Sulphur Spring Valley than in Cochise County as a whole.

Two main lines of railroad have been built through the valley—the Southern Pacific, which crosses the northern part, and the El Paso & Southwestern, which crosses the southern part. A branch of the Southern Pacific known as the Arizona Eastern extends from Cochise to Pearce and thence to Kelton Junction and Gleeson, and a line from Kelton Junction to Bisbee has been partly built. Another branch road, not now in operation, extends from Dragoon station to Johnson. A branch of the El Paso & Southwestern extends from Douglas to Kelton Junction and Courtland, and another extends from Douglas into Sonora (Pl. I). Altogether the drainage basin of Sulphur Spring Valley contains about 170 miles of railroad.

By far the most important industry in this region is the mining and smelting of copper ore. In 1908 the value of the copper, gold, silver, and lead produced within the drainage basin of Sulphur Spring Valley was $17,831,000, of which $17,495,000 worth was produced in the Bisbee district. In 1911 the Bisbee district furnished over 130,000,000 pounds of copper, which was about 43 per cent of the copper produced in Arizona and nearly one-eighth of the total production of this metal in the United States. This district ranks at present as one of the largest copper camps in the world, being exceeded in the United States only by Butte and Lake Superior. Nearly all the ore mined at Bisbee is smelted at Douglas. According to the 1910 census, the combined population of the Bisbee district, where the ore is mined, and the city of Douglas, where the smelters are located, was nearly 20,000.

Within the valley itself the principal industry has been the raising of cattle. A good growth of grass in most parts of the valley has been specially favorable for the development of this industry, whereas the arid climate and the supposed absence of water for irrigation has, until recently, made the region unattractive to agriculturists and caused it to be left uncontested to the cattlemen. In the 40 years since cattle were first brought to the valley the ranches, with their distinctive mode of life, have become well established and the cattle industry has attained large importance.

Until recently agriculture has been practically confined to a few fields supplied either by irrigation or natural subirrigation from the principal canyons in the Pinaleno and Chiricahua mountains. In the last few years the valley has received a great and sudden influx of homeseekers who are seriously attempting agriculture, but up to the present time the total value of the agricultural products has been very small. (See Pl. II, in pocket.)

The large mining population within this basin has created a market for agricultural and dairy products, and this will assist greatly in the development of the valley. Thus far the local demand for these products is only in very small part supplied from local sources.

RELATION OF THE INDIANS TO WATER SUPPLIES.

Indian relics, such as mortars, pestles, metates,[1] polished stones used in grinding on the metates, and flint chips, are found in different parts of Sulphur Spring Valley, particularly in the vicinity of Sulphur Springs, on the ancient beach ridge west of the alkali flat, and on the sand hills northeast of the flat. At the top of a butte about 50 feet high, situated only a few rods east of Sulphur Springs, 23 conical holes have been excavated in the porphyry of which the butte is composed, and other holes of the same kind are found on the sides of this butte. They range from a few inches to a foot or more in depth, and are generally deep in comparison with their diameter. They were apparently made by the Indians and used as mortars. Only one pestle was seen near the butte, but it is not surprising that most of the pestles should before this time have been carried away as relics. A view of several of the mortars is given in Plate III, *A*, to show their resemblance to potholes formed in hard rocks by eddies of running water. This locality was obviously a desirable place of abode, because the butte afforded a point of vantage from which the surrounding plain could be overlooked and because

[1] A metate is a flat, oblong stone on which grain or seeds are reduced to meal by rubbing under a smaller stone. It serves the same purpose as a mortar.

A. INDIAN MORTARS, RESEMBLING NATURAL POTHOLES.

B. RECENT EROSION IN WHITEWATER DRAW.

the springs furnished a water supply. Similar mortars are found in the Three Sister Buttes, 1½ miles east of the springs.

West of the alkali flat and north of Cochise the ancient beach described on page 36 is unusually prominent, and from it the valley to the east can be overlooked. A few stone implements were found on this beach at a spring a little over a mile from Croton Springs. Evidently this location was attractive for the same reasons as the butte at Sulphur Springs.

In secs. 14 and 23, T. 14 S., R. 25 E., 1½ to 2 miles from the northeastern margin of the barren flat, is a chain of sand hills about 50 feet high, from which a good view of the surrounding portion of the valley can be obtained. The stage road from Willcox to Dos Cabezos passes through the gap that separates the southernmost of these hills from the rest. On the tops of these hills were found a great number of stone relics consisting of large metates, small stones with polished surfaces evidently used for grinding on the metates, one broken but carefully rounded cylindrical implement suggesting a pestle, a wedge-shaped stone about 15 inches long planted deep in the ground at a small angle with the vertical, and numerous angular flint chips such as might have been produced in making arrowheads or spearheads. The implements and fragments are grouped to some extent on bare patches of ground, commonly surrounding a large metate. The implements have become partly covered with a white calcareous coating. All the stones must have been brought from some distance, for on the sand hills stones do not naturally occur at the surface.

There is no spring in the vicinity of these sand hills, but on the plain immediately west of them ground water occurs at a depth of 12 feet. On E. Brumett's farm, 2½ miles southwest of the southernmost hill, the ground water comes practically to the surface, and the oldest settlers report that there was once a seep where the artesian well on this farm is now located.

The large number of mortars and metates found in the interior of Sulphur Spring Valley indicates that considerable grinding was at one time done there. They may have been used to some extent for grinding the seeds of native plants, such as yucca or mesquite, but it is not probable that so many large mortars would have been required for this purpose. Corn could have been raised near the mountains, where small irrigation supplies are available, and could have been transported to the interior of the valley to be ground, but it seems more probable that it was raised nearer the mortars. No positive information is at hand as to whether at any time before the advent of the white men fields were cultivated or irrigation practiced in the interior shallow-water belt of the valley.

The Apache Indians depended chiefly on game for their subsistence, although they cultivated small fields in a crude manner, raising corn, beans, melons, and pumpkins. They are also reported to have made meal by grinding the corn in stone mortars or metates.[1]

RELATION OF INDUSTRIAL DEVELOPMENT TO WATER SUPPLIES.

In 1855 the Mexican boundary survey party crossed the southern part of Sulphur Spring Valley, hurriedly, because there was no known watering place along the route followed. In the same year, however, the exploring expedition that crossed the northern part found water at Croton Springs and at Ewell Spring, where Dos Cabezos is now situated. At this time Antisell [2] suggested that water could be obtained within a mile of Croton Springs by sinking wells, but apparently no one had yet suspected that any considerable part of the valley was underlain by water-bearing beds. The delay of 17 years that ensued between the time of these expeditions and that of the first settlements was, however, due to the presence of hostile Indians rather than to lack of water, for as soon as it became possible for white men to live in the region supplies of water sufficient for domestic use and ranching were rapidly discovered. As early as 1873 the report had become current that the valley was generally underlain by shallow water.[3]

Nevertheless, the location of the first settlements was determined chiefly by the position of known water supplies. Fort Grant was established at the base of the Pinaleno Mountains, where water from mountain springs could be obtained; M. L. Wood settled in Bonita Draw, where the ground was saturated with water from the Pinaleno Mountains; H. C. Hooker located his ranch (the Sierra Bonita) at the ciénega, where water was to be had by digging a few feet; and the location of practically all the other old ranches was obviously determined by the presence of springs or shallow water.

Ore deposits occur without relation to present water supplies, and hence in the arid regions many mining towns spring into existence in localities where water is obtainable only with great difficulty. In some of the mining camps of this region there was a dearth of water, especially for smelting or concentrating purposes. At least two stamp mills were erected in the shallow-water belt of Sulphur Spring Valley—one near Cochise and the other near the Soldiers Hole.

During the years of the greatest prosperity of Tombstone that camp was supplied with water from the Huachuca Mountains. Later, when the mine at Tombstone reached about the 500-foot level, a vast

[1] Barrett, S. M., Geronimo's story of his life, 1906, pp. 20, 22.

[2] Antisell, Thomas, Explorations and surveys for a railroad from the Mississippi River to Pacific Ocean, 1853–1856, vol. 7, pt. 2, 1857, p. 148.

[3] Loew, Oscar, U. S. Geog. Surveys W. 100th Mer., vol. 3, 1875, pp. 591–593.

quantity of water was encountered, and heavy pumping had to be done in order to operate below the water level.

At Bisbee small supplies of water were obtained from shallow wells and from a few springs, but there was so much difficulty in obtaining enough water for operating the small smelters in use in the early days that pumping from San Pedro River was at one time seriously considered.[1] Later the difficulty was settled by erecting smelters at Douglas and by pumping the water for general consumption from wells at Naco. The deepest workings at Bisbee have found large quantities of mineralized water which must be pumped to the surface. The water taken from the Calumet & Arizona mine is led to the Warren ranch, on the Espinal Plain, several miles south of Bisbee, where it is used for irrigating alfalfa and other crops.

The ranching development in Sulphur Spring Valley proved the existence of water under the valley but did not demonstrate the fact that this water occurs in large quantities. The smelters built at Douglas created the first demand for really large supplies, and consequently led to the drilling of deep wells and the application of severe pumping tests to these wells. The largest yield developed in these wells is obtained from the 296-foot well at the Calumet & Arizona smelter, from which, according to a test covering 21 days reported by the engineers of the company, an average of 1,106 gallons a minute is obtainable by air lift. Large supplies have also been developed at Douglas in wells drilled for the Copper Queen smelter, the railroad, and the city waterworks. At Willcox the Southern Pacific Co. sunk a shallow well, which yields generously.

The settlers who within the last few years have located in this valley have come intending to make a livelihood by cultivating the soil. The great value of irrigation water for this purpose has become manifest to all who have attempted dry farming. As a result scores of pumping plants have been installed, most of which consist of centrifugal pumps and gasoline engines and have a capacity of a few hundred gallons a minute.

PURPOSE AND SCOPE OF THE INVESTIGATION.

The settlers who come to this valley hoping to make a living by agriculture find themselves confronted by unfamiliar conditions and forced to apply methods of irrigation and cultivation in regard to which they have had little or no experience. In such a situation it is inevitable that costly mistakes will be made and that there will be some failures. The settlers are aware of these facts and desire information and advice on the subject that concerns them so vitally.

[1] Ransome, F. L., Geology and ore deposits of the Bisbee quadrangle, Arizona: Prof. Paper U. S. Geol. Survey No. 21, 1904, p. 14.

In view of these conditions the United States Geological Survey and the Arizona Agricultural Experiment Station undertook a co-operative investigation of the ground waters and the possibilities of irrigation in this valley. The general field investigation was made in the fall of 1910 by O. E. Meinzer, of the Geological Survey; the leveling was done and the examination and tests of pumping plants were made in the fall of 1910 and the spring of 1911 by F. C. Kelton, of the experiment station; 120 samples of water and 106 samples of soil were analyzed in the laboratories of the experiment station by Dr. W. H. Ross; and numerous tests of water and soil were made in the field.

PHYSIOGRAPHY AND DRAINAGE.

By O. E. Meinzer.

GENERAL FEATURES.

Arizona may be divided into three physiographic regions[1]—the plateau region, in the northeastern part; the mountain region, a belt 70 to 150 miles wide lying along the southwestern margin of the plateau region; and the desert region, which lies still farther south-west. (See fig. 1, p. 10.)

The plateau region, which forms a part of the Colorado Plateau, is underlain by nearly horizontal strata which are dissected to great depths in the Grand Canyon of the Colorado and the principal tributary canyons. A large part of the plateau is, however, only moderately undulating and is covered with pine and cedar.

The mountain region is characterized by a large number of short, nearly parallel ranges separated by broad valleys deeply filled with stream and lake deposits. In most of the region the trend of the ranges is northwest and southeast, but near the Mexican border it is nearly north and south. Both Gilbert and Ransome regard these ranges as belonging to the same system as the basin ranges of Nevada and Utah and describe them as consisting essentially of tilted blocks, presumably brought into their present position by faulting.

The border between the plateau and mountain regions is to a great extent covered with volcanic rocks.

The desert region is similar to the mountain region in structure, but differs from it in having lower ranges, more nearly buried beneath stream and lake deposits, and a hotter and more arid climate.

The area considered in this report lies within the mountain region. Most of the ranges have a northwest-southeast trend, but the Chiricahua, Swisshelm, Pedregosa, and Perilla mountains, in the southeastern part of the area, trend almost due north and south.

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[1] For a more extended description of these physiographic regions, see Ransome, F. L., Bisbee folio (No. 112), Geol. Atlas U. S., U. S. Geol. Survey, 1904, p. 1, from which this description is largely taken.

Sulphur Spring Valley is one of the broad débris-filled valleys that lie between parallel ranges or chains of ranges and are so numerous and so widely distributed over the arid regions that they must be regarded as forming one of the important physiographic types of the United States. They are, however, strictly characteristic of arid and semi-arid regions and should not be confused with the stream valleys of humid regions, from which they differ radically both in origin and form. They consist essentially of broad, gentle slopes built up of rock waste washed out from the mountains. Some of these valleys, as, for example, the southern part of Sulphur Spring Valley, have true stream valleys along their central axes; more typically, however, they have no drainage outlets, but, like the northern part of Sulphur Spring Valley, contain central playas or alkali flats. For valleys of this type that have no drainage outlets the name bolson is frequently used.

MOUNTAINS.

The trough occupied by Sulphur Spring and Arivaipa valleys is bordered by two parallel mountain chains which extend from Gila River to Mexico. (See Pl. I.) The east chain includes the Pinaleno (or Graham), Dos Cabezas, Chiricahua, Pedregosa, and Perilla mountains; the west chain includes the Galiuro, Winchester, Little Dragoon, Dragoon, and Mule mountains. The east chain is, on the whole, larger and higher than the west chain, the two loftiest ranges of the region being the Pinaleno and Chiricahua mountains.

The Pinaleno Mountains stand northeast of the northern part of Sulphur Spring Valley and extend northward on the east side of Arivaipa Valley. They rise precipitously above Sulphur Spring Valley and shed most of their waters northeastward into the Gila. The range culminates in a number of conspicuous granite peaks, the highest of which is Mount Graham. Several large canyons that converge in the vicinity of Fort Grant and Bonita contain good springs that give rise to mountain brooks, all of which disappear in the dry seasons before they reach the valley. These canyons, however, discharge large floods such as have built the huge fan on which Fort Grant is located, have saturated the ground in the vicinity of Bonita, at the base of this fan, and have formed the broad draw from Bonita to Hooker's ranch. The mountains are sufficiently lofty to support large timber, which is included within the Crook National Forest. South of Stockton Pass the range is much lower and more barren. It ends in T. 12 S., in which Sulphur Spring Valley is separated from San Simon Valley by only a low débris-covered divide over which the main line of the Southern Pacific Railroad passes.

South of the railroad pass are the Dos Cabezas Mountains, which trend somewhat east of southeast for about 20 miles. Viewed from the west, the northern part of this range appears low and barren.

Farther south, however, it culminates in two precipitous porphyry peaks that rise to about 8,000 feet above sea level and form the most distinctive landmark of this entire region. The Dos Cabezas peaks can be seen and identified from all parts of the valley except the southern extremity. The south margin of the range is formed by a sharp quartzite ridge, back of which is the shallow-water belt that has determined the location of the village of Dos Cabezos. This range appears larger when viewed from the east, in which direction it sheds most of its waters. South of the range is Apache Pass.

The Chiricahua Mountains, the largest mountains in this region, extend southward from Apache Pass for about 30 miles. In the northern portion the range has many ragged peaks, but farther south, where it is wider and more massive, it has a remarkably even crest line, a considerable part of which is more than 9,000 feet above sea level and nearly 5,000 feet above the level of the valley. The range supports a growth of tall yellow pine which is included in the Chiricahua National Forest. Numerous canyons cut both sides of the range. Some of these contain small streams that during rainy seasons may flow a short distance into the valley. The principal streams on the west side are Wash Creek, Fivemile Creek, and Ash Creek.

The Pedregosa Mountains form a short and rather low range extending southward from the Chiricahua Mountains to Silver Creek. They lie back of Sulphur Spring Valley and are drained chiefly into San Bernardino Valley.

South of the break in the mountains traversed by the El Paso & Southwestern Railroad is a low barren mass known as the Perilla Range, which extends to the Mexican line and completes the east wall of the valley. It discharges its drainage through a series of small dry canyons. Just south of the boundary a huge, red, tower-like butte forms a notable landmark.

The Swisshelm Mountains, culminating in Swisshelm Peak, project from the Pedregosa Range north-northwestward into Sulphur Spring Valley. Whitewater Draw starts from the angle between the Swisshelm and Chiricahua mountains and flows around the north end of the former. Most of the canyons in this range are short and discharge their storm waters quickly, but Leslie Canyon, near the south end, is cut entirely through the range and forms the outlet for a large drainage basin to the east.

The Galiuro Mountains constitute an extensive range, the southern part of which lies west of the northern extremity of Sulphur Spring Valley. For about 30 miles farther north the range forms the divide between Arivaipa and San Pedro valleys, but near its north end it is traversed by a canyon through which Arivaipa Creek passes to join the San Pedro. The low mountainous area south of the main Galiuro Range is known as the Winchester Mountains. The Galiuro and

Winchester mountains contain a number of springs but no stream that discharges permanently into the valley. The largest canyons, which are continued into the valley as "draws," or "dry runs," are known as High Creek, Oak Creek, Ash Creek, Riley Creek, Oak Grove Creek, and Wood Creek.

The main range of the Dragoon Mountains extends for 25 miles south from the Southern Pacific Railroad to and beyond Gleeson. For most of this distance it is a rather low range with subdued aspect, but in the vicinity of the Cochise Stronghold, northwest of Pearce, the granite mass and upturned beds of quartzite and marble have been sculptured into forms of exceptional sharpness. The space between the Dragoon and Winchester mountains is occupied by a number of low, partly disconnected ridges, known as Little Dragoon Mountains.

The Mule Mountains lie between the Dragoon Mountains and the Mexican border and form a compact group of ridges and peaks, the highest of which is Mount Ballard, with an elevation of 7,400 feet above sea level. Like the Dragoon Mountains they contain a number of springs but no stream of any consequence. Mule Gulch is the principal canyon that discharges into Sulphur Spring Valley.

STREAM-BUILT SLOPES.

ORIGIN.

The surface of Sulphur Spring Valley, like that of bolson valleys generally, consists essentially of smooth, gently inclined stream-built slopes that descend from the mountains toward the central part of the valley. Every one of the bordering ranges is cut by a series of canyons through which the flood waters of the mountains are discharged into the valley. The streamways of the canyons are steep and narrow, and consequently their waters flow swiftly and have great power to carry rock waste with them. But when these waters emerge into the nearly level valley they lose their swift velocity and drop a large part of their load of rock waste. Therefore, instead of excavating for themselves definite stream valleys they build alluvial slopes, or fans, over which they spread, and by thus spreading they decrease their carrying power still more.

After one of these streams leaves its canyon it loses water by seepage into the porous bed of rock waste over which it spreads and by evaporation into the dry atmosphere, and receives few new contributions. As a result it diminishes rapidly in volume and usually soon disappears, leaving all of the sediment that it brought from the mountains.

The stream-built slopes are as a rule steepest near the mountains from which they are supplied and become gradually more gentle as they pass downward toward the center of the valley. This difference in slope is indicated in Plate I (in pocket), which shows the 100-foot contour lines crowded closest together near the mountains, and also in figure 2, which shows the profile of a small canyon in the Mule Mountains and of the stream-built slope extending from this canyon to the center of the valley.

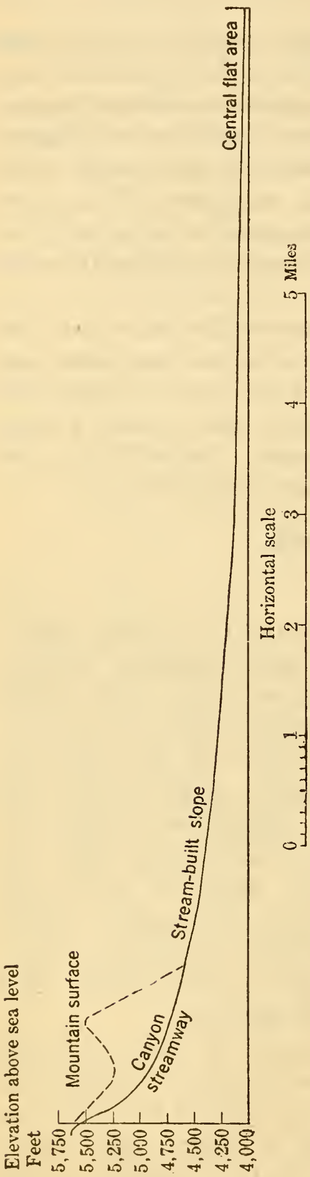


FIGURE 2.—Profile of streamway in a small canyon in the Mule Mountains and on the adjacent alluvial slope.

SHAPE AND SIZE.

The stream-built slopes, or fans, are closely adjusted to the canyons to which they belong, and any difference between two canyons is reflected in the shape and size of the corresponding fans. Short, steep canyons have short, steep fans, and their brief, torrential floods sweep large quantities of coarse débris to the mouths of their canyons but can not carry it far beyond, both because of its coarseness and because of the short distance reached by floods of this character. The longer canyons, with larger and better-watered drainage basins, have more gentle gradients and generally emerge from the mountains at lower levels, and their floods, being of greater volume and longer duration, advance farther into the valley. Consequently their fans are larger and more gently inclined. Between these two extremes there are canyons in great variety, each of them tending to develop a specific type of fan. In brief, the bed of a canyon and the surface of the corresponding stream-built slope form a single streamway, the different parts of which are in adjustment with each other (fig. 2).

A large range has, generally speaking, larger canyons than a small range, and the stream-built slope which borders it is correspondingly larger and less precipitous than that which borders a small range. Any given range, however, has canyons that differ among themselves in size and character, and its stream-built slope is therefore not a homogeneous structure but a building together of fans of different sizes and shapes.

The slope that borders the Chiricahua Mountains is four townships in width and is very gently inclined. It is directly related to these mountains in size and shape and is in contrast with the relatively narrow and steep slopes of all the smaller ranges, especially with those adjoining the Dos Cabezas and Little Dragoon ranges. (See Pl. I.)

The next slope in size within this valley is that which extends out from the Pinaleno Mountains. The broad, gently inclined plain east of Hookers Draw forms a marked contrast to the abrupt rise from this draw to the Winchester Mountains.

A similar contrast exists between the short, steep fans developed at the mouths of the short, steep canyons of the northern part of the Swisshelm Mountains and the extensive but very gently inclined fan of Whitewater Draw. The latter stretches from the buttes below the Whitehead ranch practically to the Soldiers Hole and extends around the base of the smaller fans.

STREAM-BUILT DIVIDES.

The trough occupied by Sulphur Spring and Arivaipa valleys is crossed by two drainage divides—one in the vicinity of Pearce and the other at the head of the Arivaipa, a few miles northwest of the Sierra Bonita ranch. (See Pl. I, in pocket.) Both are formed by accumulations of stream deposits, and it is significant that they are respectively opposite the two largest ranges that border the trough, namely, the Chiricahua and Pinaleno mountains. They appear to be formed essentially by the sediments washed out from these mountains, though the shape of the rock trough may also have been a factor in their development.

In the vicinity of the Pearce divide there are numerous rocky buttes, but these have contributed no important amount of sediment. They probably indicate that the average depth to bedrock is not so great here as in the open parts of the valley both north and south of the divide. Such a buried rock platform may have had an influence in determining the elevation to which the débris surface was built by the streams, although there is no difficulty in a theory that the general contour of this surface is simply the product of the floods poured out from the adjacent mountains and is not essentially modified either by the buttes or by a buried bedrock surface. Some of the streams of the Chiricahua flow north of the divide and others flow south of it, and a few have probably discharged water in both directions.

The divide northwest of the Sierra Bonita ranch, which is the divide between Sulphur Spring and Arivaipa valleys, was once farther north than it is at present. The stream-built slopes in Arivaipa Valley have been extensively eroded in recent geologic time. If the gullies caused by the erosion are, in imagination, filled, the reconstructed surface, which represents the original uneroded stream-built surface, is seen to rise for some distance northward from the present drainage divide. Moreover, Hookers Draw can be traced to the present divide, showing that it once received the drainage from areas farther north. The stream deposits accumulated to a higher level in this vicinity than in the valley farther south not only because the Pinaleno and Galiuro mountains are here larger than the mountains to the south, but also because the valley is here more narrow.

These two divides separate the trough occupied by Sulphur Spring and Arivaipa valleys into three drainage basins. The northernmost of these basins drains northward into the San Pedro and thence into the Gila; the southernmost drains southward into Whitewater Draw and thence into the Yaqui; the central basin, inclosed between the two divides, has no outlet, and the ultimate goal of its drainage is its large central flat.

RELATION OF AXIAL WATERCOURSES TO SIZE OF SLOPES.

The position of the axis of the valley depends on the relative width of the opposite slopes, and this, as has been seen, depends on the relative size of the opposite mountain ranges. For this reason Hookers Draw, which follows the axis of the northern part of the valley, is far from the Pinaleno Mountains but relatively near the Winchester Mountains. The course of Whitewater Draw is determined by similar causes. After rounding the Swisshelm Mountains it is carried beyond the center of the valley by the extensive slope which it has built. Thence it leads almost due south for several miles, the slopes on the two sides being nearly balanced, though perhaps a little heavier on the east than on the west. Near the south end of the valley, however, where the Mule Mountains develop into a range of considerable size and the opposing Perilla Mountains are small and shed only meager amounts of water into the valley, the débris from the west is distinctly heavier, and Whitewater Draw is thrown toward the east. (See Pl. I, in pocket.)

RELATION OF ALKALI FLAT TO SIZE OF SLOPES.

The position of the flat which lies in the lowest part of the north basin is determined by practically the same causes as the position of the axial draws. If the valley were everywhere of uniform width the flat would occur where the mountains and hence the alluvial slopes on both sides were smallest; if, on the other hand, the mountains were everywhere uniform in size it would occur in the widest part of the valley, in the locality most remote from the stream-built slopes. But as there are important differences in both the size of the mountains and the width of the valley, the actual position of the flat is a resultant of the two.

Thus the flat was crowded away from the northern part of the valley, where the large quantities of sediments supplied from the lofty Pinaleno Range were poured into a comparatively narrow part of the rock trough. Likewise it was crowded away from the Pearce divide, where the valley, although wide, was filled with the exceptionally large quantities of sediment delivered by the Chiricahua Mountains. Nor could it occur very near the south end of the Dos Cabezas Range or the main Dragoon Range, both of which are large enough to have extensive stream-built slopes. Chiefly as a result of these contesting influences, the alkali flat was shifted to its present position, where the bordering ranges are small and the stream-built slopes do not extend far into the valley.

In this contest, as it were, among the ranges in repelling the alkali flat to as great a distance as possible, the Pinaleno Mountains had a great advantage over the Chiricahua Mountains in having a much narrower part of the valley to fill. The effect of this handicap was to move the alkali flat several miles south of the place where it would otherwise be situated. (See Pl. I, in pocket.) The effect of the wind on the position of the flat is discussed on page 148.

Sevier Lake, in Utah, affords a still more striking illustration of this kind of contest among natural agencies, by which the position of the lowest depression of a closed basin is determined. The lake, which of course occupies the lowest depression, is crowded far from the center of the valley because of the preponderance of sediment delivered by Sevier River, the only large stream that discharges into the valley.[1] The position of Great Salt Lake is not in accord with this rule, inasmuch as the lake lies near the loftiest mountains, and this fact has led Gilbert[2] to believe that the Great Salt Lake Desert has recently been tilted by diastrophic forces.

EROSION AT NORTH END OF VALLEY.

The stream-built slopes in Gila Valley have in recent time become deeply and extensively eroded, and the erosive process has been carried up the tributary valleys,[3] including the San Pedro, Arivaipa, and San Simon. When the gullies in the Arivaipa had, by erosion at their heads, gnawed their way to the original divide between the Arivaipa and Sulphur Spring valleys they did not stop growing but attacked the smooth southward-sloping surface at the head of Sulphur Spring Valley. In this manner the divide was gradually shifted southward,

[1] Meinzer, O. E., Ground waters of Juab, Millard, and Iron counties, Utah: Water-Supply Paper U. S. Geol. Survey No. 277, 1911, p. 120.

[2] Gilbert, G. K., Lake Bonneville: Mon. U. S. Geol. Survey, vol. 1, 1890, pp. 384-387.

[3] Gilbert, G. K., U. S. Geog. Surveys W. 100th Mer., vol. 3, 1875, pp. 540-541. Ransome, F. L., Globe folio (No. 111), Geol. Atlas U. S., U. S. Geol. Survey, 1904, pp. 5, 6. Lindgren, Waldemar, Clifton folio (No. 129), Geol. Atlas U. S., U. S. Geol. Survey, 1905, pp. 5, 6.

and Arivaipa Valley was expanded at the expense of Sulphur Spring Valley. This piracy on the part of the Arivaipa is still going on and will continue indefinitely unless stopped by some conflicting process. First the waters of High Creek will be captured, then the waters of Oak Creek, and so on, until, in the distant future but in the normal course of geologic events, the gullies of the Arivaipa will extend to the alkali flat, when the north basin of Sulphur Spring Valley will no longer have an interior drainage but will all be tributary to the Arivaipa.

EROSION IN THE SOUTH BASIN.

In the soutn basin of Sulphur Spring Valley the small amount of headward erosion is confined almost entirely to the main axis, occupied by Whitewater Draw, and in general does not extend to the slopes. As compared with the dissection of Arivaipa Valley, it is insignificant.

For 10 or 15 miles above the international boundary, Whitewater Draw occupies a definite stream valley, which is a fraction of a mile wide and generally less than 25 feet deep. Upstream it gradually decreases in depth until it becomes indistinguishable from the rest of the plain that constitutes Sulphur Spring Valley. Above the Four Bar ranch the axial portion of the valley expands into a sort of alkali flat. The stream valley has a flat bottom and a mature aspect and does not appear to have been formed very recently.

Passing through the flood plain of the stream valley is a freshly cut stream channel, which in Tps. 22, 23, and 24 S., R. 21 E., has an average width of perhaps 60 feet and an average depth of about 10 feet. In the fall of 1910 the head of this channel was about at the south line of T. 21 S., and according to F. J. Randell, who lives in the NE. ¼ sec. 32, it was eroded headward fully a quarter of a mile during the rainy season of 1910. The entire channel, and especially the part within a few miles of the head, has an aspect of extreme youth. (See Pl. III, *B*, p. 16.) Near its head the level grass meadow which formerly constituted the valley has become dissected into the fantastic forms shown in Plate IV, *C* (p. 32). According to William Cowan, a pioneer ranchman, the entire channel north of the Mexican boundary has been cut since 1884. In T. 21 S. and the southern part of T. 20 S., R. 26 E., there is an interrupted channel which is narrower and in most places shallower than the channel just described. In parts of its course it taps the ground water; in other parts it is filled with impounded water. From a point several miles east of the railroad to the southwestern part of T. 20 S., R. 26 E., Whitewater Draw has no channel and no definite valley.

San Bernardino Valley belongs to the same drainage system as the southern part of Sulphur Spring Valley, but it is much more extensively dissected. Near the international boundary it contains a broad, deep, flat-bottomed stream valley with one distinct terrace excavated out of the underlying lava rock.

EROSION OF UPPER PARTS OF SLOPES.

Sulphur Spring Valley as a whole is remarkable for the small amount of erosion that has taken place on the middle and lower parts of its slopes. The dry runs that come down over many of the slopes do not occupy even shallow depressions. Sheet floods, frequently a mile or more in width, are characteristic of the valley and are largely the cause of the good growth of native grass that has made it so valuable for grazing.

The upper slopes are, however, generally eroded, the dry runs that come from the canyons occupying definite valleys that have been carved out of the stream deposits. This condition is well illustrated in the region east of the Circle I Hills and on the slope bordering the Chiricahua Mountains, but it is found on nearly all the slopes in the valley. It is shown on the topographic map (Pl. I, in pocket) by the irregular course of the contour lines near the borders of the mountains.

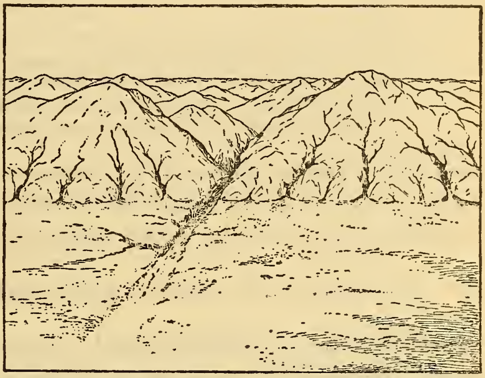


FIGURE 3.—Diagrammatic sketch showing erosion of upper slope due to differences in the size of canyons.

The erosion of the upper parts of the stream-built slopes in Sulphur Spring Valley is not due to any rejuvenation resulting from the headward erosion of the Arivaipa Valley or of Whitewater Draw. This is manifestly true of the north basin, but it is also true of the south basin, for the influence of the erosion along the axial draw has not generally extended to the upper slopes. The high-level erosion does not, however, require any special explanation, but may have resulted in two ways from the normal topographic development of the region.

In the first place, it should be noticed that it is chiefly the streamways leading from the large canyons that occupy valleys cut into the upper slopes. Thus Whitewater Draw, which probably carries more water than any other draw, occupies a deep, well-developed stream-cut valley for a number of miles below the point where it leaves its canyon. As has already been pointed out, the large canyons, with their relatively great and long-continued discharge, have been cut deeper than the small canyons with meager discharge, and hence they emerge from the mountains at lower levels. Consequently the floods from the large canyons can keep open an avenue of escape only by sweeping away the débris piled in their course by the waters discharged from the small canyons. This relation is illustrated by the diagrammatic sketch which forms figure 3.

In the second place, as the mountains are worn down and the canyons are cut deeper all the streams emerge from their rock canyons at lower levels and will sink their channels into the upper parts of the slopes which they themselves built at an earlier stage. (See fig. 4.) Obviously, as long as the basin has no outlet the load of sediment

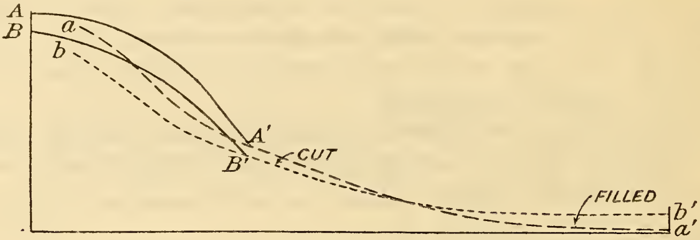


FIGURE 4.—Diagrammatic profile showing erosion of upper slope due to downward cutting of canyons. *A–A'*, Cross section of mountain; *a–a'*, bottom of canyon and surface of stream-built slope extending from mouth of canyon; *B–B'*, cross section of mountain at a later stage; *b–b'*, bottom of canyon and surface of slope at a later stage.

carried by the streams will be deposited farther down the slopes, and thus the lower parts of a bolson valley will normally be built up at the same time that the upper parts are being eroded.

EROSION OF MIDDLE AND LOWER PARTS OF SLOPES.

In addition to the high-level erosion, some freshly cut gullies are found descending the middle and lower parts of the slopes. Gullies of this type are widely distributed but are not conspicuous in the valley as a whole. They were observed in greatest abundance on the west side of the south basin, especially in the region west of Soldiers Hole. To some extent such gullies owe their existence to the partial destruction by grazing of the protective cover of grass or to other changes incident to the advent of the white man. To some extent they perhaps normally accompany the general aggrading process.

In part their explanation may be as follows: The stream that discharges over a stream-built slope changes its course frequently. As soon as it has flowed over one part long enough to build it up above the adjoining parts it is likely to be diverted along some lower path, which it will in its turn build up. Thus it happens that there are parts of a stream-built slope which for the time being receive little or no débris from the mountains, and these parts are subject to erosion just as any other sloping surface upon which rain falls.

Erosion due to still another cause occurs near the alkali flat, but this can best be discussed in a different connection. (See p. 42.)

LEVEES.

Low, regularly formed sandy or gravelly swells or ridges of a distinctive type are so characteristic of the surface of the lower slopes of this valley that they deserve mention. They were found west of the Circle I Hills, between the Four Bar and I X ranches, in the vicinity of the experimental dry farm (southwest of McNeal), and in many other localities. They resemble beach ridges in form, but differ from them in running down the slopes on which they occur instead of running horizontally as beach ridges do. They differ in soil value from the heavier loams that border them, and this difference is shown in the native vegetation which they support. In many places they sustain a growth of yucca or mesquite, although the plain on either side may be covered with grass only.

In origin these ridges are associated with the flood streams. They form the banks of streamways which are so wide, so smooth and grassy, so nearly at a level with the adjoining plain, and so seldom occupied by water that their function as stream channels is obscured. Occasionally, however, floods come down these meadows in wide, shallow sheets, depositing sediment, especially at their margins, where the current is the most sluggish. The ridges under discussion appear to be composed of the these marginal deposits.

BUTTES.

DISTRIBUTION.

Characteristic features of Sulphur Spring Valley are several score of rocky buttes, practically all of which are shown on the map (Pl. I, in pocket). A few of the buttes have names that are generally recognized, for example, Hookers Butte, Circle I Hills, Scott Hills, Pat Hills, Sulphur Springs Butte, Pearce Hill, and Sixmile Hill. A few have names that are locally used, but are not generally known; for example, the Three Sisters (1½ miles east of Sulphur Springs), Sulphur Hills (between the West Well and Three Sisters), and Square-top Hills (between Ash Creek and the Whitehead ranch). Most of the buttes, however, remain without names of any sort. Turkey Creek Ridge, Ash Creek Ridge, Whitehead Ridge, Leslie Creek Buttes, and Cowans Butte are appropriate names used in this report to designate prominent ridges and buttes which have hitherto been nameless.

These buttes are widely distributed, being found on both sides of the valley from the Arivaipa divide to the international boundary. In general they are most abundant on the upper slopes within a few miles of the mountains, but in the vicinity of Pearce and Sulphur Springs they are found in the axial portion of the valley. A great archipelago, as it were, of buttes, presenting a large variety in size, shape, and grouping, extends northwestward from the north end of the

Swisshelm Range. What may be regarded as the main chain extends from the Swisshelm Mountains to the Three Sisters, nearly in line with the main Swisshelm ridge and nearly parallel to the Dragoon Mountains. It includes Whitehead Ridge, the Squaretop Hills, Ash Creek Ridge, Turkey Creek Ridge, the Sulphur Hills, and the Three Sisters. This somewhat systematic arrangement is, however, complicated by a heterogeneously grouped assemblage of buttes extending westward from this chain to the vicinity of Pearce.

ORIGIN.

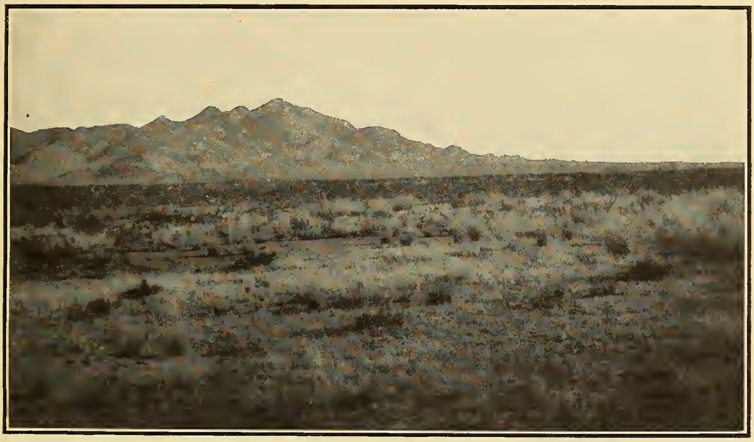
The buttes throughout the valley are conspicuous because of their isolation and the striking topographic contrast that they make with the smooth plain by which they are surrounded. They form well-known landmarks and greatly relieve the monotony of the extensive featureless stream-built slopes. They may be regarded as mountain peaks which rise from the rock floor of the valley but have become nearly submerged by the sediments that were washed out from the larger and more lofty mountains on both sides of the valley.

TOPOGRAPHIC DEVELOPMENT.

The buttes have themselves contributed comparatively small amounts of sediment. On approaching a mountain range, even a small range such as the Winchester, Little Dragoon, Dos Cabezas, or Perilla, a traveler finds himself ascending perceptibly for some distance, and when he reaches the margin of the mountains he is high above the central part of the valley. On approaching a butte no such ascent is made. The large groups of hills, such as the Circle I Hills and the Squaretop Hills, have distinct stream-built slopes, but they are tiny in comparison with the stream-built slopes of the mountain ranges. The small buttes, such as Sulphur Springs Butte, have still smaller débris slopes and project above the valley plain almost as abruptly as they would project above a sea of water. The topographic map (Pl. I, in pocket) shows to how slight an extent the contours of the valley are deflected by the stream-built slopes of the buttes. The difference between the mountains and the buttes in this respect is also shown in Plate IV, *A* and *B*, in which the Swisshelm Mountains with their prominent slope are contrasted with a butte which has practically no alluvial slope.

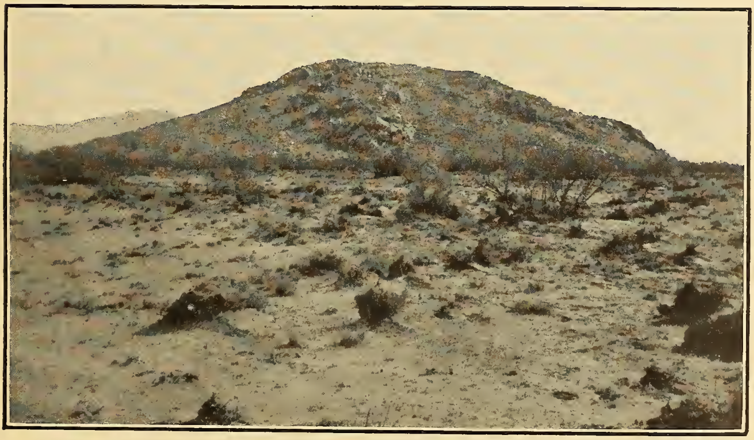
The buttes are notably less cut by canyons and gullies than the mountains. This difference forces itself upon the observer's attention especially in the morning and evening, when the shadows are cast in such a manner as to show the relief of the rock masses. The mountains then appear to be sculptured into intricate and angular forms, but the buttes seem smooth and rounded with few irregularities sharp enough to cast a shadow. The large groups, such as the Pat,

A. BUTTE SHOWING LACK OF EROSION AND OF STREAM-BUILT SLOPE.



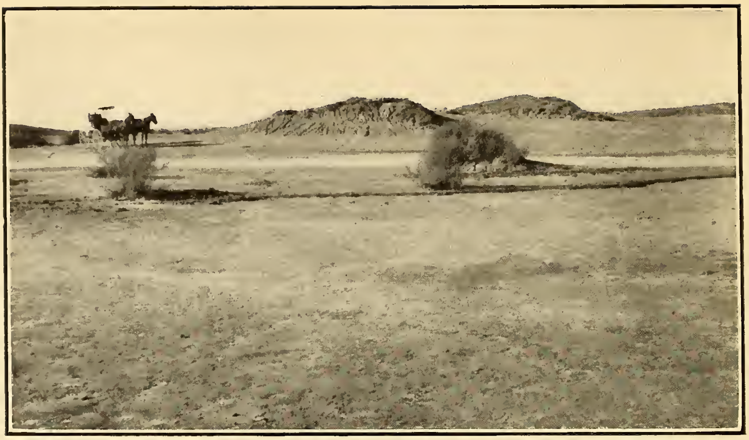
B. SWISSHELM MOUNTAINS.

Showing eroded character of mountains and prominent stream-built slope.



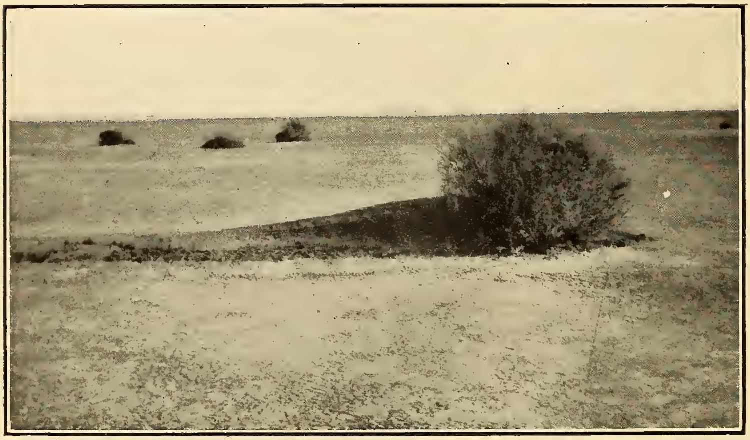
C. SCOTT HILLS.

Showing rugosity due to quartz ledge.



A. MOUNDS NEAR MARGIN OF BARREN FLAT.

Developed by differential wind erosion.



B. CLUMPS OF SALTBUSH NEAR MARGIN OF FLAT.

Showing wind deposits on northeast sides.

C. BARREN FLAT IN NORTH BASIN OF SULPHUR SPRING VALLEY.

Sulphur, Squaretop, and Circle I hills, contain some sharp ravines and are less regular in form than the small isolated buttes, though even the largest lack the angularity of the mountain masses. This difference is shown in Plate IV, *A* and *B*. It is due simply to the small size of the buttes and the consequent fact that they contain no drainage basins of sufficient extent to accumulate large enough floods to effect much erosion.

The shape of the buttes is influenced by the character and structure of the constituent rocks. The igneous masses have relatively little structure and therefore consist largely of conical or dome-shaped peaks grouped in irregular manner, as, for example, many of the buttes east of Pearce. Some of the topographic forms of the igneous buttes have, however, resulted from the structure, as, for example, certain escarpments in the Sulphur Hills. The steeply dipping, monoclinal bodies of quartzite and limestone form sharp-crested ridges in which the side toward which the beds dip is somewhat less steep than the opposite side, where the formations outcrop. The distinctive outline of these ridges attracts attention many miles away. Examples of this type are the Ash Creek Ridge, which contains upturned beds of quartzite, and the buttes near Forrest station, which consist of rather soft sedimentary beds capped by a resistant layer of limestone.

The topographic and structural equivalent of Ash Creek Ridge occurs in the conspicuous quartzite and limestone ridge that lies south of the village of Dos Cabezos and forms the southern part of the Dos Cabezas Range; the equivalent of the buttes near Forrest station occurs in the "prominent light-gray cliff which crowns Mural Hill, in the Mule Mountains, stretches like a rampart along the face of the ridge northeast of Bisbee, and gives scenic distinction to the otherwise rather commonplace hills" of this section of the mountains.[1] The topography of the Scott Hills, situated north of Willcox (Pls. I, in pocket; IV, *C*) is also an expression of the character and structure of the constituent rocks, their rugosity being due to the hard upturned ledge of quartz of which they consist. A similar topographic feature has resulted from the quartz bed in Pearce Hill.

ALKALI FLATS.

The lowest portion of the north basin is occupied by a nearly level alkali plain, which, except near its borders, is entirely destitute of vegetation and is wholly featureless. (See Pl. V, *C*.) In general it is depressed several feet below the surrounding surface, from which it is separated by an abrupt slope or low cliff. (See Pl. VII, *A*, p. 42.)

[1] Ransome, F. L., Bisbee folio (No. 112), Geol. Atlas U. S., U. S. Geol. Survey, 1904, p. 6.

The flat is roughly triangular (see Pl. I, in pocket) and has an area of about 51 square miles. It lies about 4 miles south of Willcox and 1½ miles east of Cochise, and its northwestern embayment is crossed for a distance of 3 miles by the Southern Pacific Railroad. In rainy seasons it becomes submerged by a thin layer of water, but in dry seasons its surface is hard and dry, although a mirage is likely to give the appearance of water at a distance. The agencies which have controlled the location of this flat are discussed on page 26, and the processes which have influenced its topographic form are discussed on pages 41–42.

A smaller, nearly level tract of alkali soil occurs in the south basin east of Soldiers Hole, from which it extends northward a short distance and southward for more than the width of a township. It is, however, not barren of vegetation and not so sharply separated from the surrounding area as the north flat.

LAKE FEATURES.

SIZE AND POSITION OF ANCIENT LAKE.

The north basin of Sulphur Spring Valley at one time contained a lake that was approximately 20 miles in length and 11 miles in maximum width and had a shore line of nearly 50 miles. It covered approximately 120 square miles, or 7 per cent of the entire drainage basin, and stood approximately 4,180 feet above the present sea level, or fully 45 feet above the surface of the barren flat. If it were now in existence, its waters would extend about 6 miles north of the barren flat and would reach southward within 6 miles of Pearce. The O. T. ranch, Cochise, and Servoss would be situated near its west coast, and E. Brumett's house, the Hope ranch, Thomas Allaire's ranch, and Sulphur Springs along its east shore. (Pl. I, in pocket.) The site of Willcox would be covered by a shallow sheet of water and Hado station would be submerged to a depth of about 30 feet. This ancient lake, which can appropriately be called Lake Cochise, received the drainage from the surrounding uplands but had no outlet, and it may therefore be concluded that its waters were salt.

ANCIENT BEACHES.

Along the shore of any lake or other body of standing water the waves and shore currents are active in handling the sediments which they erode from the banks or which are supplied to them by the inflowing streams. These sediments may be spread along the shore to form a beach or may be built into bars, spits, hooks, or other shore features. Where the lake bed near the shore slopes very gently and the water is consequently shallow, the sediments handled by the waves are likely to be built into a low symmetrical ridge that lies some distance from the shore and runs approximately parallel to it. The lakeward side of a beach ridge assumes all the characteristics and functions of a beach. The belt of shallow water imprisoned between the beach ridge and the shore forms a lagoon, which in the course of time is filled with sediment and converted into a marsh. If the slope of the lake bed near the shore is steep and the water deepens rapidly, the waves are more likely to beat on the shore with full force and to cut into the mainland, forming cliffs and terraces.

Some bolson valleys have been filled with water to the higher levels of the stream-built slopes, and as the higher parts are steeper and more extensively dissected than the lower, cliffs, terraces, and bars have been formed. An example of this type of bolson is Estancia Valley, in New Mexico.[1]

In the basin of Great Salt Lake the water at one time stood a thousand feet above the present lake level, and the shore line extended along the precipitous slopes of the mountain ranges. The great waves of this high-water stage dashed with full force against the rocky headlands and cut deeply into the exposed ridges, forming strikingly conspicuous cliffs and terraces.[2] The ancient Lake Cochise, in the north basin of Sulphur Spring Valley, occupied only the low central area where the slopes were gentle, and consequently the waves and shore currents produced no cliffs nor terraces but constructed comparatively large beach ridges. (See Pl. VI.)

The eastern coast of the ancient lake, from a point about 5 miles southeast of Willcox, in sec. 23, T. 14 S., R. 25 E., to a point a short distance beyond Thomas Allaire's ranch, in sec. 28, T. 15 S., R. 25 E., is outlined by a distinct and continuous beach whose total length is about 10 miles and whose course is shown on the map. (Pl. I, in pocket.) At the north end this beach abuts rather abruptly against the more recently formed sand hills; southward from Allaire's ranch it gradually becomes so indistinct that it can not be traced with certainty.

The west coast, from a point about 2 miles south and 4½ miles west of Willcox, in the NW. ¼ sec. 16, T. 14 S., R. 24 E., to a point about 2½ miles southeast of Servoss station, in sec. 31, T. 16 S., R. 25 E., is outlined by an equally distinct and continuous beach, whose total length is about 19 miles and whose course is shown on the map. It fades out at both ends.

A third beach extends southwestward from a point near the Southern Pacific Railroad, about 3½ miles southwest of Willcox,

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[1] Meinzer, O. E., Geology and water resources of Estancia Valley, N. Mex.: Water-Supply Paper U. S. Geol. Survey No. 275, 1911.

[2] Gilbert, G. K., Lake Bonneville: Mon. U. S. Geol. Survey, vol. 1, 1890.

in sec. 23, T. 14 S., R. 24 E., past J. C. Page's ranch, to the NE. ¼ sec. 29 in the same township. In sec. 29 it is interrupted but seems to be more or less nearly parallel to the main strand on the west side and finally to join that strand near the line between secs. 29 and 30. (See Pl. I, in pocket.) East of the railroad it has apparently become obscured by wind deposits. Altogether this beach has a length of about 4 miles.

In the three strands outlined the conspicuous feature is the beach ridge rather than the inner beach, but in some places the ridge becomes merged with the inner beach. For some distance between the Hope ranch and Allaire's ranch there are two nearly concentric beaches, some distance apart. The road leading between secs. 14 and 15 and secs. 22 and 23 crosses one of these beaches just south of the corner where all four sections meet and the other one nearly half a mile farther north.

The largest and most prominent shore feature is formed by the beach ridge in the vicinity of Cochise, especially south of Croton Springs, in secs. 6 and 7, T. 15 S., R. 24 E. (Pl. VI, *B*), and southeast of Cochise, in secs. 28 and 33 of the same township (Pl. VI, *C*). In the first-mentioned locality the beach ridge is 400 or 500 feet wide, fully 15 feet high on the lake side, and perhaps half as high on the land side. It consists, in fact, of two parallel ridges separated by a slight sag. Between the beach ridge and the stream-built slope lies a crescent-shaped flat, approximately a mile long and a quarter of a mile in greatest width. When the lake existed the area covered by this flat was occupied by a shallow lagoon that lay between the mainland and the outer beach. The filling which produced the flat surface was probably deposited for the most part while the lake existed, but may to some extent have taken place since. In the other locality (secs. 28 and 33), where a specially well-developed beach ridge was observed, the low ground back of the ridge is drained by a ravine that cuts through the ridge.

The beaches on both sides of the ancient lake are made more conspicuous by their characteristic flora, for they commonly support mesquite or yucca, even where they cross a plain that is covered with grass only. (See Pls. VI, *A;* VII, *C*, p. 42.)

The influence of the beaches on human development is also interesting. That prehistoric people were attracted by the view of the valley, which the west beach afforded, in a locality convenient to water, is suggested by the relics found on the large ridge in sec. 7, south of Croton Springs (p. 17). That the white settlers were likewise attracted is shown by the line of ranches and adobe ruins that characterize the beaches on both sides. The beach ridge afforded an ideal location for the ranch house, and plenty of water for the cattle and horses could be obtained just off the ridge at a depth of a

A. ANCIENT BEACH RIDGE IN NORTH BASIN.

Showing its influence on native vegetation.

B. ANCIENT BEACH.

C. ANCIENT BEACH RIDGE.

few feet. These ridges also afforded almost ideal road grades, and before the country was so generally fenced they were followed by some of the principal roads in the valley. They are almost perfectly horizontal and are only rarely interrupted by large ravines. Moreover, their elevation and gravelly constitution insure a firm roadbed even in wet weather.

The surface of a lake is, of course, level and its shore line is horizontal throughout. It is therefore to be expected that the beaches formed along its shore will all be at the same level, even though they are hundreds of miles apart, as may be the case in large lakes. If the beaches left by a lake that has dried up are not at the same level some special explanation must be sought. For example, in the basin of Great Salt Lake there is considerable discordance in the levels at which the shore features of the same lake stage occur, and this discordance is attributed by Gilbert[1] to a tilting of the region since the time when the strands were formed. In Sulphur Spring Valley the ancient strand seems to show slight differences in elevation in different localities. No theory of violent disturbance would be required to ascribe these differences to a slight tilting of the entire valley since the time when the lake existed, but they can perhaps be adequately explained by assuming that the beach was built a little higher above the water level in some localities than in others, or that in different places the beach was formed at different times and at somewhat different water levels.

Of the nearly 50 miles of shore line ascribed to the ancient lake scarcely 30 miles is outlined by definite shore features. Along the remaining 20 miles of shore line no definitely recognizable features were formed, or else these features have been destroyed or obscured by the wind. That part of the outline of the ancient lake which is not marked by shore features is conjectured from the topography of the valley, and this conjectured outline is shown on the map (Pl. I, in pocket). At the time of its maximum height the lake probably extended far north of the line occupied by the north beach ridge.

The beach ridges are largest opposite the widest and deepest part of the lake, where the waves had the longest sweep and the least retardation by friction at the bottom. They disappear toward both the north and the south ends, where over large tracts the water was very shallow.

ANCIENT LAKE BED.

In the central part of a bolson valley that has not been occupied by a lake the stream-built slopes from opposite sides approach each other with gentle gradients and may flatten out to form a central area of only very slight gradient. If, however, the central part of

[1] Gilbert, G. K., Lake Bonneville: Mon. U. S. Geol. Survey, vol. 1, 1890.

such a valley is occupied for a long time by a lake it will become filled to a certain level with sediments deposited under water, and these sediments will be so evenly distributed that the central flat will be extended and more nearly leveled. In a general way, the south basin of Sulphur Spring Valley illustrates the first-described condition and the north basin the second (Pl. V, *C*, p. 33). The barren flat in the north basin no doubt owes its flatness largely to sedimentation in the ancient lake, although its present surface seems to have been developed to some extent by agencies that have operated since the lake disappeared.

FEATURES PRODUCED BY WIND.

SAND AND CLAY HILLS.

Over an area of about 32 square miles the topography has been molded by the wind. This area (see Pl. I, in pocket) lies principally northeast of the barren flat but includes two narrow tongues of land, one extending along the eastern and the other along the northern margin of the flat. The Southern Pacific Railroad passes through the north tongue in the vicinity of Hado station and skirts the margin of the main area for 2 or 3 miles northeast of Willcox. The village of Willcox lies immediately west of the main area.

This wind-built area is characterized by ridges and hills arranged in a rather chaotic manner and separated from one another by ponds and other undrained depressions. In a region carved into hills and valleys by running water the drainage is invariably well defined, but in a region such as this the wind has scooped out basins and thrown up hills capriciously and in disregard of any drainage lines.

The wind-formed topography is not without a rude system of its own, for, as shown on the map, it comprises a series of wind-built ridges which are roughly concentric with each other and with the margin of the barren flat. The largest of these ridges are several miles long and more than 50 feet high. The smaller ridges and the irregularly shaped hills are not shown on the map, but a view of one of the smaller ridges is given in Plate XI, *C* (p. 68). In some places the depressions between the ridges and hills consist of smooth, grassy meadows which merge insensibly with the stream-built slopes; in other places they have been scooped out to form basins, some of which are filled with water during most of the year. The ponds thus produced are valued as watering places for live stock, but they are also breeding places for mosquitoes. The wind-formed topography is most pronounced about 2 or 3 miles east of Willcox, where it assumes a rather weird and fantastic aspect.

RELATION OF THE SAND AND CLAY HILLS TO DIRECTION OF STORM WINDS.

The sand and clay hills are found north and east of the barren flat, but are virtually absent on its southwest side. The materials that compose these hills were derived by the storm winds from the flat, or ancient lake bed, and were deposited on the east and north sides because in this region most of the storm winds blow from the south, southwest, or west.

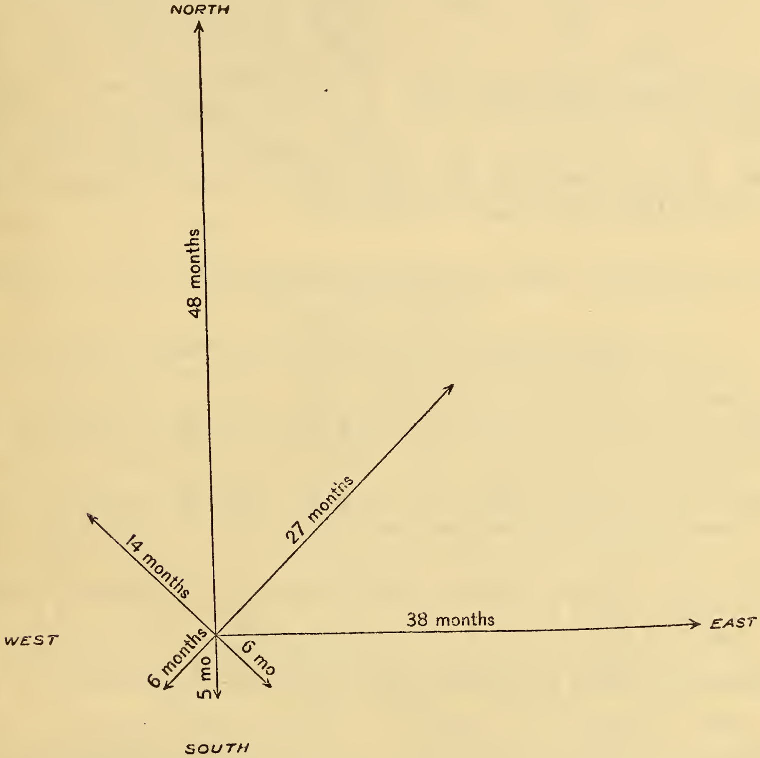


FIGURE 5.—Diagram showing prevailing direction of wind in Sulphur Spring Valley (constructed from table on p. 40).

That most of the storm winds come from the southwest is shown by records of the United States Weather Bureau and also by topographic features such as are shown in Pl. V, *B* (p. 33). The first table given below is a summary of the prevailing directions of the wind during a five-year period at the three observation stations of the United States Weather Bureau nearest the alkali flat. This table indicates that the wind may come from any direction and that during a considerable part of the time it blows from the east, but that during fully two-thirds of the time it is prevailingly from the south, west, or southwest. This fact is shown graphically in figure 5, in which the length of each arrow is proportionate to the number of months in which the wind was reported to blow in the direction indicated.

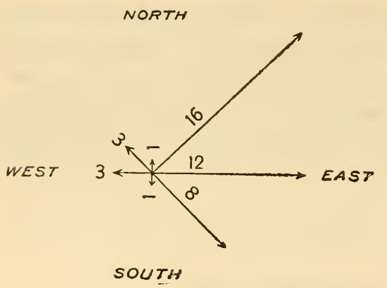


FIGURE 6.—Diagram showing direction of storm winds at Phoenix, Ariz. (constructed from table on p. 41).

The second and third tables give the prevailing direction and the direction of the highest storm wind in each month at Phoenix, where the velocity as well as the direction of the wind is observed. These tables show that although at Phoenix the prevailing direction is east, nearly all the storm winds blow from westerly directions. (See also fig. 6.) It is safe to conclude from these data that most of the storm winds in the vicinity of the alkali flat in Sulphur Spring Valley blow from the south, west, or southwest.

Prevailing direction of wind in vicinity of barren flat and wind-built area of Sulphur Spring Valley, 1905–1909.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
1905.													
Willcox	S.	S.	S.	S.	S.	S.	S.	S.	S.	S.	S.	N.	S.
Cochise	W.	W.	W.	W.	W.	W.	W.	......	SW.	......	SW.	S.	W.
Allaire's ranch	......	......	......	......	......	......	......	......	W.	W.	W.	SW.	......
1906.													
Willcox	N.	S.	S.	S.	S.	S.	S.	S.	S.	N.	N.	......	S.
Cochise	S.	W.	W.	W.	W.	W.	E.	SE.	SE.	E.	SE.	......	W.
Allaire's ranch	E.	NW.	E.	NE.	NE.	NE.	SW.	NW.	E.	SE.	E.	......	E.
1907.													
Willcox	S.	S.	S.	S.	S.	S.	S.	S.	S.	S.	......	S.	S.
Cochise	NE.	E.	SE.	SE.	SE.	W.	SE.	SW.	SE.	SE.	SE.	SW.	SE.
Allaire's ranch	SW.	E.	E.	E.	E.	E.	SE.	NE.	NE.	SW.	W.	E.	E.
1908.													
Willcox	S.	S.	S.	S.	S.	SW.	SW.	SW.	S.	S.	SW.	SW.	S.
Cochise	SW.	SW.	W.	W.	W.	W.	SW.	W.	W.	W.	W.	W.	W.
Allaire's ranch	E.	E.	W.	NW.	SW.	W.	E.	W.	E.	W.	W.	......	W.
1909.													
Willcox	SW.	S.	S.	SW.	S.	......	SW.	S.	SW.	SW.	S.	N.	SW.
Cochise	......	......	......	......	......	......	......	......	NW.	NW.	SW.	......	......
Allaire's ranch	SW.	W.	SW.	SW.	......	......	W.	SE.	E.	SW.	SW.	NW.	W.

Prevailing direction of winds at Phoenix, Ariz., 1905–1909.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1905	......	......	......	......	......	......	......	......	E.	E.	E.	E.
1906	E.	E.	E.	E.	E.	E.	E.	E.	E.	E.	E.	E.
1907	E.	E.	E.	E.	E.	E.	E.	E.	E.	E.	E.	E.
1908	E.	E.	E.	E.	E.	E.	E.	E.	E.	E.	E.	E.
1909	E.	E.	E.	E.	E.	......	......	......	......	......	......	......

Direction of highest winds at Phoenix, Ariz., 1905-1909.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1905	......	......	......	......	......	......	......	......	SE.	SW.	SW.	W.
1906	E.	SW.	W.	SW.	NW.	W.	SE.	N.	NW.	NW.	NW.	......
1907	SW.	W.	W.	NW.	SW.	W.	E.	SE.	SW.	NW.	E.	SW.
1908	W.	W.	NW.	W.	SW.	W.	S.	NW.	SW.	SW.	W.	SW.
1909	W.	SW.	SW.	SW.	SW.	......	......	......	......	......	......	......

The relation shown between the dune area and the direction of the wind is not peculiar to Sulphur Spring Valley. In San Simon Valley sand hills occur along the east side of the axial stream channel, which no doubt supplies the wind-blown material. In Estancia, Encino, and Tularosa valleys, N. Mex., the wind has excavated basins and deposited most of the excavated materials on the east and north sides[1]. The largest dunes associated with any lake, whether ancient or modern, are commonly found to leeward of the prevailing storm winds.

RELATION OF THE SAND AND CLAY HILLS TO THE ALKALI FLAT AND ANCIENT LAKE.

A part of the wind work was probably done while the lake existed and a part since it became dry. The wind is at present eroding the east and north banks of the flat (Pl. VII, *A*), but no evidence of wind erosion was observed on the flat itself. Deposition by the wind may have begun before the advent of the lake, but at no place were shore features seen to be superimposed upon wind deposits.

The principal reason for believing that a part of the wind work was done while the lake existed lies in the facts that the dunes consist chiefly of sand, whereas except very near its margin the barren flat is everywhere underlain by clay. The clay washed into the lake remained long in suspension and was carried far from the shore before it settled to the bottom, but the sand was deposited near the shore and in large part was thrown up by the waves so that the wind was able to seize it.

That much of the wind work was done since the lake epoch is indicated by the following facts: (1) Many of the dunes lie on the ancient lake bed; (2) a considerable part of the material composing the dunes consists of clay; (3) the wind is now at work; and (4) the barren flat lies at a lower level than would be expected if it were merely the bed

[1] Meinzer, O. E., Geology and water resources of Estancia Valley, N. Mex.: Water-Supply Paper U. S. Geol. Survey No. 275, 1911, p. 25.

of the ancient lake. The last-mentioned fact requires further consideration.

The barren flat appears to the eye to be perfectly level except for sun cracks and alkali protuberances, which produce irregularities of only a few inches at most. At the margin of the flat the surface as a rule rises either in a steep bank or in a more gradual incline, and within a few feet, or at most within a few rods, the barren level flat gives way to a surface which is covered with grass or bushes and which in some localities is very irregular. On the east and west sides of the flat the surface intervening between the beaches and the flat has distinctly more gradient than the surface immediately outside of the beaches. Indeed, the slope between the beaches and the flat is so steep that many gullies have started, most of which are being eroded headward toward the beaches, but a few of which have already been cut through them. This relatively steep slope immediately surrounding the flat may have resulted in part through the deposition near the shore of the coarse material brought into the lake. In part, however, it may be due to wind erosion since the dissection of the lake.

Apparently the wind is at present cutting back the north and east banks of the flat (see Pl. VII, *A*), and it seems probable that this process of progressively cutting back the banks on the leeward side has been important in the development of the flat. Near the margin a few small outliers of clay remain, generally protected from wind erosion by clumps of saltbush, but in time these outliers will no doubt be cut away. Outliers of this type are shown in Plate V, *A* (p. 33), but others are more completely isolated. The ground-water level establishes a plane below which wind erosion is impossible, and consequently a shallow-water region subjected to wind erosion is likely to develop a level surface.

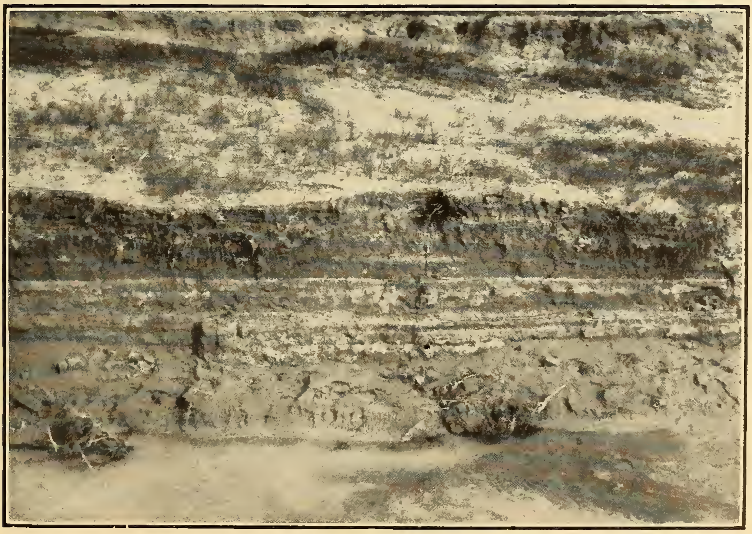
FEATURES PRODUCED BY SPRINGS.

Several small knolls occur at certain springs of the Croton Springs group, near the northwest angle of the barren flat, in or near the southern part of sec. 36, T. 14 S., R. 24 E. The largest knoll (see Pl. VII, *B*, and fig. 7) is about 20 feet in diameter and 4 feet high, and stands on a conical platform 150 to 200 feet in diameter and 5 to 10 feet high. It was apparently formed by the combined work of the spring and the wind. The spring produced a marshy area in which rushes and other plants thrived. When the wind struck this clump of vegetation it was checked, and consequently deposited the sand and dust which it was driving along. Once lodged among the rushes, the sand and dust became wet and could not be carried farther. Each generation of plants left its remains to be mingled with the mud,

A. CROSS-BEDDED WIND DEPOSITS AT MARGIN OF BARREN FLAT.

Eroded by wind and water.

B. TYPICAL SPRING-BUILT KNOLL AT CROTON SPRINGS.



C. ANCIENT LAKE SEDIMENTS.

and thus to be in part preserved. Gradually the accumulation of sand, clay, and vegetable matter grew until it attained its present proportions as a distinct though small topographic feature.

Probably one of the essential conditions for the formation of a knoll is that as the knoll develops it shall assume the character of an upright tube, in order that the water will not ooze out at the lowest level, but will be lifted to the top of the knoll. When the water no longer rises to the top, either because of leakage through the walls of the tube or because the limits of artesian pressure are reached, the knoll can grow no higher. At the time the knoll just described was visited no water was being discharged from the top, but the ground was wet virtually to the top and there were signs of former discharge. On boring into the top of the knoll the groundwater level was struck at a depth of less than a foot and at a level several feet above the surface of the surrounding plain. After a depth of about 2 feet had been reached the auger could easily be pushed down without boring. These conditions show that this knoll has to some extent the upright tube structure. That the tube is not entirely impervious is shown, however, by the seepage that occurs at the base of the knoll. (See fig. 7.) The wind erosion manifest on the southwest side of this knoll shows how quickly the entire structure would be reduced to the level of the surrounding plain if the supply of water were for any reason cut off so that the material of the knoll would no longer be kept wet.

Knolls of this type are not confined to Sulphur Spring Valley. Much larger knolls, apparently formed in the same manner, occur in Snake Valley, Utah,[1] and in the Tularosa Basin, N. Mex.

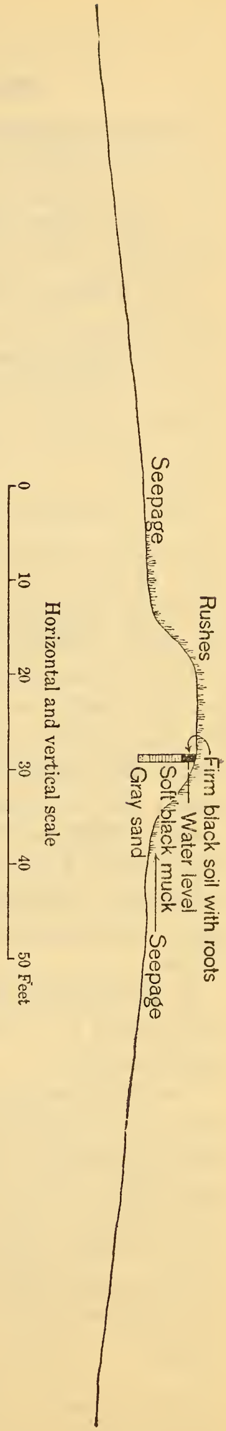


FIGURE 7.—Cross section of knoll at Croton Springs.

[1] Meinzer, O. E., Ground water in Juab, Millard, and Iron counties, Utah: Water-Supply Paper U. S. Geol. Survey No. 277, 1911, pp. 44–45.

GEOLOGY.

By O. E. Meinzer.

PREVIOUS WORK AND LITERATURE.

Thomas Antisell and C. C. Parry, the geologists who accompanied the two expeditions that crossed Sulphur Spring Valley in 1855, made some observations on the geology of the valley and adjoining mountains, and Antisell attempted a reconnaissance geologic map and section of the region.

G. K. Gilbert, who in connection with the Wheeler Survey visited the northeastern part of this region in 1873, made a number of valuable observations on the geology of the Pinaleno, Dos Cabezas, and northern Chiricahua ranges, drew several sections of the formations between the Dos Cabezas and Fort Bowie, and formulated a theory of the structure and origin of the mountains that is still generally accepted.

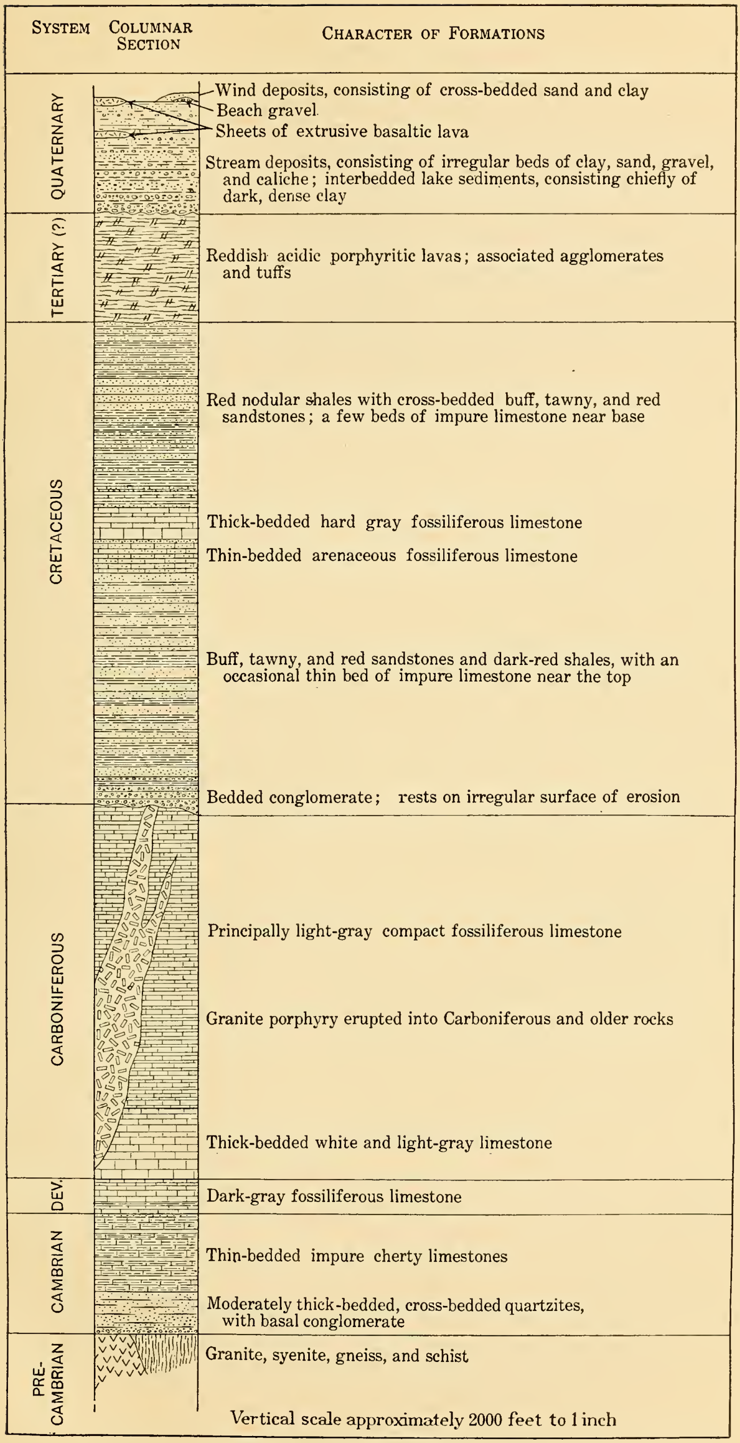
Since the late seventies, when rich ore bodies were discovered in this region, numerous accounts of the Tombstone, Bisbee, Cochise, Dos Cabezos, and Turquoise mining districts have been published, and most of these accounts include brief statements of the geologic relations. Among these accounts may be mentioned a description of the Cochise district by L. O. Kellogg, published in 1906. Two popular works on Arizona were published, one in 1878 by R. J. Hinton and the other in 1881 by Patrick Hamilton. Both books sketch the geology of Arizona and contain meager statements in regard to the geology of the region under consideration. More recently William P. Blake made a cursory study of the Galiuro Mountains and E. T. Dumble a reconnaissance through the Dragoon, Mule, Swisshelm, Chiricahua, and Dos Cabezas mountains. Dumble's paper contains the first recorded mention of Cretaceous rocks in this region.

By far the most extensive and valuable geologic work in the region was that of F. L. Ransome in his investigation of the Bisbee quadrangle in 1902.

The publications based on investigations specifically mentioned above are included in the following list. They are concerned chiefly with the geology of the rock formations found in the mountains and especially with the geology of ore deposits. The study of the ground waters of the valley has, on the other hand, involved a careful examination of the physiographic and geologic features of the valley itself but has not required any detailed study of the geology of the surrounding mountains:

Parry, C. C., Mexican Boundary Survey, vol. 1, pt. 2, Geology and paleontology, 1857.

Antisell, Thomas, Explorations and surveys for a railroad from Mississippi River to Pacific Ocean, 1853–1856, vol. 7, pt. 2, Geological report, Washington, 1857.



COLUMNAR SECTION.

Scale approximately 2,000 feet to 1 inch. Section below Tertiary taken chiefly from Bisbee folio.

Gilbert, G. K., and Loew, Oscar, U. S. Geog. Surveys W. 100th Mer., vol. 3, 1875.
Hinton, R. J., The handbook of Arizona, San Francisco, and New York, 1878.
Hamilton, Patrick, The resources of Arizona, 1st ed., Prescott, Ariz., 1881; 2d ed., San Francisco, 1883; 3d ed., San Francisco, 1884.
Dumble, E. T., Notes on the geology of southeastern Arizona: Trans. Am. Inst. Min. Eng., vol. 31, 1902, pp. 696–715.
Blake, William P., Geology of the Galiuro Mountains, Ariz., and of the gold-bearing ledge known as Gold Mountain: Eng. and Min. Jour. vol. 73, 1902, pp. 546 and 547.
Ransome, F. L., Bisbee folio (No. 112), Geol. Atlas U. S., U. S. Geol. Survey, 1904.
Kellogg, L. O., Sketch of the geology and ore deposits of the Cochise mining district, Cochise County, Ariz.: Econ. Geology, vol. 1, 1906, pp. 651–659.

PRE-QUATERNARY GEOLOGY.

FORMATIONS.

PRE-CAMBRIAN SCHIST.

Pre-Cambrian schist, formed by the metamorphism of a sedimentary rock, comes to the surface over an extensive area in the Mule Mountains. Schist probably belonging to the same formation is also know in the Dragoon and Little Dragoon ranges and in the vicinity of Fort Bowie. The small butte 5 miles northwest of Bonita post office (see Pl. I) consists of dark schist with numerous included quartz veins. The Scott Hills (Pl. IV, *C*, p. 32), 3½ miles north of Willcox, consist of a quartz mass whose geologic relations are concealed by the valley fill. A similar quartz mass in Pearce Hill is associated with igneous rocks.

PALEOZOIC QUARTZITES AND LIMESTONES.

The Paleozoic rocks of southeastern Arizona consist of a succession of quartzite and limestone beds which rest with pronounced unconformity on the pre-Cambrian schist. In the Bisbee quadrangle the Paleozoic formations have a maximum thickness aggregating not less than a mile, of which 1,200 feet is Cambrian, 340 feet Devonian, and the rest Carboniferous. Although the Ordovician and Silurian systems are not represented, no noticeable unconformity exists between the Cambrian and Devonian, the entire succession of Paleozoic beds apparently forming one uninterrupted series. (See columnar section, Pl. VIII.)

In the Bisbee quadrangle the Cambrian system includes two formations—a quartzite about 430 feet thick with a basal conglomerate resting on the unconformable schist surface and an overlying limestone about 770 feet thick. Resting on the Cambrian limestone is the Devonian limestone, which in turn is succeeded by lower Carboniferous limestone and a great thickness of upper Carboniferous limestone.

The mountains which border the southern and central parts of Sulphur Spring Valley consist in large part of quartzite and dark gray indurated limestone which without question represent in general the Paleozoic rock systems that are found in the Mule Mountains.

Quartzite and limestone are abundant in the Dragoon Mountains, constitute the first ridge of the Little Dragoon Mountains north of the railroad, and are found in the vicinity of Johnson. In the Cochise Stronghold the quartzite beds are upturned, forming steep mountain walls, and the limestones have been converted into marble.

In these mountains Dumble differentiated Carboniferous, Devonian, and older Paleozoic rocks. The southern part of the Dos Cabezas Range consists of a quartzite, limestone, and shale series in which Carboniferous and earlier Paleozoic fossils have been found. Paleozoic limestones are also exposed in the Swisshelm Range.

A number of the buttes (see Pl. I), especially Ash Creek Ridge and many of the ridgelike hills between Ash Creek Ridge and the Swisshelm Mountains, consist of quartzite and dark-gray indurated limestone. In only a few of these isolated rock outcrops were Paleozoic fossils found, but in general the rocks bear a strong lithologic and topographic resemblance to the rocks in the mountains that are known to be Paleozoic.

CRETACEOUS SEDIMENTARY ROCKS.

The Cretaceous formations of this region form a series of conglomerates, sandstones, shales, and limestones of Lower Cretaceous (Comanche) age. In the Bisbee quadrangle, where they have been carefully studied, they rest unconformably on Paleozoic and pre-Cambrian rocks and attain a maximum thickness nearly or quite as great as that of the Paleozoic formations in the same area. The most distinctive Cretaceous formation, in respect to its lithology, the fossils that it includes, and the topographic forms that it produces, is the Mural limestone, which occurs near the middle of the series.

Within the Sulphur Spring Valley drainage basin, the Cretaceous rocks have their greatest development in the Mule Mountains and, according to Dumble, in the vicinity of Rucker Canyon in the Chiricahua Mountains.

In the central and northern parts of this region Cretaceous formations have not been recognized. The Little Dragoon Mountains, contain a widely distributed conglomerate whose constituent pebbles are derived chiefly from Paleozoic limestones. This conglomerate must be younger than the limestones whose pebbles it includes, but its age has not been definitely determined.

The only Cretaceous outcrops recognized within the valley are in the group of buttes in the vicinity of Forrest station. These buttes are capped with Mural limestone and have an aspect distinctly different from that of the other buttes.

IGNEOUS ROCKS.

Igneous rocks and beds composed of volcanic fragments occur widely throughout the drainage basin of Sulphur Spring Valley. They comprise the bulk of the Pinaleno, Galiuro, Winchester, Chiricahua, and Perilla ranges, form a large part of the mass of the Dos Cabezas Range, comprise the Dos Cabezas peaks, outcrop extensively in the Little Dragoon Mountains between Johnson and Dragoon station, occur at the surface in the Cochise Stronghold and adjacent area to the south, are exposed throughout the southern part of the Dragoon Range, are found over a large area in the Mule Mountains, overlie the limestones in the Swisshelm Mountains, and constitute a vast majority of the buttes in the valley.

The igneous rocks appear to belong to at least four distinct groups widely separated in age. Three of these groups are pre-Quaternary, one being pre-Cambrian, one post-Carboniferous and pre-Cretaceous, and one probably Tertiary.

The coarsely crystalline, granitic, and syenitic gneisses which constitute the main mass of the Pinaleno Mountains and form the core of the Dos Cabezas Range were regarded by Gilbert as pre-Cambrian. They are associated with the pre-Cambrian schist and are probably to be correlated with the pre-Cambrian granite in the Clifton quadrangle[1] and the pre-Cambrian granitic intrusions in the schists of the Globe quadrangle.[2]

In the portion of the Mule Mountains lying in the Bisbee quadrangle no pre-Cambrian granitic intrusive rocks are found. The large body of granite and granite porphyry exposed is of much later origin, as is shown by the fact that many of the granite porphyry dikes have been intruded into the upper Carboniferous limestones. The pre-Cretaceous age of these rocks is established by the fact that they have supplied pebbles to the basal Cretaceous conglomerates. The large masses of granite found in the Dragoon and Little Dragoon ranges probably belong, at least in part, with the granite and granite porphyry of the Mule Mountains.

The most abundant and widely distributed igneous rocks of this region are red, reddish-gray, and yellowish acidic lavas of probable Tertiary age. They have a stony groundmass in which are embedded numerous small phenocrysts, chiefly of quartz, feldspar, and mica. Rocks that appear to belong to this group are found in the lower parts of the Pinaleno Range, are extensively developed in the Dos Cabezas and Chiricahua ranges, lie above the limestone in the Swisshelm Mountains, and constitute the main mass of the Perilla Mountains. They also occur extensively in the Galiuro Mountains, comprise most of the Winchester Range, and are widely exposed in the southern

[1] Lindgren, Waldemar, Clifton folio (No. 129), Geol. Atlas U. S., U. S. Geol. Survey, 1905, pp. 5, 6.
[2] Ransome, F. L., Globe folio (No. 111), Geol. Atlas U. S., U. S. Geol. Survey, 1904, pp. 6, 7.

part of the Dragoon Mountains. They form most of the buttes in the valley. (See Pl. I.)

In the Mule Mountains several small dikes of light-gray porphyritic rock containing small phenocrysts of feldspar and mica are intruded into the Cretaceous beds and are therefore younger than these beds. Throughout most of the region the Cretaceous beds are absent and the youngest pre-Quaternary rocks with which the lavas come into contact are either Paleozoic or pre-Cambrian. The age of these lavas can therefore not be definitely fixed. Probably they belong to the general group of igneous formations that occur very extensively farther north, and that, in the vicinity of Clifton, Ariz., appear to be much younger than the Lower Cretaceous sedimentary beds.[1]

The Galiuro Mountains are composed in large part of roughly stratified, gently dipping agglomeratic beds whose peculiar light-colored groundmass contains numerous large rock fragments of various sorts. This formation attains a thickness of hundreds of feet and is sufficiently resistant to weathering to form high, precipitous, flat-topped ridges. It rests upon volcanic rocks and contains porphyritic inclusions but in many places is also intruded and overlain by lavas. Agglomerates and tuffs are also found in other localities.

The basaltic lavas found in a few places in this region are, at least in part, of Quaternary age and are therefore described under the heading "Quaternary geology." (See pp. 68–70).

STRUCTURE.

The sedimentary and metamorphic formations of this region belong to four distinct groups of formations—pre-Cambrian, Paleozoic, Cretaceous, and Quaternary, the last being the valley fill described under "Quaternary geology" (pp. 52–78). Generally speaking, each group consists of a succession of conformable beds separated by a great structural and erosional unconformity from each of the other groups with which it comes into contact. The pre-Cambrian rocks are the most profoundly altered, the sandy beds from which they are derived having been metamorphosed into crystalline schists. The Paleozoic formations, though much less altered than the pre-Cambrian, have become thoroughly indurated and greatly changed from their original condition. The sandstones have been converted into quartzite and the limestones have in some places been transformed into marble. The Cretaceous beds are less altered and less indurated, and the Quaternary materials are largely incoherent. Similar differences exist in the amount of deformation. The pre-Cambrian schists have been more profoundly deformed than the

[1] Lindgren, Waldemar, Clifton folio (No. 129), Geol. Atlas U. S., U. S. Geol. Survey, 1905.

Paleozoic beds; the Paleozoic rocks have undergone decidedly more deformation than the Cretaceous; and the Cretaceous rocks have been subjected to extensive deformation which has not been shared by the valley fill.

The deformation in this region consisted chiefly of great faulting movements by which the crust of the earth was broken into blocks of various sizes, and these blocks were tilted in different directions and at different angles. To some extent the crust was compressed into folds, but more commonly it was broken and faulted. The fault theory of rock structure was clearly stated by Gilbert and has been corroborated by the work of Ransome in the Bisbee quadrangle.

The structure of the earth's crust in this region is further complicated by the igneous rocks which are intruded into and spread over the sedimentary formations. Indeed, throughout a large part of the region the sedimentary formations are entirely concealed by igneous rocks.

GEOLOGIC HISTORY.

MAJOR DIVISIONS.

The geologic history of the region under consideration can be outlined as follows:[1]

1. Pre-Cambrian sedimentation, deformation, volcanism, and metamorphism.
2. Pre-Cambrian erosion.
3. Paleozoic and later events:
    a. Paleozoic sedimentation.
    b. Post-Carboniferous deformation, volcanism, and erosion.
    c. Cretaceous sedimentation.
    d. Post-Cretaceous deformation, volcanism, and erosion.
    e. Quaternary erosion and deposition (treated under the heading "Quaternary geology".)

The following account is in large part abbreviated from Ransome's Bisbee folio:

PRE-PALEOZOIC SEDIMENTATION, DEFORMATION, VOLCANISM, AND METAMORPHISM.

The dim, timeworn record of the oldest known eon is found in the pre-Cambrian schist. This formation probably consisted originally of sediments derived from still more ancient rocks and deposited in a pre-Cambrian sea. Long before Cambrian time these sediments were altered to crumpled crystalline schists and were, therefore, presumably deeply buried beneath other rocks and intensely folded and compressed. In some parts of the region they were apparently intruded by deep-seated bodies of molten rock which solidified to form granite, syenite, and gneiss. As a result of the folding and intrusion they were probably elevated as an extensive mountain mass.

[1] Ransome, F. L., Bisbee folio (No. 112), Geol. Atlas U. S., U. S. Geol. Survey, 1904, pp. 12, 13.

PRE-PALEOZOIC EROSION.

During the second eon, which may not have been sharply marked off from the preceding one, this mountainous land was eroded, and perhaps underwent many vicissitudes, involving oscillations in level and burial beneath fresh sediments which were again stripped away by erosion. All that is recorded, however, is a vast interval of erosion during which mountains were brought low and rocks bearing the stamp of deep-seated igneous and metamorphic processes were exposed at the surface of a nearly level plain of erosion.

PALEOZOIC SEDIMENTATION.

With the opening of Cambrian time this plain sank beneath the sea. The waves, as the shore line encroached upon the lands, rounded the fragments, chiefly of vein quartz, that lay on the subsiding land surface, added to these fragments such coarse material as they carved from the schists by direct attack, and spread the detritus evenly over the sea bottom, supplying the material for the basal Cambrian conglomerate. As the shore advanced inland sand, which later became quartzite, was deposited above the conglomerate. Then a change took place. Either increased subsidence carried this part of the sea bottom beyond the reach of shore currents having sufficient power to transport sand, or the nearest land mass remaining above water no longer supplied sandy sediments. In the clear waters lime-secreting animals made their appearance and furnished the material for the fossiliferous Cambrian limestone.

The Ordovician and Silurian periods, which followed the Cambrian and represent a very long lapse of time, left no record in the Bisbee quadrangle nor, so far as known, within the region here considered, although Ordovician beds occur in the vicinity of Clifton.[1] The fossiliferous Cambrian beds are succeeded with no visible stratigraphic interruption by a limestone that includes abundant characteristic Devonian fossils.

Whatever may have been the conditions during the Ordovician and Silurian periods, this region, or at least a part of it, was in the Devonian period covered by an open sea of moderate depth, in which flourished abundant marine organisms that contributed their calcareous parts to form the Devonian limestone. That there was still a land mass rising above the sea at no great distance is shown by the occurrence of some shale beds within the Devonian formations.

So far as known the deposition of limestone together with a small amount of clayey sediment occasionally washed in from the land continued from the Devonian period to the later part of the Carboniferous.

[1] Lindgren, Waldemar, Clifton folio (No. 129), Geol. Atlas U. S., U. S. Geol. Survey, 1905, p. 3.

POST-CARBONIFEROUS DEFORMATION, VOLCANISM, AND EROSION.

With the close of the Carboniferous period the long era of Paleozoic sedimentation, during which deposits had piled up to a thickness of approximately a mile, came to an end, and the region was elevated above sea level. To this elevation faulting, folding, and igneous intrusions all contributed.

During Triassic and Jurassic time the mountainous country elevated by the post-Carboniferous deformation was subjected to erosion. If any sediments were deposited within the region during these periods no trace of them has been found.

CRETACEOUS SEDIMENTATION.

Erosion had stripped away large parts of Paleozoic beds and had given the region a moderately hilly topography when the Cretaceous period was introduced by a submergence of at least parts of its southern portion. The comparative rapidity of the submergence is shown by the variant size and very incomplete rounding of the pebbles that form the basal Cretaceous conglomerate. These pebbles were evidently subjected for only a brief time to the wear of the waves and were then buried beneath the fine gravels, sands, and muds of the overlying formations. Further evidence that the subsidence was, locally at least, a geologically rapid movement is found in the hilly topography that underlies a considerable part of the Cretaceous beds. The pre-Cretaceous surface sank beneath the water before the waves could reduce its inequalities by planation or do more than slightly rework the stony detritus that littered its slopes and lay in its hollows.

After a large amount of sand and silt had accumulated in a sea that was apparently poorly provided with animal life, a change took place in the character of the sediments. They became more calcareous and gradually passed into the impure limestones, many of them crowded with marine shells that make up the lower member of the Mural limestone. These fossiliferous calcareous muds were in turn succeeded by the fairly pure limestone beds of the upper member of the Mural limestone, indicating deposition by a sea containing abundant animal life. The 650 feet of Mural limestone, however, mark only an episode in a general accumulation of sands and silts, as is shown by the return to conditions of sedimentation similar to those which prevailed before the Mural limestone was deposited. All the formations laid down during this submergence, aggregating nearly 5,000 feet of sediments, belong to the Lower Cretaceous (Comanche) epoch. How much more material was deposited during later Cretaceous and Tertiary time is not known.

POST-CRETACEOUS DEFORMATION, VOLCANISM, AND EROSION.

Since the deposition of the Cretaceous beds the rocks of the region have been further deformed by folding and faulting, have been intruded and to a great extent covered by enormous masses of molten lava, and have been subjected to erosion. The exact sequence of these events is not revealed. Both deformation and volcanic activity probably occurred intermittently over a long period, and erosion probably went on continuously in some parts of the area.

QUATERNARY GEOLOGY.

FORMATIONS.

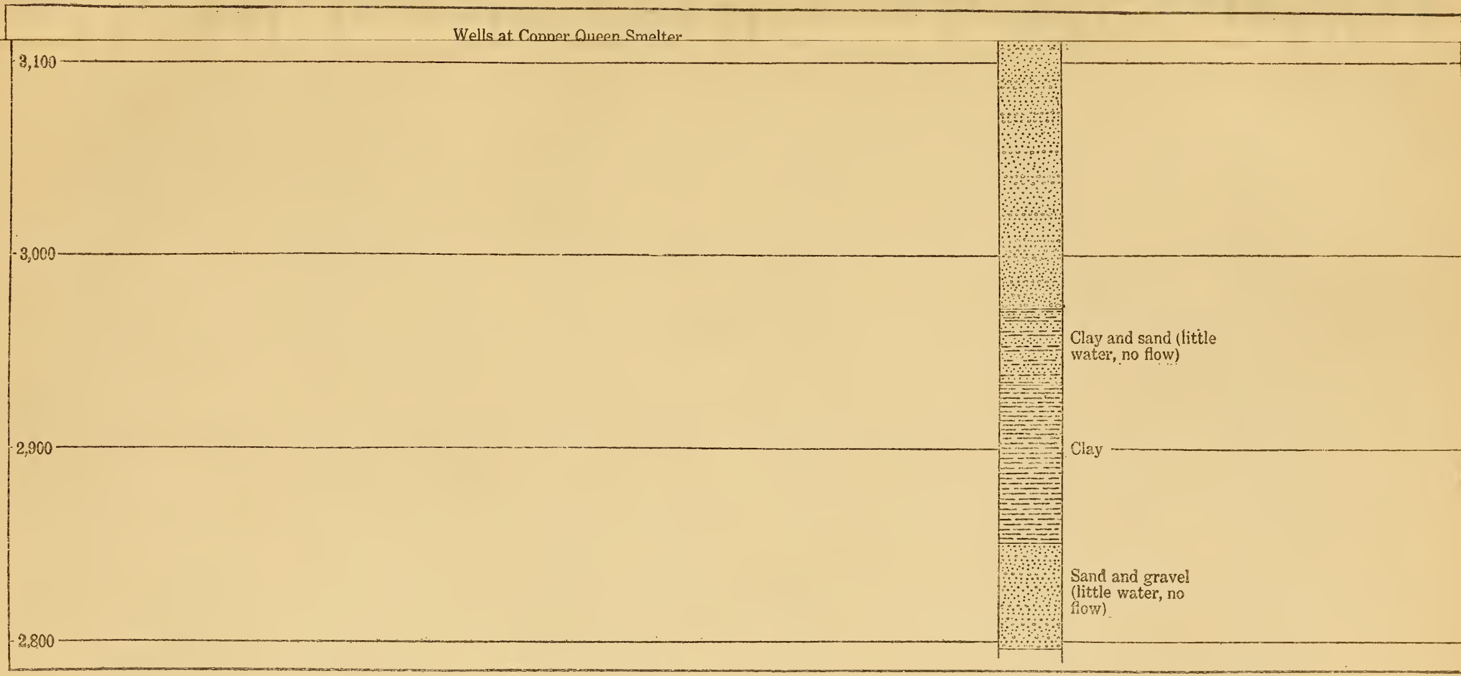
PRINCIPAL CLASSES.

The rock trough in which Sulphur Spring Valley lies has been constructed by the deformation and erosion of the rocks that have just been described. Since its construction it has been partly filled with sediments supplied by these rocks and washed out from the mountains which form its borders. These sediments are known as valley fill. For the most part they remain in the position in which they were deposited by the streams, but to some extent they have been handled by waves and lake currents, by the wind, or by underground waters, and have been redeposited according to the laws that govern each of these agencies. The materials that have not been rehandled since they were washed out from the mountains are known as stream deposits.

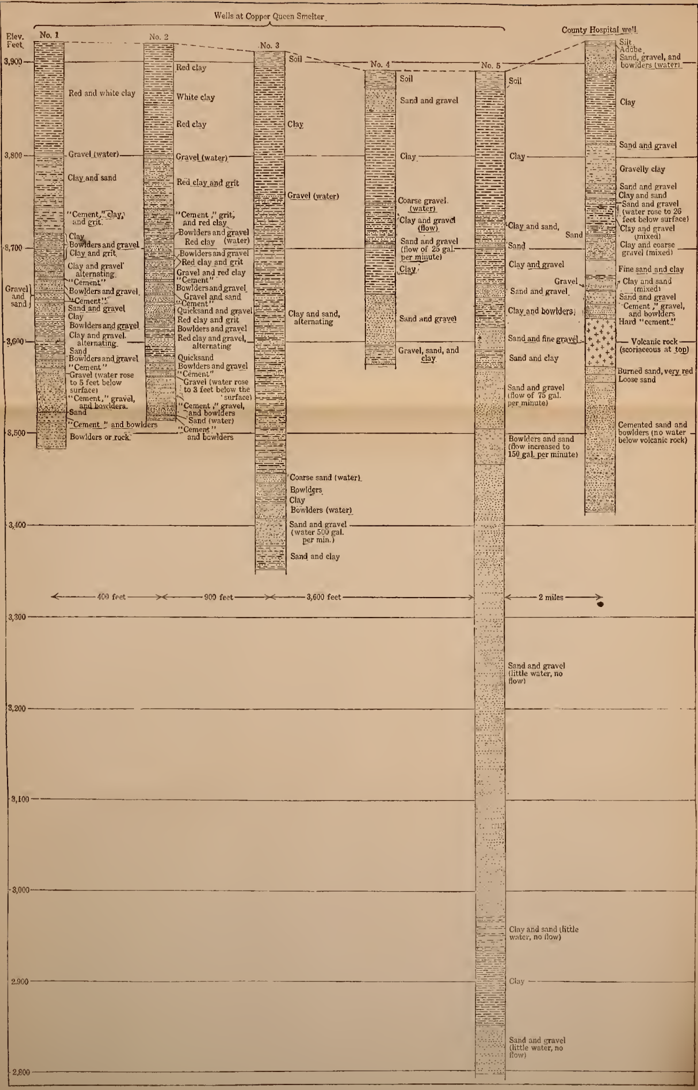
STREAM DEPOSITS.

Distribution and thickness.—The stream deposits lie at the surface over more than nine-tenths of the area of the valley and over more than one-half of the area of the entire drainage basin. (See Pl. I.) These deposits have not been very much deformed or eroded, and their edges are therefore not exposed as are the edges of the older formations in the mountains. Hence not much direct information in regard to their thickness and character can be obtained except by drilling wells. In fact, they form a blanket which to a great extent conceals not only the structure of the rocks below the valley, but also the geologic record of the valley fill itself.

The average width of the débris-filled valley is about 20 miles, and the maximum distance between the margins of opposite mountain walls is over 30 miles. The average inclination of the sides of the mountain ranges, from crest to margin, is at least several hundred feet to the mile, and in some places reaches 1,000 feet to the mile. If the sides of opposite ranges are projected toward each other, so as to form a V-shaped rock trough, the axis of the trough may easily be several thousand feet below the surface of the valley, the intervening space being occupied by valley fill. In fact, however, the rock floor



SECTIONS OF THE VALLEY FILL AT DOUGLAS, ARIZ.



SECTIONS OF THE VALLEY FILL AT DOUGLAS, ARIZ.

on which the valley fill rests is irregular, as is shown by the numerous buttes, which are merely parts of the rock floor that stand so high that they have not yet been covered by sediment.

At the Copper Queen smelter in Douglas a well sunk to the depth of 1,095 feet passes through nothing except characteristic stream deposits (Pl. IX); at the old Douglas waterworks a well 884 feet deep passes through valley fill and interbedded lava and ends in "sandstone," which is probably also valley fill; on the Van Meter ranch, 3 miles southeast of Soldiers Hole, a well is said to have been drilled over 1,000 feet deep without reaching bedrock; at Kelton Junction a railway well 650 feet deep appears to end in valley fill; at Willcox two wells between 400 and 500 feet deep have been drilled without striking rock; and several other wells over 400 feet deep have been reported, all of which apparently end in valley fill. Along Gila Valley and some of the tributary valleys that are comparable with Sulphur Spring Valley the stream deposits have become extensively eroded and thicknesses of over 1,000 feet are revealed.

It is of course likely that there are projections of the rock floor which have been entirely submerged by sediments. Where such buried buttes exist the stream deposits may be very thin, although there may be no surface indications of the unusual conditions. Rock has been struck by the drill at many points in the vicinity of mountains and buttes, but several hundred feet of valley fill is not uncommonly penetrated within a fraction of a mile from projecting rock masses. The well of the Commonwealth Mining Co. and the well of Harper & Williams in Pearce are almost at the base of Pearce Hill, yet the former passes through about 285 feet of gravel and clay before entering igneous rock and the latter ends in valley fill at a depth of 240 feet. The Southwest wells, which are encircled by buttes, go to depths of 150 and 222 feet, but both are said to enter rock. A number of holes drilled among the buttes in the vicinity of Leslie Creek have also struck rock at reported depths of 65 to 280 feet.

All lines of evidence indicate that the valley fill of Sulphur Spring Valley, consisting chiefly of stream deposits, is in few places less than several hundred feet thick, and that over large areas remote from mountains and buttes it may be more than 1,000 feet thick.

Character.—The stream deposits consist of clay, silt, sand, gravel, and bowlders, of various mixtures of these materials, and of these materials firmly bedded in a cement matrix consisting for the most part of lime carbonate (Pl. IX). On the whole, the clayey deposits largely predominate. They are prevailingly of a pale-reddish color, but may be blue or, less commonly, almost white.

A stream confined within a steep, narrow canyon may flow so swiftly that it will transport not only clay and sand, but pebbles and bowlders as well. When, upon reaching the valley, its carrying power is diminished it will as a rule drop first the bowlders, then the pebbles, and then the sand, but it may hold the impalpable particles of clay in suspension until it disappears by seepage and evaporation or collects on the flat in the center of the valley. In this way the streams tend to sort the débris which they handle, depositing the coarsest material nearest the mountains and the finest farther out in the valley. This general sorting process is evident on all the stream-built slopes. The soil of the upper part of a slope is generally too stony to be cultivated, and the soil of the lowest part is likely to consist of heavy clay that is likewise poorly adapted for agriculture. The loams, which make good farming land, are found chiefly on intermediate parts of the slope. This gradation in soil is manifested by corresponding zones of vegetation. It is also forced on the attention of well drillers. Holes drilled on the upper slopes not uncommonly become so crooked that they have to be abandoned because the drill is deflected by bowlders—a difficulty not encountered in the lower parts of the valley.

In the vicinity of buttes and small mountain ranges the transition from coarse to fine deposits may be abrupt. The débris from these small rock masses is generally coarse, and in the very small buttes it forms a talus rather than a stream-built slope. This coarse material is not carried far from the parent rock mass, and within a short distance it is surrounded by fine sediments brought from large mountains much farther away. The sorting done by the streams is very imperfect. In places the carrying power of the water diminishes so suddenly that pebbles, sand, and clay, and sometimes even bowlders and clay, are dropped simultaneously, and the resulting deposit has a clayey matrix which includes grit, pebbles, and even bowlders. Indeed, the beds reported by drillers as clay are commonly not clay in the strict sense, but contain large proportions of gritty material and numerous small embedded pebbles. They are not, like true clay, impervious to water, but allow a slow seepage which supplies many shallow domestic wells. On the other hand, the beds reported as gravel are not all composed of clean gravels but may consist of pebbles and bowlders so completely embedded in a clayey matrix that the bed will yield no more water than a bed of so-called clay.

The successive floods that issue from any canyon differ greatly in size and therefore in carrying power. A large flood will sweep coarse materials far into the valley and will roll great bowlders to incredible distances from the mountains. A small flood will be powerless to move bowlders at all, and its waters will disappear soon after leaving the mountains and will therefore deposit even the finest portion of their load on the upper part of the slope. As a result fine sediments are thrown down upon beds of coarse débris, and at any given point the drill penetrates successive beds of different character. This condition is shown by the sections of all wells that pass through the stream deposits. It is illustrated by the sections of the Copper Queen smelter wells Nos. 1 and 2 (Pl. IX). The other well sections given in Plate IX show a less rapid succession of strata probably for the simple reason that they were reported in less detail by the drillers. To some extent the pebbly clays mentioned above are produced by the percolation of muddy waters into gravel beds.

A stream does not build all parts of its slope simultaneously. It takes its course over one part of the slope until by deposition of its load it has elevated this part above the rest. Then the stream, always seeking the lowest levels, breaks away from the elevated tract and builds up another part of the slope. Frequently also the waters divide after emerging from the canyon, small streams spreading out over parts of the slope and depositing the fine materials while the main stream sweeps over an adjacent part and deposits only coarse material at the same level. Consequently a stream deposit has little continuity, especially in a direction at right angles to the slope. This condition is everywhere observed by drillers and causes great surprise. Two wells not far apart may have very different sections. For example, at a given level water-bearing sand or gravel may occur in one well and nothing but clay be found in the other. The Copper Queen Smelter wells Nos. 1 and 2 (Pl. IX) are close together and their sections as reported by the driller are practically identical, but the sections of five other Copper Queen wells, all within short distances of one another, show little similarity. They all pass chiefly through clayey beds within the upper 150 feet and find sand and gravel at lower levels, but it is not possible to correlate the individual strata, whereas marine and lacustrine formations can generally be correlated in spite of inaccuracies in the drillers' logs.

The people of the valley commonly speak of the first, second, and third water-bearing strata as if each stratum were a well-defined bed extending without interruption beneath a large area. In fact no continuity generally exists. The first water-bearing sand in one well may not be continuous with the first water-bearing sand in a well near by. It may be a bed which in the other well is absent, or lies above the water level, or dips down and is known as the second stratum.

The stream deposits are not entirely incoherent. At certain horizons they have become thoroughly cemented by lime carbonate and may be almost as hard as some of the rock formations outcropping in the mountains (Pl. IX). In many places a layer of caliche is found within a few feet of the surface, but cemented beds may occur at any level, and on the whole they probably increase with depth. A certain amount of cementation has taken place in nearly all the stream deposits, as is shown by the fact that wells do not require curbings above the water level, and also by the pale colors and effervescence with acid of most of the materials brought to the surface in drilling.

Correlation.—The detrital fill of Sulphur Spring Valley is believed to correspond in age and mode of origin to the dissected valley deposits along the upper Gila and its tributaries, which Gilbert studied in 1873 and to which he gave the name Gila conglomerate. Such a correlation is clearly suggested in the following description:[1]

The Gila conglomerate.—A system of valley beds, of which a conglomerate is the characteristic member, is exhibited in section along the gorges of the upper Gila and its tributaries. The bowlders of the conglomerate are of local origin, and their derivation from particular mountain flanks is often indicated by the slopes of the beds. Its cement is calcareous. Interbedded with it are layers of slightly coherent sand, and of trass, and sheets of basalt; the latter, in some cliffs, predominating over the conglomerate. One thousand feet of the beds are frequently exposed, and the maximum exposure on the Prieto is probably 1,500 feet. They have been seen at so many points by Mr. Howell and myself that their distribution can be given in general terms. Beginning at the mouth of the Bonita, below which point their distinctive characters are lost, they follow the Gila for more than 100 miles toward its source, being last seen a little above the mouth of the Gilita. On the San Francisco they extend 80 miles; on the Prieto, 10; and on the Bonito, 15. Where the Gila intersects the troughs of the Basin Range system, as it does north of Ralston, the conglomerate is continuous with the gravels which occupy the troughs and floor of the desert plains. Below the Bonita it merges insensibly with the detritus of Pueblo Viejo Desert. It is, indeed, one of the "Quaternary gravels" of the desert interior, and is distinguished from its family only by the fact that the watercourses which cross it are sinking themselves into it and destroying it, instead of adding to its depth. It is in its relation to the rivers that it is chiefly interesting; in the accumulation and subsequent excavation of the beds there is recorded a reversal of conditions that may have a broad meaning. The base of the series in its deepest parts is not exposed, and if we go back to the beginning of its deposition we have to picture the valleys as deeper than they are revealed at present.[2] During the accumulation the altitude of the drainage lines steadily increased—their altitude, that is, in relation to the surrounding mountains—and it attained its maximum when the top of the conglomerate was laid, since which time it has as steadily diminished. There is no difficulty in comprehending the present action, for it is the usual habit of swift-flowing streams to cut their channels deeper; but to account for the period of accumulation there must be assumed some condition that has ceased to exist. Such a condition might be either a barrier, somewhere below the region in question, determining the discharge of the water at a higher level than at present, or it might be a general depression of the region, in virtue of which the ocean (now 300 miles away) became a virtual barrier. With either hypothesis, a change of more than 1,000 feet must be considered.

In a description of the same formation in the Globe quadrangle Ransome makes the following statements:[3]

The Gila formation is essentially a valley deposit, having usually, in spite of deformation and dissection, a still recognizable relation to the larger features of the existing

[1] Gilbert, G. K., U. S. Geog. Surveys W. 100th Mer., vol. 3, 1875, pp. 540, 541.

[2] The postulate is not absolutely tenable, since the corrugation by which troughs are produced and the filling of those troughs by detritus go forward simultaneously, but it introduces no fallacy in its present use.

[3] Ransome, F. L., Globe folio (No. 111), Geol. Atlas U. S., U. S. Geol. Survey, 1904, pp. 5, 6.

topography. It lies indifferently upon the eroded surfaces of all the other rocks of the quadrangle, with the exception of basalt, which occurs as an intercalated flow between the conglomeratic beds and is therefore of contemporaneous age * * *. The rapid variation in character, the coarseness of the bowlders, the distribution of the material with reference to existing mountain ranges, the nature and dip of the stratification, and the frequent abrupt changes observable in both vertical and horizontal sections all point decisively to the result of fluviatile action. The bulk of the Gila formation as it occurs in the Globe quadrangle was deposited by streams and resembles the material found in the beds of the prevailing dry arroyos to-day. * * * The occurrence of large angular blocks near the mountains, with the rapid gradation into finer materials toward the middle of the depositional tract, points to tumultuous transportation—to torrential rushes of water, by which large quantities of rock waste were transported in a short time from the mountain slopes to the valley, with little of that rounding of individual fragments which characterizes the action of streams having a more constant flow, and in which the materials as a rule travel more leisurely to greater distances before coming to rest.

The Gila conglomerate in the Clifton quadrangle has been studied by Lindgren,[1] whose conclusions in regard to it agree with those of Gilbert and Ransome.

Gilbert makes no mention of any deformation of this formation, and Lindgren states that so far as known the Gila conglomerate has not been warped or dislocated by faulting in the Clifton area. Ransome, however, found that in both the Globe and Ray quadrangles it has locally been affected by extensive deformation. Except the slight possible tilting shown by the ancient beaches, no evidences of deformation were observed in Sulphur Spring Valley, unless, indeed, the tilted conglomerates east of Johnson, which were mentioned as possibly Cretaceous, should prove to belong to the Gila conglomerate.

BURIED LAKE (?) BEDS.

Beds in the north basin.—A well sunk some years ago on the present premises of C. T. McGlone, near the southeast margin of the village of Willcox, is reported to have reached a depth of 480 feet and to have penetrated a bed of clay that does not seem to be a stream deposit. In the upper 280 feet the section appears from the reports to consist of ordinary stream deposits, including several layers of coarse water-bearing gravel. From 280 to 480 feet, however, the drill passed through a homogeneous stiff clay, called talc by the driller, presumably because it was so fine grained and so entirely wanting in grit that, like true talc, it was smooth to the touch. This clay was dark blue at the top and jet black farther down, but when exposed to the air it turned yellow. It is also reported to have had a strong odor. The black color is probably due to impregnation of the formation with sulphides, which become rapidly oxidized when they are brought into contact with the air, and the odor is probably due to the presence of hydrogen sulphide. Throughout the 200 feet that was penetrated the forma-

[1] Lindgren, Waldemar, Clifton folio (No. 129), Geol. Atlas U. S., U. S. Geol. Survey, 1905, pp. 5, 6.

tion is reported to have yielded no water whatever. When the hole was abandoned the drill was working in this clay and there is no means of estimating to what depth it may extend. A well drilled for the ice plant in Willcox is also said to have been carried to a depth of 400 feet or more and to have revealed the same bed of black clay.

In a 200-foot well on the farm of J. C. Page, in the NE. $\frac{1}{4}$ sec. 22, T. 14 S., R. 24 E., about a mile north of Hado station, the upper 85 feet of material is reported to consist of a succession of beds, several of them water-bearing and the remaining 115 feet of homogeneous, compact, nonwater-bearing clay, which had a foul odor and is variously described as "dark blue" and "perfectly black." Several other wells near the barren flat seem to have entered a similar clay, but information in regard to them is vague. Clay of the same character underlies the barren flat.

This black clay is very different from the typical "clay" beds of the stream deposits, which are commonly gritty and of a reddish color and are interrupted at many horizons by seams of sand and gravel. It obviously represents deposition from quiet waters. It could possibly have been formed by deposition from temporary sheets such as flood the barren flat at the present time, but an uninterrupted thickness of 200 feet suggests that it was formed at the bottom of a permanent lake or other large body of water. On the barren flat clay of this type underlies the surface at about 4,135 feet above sea level. In Page's well it was struck at about 4,070 feet, and in Willcox it was encountered at about 3,880 feet. It is not improbable that if a series of wells were drilled between Willcox and Page's and between Page's and the flat the ordinary stream and wind deposits would be found to feather out toward the flat, and the body of black clay below the flat would be found to be continuous with that penetrated at Page's and in Willcox. The uneven upper surface of the black clay could then be explained either by assuming that the clay body had been partly removed by erosion and the space had later been refilled by stream or wind deposits, or by the much more probable assumption that the lake had gradually contracted, so that stream deposition was taking place at Willcox while lake sedimentation was still going on at Page's, and that at a later time stream deposition was taking place at both Willcox and Page's while lake sedimentation was still in progress where the flat is now situated. Under either hypothesis the clay bed underlying Willcox represents an epoch of submergence much more ancient than that represented by the beaches and must have been separated from the later submergence by an interval during which stream deposition was taking place over the zone that borders the flat.

No beds have been reported in the south basin comparable to the buried black-clay beds in the vicinity of Willcox. The section of the

1,095-foot well at the Copper Queen smelter indicates the absence of such beds, at least in the vicinity of Douglas.

Beds in San Simon Valley.—In drilling a deep well at San Simon (see fig. 1, p. 10) a 430-foot bed of dense homogeneous, "sticky," dark-blue, nonwater-bearing clay with an odor of hydrogen sulphide was struck 145 feet below the surface, or at a level 3,465 feet above the sea. This formation is overlain by successive strata of "yellow clay," sand, and gravel, which appear to be ordinary stream deposits, and is underlain by a series of alternating beds of sand, clay, "caliche and pebbles," etc., which have been penetrated by the drill for 275 feet and which appear to consist in whole or in part of stream deposits that have become consolidated and cemented to a greater extent than the stream deposits nearer the surface. (See fig. 8.) This thick bed of well-assorted clay bears a strong resemblance to the black-clay formation in Sulphur Spring Valley and, like it, suggests if it does not demand a theory of lake origin.

About 18 miles northwest of San Simon station, along the west side of the axial draw of San Simon Valley, 15 or 20 feet of a series of stratified beds is exposed. This series consists of layers of gypsiferous dark-gray and brown clay, alternating with layers of volcanic ash, or tuff. (See Pl. X, *A*.) The tuffaceous material has a mottled appearance, cream, which is the predominant hue, blending with pure white and delicate shades of brown and green. Its bright colors attract attention by their strong contrast with the dull, gray hues of the desert. It consists of small, loosely aggregated fragments and is minutely vesicular and of low specific gravity. The most massive bed observed is about 6 inches thick and forms the cap rock that protects the underlying less resistant clay.

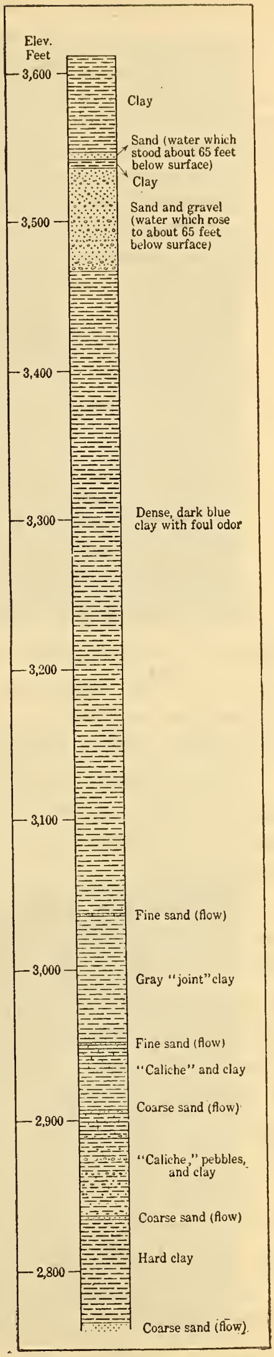


FIGURE 8.—Section of artesian well at San Simon, Ariz.

What appears to be the same series of outcrops was observed by Oscar Loew in 1873 and is described by him as follows:[1]

On the plain extending from Fort Bowie to the Peloncillo Mountains, about 4 miles south of Whitlock's ciénega, are found stratified deposits of a yellowish soft porous material, in thickness from 12 to 13 feet, and in extent about one-sixth of a mile. The mass easily crumbled to powder between the fingers, had no similarity at all to clay, and the presence of very fine grit could be distinctly recognized.

On digestion with strong acids, a complete decomposition was effected. Alumina, lime, magnesia, oxide of iron, and alkalies were dissolved, while silicic acid was separated, and remained with the fine grit, which proved to be plain silica. It follows, therefore, that this tuff is a mixture of free particles of quartz with hydrous silicate.

Analysis of San Simon tuff.[2]

Silica	64.61
Alumina	14.32
Oxide of iron	2.98
Lime	3.01
Magnesia	1.36
Soda	3.19
Potassa	Trace.
Water	10.42
	99.89

Exposures were seen at two places about a mile apart, and the main beds in the two places could be correlated with each other. No outcrops of this character were observed between the locality of these exposures and Rodeo, N. Mex.; the valley below these exposures was not seen. The outcrops occur about 3,400 feet above sea level.

The stratified deposits are not related to the present topography. Except where they have been exposed by recent erosion they are buried beneath stream deposits, like the clay bed struck at San Simon station.

Beds in San Bernardino Valley.—A compact blue clay approximately 45 feet thick is reported to have been penetrated in each of the nine wells drilled on Slaughter's ranch, in San Bernardino Valley. It was struck at a level which ranges in the different wells from about 280 to more than 300 feet below the surface and is approximately 3,450 feet above the sea. This clay is sufficiently different from the ordinary stream deposits to have been recognized as a distinct stratum by those who drilled the wells. Apparently it is underlain by stream deposits of the usual type.

Beds in San Pedro Valley.—A series of stratified beds outcropping in the San Pedro Valley (see fig. 1, p. 10) was discovered and studied by Blake,[3] who made the following statements in regard to them:

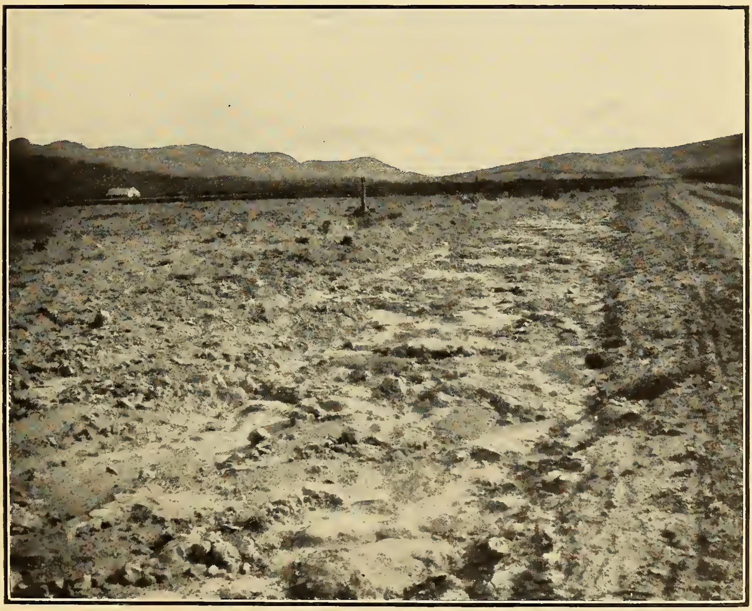
On both sides of San Pedro Valley there are unconsolidated red clays and sediments in horizontal beds of great thickness, often terraced by the river erosion, and extending

[1] U. S. Geog. Surveys W. 100th Mer., vol. 3, 1875, pp. 643, 644.

[2] Analysis at 100° C.

[3] Blake, W. P., Lake Quiburis, an ancient Pliocene lake in Arizona: Univ. Arizona Monthly, vol. 4, No. 4, February, 1902.

A. STRATIFIED BEDS IN VALLEY FILL OF SAN SIMON VALLEY.



B. CALICHE EXPOSED BY GRADING OF ROAD.

high up on the sides of the bordering mountains. One of the best cross sections is found on the line of the Southern Pacific Railway, which crosses the valley nearly at right angles to its course at Benson. Benson, in the bottom of the valley, has an altitude of 3,576 feet above the sea. The river is about 50 feet lower. The lacustrine clays rise from this point on each side to a height of about 3,800 feet. * * *

Sediments similar to those around Benson border the valley northwards toward the Gila Valley. We there also find in addition thick beds of diatomite mingled with the fine volcanic ash. These diatoms are mostly marine species, according to Dr. D. B. Ward, of Poughkeepsie, but some fresh-water forms are present. San Pedro Valley thus appears to have been occupied by sea water. It was open on the north to the great open valley of the Gila and Salt River and would appear to have existed as a partly landlocked estuary, at least in the upper portion between the Dragoon Mountains and the Whetstones and Huachucas.

In another paper [1] Blake says:

The diatom fossils occur in thick beds many square miles in area, in horizontal layers cut through by ravines, and probably 100 feet in thickness. These beds when freshly broken are snow-white and chalk-like in appearance but are siliceous and not calcareous in composition. Under the microscope the diatoms are seen to be distributed through or mingled with nearly colorless vitreous particles, apparently a very finely divided volcanic ash or dust, such as may have been wafted by the wind and deposited in a lake or estuary of quiet water.

The gypsum in these beds is described by Blake [2] as follows:

The gypsum along San Pedro River occurs in horizontal beds, probably of Pliocene or post-Pliocene age. The strata are soft, unconsolidated gray sandstones and clays and appear to be the lower members of the same series in which the beds of diatomite and volcanic ash are found. The gypsum is interstratified conformably in comparatively thin layers or seams, rarely more than a few inches in thickness. These layers appear to have been formed subsequent to the deposition of the strata by crystallization from the infiltration of gypseous solutions. The mineral occurs as selenite and also in the fibrous form as satin spar.

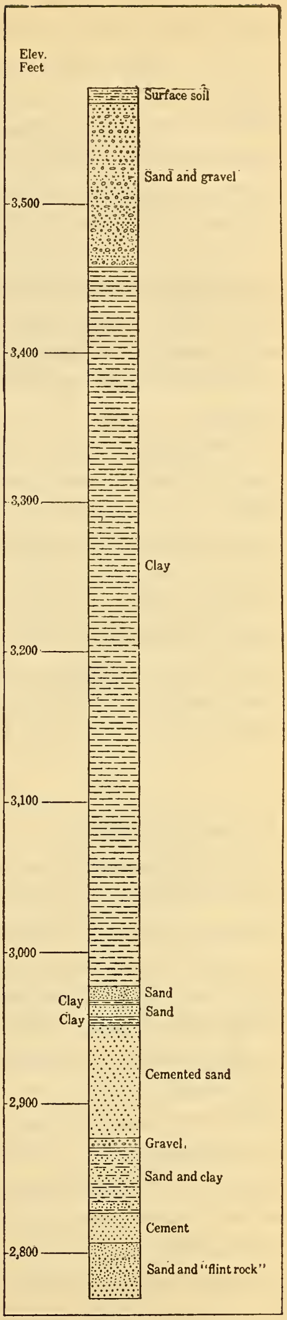


FIGURE 9.—Section of railroad well at Benson, Ariz.

[1] Blake, W. P., Arizona diatomite: Trans. Wisconsin Acad. Sci., vol. 14, pt. 1, 1903, pp. 107–111.
[2] Blake, W. P., Gypsum deposits in the United States: Bull. U. S. Geol. Survey No. 223, 1904, pp. 100–101.

The stratified beds outcropping in San Pedro Valley seem to have the same general relation to stream deposits as those at San Simon. Except where they have been exposed by recent erosion they are buried beneath stream deposits [1] whose accumulation has apparently obliterated every trace of the ancient lake topography. Though the section of the railroad well at Benson (fig. 9) is not given definitely enough to permit positive conclusions, it suggests that the stratified beds are underlain by stream deposits.

Beds in the Ray quadrangle.—In the vicinity of Ray, Ariz., on the south side of Gila River, near the mouth of the San Pedro, stratified beds occur which were evidently laid down at the bottom of a lake or other body of standing water. These beds comprise part of the valley fill and are overlain and probably also underlain by stream deposits.[2]

Correlation.—The buried clay beds of Sulphur Spring and San Simon valleys, the outcropping strata of tuff and clay in San Simon Valley, the extensively exposed series of clay, sandstone, diatomaceous earth, tuff, and gypsum in San Pedro Valley, the stratified beds in the Ray quadrangle, and possibly the buried clay bed in San Bernardino Valley indicate deposition at the bottom of a lake or other body of standing water. So far as known they have similar relations to the rock troughs and to the stream deposits, and it is not unlikely that they are of the same age and were produced by general conditions that affected all southeastern Arizona.

YOUNGER LAKE DEPOSITS.

Stratified lake beds.—In the north basin of Sulphur Spring Valley, upon the clay bed just described as probably of lake origin, rests a more recently deposited mantle of clay, sand, and gravel, which is shown by many well sections and natural and artificial exposures to consist of ordinary stream deposits. Superimposed on the stream deposits are the ancient beaches, which remain to-day almost perfectly preserved. While the beaches were being formed by the waves along the shore, sedimentation must have been taking place over the submerged area.

Except near its borders the interior of the barren flat is underlain by a homogeneous, fine-grained plastic clay, such as might have been deposited at the bottom of a permanent lake, though it might also perhaps have been deposited during temporary shallow submergences, such as the flat occasionally experiences at present. At a number of points in the interior of the flat holes were bored to a depth of 12 feet, but in none of these was anything except the homogeneous

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[1] Antisell, Thomas, Explorations and surveys for a railroad from Mississippi River to Pacific Ocean, 1853–56, vol. 7, 1857, pt. 2, Geol. Rept., pp. 143–144.

[2] Ransome, F. L., and Umpleby, J. B., unpublished data.

plastic clay found. As the flat contains no natural outcrop and no artificial excavation, there is little opportunity to study the stratification or lamination of this clay. It may reasonably be supposed that, to a certain depth, this clay represents sedimentation in the lake which formed the beaches. If, as is not unlikely, the clay beneath the flat is several hundred feet thick and belongs to the same great body of clay that was penetrated in the deep well at Willcox, only a small part of this total thickness can be correlated with the beaches and ascribed to the last submergence.

Near the margin of the flat and in the zone between the flat and the beaches the strata revealed in borings and in numerous artificial and natural exposures consist chiefly of alternating layers of sand and clay, which change rapidly from place to place and thus differ radically from typical even-bedded and well-assorted lake sediments. The only locality in which were found beds approaching the laminated appearance of typical lake sediments is along the extreme northeastern border of the flat, in secs. 26 and 27, T. 14 S., R. 25 E., where about 4 feet of soft laminated beds of clay, sand, and alkali outcrop along the sides of one of the gullies leading to the flat. (See Pl. VII, *C*, p. 42.)

Thoroughly stratified beds are not commonly found beneath the sloping marginal parts of an ancient lake bottom where the shallow waters were agitated by waves, shore currents, and incoming floods. The apparent scarcity of typical lake beds is perhaps adequately explained by the total absence of exposures in the parts of the lake remote from the shore.

Beach materials.—The beaches and beach ridges of the ancient lake are built chiefly out of pebbles that are more or less water worn and are covered with a gray coat of lime carbonate. In localities where the waves found few pebbles, as, for example, southeast of Servoss station, particles of caliche, or white hardpan, were rounded into pebbles and used in building the beach.

The gravelly character of the beaches is illustrated in Plate VI, *B* and *C* (p. 36). An excellent cross section of a beach is exposed a mile northeast of Cochise in a wash following an abandoned railway cut between the railroad and the wagon road leading from Cochise to Willcox. In cross section the beach here forms a lens several rods long and about 4 feet in maximum thickness. It is composed of smooth pebbles of different sizes, averaging perhaps the size of a hen's egg, cemented into a conglomerate by lime carbonate.

Lagoon deposits.—In some localities swamps or lagoons were formed between the beach ridge and the mainland. These shallow but sheltered strips of water were gradually filled with vegetable matter and fine-grained sediments contributed by different agencies. The largest deposit of this kind is south of Croton Springs, in secs. 6 and 7, T. 15 S., R. 24 E.

WIND DEPOSITS.

The wind deposits east and north of the flat consist of sand and clay, the sand greatly predominating. So far as known they rest on the stream deposits and ancient beach gravels. They probably attain a maximum thickness of 100 feet in the highest ridges, but their average thickness is much less. As the barren flat is underlain almost exclusively by clay, it is probable that most of the sand was supplied by the waves of the ancient lake. The clay was probably derived from the flat after the lake became dry.

The deposits of clay are all near the flat. For the most part they consist of low ridges or mounds at its very margin. The sand has in general been carried farther. This difference is due chiefly to the fact that the wind can drive sand more readily than clay; it may be due in part to a difference in the length of time that the wind has had possession of each material. Plate VII, *A* (p. 42), shows an eroded bank at the margin, the lower part of which consists of wind-blown clay and the upper part of wind-blown sand. The small terrace along the line of contact between the two materials shows that the wind is removing the sand more rapidly than the clay.

As the wind can handle only comparatively small grains, the wind deposits are free from coarse material such as gravel. On the tops of some of the sand hills in this valley there are numerous stones of different sizes, but these were all transported to their present position by man, as is shown by their polished or fractured surfaces. Crusts of lime carbonate have also formed near the surface since the deposition of the sand, and in some places these have been broken, producing hardpan pebbles or rocks. The sand and clay are not completely sorted. The soil in much of the sand-hill area consists of sandy loam rather than of sand, and the clay hills contain a gritty admixture.

The sand is gray, and in some places is firmly cemented. The clayey deposits are commonly reddish brown. Both sand and clay are indistinctly stratified and cross-bedded. (See Pl. VII, *A*.)

More or less wind-blown material is widely distributed over the valley, but the limits shown on Plate I embrace only the area in which wind deposits occur as a definite formation with characteristic wind topography. An area of several square miles in the northern part of T. 16 S., R. 25 E., especially in secs. 3, 4, 9, 10, 16, and 17 and adjacent tracts, between Allaire's ranch and Sulphur Springs, has a sandy loam soil beneath which lies a formation of gray sand and grit. This formation is rather homogeneous throughout and is commonly cemented by calcium carbonate, to which it owes its gray appearance. In some places it reaches a thickness of 20 feet and in well sections is seen to rest on typical reddish stream deposits. This formation is distinctly different from ordinary stream deposits and has the appearance of a wind deposit, but in some places it contains small pebbles which it is difficult to believe were transported even by storm winds.

DEPOSITS MADE BY GROUND WATER.

Caliche.—In many parts of the valley a layer of caliche is encountered, generally about 2 or 3 feet below the surface. It consists of ordinary valley fill, which is firmly cemented and to some extent replaced by lime carbonate and other precipitates. It is best developed beneath the slopes bordering the ranges that contain an abundance of limestone, but it is also found in localities where the adjacent mountains consist entirely of granitic and porphyritic rocks. Plate X, *B* (p. 60), shows caliche on the slope east of Douglas as it has been exposed in grading a wagon road.

Throughout most of the valley the soil at the surface contains abundant lime carbonate. Only in soils that are exceptionally well drained, such as the porous soils of the sand-hill area and the soils of certain eroded slopes, has the lime carbonate been leached out. Fortunately for agriculture, within the first foot or two of the surface the lime carbonate is not sufficiently abundant to cement the soil appreciably, but below this depth it is much more abundant. In some localities it forms a layer almost as hard as limestone; more commonly it has not developed into a rock, but has made the subsoil harder than ordinary soil. The hard layer is generally not more than a few feet thick.

Downward the caliche gradually becomes softer, and at considerable depth the amount of lime carbonate is usually much less. The layers of "cement" reported by drillers at various depths (for example, those shown in Pl. IX and fig. 8) are probably at least in part buried layers of caliche that were formed at the surface long ago.

The caliche has a definite relation to the surface, but it has no relation to the ground-water level, either present or past. It occurs within a few feet of the surface, both where the ground water is shallow and where it is at depths of several hundred feet. Much has been written about caliche, but the exact processes by which it is produced are not yet well understood. It is evidently formed by precipitation of lime carbonate dissolved in water in the ground. As it is formed near the surface the precipitation is probably due to evaporation of this water. However, the lime carbonate is not in general derived from the main body of ground water because water can not be lifted by capillarity through a vertical distance of much more than 10 feet. A portion of the water that is poured in floods over the slopes seeps only a short distance into the ground and is eventually evaporated without reaching the ground-water level. This flood water dissolves some of the lime carbonate over which it flows, and when it evaporates it must leave its load of lime carbonate in the soil near the surface. The caliche is probably composed of this lime carbonate. The fact that caliche does not generally occur at the surface but rather a few feet below it appears to be due to downward leaching, especially within the zone in which carbonic acid, necessary to dissolve lime carbonate, is supplied by decaying vegetation.

Alkali.—Soluble salts, such as sodium carbonate, sodium sulphate, and sodium chloride, form a considerable proportion of the deposits that underlie the low areas in both basins of Sulphur Spring Valley. Like caliche, these salts are accumulated near the surface, and, like caliche, deposits formed at the surface may later become deeply buried. Unlike caliche, these salts are derived largely from the main body of ground water and they do not generally accumulate where the ground water is too deep to be drawn to the surface by capillary action. Alkali that is found in quantity in localities where the ground water can not reach the surface by capillarity has generally accumulated at a time when the ground water stood higher.

Alkali differs from lime carbonate in being much more soluble, and for that reason it is leached out of an upland soil where the lime carbonate accumulates. The subject of alkali is more fully treated on pages 160–181.

Sulphides.—The barren flat is underlain to an unknown depth by a jet-black deposit. Holes were bored in many different parts of the flat and everywhere the black material was encountered. At several points near the north end of the flat the upper surface of the black material was found practically to coincide with the ground-water level, which was approximately 4 feet below the surface. In the interior of the flat, where the clay is so fine grained that no definite water level exists, the black material was not encountered until depths of 9 to 11 feet were reached. At one point near the east margin the change of color occurred at a depth of 9½ feet, though the water level stood only 4 feet below the surface. At another point near the east margin the change of color occurred at a depth of 9 feet, though the water level was 5⅓ feet below the surface. In both of the borings near the east margin the color was dark blue instead of the characteristic black.

As shown in figure 10, the black color is not associated with any particular kind of material. In the interior only fine-grained clay was found, but near the north margin strata of sand were penetrated, which are as black as the clay, although when the impurities are washed out the sand is found to consist of granules of clear quartz. The black materials give off an odor of hydrogen sulphide, and this odor is intensified when the materials are treated with acid. When brought into contact with air, the color changes rapidly from black to light yellow. The black substance also contains organic matter.

The acid test proves the presence of sulphides. These sulphides give the black color. When brought into contact with the oxygen of the air, they become oxidized and their color is destroyed. The sulphides may be derived from sulphur in the organic matter or may result from the reduction of sulphates through the agency of organic matter. Considerable quantities of sulphates have been deposited in the beds underlying the flat, as is indicated by the soil analyses given on page 172 and by the water analyses given on page 154. A certain amount of organic matter is generally embedded with the sediments laid down at the bottom of a lake, where it is

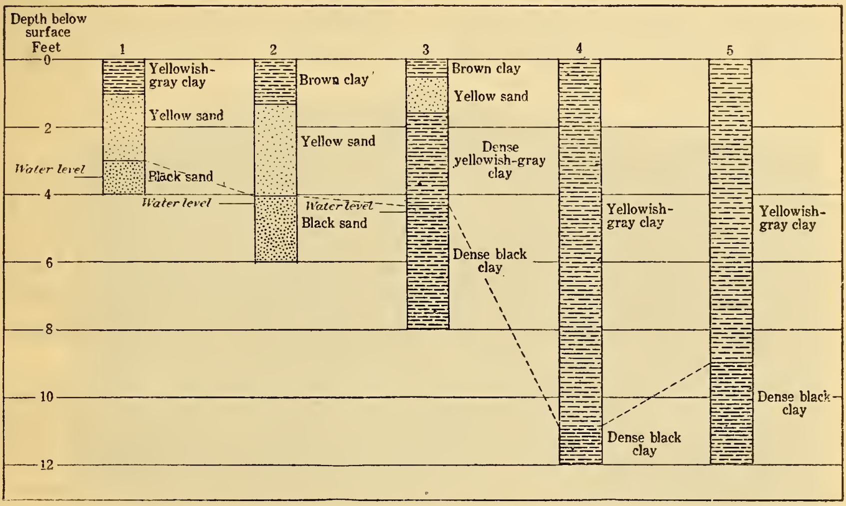


FIGURE 10.—Sections of borings on the barren flat. Nos. 1, 2, and 3, near north margin of flat; 4, near center of flat; 5, in southern part of flat.

protected by the water from complete oxidation. Below water level the sulphides are preserved by the ground water, but above the water level they have come into contact with the air and are oxidized. The upper surface of the black substance probably coincides approximately with the water table.

The mud surrounding Sulphur Springs and Croton Springs and composing the knoll springs of the Croton Springs group is also black and has an odor of hydrogen sulphide, which is intensified when acid is applied. This mud no doubt owes its blackness chiefly to the presence of sulphides, although it also contains much dark-colored organic matter. The organic matter and the constantly renewed supplies of water together tend to prevent the oxidation of the black mud.

Knoll spring deposits.—The knolls that have been built over several of the springs of the Croton Springs group contain very little substance precipitated by the escaping water. They are composed chiefly of roots and other organic matter embedded in mud, which rests on a deposit of gray sand. The spring water has been instrumental in two ways in holding the dust and clay that was driven thither by the wind. First, it produced vegetation, which broke the force of the wind and allowed the dust and sand to settle, and, second, it wet the deposits of dust and sand, and thus secured them against further wind action. By supplying the moisture necessary for plant growth it produced the organic matter which composes a large part of the knoll deposits, and by covering the dead roots, stems, and leaves it protected them from decomposition and allowed them to accumulate. Hydrogen sulphide in the water probably assisted in preserving the vegetable matter from decomposition. (See pp. 42–43.)

LAVA BEDS.

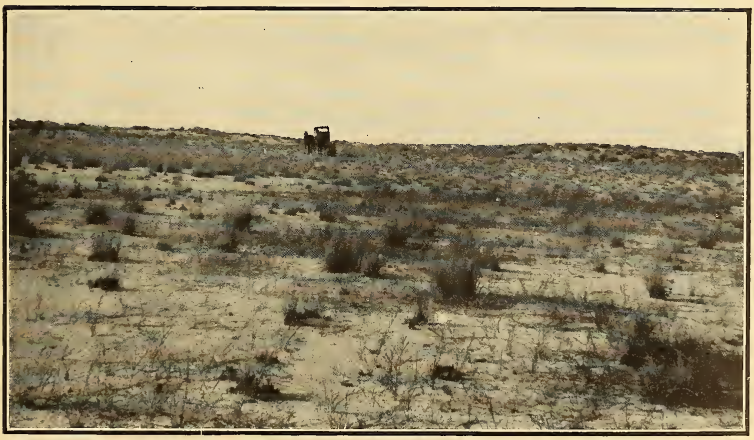
Dark vesicular basaltic lava lies at the surface in a low mound or mesa 2 miles east of Douglas. It is exposed over most of the NE. ¼ sec. 7, T. 24 S., R. 28 E., and on small adjacent tracts. Similar beds of lava occur in the mountainous area farther east and cover a large part of San Bernardino Valley east of the mountains. Dark basaltic vesicular lavas are also found in considerable abundance in the foothills of the Galiuro Mountains west of Hooker's ranch.

In a well 884 feet deep at the pumping plant of the Douglas public waterworks, situated in the northeastern part of the city, the drill struck a bed of lava which is described as being black and glassy but not difficult to penetrate. It is also said to have given off a bad odor. This bed of lava was struck about 340 feet below the surface and was found to be approximately 100 feet thick. Valley fill, consisting chiefly of stream deposits, appears to lie both above and below the lava.

In a well at the county hospital northwest of Douglas, in the NW. ¼ sec. 3, T. 24 S., R. 27 E., a bed of lava 53 feet thick was struck at a depth of 299 feet. The core brought up in drilling revealed vesicular basaltic lava similar to that found in the outcrop east of Douglas and in the extensive exposures of San Bernardino Valley. The numerous spherical cavities, which range in general between several millimeters and a centimeter in diameter, are partly filled with light-colored secondary minerals. The section shown in Plate IX (p. 52), which is based on the log furnished by the driller, F. O. Mackey, shows that the deposits both above and below the lava consist of ordinary stream deposits. Immediately overlying the lava 10 feet of "cement" is reported, the lower 4 feet of which is designated "hard cement." A core of the formation at the contact between the "hard cement"

A. HILL OF LIMESTONE NEARLY SUBMERGED BY LAVA.

B. LAVA BED RESTING ON STREAM DEPOSITS.



C. TYPICAL WIND-BUILT RIDGE.

and the lava consists of a reddish calcareous cement in which are embedded pebbles and fragments of lava which in places are stained yellow. The deposits immediately below the lava are reported to be intensely red.

Over a large part of San Bernardino Valley the lava lies at the surface, and in many places it can be seen resting on ordinary stream deposits. For a foot or more below the lava the sediments have been somewhat altered by heat and present a pink color. Plate XI, *B*, shows a bed of lava resting on ordinary stream deposits in the valley of Silver Creek, a short distance east of the divide between Sulphur Spring Valley and San Bernardino Valley. Plate XI, *A*, shows a low hill of Paleozoic limestone in San Bernardino Valley surrounded and partly submerged by a lava flow. A deep gorge on the opposite side of the hill has been cut through the lava, exposing underlying stream deposits and limestones which were entirely covered by lava but which have again been exposed by the erosion of the gorge. The foreground of this picture gives some conception of the amount of weathering that has taken place since the outpouring of the lava. The soil is very meager and the vegetation is accordingly scant, but the surficial part of the lava has nevertheless been greatly altered by the weather since its extrusion. The time required to cut the gorge and produce the amount of weathering shown was long in the ordinary sense, although brief according to geologic standards.

All nine of the flowing wells on Slaughter's ranch, in San Bernardino Valley, are reported to have penetrated a sheet of lava at some level above the clay bed described on page 60. Several feet of sediments immediately below the lava were found to be red, but the sediments immediately above the lava did not show any unusual color.

A lava bed is necessarily younger than the sediments on which it rests, but may be either older or younger than the overlying sediments. If it was poured out on the surface and later became buried beneath sedimentary deposits, it is, of course, older than these deposits; if, on the other hand, it did not reach the surface but was injected between two sedimentary beds, it is younger than both and may be younger than any of the beds that occur above it. The vesicular or spongy texture of the bed penetrated in the well at the county hospital indicates that this lava was poured out on an ancient land surface, for if it had been intruded beneath the beds that now rest on it the pressure would have been too great to allow gas bubbles to form. The upper contact of this bed also seems to indicate that the lava was spread over the surface, was later weathered and eroded to some extent, and was finally buried beneath stream deposits which included pebbles derived from the lava. Moreover, if the lava had been intruded the overlying deposits would have been altered to as red a color as the underlying deposits. The lava encountered in the San Bernardino wells was probably also poured over an ancient surface and was later buried beneath stream deposits, for if it had been intruded beneath the beds that now rest on it these beds would have been altered by the heat of the lava and would show the same red color as the sediments immediately below the lava.

If the lava in the county hospital wells represents a surface flow it is without much doubt older than the lava at the surface 2 miles east of Douglas, for it seems probable that the 300 feet of stream deposits that lie above the lava at the county hospital were nearly all laid down before the lava east of Douglas was extruded. The surface bed and the buried bed at Slaughter's ranch give still stronger evidence of two epochs of volcanic activity, for the surface lavas in that locality are shown by outcrops to rest on stream deposits.

The basaltic lava in the region west of Hooker's ranch appears to be much younger than the Tertiary acidic lavas. No evidence of its age relative to the valley fill was discovered, but the probabilities favor its correlation with the rocks of Douglas and San Bernardino Valley.

GYPSUM DEPOSITS.

Several small deposits of gypsum occur at the surface about 5 miles east of Douglas. They lie on the upper part of the slope near the mountains and are in close relation to a chain of rock hills which extends westward from the mountains. The gypsum is in the form of cream-colored powder with no large crystals. It contains no grit nor pebbles but has an admixture of lime carbonate which effervesces freely when treated with acid. One of the deposits which hugs the east side of a small draw forms a strip several hundred feet wide and perhaps a mile long, and has a maximum thickness of about 6 feet. Some of the other deposits show a less definite relation to the topography. Where the base of any deposit is exposed the powdery material is seen to rest on ordinary pebbly stream deposits. The gypsum is scraped up and hauled in wagons to Douglas, but in the near future a small calcining plant is to be installed at the deposits.

The origin of the gypsum was not definitely ascertained. No rock formation with interbedded gypsum was observed in the region and the gypsiferous locality lies so far above the ground-water level and is so well drained that the gypsum can not have been formed by deposition from evaporating waters since the present topography has come into existence. Moreover, the area of its occurrence is small and its influence on the quality of the ground waters is likewise very local. Except in this small area east of Douglas and in the low alkali tracts, gypseous deposits are rare in Sulphur Spring Valley.

It is significant that these deposits are in close relation to rock hills which consist in large part of limestone with injected bodies of lava. In regard to the formation of gypsum Adams[1] makes the following statement:

Gypsum may be formed in the laboratory by the chemical action of sulphuric acid on carbonate of lime. In nature this reaction may take place in a number of ways. Lime is quite universally distributed in the rocks. Unimportant quantities of sulphuric acid form in nature by the oxidation of sulphurous acid and hydrogen sulphide. Sulphurous acid is known to escape from volcanoes and about fumaroles.

Possibly the gypsum east of Douglas has been formed by the action of volcanic products on the limestone through which they were forced. The foul odor given off by the lava in the Douglas city well may lend a little additional support to such a theory.

The relation of the gypsum to the watercourses suggests that it has been washed to its present position by running water, but its freedom from coarse particles and its tendency to occur on the east side of watercourses suggest wind action. Perhaps wind and water have cooperated in bringing the material to the localities where it now lies.

GEOLOGIC HISTORY.

EARLY HISTORY OF THE ROCK TROUGH.

The age and mode of origin of the rock trough occupied by Sulphur Spring Valley are largely matters of conjecture, the record having been buried beneath the great mass of sediments that form the valley fill.

Gilbert's theory of the origin of the valleys of the Basin Range system is stated in the following brief quotation:[2]

The ridges of the system occupy loci of upheaval and are not mere residua of denudation; the valleys of the system are not valleys of erosion but mere intervals between lines of maximum uplift. * * * The movements of the strata by which ridges have been produced have been in chief part vertical along planes of fracture and have not involved great horizontal compression.

That Gilbert meant to apply this theory to the mountain region of Arizona, including the drainage basin of Sulphur Spring Valley, is definitely shown by his statement that in the Chiricahua Range (including the Dos Cabezas Range) "the structure is monoclinal, demonstrably due to faulting," and that the structure is presumably the same in the other ranges of the region.[3]

This theory that the rock troughs are formed essentially by the tilting of great blocks into which the earth's crust has been broken is supported by later investigations and is generally accepted at present as the correct explanation. However, it does not preclude the possibility that in any given valley folding and erosion may have been important in producing the rock trough.

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[1] Adams, G. I., Gypsum deposits in the United States: Bull. U. S. Geol. Survey No. 223, 1904, p. 15.

[2] Gilbert, G. K., U. S. Geog. Surveys W. 100th Mer., vol. 3, 1875, pp. 41, 42.

[3] Idem, p. 517.

There is great uncertainty as to the age of the trough. The youngest sedimentary strata known to have been radically deformed are of early Cretaceous age. The rugged topography of the ranges makes it probable that these ranges have been lifted in part in late Tertiary or in Quaternary time, for otherwise they would by this time have been reduced through weathering and erosion to more subdued forms. In all probability the elevation of the ranges has proceeded step by step during an extended period, and the filling of the intervening trough was begun long before the last elevating movement took place. Earthquakes in this region since the coming of the white man suggest that the deformation may still be in progress, but the valley fill was nowhere seen to be faulted, as it is in many places in the similar valleys of Utah.

EPOCHS OF STREAM WORK.

The age of the oldest stream deposits that lie on the floor of the rock trough is as uncertain as the age of the trough itself. In the absence of definite evidence the Gila conglomerate has been tentatively assigned to the Quaternary by Gilbert, Ransome, and Lindgren. As to the age of the valley fill of the region under consideration, Ransome states: "It is possible that some of the unconsolidated material penetrated by deep wells in Sulphur Spring Valley may be Tertiary, but there is as yet no evidence justifying the separating of these deposits from the overlying Quaternary accumulations." In the present investigation no facts have been discovered that would allow a more definite statement. Existing evidence indicates that the diatomaceous earth in San Pedro Valley belongs to the same period as the rest of the valley fill and that it lies stratigraphically above the oldest stream deposits of that valley, but this relation has not been definitely proved. About 34 fossil species were identified by D. B. Ward in this earth. According to A. M. Edwards, who also examined the fossils, most of the species represented are still living, but one living species is found among the fossils of a Miocene formation and another among the fossils of an upper Pliocene formation. On the strength of this fossil evidence and in view of the general probabilities, Blake [1] favored the hypothesis that the diatomaceous earth and the entire stratified lake or marine series of San Pedro Valley is late Tertiary, although he recognized the inconclusive character of the evidence and the possibility that they are Quaternary.

In southeastern Arizona the Quaternary period includes two epochs of stream work—an epoch of aggradation followed by an epoch of degradation. In the first epoch the streams filled the rock

[1] Blake, W. P., Arizona diatomite: Trans. Wisconsin Acad. Sci., vol. 14, pt. 1, 1903, pp. 107–111; Lake Quiburis, an ancient Pliocene lake in Arizona: Univ. Arizona Monthly, vol. 4, No. 4, February, 1902.

troughs with sediments wrested from the mountains; in the second epoch they attacked these valley deposits and transported them seaward. In the first epoch the streams built up smooth, gently inclined débris slopes; in the second they cut gullies and gorges into these slopes, thereby converting nearly level plains into rugged hill country. Such a change in the work done by streams may result (1) from changes in the elevation of the region relative to sea level or some other base level, (2) from changes in the rainfall and other climatic conditions, or (3) from the normal development of an erosion cycle.

The mountain tracts were elevated more rapidly than the processes of degradation could reduce them. This may have been due to a rapid rate of uplift, to a slow rate of degradation resulting from unfavorable climatic conditions, or to both. The elevation of the mountains threw the streams out of adjustment. From the mountain tops to the bottoms of the rock troughs they had very steep grades, but thence to the ocean they had only slight grades or possibly no grade at all. Consequently the loads which they gathered in their mountain courses were deposited in the valleys as valley fill. If no further changes in level had occurred and if the streams had been allowed to work on unmolested, the consummation of their work would inevitably have been a peneplain—that is, the region would finally have been reduced approximately to sea level. As the mountains would have become lowered and furnished less sediment, the streams would have begun to cut into the valley fill. This explanation does not, however, account adequately for the erosion phenomena of southeastern Arizona, for the erosion has been too great and too rapid, especially in view of the still youthful aspect of the mountains, to be fully explained in this way. Moreover, the erosion features have not been developed simultaneously over the whole region, as would be expected under this explanation, but are the result of headward erosion—a fact plainly shown in Arivaipa Valley and in numerous other valleys whose drainage is tributary to the Gila.

Change in climate may cause a change in the character of stream work. The bolson valleys of the arid West would probably not have been developed in a humid climate, and if this arid region were in the future given a copious rainfall the resulting large streams, with their greatly augmented carrying power, would no doubt dissect the valley fill. In view of the present aridity, however, the climatic hypothesis seems inadequate to explain the great amount of erosion that has taken place in the débris-filled valleys of southeastern Arizona.

In his study of the Gila conglomerate, Gilbert[1] came to the following conclusions:

To account for the period of accumulation there must be assumed some condition that has ceased to exist. Such a condition might be either a barrier somewhere below the region in question, determining the discharge of the water at a higher level than at present, or it might be a general depression of the region, in virtue of which the ocean (now 300 miles away) became a virtual barrier. With either hypothesis, a change of more than 1,000 feet must be considered.

The erosion of the valley fill of southeastern Arizona began a long time ago, as is witnessed by the mature dissection of some of the valleys,[2] but it was brought about by the headward erosion of the gullies belonging to the Gila or some other drainage system, and any given area was not affected until the gullies were eroded back to that area. Most of Sulphur Spring Valley has not yet felt the effects of the erosion cycle.

A bodily lifting of the region a thousand feet or more would not have affected the topographic relations in the north basin, for example, and would not have interfered with the stream-building process that was going on. The floods poured from the mountains into Sulphur Spring Valley are still building up their slopes essentially as they would be doing if other bolson valleys of the region had not been dissected.

However, the work of erosion has been carried up the Arivaipa; the north end of Sulphur Spring Valley has already been attacked; and a small area that once belonged to this valley has been captured by the Arivaipa drainage system and is now suffering vigorous erosion.

LAKE EPOCHS.

A lake existed in the north basin of Sulphur Spring Valley in comparatively recent geologic time, and a larger lake probably existed in an earlier epoch. Apparently the succession of events was somewhat as follows:

During the early history of the rock trough the streams brought sediments from the mountains and deposited them in the valley. Then a part of the north basin and possibly also a part of the south basin became submerged, and sediments settled at the bottom of a large body of standing water, while stream deposition continued on the higher tracts that were not submerged. In the course of time the body of standing water disappeared or nearly disappeared, either by drying up or by being drained, and stream deposits were laid down to a considerable depth where the water had stood. By the close of this epoch of stream deposition the valley slopes had

[1] Gilbert, G. K., U. S. Geog. Surveys W. 100th Mer., vol. 3, 1875, p. 541.
[2] See, for example, Ransome, F. L., Globe folio (No. 111), Geol. Atlas U. S., U. S. Geol. Survey, 1904.

been built up almost to their present height and form. Then came another submergence, during which the lowest parts of the north basin were covered by a lake which remained for only a brief time as compared with the earlier epoch of submergence, but which was, nevertheless, in existence long enough to build large beach ridges. Since this lake dried up only a small amount of stream work but a more conspicuous amount of wind work has been accomplished.

The early submergence may have been due to a lake that was produced by an epoch of humid climate and was confined to the north basin. The south basin may then, as now, have drained into Yaqui River. On the other hand, it is possible that the body of water in this valley was an arm of a larger sea that extended also into San Simon and San Pedro valleys. The diatomaceous earth of San Pedro Valley contains fresh-water fossils, and also fossils of species that have been found only in marine beds.[1] The marine fossils suggest that since the rock troughs of southeastern Arizona have come into existence and have been partly filled with sediments the region may have been so far depressed that the troughs were temporarily invaded by the ocean. With this hypothesis the subsequent great elevation of the region relative to the sea would account for the erosion cycle now in progress.

The last lake must have owed its existence to a more humid climate than prevails at present. When the climate again became arid the lake dried up. As already stated, a small area which once drained into the north basin of Sulphur Spring Valley now discharges its floods into the Arivaipa, but if this diverted drainage were returned to Sulphur Spring Valley the change would certainly not be adequate to restore the ancient lake.

The ancient beaches remain almost unchanged since the lake withdrew from them. If the trivial postlacustrine changes are compared with the work represented by the filling of the valley to a depth of 200 or 300 feet since the deposition of the clay bed at Willcox, it becomes evident that the period since the disappearance of the lake that made the beaches was many times shorter than the time since the early submergence which produced the buried clay bed. If the postlacustrine changes are compared with the work done since the rock trough began to fill with sediments, the postlacustrine epoch appears still more brief. In this respect the ancient lake of Sulphur Spring Valley accords with Lake Bonneville and the other ancient lakes of the arid West, which are believed to be of Pleistocene age and to have been formed at the same time and by the same climatic change which caused the great continental glaciers.

[1] Blake, W. P., Arizona diatomite: Trans. Wisconsin Acad. Sci., vol. 14, pt. 1, 1903, pp. 108–110.

Huntington [1] has shown that since the close of the glacial epoch and within historic times there have been important variations in humidity, and he believes that a given climatic change was not confined to one region, but affected the entire world at the same time. He cites a basin on the Bolivian Plateau in South America which contains an ancient strand lying 150 feet above the level of the present shallow salt lake and yet bearing evidence of having been traversed by man during a time when the lake was at or near the level of the strand.[2] This change in the lake level appears to involve at least as great a climatic change as is indicated by the beaches of Sulphur Spring Valley and suggests the possibility that the last ancient lake of Sulphur Spring Valley may be postglacial. However, in the absence of definite evidence and in view of the apparent accordance of the lake features of this valley with those of the recognized Pleistocene lakes of the West, the last lake epoch of Sulphur Spring Valley must be tentatively referred to the Pleistocene.

The Pleistocene epoch included several periods during which sheets of glacial drift were spread over portions of the continent. These periods of glaciation were separated by intervals of mild climate, during which the ice sheets disappeared. If the cold, humid conditions that produced the glaciers also produced the ancient lakes of the West, as is generally supposed, then there must have been several lake epochs, each contemporaneous with a glacial epoch, and the valley fill of a typical bolson valley may be expected to include lake beds at different horizons, separated by stream deposits, each lake bed corresponding in age to a sheet of glacial drift.

In regard to the age of the successive ice epochs Calvin states: [3]

> The oldest glacial deposit in which the accumulating effects of continuous time is recorded is the Kansan; the youngest is the Wisconsin; and between the two the differences in age seem almost immeasurable. Comparing the weathering and erosion in the central, intermorainic part of the Wisconsin with the corresponding evidences of change in the Kansan, the differences must be expressed by a number greater than one hundred * * *. Making every possible allowance, there is no escape from the conclusion that the Pleistocene was a long, long period, compared with which the recent period, or postglacial time, would have to be represented by a very small fraction.

If the valley fill of Sulphur Spring Valley was deposited since the beginning of the Pleistocene and the ancient beaches were formed at the same time as the Wisconsin glacial drift sheet, then it is possible that the buried clay bed struck in the deep wells at Willcox was formed at the same time as one of the older drift sheets—for

[1] Huntington, Ellsworth, The pulse of Asia, 1907.

[2] Huntington, Ellsworth, The climate of the historic past: Monthly Weather Review, U. S. Weather Bureau, 1908, p. 448.

[3] Calvin, Samuel, Present phases of the Pleistocene problem in Iowa (presidential address): Bull. Geol. Soc. America, vol. 20, 1909, p. 152.

example, the Kansan. The fact should, however, not be overlooked that these suggested correlations are wholly hypothetical and are as yet not supported by any definite proofs.

EPOCHS OF VOLCANIC ACTIVITY.

After sediments washed from the mountains had accumulated in the rock trough to a depth of a good many hundred feet a basic lava was poured over the surface in the vicinity of Douglas. When the lava reached the surface its gases were released, but it cooled so rapidly that it became a solid mass before all the gas had escaped. Hence the lava is scoriaceous—that is, it contains spherical cavities formed by the bubbles of gas. After the lava had solidified it became gradually covered with sediments which the streams continued to throw down, until it was buried beneath about 300 feet of stream deposits and the surface of the valley had been built up almost to its present elevation and contour. Then apparently another sheet of the same kind of lava was poured over the surface in the same part of the valley. Since the last extrusion enough time has elapsed for the lava to become considerably weathered near the surface, but not enough for it to cool off entirely, as is shown by the temperature of the well waters in the vicinity, nor for it to be entirely covered by stream deposits.

The amount of lava extruded in Sulphur Spring Valley in the Quaternary period—that is, during the time that the valley fill was deposited—is insignificant as compared to the amount brought to the surface or near the surface during earlier periods. The small Quaternary extrusions in Sulphur Spring Valley were, however, associated with much more extensive igneous processes, for in San Bernardino Valley and at the head of San Simon Valley the Quaternary period was characterized by great volcanic activity.

As the lava beds are remote from the lake beds their relative ages can not be determined. The buried lava bed was struck at depths of 299 and 340 feet; the buried clay bed was struck at a depth of 280 feet in Willcox and closer to the surface at one or more points nearer the alkali flat. The thickness of the material lying above a bed gives some measure of its age, and the deposition of 200 feet or more of fine sediments must have required a much longer time than the extrusion of a bed of lava. The volcanic ash found in the stratified beds of San Simon and San Pedro valleys shows that there was some volcanic activity in the region during the submergence in these two valleys, but there is no way of correlating this activity with the volcanic activity in Sulphur Spring Valley. The last epoch of volcanic activity in Sulphur Spring, San Bernardino, and San Simon valleys was so recent that the topographic features which it produced have not yet been buried nor destroyed by the weather. In this respect the last volcanic epoch resembles the last lake epoch.

RECENT CHANGES.

The changes which have been taking place recently and which appear to be now going on may be summarized as follows:

1. Weathering and stream erosion in the mountains, on the upper parts of the stream-built slopes, and to some extent on the middle parts of these slopes.
2. Stream deposition in the lower parts of the valley.
3. Probable enlargement of the barren flat by wind erosion.
4. Transportation of wind-borne sediments northeastward from the flat.
5. Deposition of caliche on the slopes and concentration of alkali on the flat and in other low places.
6. Stream erosion in a zone surrounding the barren flat.
7. Stream erosion in the lower course of Whitewater Draw.
8. Stream erosion and piracy at the north end of the valley.

RAINFALL.

By O. E. Meinzer.

RECORDS.

Rainfall observations have been made for the United States Weather Bureau at five points in Sulphur Spring Valley (see Pl. II, in pocket) and at about 10 points in the adjacent mountains. The records for some of the stations extend over only a brief period or have many interruptions, but at several stations observations were made continuously during many years. The oldest and longest record is that at Fort Grant, where observations were made for 32 years, from 1873 to 1905. Observations were begun at Willcox in 1880, at Bisbee in 1889, and at Allaire's ranch in 1894. The record at each of these three stations is nearly continuous from its beginning to the present time. Thus, up to the end of 1910, the Willcox record covers 30 years, the Bisbee record 21 years, and the record for Allaire's ranch 16 years. At Dragoon Summit (Russelville) observations were made from 1890 to 1900, at Dragoon station from 1889 to 1905, at Tombstone from 1897 to the present, and at Cochise from 1899 to the present. The Dragoon and Tombstone records, however, show numerous interruptions. At Douglas a complete record has been kept since 1904.

The rainfall records are valuable in furnishing some basis for quantitative estimates of the water supply and for intelligent action in agricultural undertakings. It is important to know not only the total precipitation, but also its fluctuations from year to year, its distribution over the different seasons of the year, and whether it falls in protracted rains or in heavy showers of brief duration. Very much light is thrown on all these questions by the long and faithful records that have been kept, and great credit is due to the observers who, without pay, have rendered this patriotic service.

The following tables, compiled from the reports of the United States Weather Bureau, give the monthly and annual rainfall records for all stations in the valley and adjacent mountains. Throughout this paper the term "rainfall" is used to mean all of the precipitation, including water that falls in the form of snow.

Monthly and annual rainfall, in inches, for Sulphur Spring Valley and the adjacent mountains.

Allaire's ranch (S. ½ sec. 28, T. 15 S., R. 25 E.).

[Elevation, 4,184 feet.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1894	......	......	......	......	......	......	......	0.98	0.18	0.70	0.00	0.87	......
1895	0.58	0.05	T.	T.	0.63	0.40	1.94	2.48	2.17	.51	1.51	.22	10.49
1896	.18	.26	0.17	T.	.00	.17	3.07	1.85	4.62	3.59	.28	.32	14.51
1897	1.29	.12	.27	0.00	T.	*a* T.	1.77	1.56	.83	.02	.00	.07	5.93
1898	1.27	.06	.40	.56	T.	.03	4.43	2.97	.84	.00	.55	1.31	12.42
1899	.34	.24	.17	.47	.00	.25	2.65	.57	1.84	.29	.75	.11	7.68
1900	.22	.58	.66	.60	.01	T.	1.60	.72	3.44	.16	.69	.10	8.78
1901	1.00	1.31	.51	.19	.16	.00	5.15	1.93	.54	.87	.45	.17	12.28
1902	.36	.05	.51	.00	.08	.02	1.48	2.92	.32	.40	1.72	2.22	10.08
1903	.04	.54	1.32	.00	.40	.33	1.11	3.73	1.06	.00	.00	.07	8.60
1904	.32	.17	.18	.00	.61	.00	2.09	3.32	.21	.60	.03	.79	8.32
1905	2.21	3.77	4.11	1.12	.00	.62	1.04	3.61	1.27	.56	3.12	.61	22.04
1906	.36	1.63	.42	.17	.03	.05	3.16	3.90	.04	.17	.95	3.08	13.96
1907	2.52	.55	.14	.14	.58	T.	2.84	5.65	1.42	1.83	1.67	.00	17.34
1908	.87	1.21	.48	.31	.04	.01	4.76	2.11	.64	T.	.37	1.26	12.06
1909	.17	.82	1.18	.00	T.	.96	2.91	6.41	.82	.00	.19	.46	13.92
1910	.55	.00	.12	.05	.00	1.08	1.70	3.25	1.79	.11	1.59	.01	10.25
Average	.77	.71	.66	.23	.16	.24	2.61	2.82	1.30	.58	.82	.69	11.59

Bisbee.

[Elevation, 5,500 feet.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1889	......	......	......	......	......	......	......	0.73	3.79	0.38	0.20	0.29	......
1890	2.34	0.27	0.24	0.15	0.00	0.03	6.07	5.71	1.73	1.06	.63	1.99	20.22
1891	.55	1.69	.75	.00	.72	.31	.62	8.55	.67	.00	.00	.48	14.34
1892	1.64	2.39	1.51	.60	.00	.24	1.37	2.59	.44	1.48	.29	.37	12.92
1893	.03	.88	2.05	.00	.52	.00	5.20	4.15	1.71	.05	.00	.20	14.79
1894	.61	1.25	1.91	.00	.00	.00	1.63	8.73	.39	1.47	.00	1.31	17.30
1895	1.20	.08	.00	.20	.23	.10	2.02	4.70	2.44	1.12	2.23	.48	14.80
1896	.55	1.04	.27	.23	.00	.45	4.29	3.10	2.35	7.82	.40	.36	20.86
1897	2.50	.35	.10	.00	.05	.18	7.36	2.95	3.14	.52	.00	.44	17.59
1898	2.57	.26	1.94	.47	.00	1.91	8.86	3.84	2.11	.00	1.01	2.90	25.87
1899	.52	.51	.40	*a* .35	T.	.25	4.83	4.77	2.85	1.69	.16	.06	16.39
1900	.54	1.41	2.23	.97	T.	T.	1.12	1.38	6.54	T.	1.31	.28	15.78
1901	1.72	2.57	.88	.12	.17	T.	3.11	2.97	.94	2.56	.59	.10	15.73
1902	.68	.00	.29	.00	.40	.30	.54	5.48	1.64	.30	1.55	1.85	13.03
1903	.30	1.17	1.71	.00	.43	.60	1.20	6.28	.30	.00	.00	*a* .15	12.14
1904	.12	.40	T.	.00	1.12	.22	2.59	5.77	.43	1.34	.16	1.33	13.48
1905	1.12	5.71	5.26	4.04	.00	......	......	......	......	......	......	......	......
1906	1.36	2.31	1.11	.05	.01	.02	4.86	2.75	.74	.44	1.23	5.10	19.98
1907	5.36	.38	.48	1.03	1.67	T.	4.62	4.97	1.19	.96	2.93	.00	23.59
1908	1.09	2.11	.36	.40	.23	T.	4.51	8.17	1.90	T.	.45	1.79	21.01
1909	.21	1.18	1.52	.00	.00	.78	5.66	9.59	.65	T.	.23	1.50	21.32
1910	.26	.15	.07	.07	T.	.54	5.72	3.22	1.84	.24	.61	.13	12.85
Average	1.21	1.24	1.10	.42	.27	.29	3.80	4.78	1.80	1.02	.66	1.00	17.59

Bonita (SW. ¼ sec. 2, T. 10 S., R. 23 E.).

[Elevation, about 4,500 feet.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1906	......	......	......	0.20	T.	0.00	2.05	3.40	0.30	0.00	0.70	3.62	......
1907	4.48	0.70	0.27	.50	.53	.00	3.27	3.59	.55	1.48	2.04	0.00	17.41
1908	.67	2.70	.73	.45	.31	T.	3.87	2.36	.19	T.	.27	2.17	13.72
1909	.35	1.18	1.30	.00	.00	.25	2.11	2.64	1.82	......	......	.60	......
1910	......	.00	.00	.30	.00	......	......	......	......	.12	.84	......	......

a Estimated.

Monthly and annual rainfall, in inches, for Sulphur Spring Valley and the adjacent mountains—Continued.

Chiricahua Mountains.

[Location and elevation not known.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1889	......	......	......	......	......	......	......	......	0.94	1.42	0.0	1.55	......
1890	3.80	0.0	0.0	0.89	0.0	0.0	1.18	3.83	2.19	2.85	1.72	2.90	19.36
1891	1.50	1.33	.00	......	.50	.70	1.19	8.93	8.24	......	......	3.15	[a]25.54
1892	.75	......	2.62	2.60	.00	2.75	......	......	.02	......	1.87	1.18	......
1893	.45	1.08	2.40	.00	1.76	.29	3.87	10.98	.00	T.	......	......	[b]20.88
1894	1.60	......	1.80	......	......	......	......	......	......	......	......	......	......

Cochise.

[Elevation, 4,219 feet.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1899	......	0.21	0.15	0.26	0.00	1.12	2.61	0.83	3.40	0.00	0.00	0.00	......
1900	0.00	.80	.50	.00	.00	.00	.00	.00	T.	.00	.00	T.	1.30
1901	.69	2.12	.53	.10	.60	.00	2.65	2.04	.50	1.06	.72	.07	11.08
1902	T.	.00	.45	.00	20	.00	.36	1.36	.00	.10	1.95	2.08	6.49
1903	T.	4.20	1.05	.00	.62	.00	.86	2.00	1.22	.00	.00	.00	9.95
1904	.40	.00	.00	.00	.70	.00	3.00	3.17	.25	.50	.00	.30	8.32
1905	2.18	3.20	4.70	1.12	.00	.53	2.22	2.25	2.30	.30	2.65	.82	22.27
1906	.32	1.80	.40	.15	T.	.00	1.22	3.37	.10	T.	.50	2.77	10.63
1907	2.93	.20	.00	.10	.50	.00	3.45	3.94	.85	1.92	1.93	.00	15.82
1908	.32	1.46	.65	.30	.10	T.	3.50	.88	.70	.08	.40	.95	9.34
1909	.00	......	......	......	.00	T.	1.95	2.87	.66	.00	.42	.93	......
1910	.75	T.	.10	.25	T.	.20	2.61	3.55	4.70	T.	.74	.00	12.90
Average	.69	1.27	.78	.21	.23	.16	1.87	2.04	1.22	.33	.78	.66	10.24

Courtland.

[Elevation, 4,543 feet.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1910	0.52	......	0.25	0.00	0.03	0.81	2.17	2.55	0.04	0.03	0.89	0.00	......

Dos Cabezos.

[Elevation, 5,250 feet.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1889	......	......	......	......	......	......	......	......	0.58	1.11	T.	0.12	......
1890	1.28	0.29	0.08	0.95	0.0	0.03	3.90	5.07	1.36	1.12	0.42	2.31	16.81
1891	.40	2.16	.54	......	1.15	.34	.43	2.05	.79	.00	T.	.76	8.62
1892	.66	2.27	......	......	T.	.10	1.82	1.10	.05	1.06	.0	......	......
1909	.63	1.46	1.62	.00	.00	1.44	4.61	2.31	1.83	.00	.26	.95	15.11
1910	.93	.00	.15	.68	.00	1.24	4.06	1.88	.32	.00	1.30	.00	10.56

Douglas.

[Elevation, 3,930 feet.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1903	......	......	......	......	......	......	......	......	......	......	......	T.	......
1904	0.02	0.10	T.	0.00	.51	0.09	3.08	1.68	0.92	1.49	0.00	1.09	8.98
1905	.80	2.69	2.75	1.91	.00	1.25	1.74	3.27	1.86	1.00	2.73	.70	20.70
1906	.32	1.07	.90	.15	.00	.23	1.72	4.80	.89	.31	.37	2.36	13.12
1907	1.94	.31	.37	.21	.99	.00	2.66	3.72	1.50	.63	2.41	.00	14.74
1908	.50	.80	.40	.08	.13	.08	3.74	2.12	.90	.05	.53	1.16	10.44
1909	.02	.31	1.03	.00	.00	.29	3.50	4.03	.66	.11	.02	.99	10.96
1910	.20	.20	.10	.02	.02	1.07	2.52	4.48	.85	.18	.66	.02	10.32
Average	.54	.78	.79	.34	.23	.42	2.71	3.44	1.08	.54	.96	.79	12.62

[a] Summation omitting April and October.
[b] Summation omitting November.

Monthly and annual rainfall, in inches, for Sulphur Spring Valley and the adjacent mountains—Continued.

Dragoon.

[Elevation, 4,614 feet.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1891	0.36	2.18	0.38	0.00	0.83	0.00	0.95	0.40	......	......	......	......	......
1892	1.10	2.67	.97	......	......	.00	1.54	1.54	0.19	0.37	......	......	......
1893	.29	.77	.93	.00	1.40	.00	3.31	4.49	......	......	......	......	......
1894	.43	1.77	......	.00	.00	......	1.69	4.78	......	......	......	......	......
1895	1.23	......	......	.17	.57	.00	1.25	3.63	1.55	.55	2.18	1.26	......
1896	.35	1.19	.00	.10	.00	.71	2 70	.75	4.33	5.10	.80	.00	16.03
1897	2.11	.00	.32	.00	95	.00	2.51	3.92	3.10	.05	.00	.00	12.96
1898	3.22	.00	.84	1.44	.00	.32	3.90	2.55	.00	.00	.00	1.40	13.67
1899	1.63	.00	.21	.22	.00	.00	4.86	3.10	2.88	.00	......	.00	......
1901	.69	1.47	T.	.52	.21	.00	2.32	3.06	.84	2.05	.90	T.	12.06
1902	.60	1.15	.45	.00	.71	.00	.00	2.65	.33	.70	1.04	2.70	10.33
1903	.00	1.15	......	......	T.	T.	.40	1.88	.99	.00	.00	.00	......
1904	.10	.20	.00	.00	......	.00	1.60	3.10	.00	.00	.00	.00	......
1905	......	......	4.00	......	.00	.89	......	......	......	......	......	......	......

Dragoon Summit (Russelville).

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1890	......	......	......	......	......	......	......	2.13	2.10	1.41	0.64	0.18	......
1891	0.33	1.99	0.38	0.00	1.06	a0.25	0.96	.00	.14	.00	.11	T.	a5.22
1892	.13	1.83	.71	.29	.04	.18	1.17	1.66	.45	.12	.23	.20	7.01
1893	.00	1.44	1.15	.00	1.62	.00	3.92	3.19	1.13	.00	.00	.40	12.85
1894	.43	1.38	.92	.00	.00	.00	6.40	5.01	.67	.78	.00	1.70	17.29
1895	1.75	.00	.00	.15	.18	.10	.42	4.00	1.27	.09	2.77	.00	10.73
1896	.39	.02	.49	.09	.00	.49	2.04	.87	3.11	4.45	.40	.05	12.40
1897	2.24	.54	.10	.00	.33	.00	1.23	2.15	2.27	......	.00	......	......
1898	.81	.00	.00.	.75	.00	.52	2.70	2.38	1.51	.00	.49	2.28	11.44
1899	1.02	.13	.00	.00	.00	.35	3.32	2.34	1.04	.90	.28	.06	9.44
1900	1.10	.78	.96	.22	.00	.00	.40	.30	2.41	.90	.95	.10	8.12

Fort Grant.

[Elevation, 4,916 feet.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1873	0.00	1.00	1.00	0.00	0.50	1.40	1.70	5.70	2.50	0.46	3.38	1.75	19.39
1874	1.58	2.87	2.45	.58	.07	.00	2.70	2.01	.00	1.47	.38	3.78	17.89
1875	2.48	1.44	1.95	1.52	.00	.50	7.02	1.08	4.59	.01	.20	.12	20.91
1876	.26	.24	.44	T.	a.26	.65	5.27	7.41	1.99	2.86	1.00	a.22	20.60
1877	.17	1.50	.30	.42	.66	.00	.94	2.94	.83	.71	.02	2.20	10.69
1878	.23	.50	.37	.18	.00	.32	6.44	4.93	.20	.00	1.90	1.39	16.46
1879	1.38	.47	.85	.07	.00	.08	2.59	1.12	2.18	1.83	.87	1.38	12.82
1880	.60	.48	.85	.08	.00	1.32	5.63	3.73	1.01	.47	.00	1.57	15.74
1881	.05	.33	.89	.84	.26	T.	5.53	5.47	3.84	1.02	.08	.65	18.96
1882	.86	1.26	1.84	.07	.81	1.47	2.02	4.73	.80	.00	79	.17	14.82
1883	1.21	1.40	1.27	.03	1.16	1.26	2.90	3.07	.42	1 21	11	1.44	15.48
1884	1.12	4.62	3.87	.47	.81	1.20	.67	2.41	.98	3.06	.53	5.93	25.67
1885	.31	1.02	1.40	.04	.25	.73	.93	1.58	.81	.03	1.30	.81	9.21
1886	2.46	1.29	.53	.30	.04	a.00	a.10	3.40	3.49	.57	.10	.09	12.37
1887	.11	2.58	T.	.36	.16	.85	9.00	6.20	4.20	.37	.28	.21	24.32
1888	.12	.44	.83	.50	.18	.02	4.27	.52	.78	1.19	3.67	1.68	14.20
1889	1.99	1.28	1.04	.13	T.	1.06	3.57	1.35	.69	.94	.16	1.11	13.32
1890	1.58	.46	.46	.92	.01	.20	3.24	4.54	1.36	1.62	.34	2.01	16.74
1891	.82	3.78	.28	.00	1.40	.10	1.19	2.25	1.21	.00	.00	1.18	12.21
1892	.96	1.59	1.66	.64	.35	.00	.86	1.00	.11	.46	.12	.15	7.90
1893	.56	.59	1.26	.00	.58	.00	4.24	2.00	3.87	T.	.40	.35	13.85
1894	.38	3.43	.66	.13	.37	.00	2.55	1.98	.14	1.10	.00	2.79	13.53
1895	1.65	.37	.02	.07	.30	.14	1.09	4.02	1.69	1.21	2.05	.61	13.22
1896	.29	.50	.34	.00	.00	.90	1.88	2.68	2.91	4.89	.46	.24	15.09
1897	4.09	T.	.27	.00	.04	.09	2.05	1.91	4.75	.33	.00	.34	13.87
1898	2.23	T.	.53	1.60	.00	.37	2.65	4.41	.67	.00	.50	1.30	14.26
1899	.74	.35	.25	.05	.00	.46	3.21	.52	69	30	.70	.17	7.44
1900	.31	.53	.58	.48	T.	T.	.50	2.24	4.30	.16	2.37	T.	11.47
1901	2.05	.50	.80	T.	T.	.00	4.37	1.32	1.20	1.64	.52	T.	12.40
1902	.20	.40	.15	T.	.30	T.	.90	3.40	1.25	.90	.20	2.00	9.70
1903	T.	.09	2.05	T.	.50	.69	.12	3.10	1.60	.00	.00	.40	8.55
1904	.51	.31	.14	.00	.40	.61	1.35	.62	.65	.31	.01	.16	5.08
1905	.36	2.34	.99	1.21	.00	.17	.13	2.07	......	......	......	......	......
Average	.96	1.15	.92	.32	.29	.44	2.78	2.90	1.74	.91	.70	1.13	14.24

a Estimated.

Monthly and annual rainfall, in inches, for Sulphur Spring Valley and the adjacent mountains—Continued.

Tombstone.

[Elevation, 4,550 feet.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1889	......	......	......	0.00	......	......	3.59	2.03	......	......	T.	......	......
1890	2.51	0.00	......	......	0.00	0.00	4.14	6.26	2.96	......	......	......	......
1891	......	......	......	......	......	......	......	......	......	0.00	0.00	0.11	......
1892	......	......	......	.00	......	......	......	......	......	......	......	......	......
1893	......	......	......	......	......	......	4.01	3.75	......	......	......	......	......
1897	......	......	.25	T.	T.	T.	3.24	4.41	5.23	.05	.00	.23	......
1898	.99	T.	.69	.83	.00	.38	4.24	3.68	.85	.00	.55	1.29	13.50
1899	.33	.40	.19	.36	T.	.65	3.50	1.56	1.07	......	......	......	......
1900	......	......	......	......	......	......	1.55	1.98	3.21	.00	.25	.09	......
1901	.89	1.19	.31	.24	.20	T.	3.23	5.13	1.23	1.51	.77	.14	14.84
1902	.13	T.	.31	.00	.06	.33	.85	4.07	1.50	.11	......	......	......
1903	......	......	......	......	.08	.60	3.09	2.22	1.30	.00	.00	......	......
1904	.04	......	......	......	1.10	.02	3.50	4.36	.23	1.53	.00	.74	......
1905	1.96	3.84	4.78	1.41	.00	1.29	3.15	4.19	2.10	.66	3.46	1.00	27.84
1906	.35	1.68	.24	......		.00	2.77	2.81	.60	.43	......	2.72	......
1907	3.38	.61	.21	.23	1.60	.00	3.44	4.80	1.66	.70	2.68	.00	19.31
1908	.76	1.45	.35	.35	.07	.00	3.71	4.60	.32	.00	.45	1.48	13.54
1909	.18	.81	2.05	.00	.00	.07	3.03	5.83	1.81	.05	.15	.93	14.91
1910	.18	.00	.13	.14	.00	.81	4.91	4.05	.94	.09	.52	.00	11.77

Walnut ranch (10 or 15 miles east of Douglas).

[Elevation, 5,600 feet.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1889	......	......	......	......	......	......	......	......	......	......	0.13	0.54	......
1890	1.77	0.08	0.00	0.29	0.00	0.00	5.06	4.89	1.06	2.11	0.41	*a*1.99	17.66
1891	.87	1.70	.51	*a*.00	.92	.29	.30	3.85	.88	.00	.00	.86	10.18
1892	1.46	2.19	1.80	.92	.00	.49	2.87	3.40	.36	1.83	.18	.59	16.09
1893	T.	.96	1.67	.00	.81	.00	2.53	5.25	2.82	.13	T.	.48	14.65
1894	.60	2.34	2.46	.00	.00	.08	2.97	3.96	.48	1.82	.00	1.68	16.39
1895	.87	.00	.07	.00	.52	.06	5.51	3.01	1.93	.47	3.30	.61	16.35
1896	.76	1.05	.49	.31	.00	.13	6.92	1.54	4.17	5.45	.29	.37	21.48
1897	3.31	.24	.46	.00	.48	.33	4.49	2.71	......	......	......	......	......

Wilgus.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1890	......	......	......	1.19	......	0.00	3.55	5.94	2.20	1.25	0.63	2.80	......
1891	0.90	1.70	0.40	.00	0.85	.30	2.95	2.43	1.03	.00	.05	.45	11.01
1892	1.00	1.75	1.47	.65	T.	.10	3.32	......	.25	1.65	.25	.40	......
1893	.15	1.10	1.90	.00	.35	.10	6.47	4.29	2.75	T.	.05	.40	17.56
1894	.66	1.60	1.55	.00	T.	.05	2.81	6.67	.10	.60	.00	.78	14.82
1895	1.35	.12	.06	.10	.79	.23	3.89	2.36	2.05	.58	3.30	.53	15.36
1896	.35	.65	.50	.42	.00	......	......	......	......	......	......	......	......

a Estimated.

Monthly and annual rainfall, in inches, for Sulphur Spring Valley and the adjacent mountains—Continued.

Willcox.

[Elevation, 4,164 feet.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1880	......	......	......	......	......	......	......	......	......	0.04	0.00	0.40	......
1881	0.02	0.00	2.95	T.	0.00	a0.10	3.97	5.17	0.00	.00	.00	.00	12.21
1882	a.12	1.15	.00	0.00	.00	a.21	.11	3.46	1.56	.00	.58	.32	7.51
1883	1.25	.31	.41	.00	.83	6.03	1.56	3.15	.04	.30	.00	.86	8.24
1884	.80	1.61	1.75	.00	.00	.04	1.17	1.54	.14	3.59	4.25	3.49	18.38
1885	.05	.63	1.52	.03	.00	.34	1.78	2.10	1.11	.00	.56	.19	8.31
1886	1.36	.79	.15	.01	.00	T.	.37	2.14	1.68	.36	.58	.08	7.52
1887	T.	1.83	.00	.03	.18	.47	3.82	5.31	2.96	.45	.22	.92	16.49
1888	.36	1.21	1.13	.03	.14	.08	3.68	.42	.50	1.15	1.86	1.37	11.93
1889	1.31	.90	1.06	.04	.00	.13	4.91	.97	2.91	.83	T.	.62	13.68
1890	1.61	.35	.22	.63	.00	.15	4.67	5.71	2.05	1.03	.36	1.14	17.92
1891	.47	2.37	.46	.00	.82	.14	T.	2.10	.22	.00	.00	.85	7.43
1892	.05	1.45	.84	.25	1.02	2.00	.97	.94	.32	.00	.00	.17	8.01
1893	.00	.10	.79	.00	.50	.00	a3.25	1.03	.93	.00	.00	.00	6.60
1894	.50	1.37	.77	.00	.00	.00	.00	1.52	.27	.78	.00	.67	5.88
1895	.11	.00	.00	.00	.77	.00	1.92	3.06	.11	.08	1.59	.40	8.04
1896	.27	a1.10	.05	.00	.00	.00	1.46	1.77	1.35	3.17	.30	.00	9.47
1897	1.47	.00	.29	.00	.00	.05	1.55	.86	1.15	.04	.04	.21	5.66
1898	1.25	.00	.28	.27	.00	.03	3.13	1.55	.20	.00	.08	1.37	8.16
1899	.52	.30	.28	.40	.00	a.95	2.30	.51	1.26	.22	.30	.00	7.04
1900	.18	.79	.35	.14	.00	.00	.56	1.57	1.97	.17	.48	.00	6.21
1901	1.75	.55	.31	.00	.16	.00	1.13	2.29	.30	.66	.20	.10	7.45
1902	.35	.00	.60	.00	.40	.00	.40	2.70	.78	.20	.75	1.00	7.18
1903	.21	.73	a1.10	.00	1.00	.59	.86	.84	.65	.00	.00	.00	5.98
1904	.10	.20	.21	.00	.35	.25	1.62	4.65	.85	.61	.00	.75	9.59
1905	2.56	3.91	5.00	1.41	.00	.77	1.34	1.89	1.58	.37	3.63	1.06	23.52
1906	.78	1.25	.59	.25	.00	T.	2.50	7.76	T.	.00	.73	4.07	17.93
1907	3.72	.80	.00	.55	1.00	.05	3.39	3.60	.53	2.24	1.95	.00	17.83
1908	.71	2.15	.58	.24	.12	T.	3.89	1.63	.34	T.	.41	1.09	11.16
1909	.31	.66	2.74	.00	.00	.50	3.26	4.16	1.00	.00	.22	.50	13.35
1910	.83	.00	T.	.10	.00	.23	2.45	1.09	1.58	.12	1.12	.25	7.77
Average	.76	.89	.81	.15	.24	.24	2.07	2.51	.94	.53	.65	.71	10.50

a Estimated.

Summary of average monthly and annual rainfall, in inches, at stations in Sulphur Spring Valley and adjacent mountains.

Station.	Length of record.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
	Years.													
Allaire's ranch	16	0.77	0.71	0.66	0.23	0.16	0.24	2.61	2.81	1.30	0.58	0.82	0.69	11.59
Bisbee	21	1.21	1.24	1.10	.42	.27	.29	3.80	4.78	1.80	1.02	.66	1.00	17.59
Cochise	12	.69	1.27	.78	.21	.23	.16	1.87	2.04	1.22	.33	.78	.66	10.24
Douglas	7	.54	.78	.79	.34	.23	.42	2.71	3.44	1.08	.54	.96	.79	12.62
Fort Grant	33	.96	1.15	.92	.32	.29	.44	2.78	2.90	1.74	.91	.70	1.13	14.24
Willcox	30	.76	.89	.81	.15	.24	.24	2.07	2.51	.94	.53	.65	.71	10.50

GEOGRAPHIC DISTRIBUTION.

Willcox, Allaire's ranch, Cochise, and Douglas are all situated in the low parts of the valley and have no great difference in altitude. The average yearly rainfall at Willcox for the past 30 years has been 10.50 inches, the average at Allaire's ranch for the past 16 years has been 11.59 inches, the average at Cochise for the past 12 years has been 10.24 inches, and the average at Douglas for the past 7 years has been 12.62 inches. These small differences do not warrant the con-

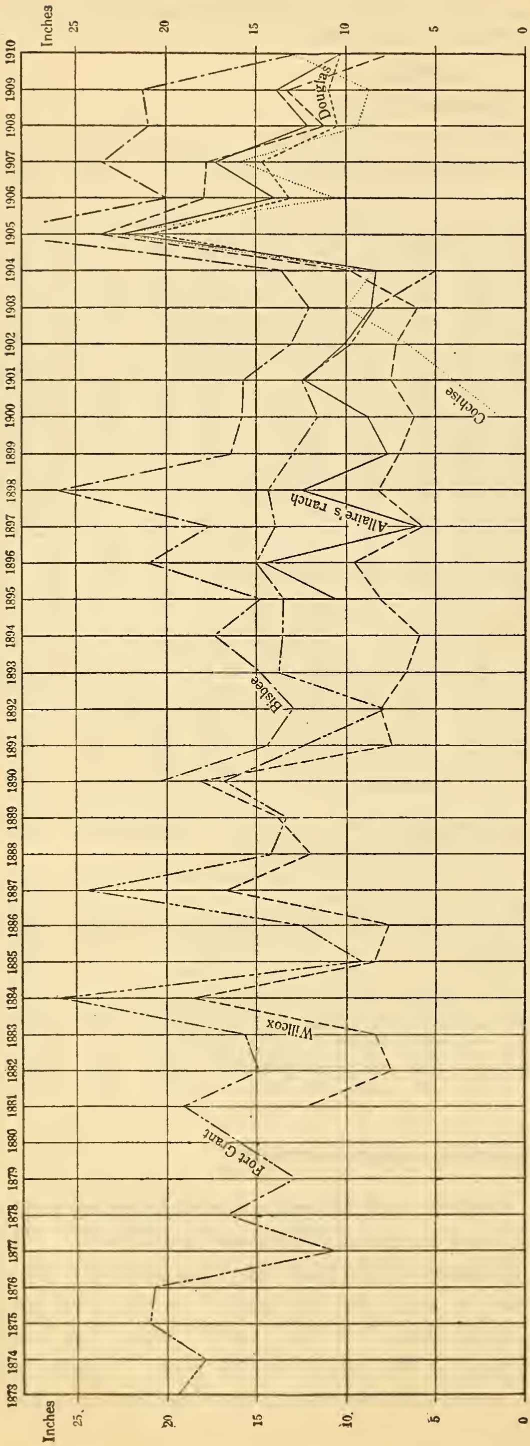


FIGURE 11.—Diagram showing annual rainfall in Sulphur Spring Valley and adjacent mountains.

clusion that there is any real difference in the rainfall at these four stations. They are in part due to differences in the years that entered into the averages and are also probably in part accidental. The excessive rainfall of 1905 affected the average for the short record at Douglas much more than it affected the long record at Willcox. Thus the average for Douglas is higher than the average for Willcox, notwithstanding the fact that since observations are being made at both points more rain has fallen at Willcox than at Douglas. (See fig. 11.) By giving proper weight to the length of each record, the average for the four stations is found to be 10.72 inches, and this figure may be taken as the average rainfall for the past 30 years in the lower parts of the valley.

Fort Grant is about 4,900 feet above sea level and is situated near the upper margin of a high stream-built slope at the west base of the lofty Pinaleno Mountains. At this place the average rainfall for 33 years was 14.24 inches. During the 24 years, from 1881 to 1894, inclusive, that its record can be compared with the records for any of the four stations in the valley proper, the average for Fort Grant was 13.49 inches, as against an average of 9.81 inches for the valley stations. This difference is graphically shown in figure 11. A comparison of the Fort Grant record with records of the four stations in the valley proper suggests that the rainfall may be generally greater near the mountains than in the lower parts of the valley; but it does not prove that the difference is everywhere as great as at Fort Grant. The height of the slope and the altitude of the adjacent mountains are probably important factors, and there may also be a difference between the east and west sides of the valley.

At Bisbee, which is located in the Mule Mountains, about 5,500 feet above sea level, the average rainfall for 20 years was 17.59 inches, the average for the four valley stations during the same years being 9.76 inches. This difference is clearly illustrated in figure 11.

The other stations in the mountains show heavier rainfall than the valley stations, but their records are too fragmentary to be averaged.

The diagram in figure 12 shows the general relation of rainfall to altitude in southeastern Arizona. It was compiled by G. E. P. Smith from the available rainfall records of the region.[1]

The forests on the Chiricahua and Pinaleno ranges indicate that the precipitation on the lofty portions of these ranges is greater than at Bisbee, where the timber was originally less heavy. Gannett [2] states that the lower limit of yellow-pine timber is not far from the lower limit of the area having over 20 inches of rainfall. On the west side of the Chiricahua Mountains, the highest peaks of which rise to altitudes of over 9,000 feet, yellow pine grows at altitudes of 6,000 feet and even lower, but it is most luxuriant at 7,000 to 8,000 feet. On less lofty mountains, however, yellow pine is not generally found even at altitudes of more than 7,000 feet. This condition suggests that more rain falls at a given altitude in a lofty mountain range than at the same altitude in a lower range. Likewise it is probably true that more rain falls at Fort Grant than at the same altitude on a stream-built slope adjacent to a lower mountain range.

SEASONAL DISTRIBUTION.

The principal rainy season covers about two months, extending from July to September. (See fig. 13.) Fully half of the rain falls in this season, most of it being precipitated in a few heavy showers. (See

[1] Bull. Arizona Agr. Exp. Sta. No. 64, 1910, p. 109.

[2] Gannett, Henry, Distribution of rainfall: Water-Supply Paper U. S. Geol. Survey No. 234, 1909, p. 9. See also Woolsey, T. S., Western yellow pine in Arizona and New Mexico: Bull. Forest Service No. 101, U. S. Dept. Agr., 1911.

fig. 14.) Thus at Allaire's ranch 47 per cent of the rainfall in 1910 occurred during four days, of which one was in the later part of July, two were in August, and one was in the first week of September.

The driest part of the year is in the spring. Both at Willcox and at Allaire's ranch the average rainfall during the period covering April, May, and June has been only 0.63 inch, or only a little over one-twentieth of the total rainfall. In many months there is no rainfall

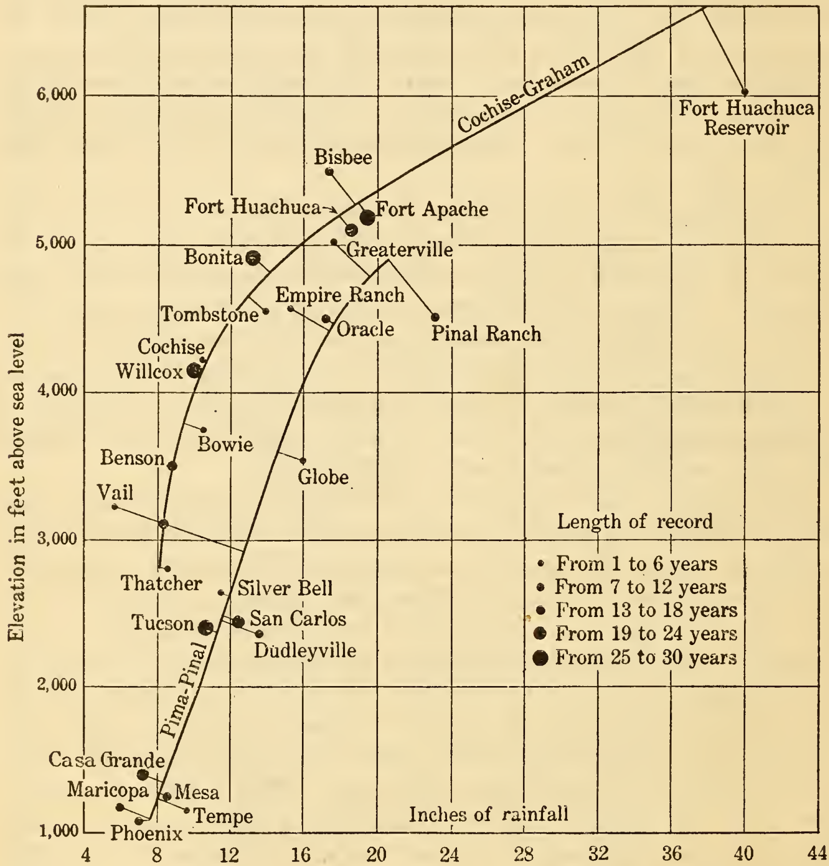


FIGURE 12.—Diagram showing relation of rainfall to altitude in southeastern Arizona. The upper curve applies to Cochise and Graham counties; the lower one to Pima and Pinal counties. After G. E. P. Smith.

whatever and only rarely during this season does the land receive a good wetting.

In the winter there are occasional rains, and the average monthly precipitation in the valley during this season amounts to approximately three-fourths of an inch. In the autumn, after the rainy season, there is usually little rainfall.

The year can be divided into two relatively rainy and two relatively dry seasons, the rainy seasons coming in the middle of the summer and in the winter, and the dry seasons in the spring and in the fall. The rainy seasons are, however, only relatively rainy, for between the sudden heavy downpours there are periods of severe drought.

FLUCTUATIONS FROM YEAR TO YEAR.

The wettest year on record in Sulphur Spring Valley was 1905. At each of the five stations at which observations were made the rainfall during that year broke all previous records and at none of them has the record for that year been reached since. The precipitation in 1905 at the four valley stations—Willcox, Cochise, Allaire's ranch, and Douglas—averaged 22.13 inches, or more than twice as much as the average for the past 30 years. At Tombstone it reached the unprecedented total of 27.84 inches. At Bisbee the 1905 record is not complete, but during the first five months the rainfall was nearly four times as great as the average at that station for these months. The excess in 1905 was due to heavy rains in the winter months and in November. The summer rainy season had only about the average amount of rain, and the spring drought was nearly as severe as in other years.

Other notably high records of annual rainfall are: Bisbee, 25.87 inches in 1898; Fort Grant, 25.67 inches in 1884 and 24.32 inches in 1887; Willcox, 18.38 inches in 1884, 16.49 inches in 1887, 17.92 inches in 1890, 17.93 inches in 1906, and 17.83 inches in 1907; Cochise, 15.82 inches in 1907; and Allaire's ranch, 17.34 inches in 1907.

The most extreme drought recorded was in 1900 at Cochise, where only 1.30 inches of rain was reported to have fallen during

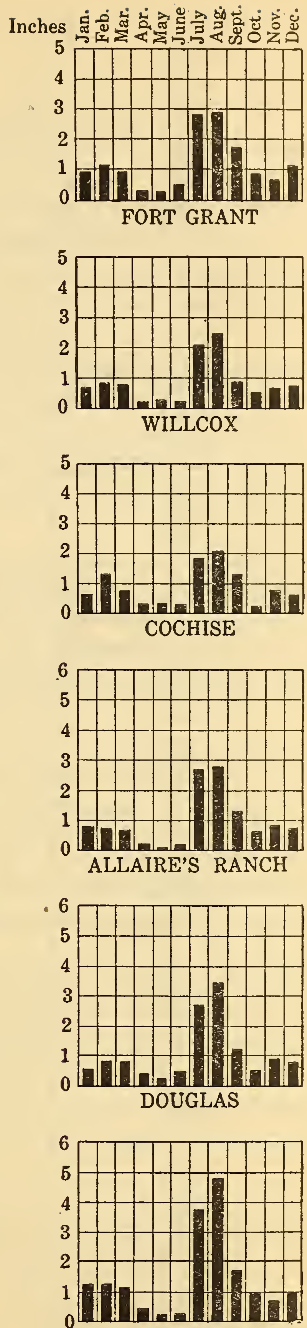


FIGURE 13.—Diagram showing monthly rainfall in Sulphur Spring Valley and adjacent mountains.

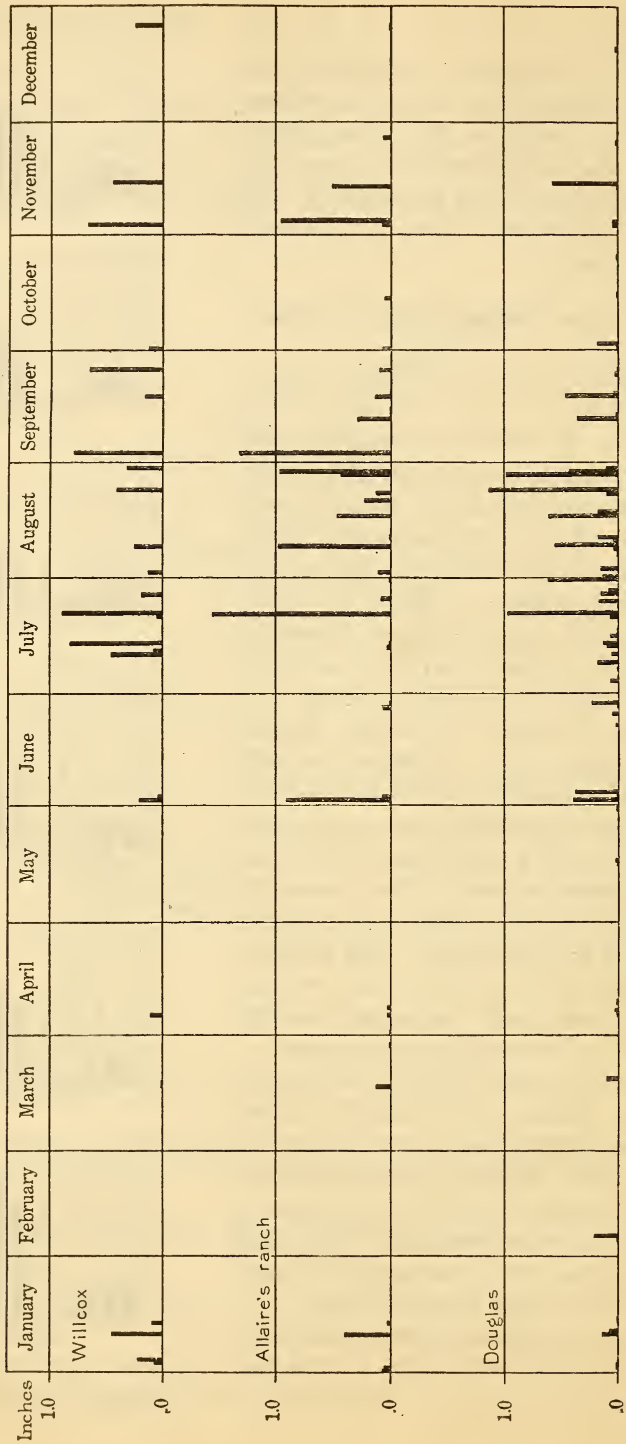


FIGURE 14.—Diagram showing daily rainfall in Sulphur Spring Valley in 1910.

the entire year and no rain whatever after March. There is, however, no way of testing the reliability of this report, and it is possible that the abnormal record is due to error. The least annual rainfall recorded at Fort Grant was 5.08 inches in 1904, the least at Willcox was 5.66 inches in 1897, and the least at Allaire's ranch was 5.93 inches in the same year. The rainfall was less than 10 inches during 6 out of 33 years at Fort Grant, during 5 out of 10 years at Cochise, during 5 out of 16 years at Allaire's ranch, and during 19 out of 30 years at Willcox. At Bisbee the annual rainfall has not been less than 12 inches during the 21 years that observations have been made at that station.

It is evident from the foregoing discussion that at any given station the fluctuations in the annual rainfall are very great. For example, the recorded range at Allaire's ranch is between 5.93 and 22.04 inches; at Willcox, between 5.66 and 23.52 inches; at Fort Grant, between 5.08 and 25.67 inches; and at Cochise, between 1.30 (?) and 22.27 inches.

Figure 11 shows that in a very general way series of dry and wet years have succeeded each other. Since 1905 the annual rainfall has, on the whole, decreased. The years 1906 and 1907 ranked well above the average, 1908 and 1909 were near the average, and 1910 was somewhat below the average. Immediately preceding 1905 there were several unusually dry years.

COMPARISON OF 1910 WITH PREVIOUS YEARS.

As a large proportion of the settlers attempted agriculture in Sulphur Spring Valley for the first time in 1910, and as it is generally believed by them that this year was abnormally dry, it is worth while to compare the 1910 record with the records of the preceding 29 years.

The average rainfall in 1910 at the four valley stations—Willcox, Cochise, Allaire's ranch, and Douglas—was 10.31 inches, and the average for the valley during the last 30 years is 10.72 inches. Figures 14 and 15 show that the principal deficiency occurred in February, March, October, and December, that rather more rain fell during the rainy season than in an average year, and that the drought from April to July was not abnormal.

Since the beginning of the records Douglas has had five years with more rain than 1910 and one year with less; Allaire's ranch has had nine years with more and six years with less, and Willcox has had eighteen years with more and eleven years with less. Five of the thirty years, since the beginning of observations at Willcox, have had notably more rain than 1910. These were 1884, with 18.38 inches; 1887, with 16.49 inches; 1890, with 17.92 inches; 1905,

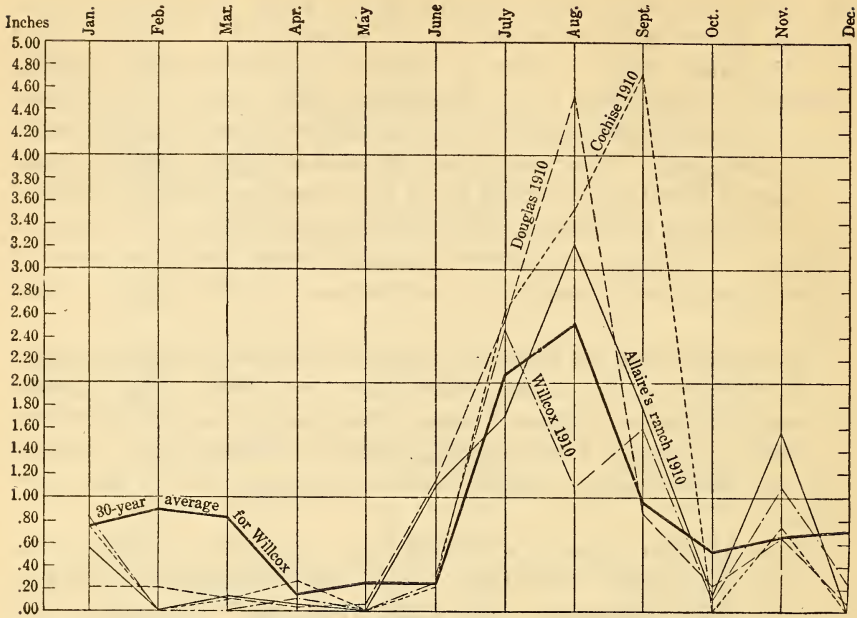


FIGURE 15.—Diagram showing deviations in 1910 from average monthly rainfall in Sulphur Spring Valley.

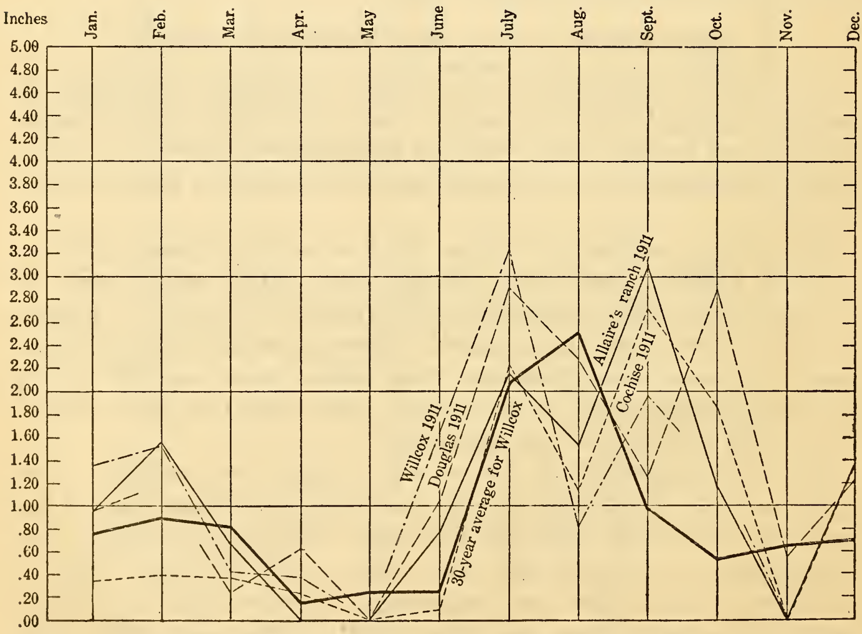


FIGURE 16.—Diagram showing deviations in 1911 from average monthly rainfall in Sulphur Spring Valley.

with 22.08 inches; and 1907, with 16.63 inches. But even these five relatively wet years had little rain from April to July, and in some of them the spring drought appears to have been about as severe as in 1910.

The conclusion must be reached that although somewhat less than the average amount of rain fell during 1910, the year was not radically different from the average and was by no means the driest year on record.

Figures 16 and 17 show the deviations from the average monthly rainfall in 1911 and 1912 at the four stations.

FIGURE 17.—Diagram showing deviations in 1912 from average monthly rainfall in Sulphur Spring Valley.

OCCURRENCE AND LEVEL OF GROUND WATER.

By O. E. MEINZER.

METHODS OF INVESTIGATION.

The depth to water was measured in about 400 widely distributed wells and borings in Sulphur Spring Valley and was reported by reliable persons for about 150 additional wells, making a total of approximately 550 points at which the depth of the ground water beneath the surface was ascertained. These data were used as the basis for outlining on Plate II (in pocket) the areas having specified depths to ground water.

At 271 of the measured wells the depth to water was referred to definite bench marks, and these points of reference were connected with each other by lines of levels. The bench marks for most of the wells are the tops of the curbs or well platforms and are indicated by three notches cut into the wood. This work, all of which was done by F. C. Kelton, determined the altitude at which ground water occurs at 271 points in the valley, and furnished the basis for the 10-foot ground-water contours shown on the map. These contours are not shown for the upper parts of the slopes, where, because, of the scarcity of wells and the necessary limitations of the work, no levels were run. See also the table on pp. 117–121.

MAIN BODY OF GROUND WATER.

FUNCTION OF THE ROCK TROUGH.

The rock trough which embraces Sulphur Spring Valley is composed of igneous and hard sedimentary formations through which water can not readily pass. The valley fill, on the other hand, includes more or less unconsolidated and porous materials. The rain water that is not drained away through Whitewater Draw and that escapes immediate evaporation seeps downward through the pores of the valley fill but is held within the rock trough. It is as if a dish were partly filled with sand and then water poured on the sand in the dish. The rock trough forms, however, a rather leaky dish, and if the rainfall did not furnish new supplies the water would no doubt all eventually escape from the valley fill. The ground water not only drains away at the north and south ends, where rock walls are lacking, but it no doubt also seeps slowly through crevices and pores in the floor and sides of the rock trough itself. These losses are, however, more than counterbalanced by the contributions from rainfall, as is shown by the fact that the valley fill has become saturated practically to the surface in the lowest places, and that in these places the ground water soaks upward to the surface and is removed quietly but in great quantities by evaporation.

CONDITIONS GOVERNING SLOPE OF WATER TABLE.

In the lowest parts of the valley the sediments are saturated nearly to the top, but in other localities the upper portion of the valley fill is nearly dry, and it is only at some depth that all pores and crevices are commonly occupied by water. A well is dry until it is sunk to the ground-water table, and as a rule the depth to water in a well shows the approximate depth of the water table below the surface.

The water table stands at different levels, however, in different localities. For example, at the north end of the barren flat it is 4,130 feet above sea level; at Willcox it is 4,154 feet; at the old O. T. ranch it is 4,181 feet; at the premises of S. N. Kemp, a quarter of a mile west of the O. T. ranch, it is 4,190 feet; and at the J. H. ranch it is 4,207 feet. At Allaire's ranch it is 4,146 feet above sea level, at Sulphur Springs it is 4,196 feet, at Pearce it is 4,189 feet, at the West well it is 4,253 feet, and at Light post office it is 4,329 feet. At the smelters in Douglas it is less than 3,900 feet above sea level, 4½ miles west of the smelters it is 3,960 feet, and at the Soldiers Hole it is 4,130 feet. The shape of the ground-water table, or surface below which the ground is saturated, is shown on the map (Pl. II) so far as the available data permit.

If the ground water received no new contributions and if it could not escape from the valley it would gradually seek a common level and the water table would become flat like the surface of a lake. In fact, however, it receives large contributions in some localities and sustains heavy losses in others. Where it receives contributions the water level is raised; where it sustains losses the water level is depressed. The ground water, like water on the surface, tends to flow from the highest levels to the lowest, and consequently it moves, very slowly indeed, from the principal areas of intake to the principal areas of disposal. The slope of the water table therefore shows the direction in which the ground water is moving and indicates the areas of intake and the areas of disposal. For example, as the ground water stands 4,207 feet above sea level at the J. H. ranch and only 4,130 feet at the barren flat, it is not in equilibrium but must tend to flow from its higher level at the J. H. ranch to its lower level at the flat. If this difference in level is a permanent condition and if there is a constant current of ground water from the J. H. ranch toward the flat, there must obviously be a perennial source of supply from the region north of the ranch and a continual disposal of the oncoming waters at the barren flat.

Other things being equal, the steeper the slope of the water table the more vigorous will be the underflow. For instance, the water table descends 77 feet in the 14 miles from the J. H. ranch to the barren flat, an average of 5½ feet to the mile; but it descends about the same distance in the 6½ miles from Light to the West well, making an average slope of 12⅗ feet to the mile. This difference in the gradient indicates that if the conditions are otherwise the same the underflow is more vigorous between Light and the West well than between the J. H. ranch and the barren flat, and consequently that the supply for the vicinity of Light is more copious than the supply for the vicinity of the J. H. ranch.

A difference in the slope of the water table does not in itself, however, prove that the underflow is more vigorous, for the rate of flow depends also on the ease with which the water can penetrate the formation. Thus, the ground water passes but slowly through clayey sediments or cemented gravels, even though it has a steep gradient, but it flows readily, even with slight gradient, through clean, coarse gravel. The water level may be considerably lower on one side of a chain of buttes than on the other, indicating not that there is unusually vigorous underflow, but rather that the underflow is obstructed by the buttes.

RELATION OF WATER TABLE TO SURFACE.

Both the form of the surface of the valley and the form of the water table are the expression of the interaction of certain natural laws; the first is governed in its main features by the laws of stream gradation, the second by hydraulic laws. The surface of the valley has, generally speaking, been built highest in the localities that received the largest supplies of sediment. In a similar manner, the ground-water table is maintained at the highest level in the localities that receive the largest accessions of ground water. The two are closely related, for the floods which wash out the largest quantities of sediment also furnish the largest contributions of ground water. Hence, both the surface of the valley and the ground-water table slope from the mountain borders toward the central axis, and both are highest near the largest mountains whence come the heaviest floods. In general, however, the grade established by the streams is much steeper than that required for the underground circulation. Hence, the water table is in general at the greatest depths beneath the surface in localities adjacent to lofty mountains, notwithstanding the fact that in these localities it is highest above sea level.

The depth to ground water is less than 100 feet throughout a belt of land that extends along the axis of the valley from a point only 10 miles south of the Arivaipa divide to the Mexican border. This belt is about 80 miles long and has an average width of about 8½ miles. Beginning at the north with the width of Hookers Draw, it widens southward until in the vicinity of the barren flat it attains a width of nearly 15 miles. South of the flat it becomes more constricted, and along the divide it narrows to only 3 or 4 miles. Between Soldiers Hole and the Four Bar ranch it expands to a width of nearly 10 miles, but farther south it gradually narrows to less than 6 miles. This belt includes approximately 675 square miles, or somewhat more than one-third of the entire valley and nearly one-fourth of the entire drainage basin. About 425 square miles of its area lie in the north basin and 250 square miles in the south basin. These estimates do not include the areas of shallow water in the mountains nor the shallow-water tracts along the upper courses of the principal draws.

Along the divide between the north and south basins the depth to water is more than 50 feet, and hence the area having less than 50 feet to water is separated into two tracts, one in each basin. The northern tract is in the form of a lens 35 miles long and 13 miles in maximum width. It extends south-southeastward from a point a short distance north of the J. H. ranch nearly to the West well and includes about 285 square miles. The southern tract extends from a point about a mile north of the Brophy windmill southward to the Mexican border, a distance of nearly 35 miles. In the vicinity of the southern alkali flat it widens to 7½ miles and extends far toward the Swisshelm Mountains. South of the Four Bar ranch it forms a narrow belt on both sides of Whitewater Draw. The southern tract is about 125 square miles in extent, and the combined area of the two tracts is about 410 square miles.

The land having ground water at a depth of less than 25 feet occurs in two tracts that lie within the two 50-foot tracts. The northern tract comprises the barren flat, a large nearly level area north of the flat, a narrow belt on each side of the flat, and a lowland plain extending from the flat to a point about 2½ miles southeast of Sulphur Springs. It includes about 175 square miles. The southern tract covers only about 45 square miles. It surrounds the southern alkali flat, south of which it contracts into a belt that averages less than a mile in width and that closely follows Whitewater Draw. The total area over which ground water is within 25 feet of the surface is about 220 square miles.

The north basin contains a tract of about 125 square miles over which ground water stands less than 15 feet below the surface. This tract includes the barren flat, an area of about 40 square miles lying north of the flat and extending a short distance beyond the township line that passes through Willcox and the O. T. ranch, a narrow belt on the east and west sides of the flat, and a tongue of land reaching from the south end of the flat to a point a short distance beyond Sulphur Springs. In the south basin the tract that has water within 15 feet of the surface covers scarcely 25 square miles, or one-fifth the area of the northern tract. It extends from a point about a mile north of Soldiers Hole to the Mexican border, but most of its area is included within the expanded belt that embraces the southern alkali flat. Southward from the Four Bar ranch it contracts, and from about the southern line of T. 21 S. to the city of Douglas, a distance of 18 miles, it is confined to the flood plain and in some sections to the stream channel of Whitewater Draw.

Over many square miles the ground water stands at depths of less than 10 feet, over considerable areas it stands at depths of less than 5 feet, and in several localities it comes to the surface, forming springs, seeps, and water holes.

At the township corners immediately west of Willcox the depth to water is about 10 feet, at the O. T. ranch it is about 11 feet, and over most of the area between these points and the barren flat it is between 5 and 10 feet, except on the wind-built ridges, where the depth is greater. In several borings along the northern margin of the flat the depth to water was about 4 feet. On the west side of the flat there is a narrow strip of very shallow water, and at certain localities, as at Croton Springs, near the northwest angle of the flat, and in the vicinity of Roger's flowing well, east of Cochise (Pl. II, in pocket), the water comes to the surface; in the knoll springs it is above the surface of the surrounding land. A similar narrow belt of very shallow water borders the barren flat on the east. At the schoolhouse near the northeast corner of sec. 2, T. 15 S., R. 25 E., the depth to water is 6 feet; nearer the flat it is only 4 feet; at Brummet's flowing well, on the next section north, a seep is said to have formerly existed; and a number of the gullies in this vicinity, called "death traps," have been cut down to the water level. Very shallow water also occurs between the flat and McCall's ranch (Pl. II), near which the depth is less than 5 feet, and in the vicinity of Sulphur Springs, where over a considerable area the depth is likewise less than 5 feet. In the interior part of the barren flat itself the ground is moist to the top, but borings to the depth of 12 feet did not discover any definite water level, probably because the clay is so fine grained that it is almost impervious.

The flat in the south basin contains areas aggregating a number of square miles over which the depth to water is less than 10 feet, and along a narrow belt from Soldiers Hole to a point southeast of the Four Bar ranch the depth is less than 5 feet. In some localities Whitewater Draw appears to tap the ground water, but more commonly it is 5 to 10 feet above the water table.

The data in regard to the depth of the water table below the surface in Sulphur Spring Valley can be summarized as follows:

Area of tracts in Sulphur Spring Valley having specified depths to ground water.

Depth.	North basin.	South basin.	Entire valley.
Feet.	*Sq. mi.*	*Sq. mi.*	*Sq. mi.*
Less than 15	125	25	150
15 to 25	50	20	70
25 to 50	110	80	190
50 to 100	140	125	265
Less than 25	175	45	220
Less than 50	285	125	410
Less than 100	425	250	675

RELATION OF WATER TABLE TO SOURCE OF SUPPLY.

The contours of the water table on the map (Pl. II) show that it slopes from the Pinaleno, Dos Cabezas, Chiricahua, Winchester, Dragoon, and Little Dragoon mountains toward the barren flat. They indicate, therefore, that the ground water is replenished chiefly from these mountains and that it moves from the mountain sources toward the flat. In the south basin the contours have not been extended far enough to indicate very clearly their relation to the mountains; if they were extended they would probably show more plainly that the water table slopes away from the margins of the mountains, where the principal underground supplies are received.

The map also indicates to some extent the relative amounts of ground water that are contributed by the different ranges. It shows, for instance, that, as would be expected, the supply from the Chiricahua Mountains is much greater than that from the northern part of the Dos Cabezas Range. The 4,170-foot water contour passes within a mile of the north end of the Dos Cabezas Range, but remains about 20 miles from the Chiricahua Mountains; the water level within a mile of the Dos Cabezas Range is only 40 feet above that of the barren flat, but the water level 6 or 7 miles from the margin of the Chiricahua Mountains is 230 feet above the water level of the flat; the slope of the water table, as far as it was determined, is 6 feet to the mile between the north end of the Dos Cabezas Range and the flat, but averages $11\frac{1}{2}$ feet between the Chiricahua Mountains and the flat. (See Pl. II.)

The map also shows that the underground supply from the Chiricahua Mountains is greater than that from the Dragoon Mountains. The large contribution of sediments by the Chiricahua Mountains is the cause, at least in part, of the high ground that divides the surface drainage of the valley (p. 25). Likewise its large contributions of water have raised the water level above the level farther north and south, and have thus separated the underground waters into two independent systems, one of which drains toward the barren flat and the other southward into Mexico. The water from the Chiricahua Mountains, both surface and underground, is divided, a part being sent into each basin. That larger amounts of sediment were contributed by the Chiricahua Mountains than by the Dragoon Mountains is shown by the fact that the axis of the valley is much nearer the latter, and a corresponding difference in the contributions of ground water is indicated by a similar position of the axis of the water table. The water table in this part of the valley descends toward the west for four-fifths of the distance from the Chiricahua Mountains to the Dragoon Mountains and, according to the data obtained, continues its westward descent for considerable distances beyond the axis of the valley itself, where the surface slopes toward the east. (See fig. 18 and Pl. II.)

The ground water stands at a higher altitude near the axis of the valley southwest of the Sulphur Hills than it does in the vicinity of

Pearce, which is 5 miles southwest of the axis and more than 100 feet higher. From the Southwest wells westward to the railroad the water table descends continuously, although within a few miles of

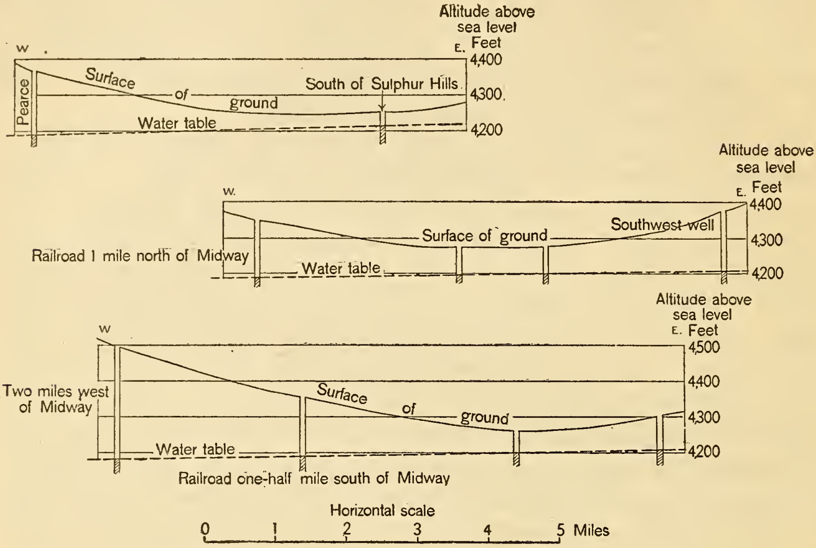


FIGURE 18.—Sections showing westward inclination of water table west of axis of Sulphur Spring Valley, in region opposite Chiricahua Mountains.

the railroad the surface rises toward the Dragoon Mountains. In a well 2 miles west of the railroad, in the SW. ¼ sec. 26, T. 18 S., R. 25 E., the water stands at a lower altitude than in the wells near the

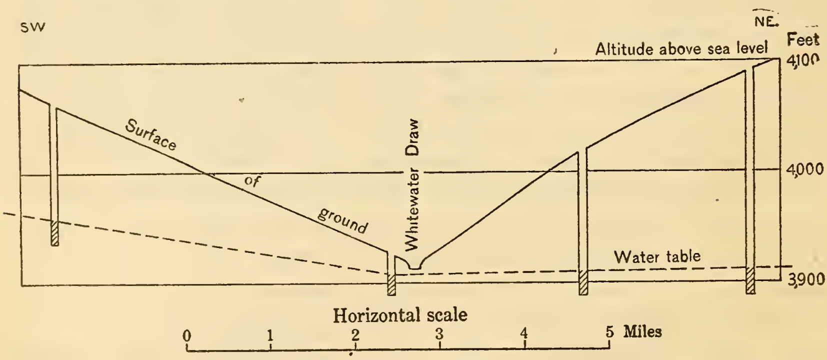


FIGURE 19.—Section in vicinity of Douglas, showing difference in inclination of water table on opposite sides of valley.

axis of the valley, although it is more than halfway up the slope of the Dragoon Mountains and on ground more than 200 feet above the axis of the valley. This persistent westward slope of the water table probably indicates that the water from the Chiricahua Mountains is greatly in excess of the water from the Dragoon Mountains and that it is carried far beyond the center of the valley.

In the northern part of the south basin the largest supplies of ground water come from the east, but in the southern part the conditions seem to be reversed, more copious supplies apparently being furnished by the Mule Mountains than by the Perilla Range. Not only does the axis of the water table swing eastward with the axis of the valley, but, as is shown in Plate II and figure 19, the slope of the water table is much steeper on the west than on the east side. Along the line of the section shown in figure 19 the water table on the west side descends 55 feet in 4 miles, or about 11 feet to the mile, whereas on the east side it descends only 7 feet in the same distance, or less than 2 feet to the mile. Since there is no corresponding difference in the slope of the surface, there is a wider belt with moderate depth to water on the west than on the east side. The difference in water supply from opposite sides of the valley suggested by the difference in the gradient of the water table may well be explained by the difference between the Mule and Perilla ranges in both width and altitude.

EFFECT OF THE BUTTES ON THE WATER TABLE.

The depth to water was not measured in enough wells in the vicinity of the buttes to determine very definitely their effect on the water table. The supplies of water furnished by the buttes are probably too small to raise the water table greatly. For instance, the water level is at no higher altitude in the well at Pearce, which is near the base of a butte of considerable size, than in the well of W. H. Scofield, 4 miles northwest of Pearce, on lower ground and far from any butte. A number of other wells situated near buttes are listed in the table on pages 117–120, and in none of them does the water level seem to be higher than would be expected if the buttes were not present.

The chief effect of the buttes on the ground water seems to be in obstructing its flow, thereby causing a depression of the water table on the leeward sides of the buttes. Such a depression is suggested by the water level in a number of wells near the chain of buttes that extends from the Sulphur Hills to the Swisshelm Mountains.

RELATION OF WATER TABLE TO DISPOSAL OF GROUND WATER.

In the south basin the water table slopes southward, descending from about 4,190 feet above sea level at the divide, south of Pearce, to about 3,890 feet where Whitewater Draw crosses the international boundary (Pl. II). Near the divide the gradient is slight, the ground water standing almost at a level over an extensive area south and southeast of Pearce. From the vicinity of Caliente station to the southern limits of the region, however, the gradient averages nearly 10 feet to the mile and corresponds closely to the gradient of the axis of the valley. This slope indicates that the entire body of ground water in the south basin is moving slowly southward to some undetermined destination in Mexico.

Wherever the water stands within 5 or 10 feet of the surface it soaks upward through the soil and evaporates, and in this way large quantities of ground water may be returned to the atmosphere. In the low flat south of Soldiers Hole there appears to be an area of considerable extent over which this process is taking place, and it is not unlikely that an important part of the underground supply furnished by the Chiricahua Mountains through the upper course of Whitewater Draw is thus returned to the atmosphere. In some parts of Whitewater Draw in its course between the flat and Douglas ground water is also disappearing by this process or by seepage. The draw is so narrow that the quantity of water disposed of can not be large, but it may have some influence in preventing the axis of the water table from being shifted far to either side of the axis of the valley.

In the north basin the water table has, generally speaking, the form of an inverted cone—that is, it slopes from all sides in the direction of the alkali flat. (See Pl. II, in pocket.) It resembles the surface of the basin in general contour, but its slopes are less steep and have fewer irregularities. This shape of the water table indicates that on all sides the underflow is toward the alkali flat, and it suggests that the disposal of the ground waters of the north basin occurs in great part in the vicinity of the flat. A large portion of the area of 125 square miles in which the depth to water is less than 15 feet is yielding ground water to the atmosphere, and this loss of ground water no doubt causes the great depression of the water table and directs the underflow throughout almost the entire basin toward the flat.

The moist condition of the clay near the surface in all parts of the flat indicates that even in the interior the ground water is within reach of evaporation. But the alkali flat is so large and yet so nearly level that the water table beneath it can have only a very slight gradient. (See Pl. II.) Both the slight gradient and the fact that the clay in the interior is very fine indicate that the ground water is disposed of but slowly in the interior, and that the movement of ground water from the margin of the barren flat toward the interior is sluggish. The largest quantities of water are probably lost near the margin, where the sediments are somewhat coarser.

Near the northwest angle of the barren flat, and at several other places along its margin, the ground water comes to the surface in the form of springs or seeps, the largest of which are Croton Springs.

Sulphur Springs are situated 5 miles from the flat and 65 feet above it. As shown on Plate II, they occur in an area in which the ground-water level is exceptionally high.

In going from the flat to Arivaipa Valley the southeastward slope of the water table becomes progressively less steep. For several miles north of the flat it is about 10 feet to the mile, or nearly the same as the slope of the valley; in the vicinity of the J. H. ranch it is about 4 feet to the mile, or decidedly less than the slope of the valley; and nearer Hooker's ranch, where the most northerly wells that reach the main body of ground water are situated, the southward slope appears to be hardly more than 1 foot to the mile. Arivaipa Valley has been cut lower than the northern part of Sulphur Spring Valley, and the ground water beneath the northern part of Sulphur Spring Valley is probably drawn toward the Arivaipa, thus depressing the water level; in other words, the ground-water divide is probably south of the surface-water divide. Shallow water occurs in the principal draws near the north end of the valley (Pl. II and p. 105); but at some distance from these draws, where only the main body of ground water probably exists, the depth to water is likely to be rather great.

VARIATIONS IN THE WATER LEVEL.

An equilibrium exists between the amount of water annually added to the underground store and the amount annually removed from this store by evaporation and seepage. This balance tends to be maintained through changing climatic conditions by fluctuations in the ground-water level, whereby the rate of underflow and the amount of evaporation and seepage are regulated. If the rainfall should decrease and the annual increment to the underground store be diminished, then, by the excess of loss over gain, the ground-water level would be lowered, and this lowering would decrease the flow of the springs and the evaporation from the low areas. Eventually a level would be reached at which loss would no more than balance gain. The same adjustment would take place if the rainfall remained the same but the evaporating power of the atmosphere were to increase. If, on the other hand, the amount of rainfall should increase or the evaporating power decrease, or, what is much more probable, should both these changes take place at the same time, then the ground-water level would rise, new springs would burst forth, and evaporation would take place over a larger area, until loss would once more be great enough to balance gain.

The fluctuations in the water level, which no doubt occur as rainy and dry seasons alternate and rainy and dry years or periods of years succeed each other, imply that the ground-water contours do not remain stationary and that the areas having specified depths to water do not have fixed boundaries. The map (Pl. II) merely shows the position of the contours and boundaries at the time the measurements were made. At some periods in the past, probably in Pleistocene time, when throughout the continent the climate was notably cold and humid, the water level in the north basin rose greatly, and equilibrium between increment and disposal was not established until a lake had accumulated that exposed about 120 square miles of water surface to continuous and unrestricted evaporation. The drainage in the southern part of the valley probably prevented an equally great rise in the water level of the south basin.

The field work did not cover a sufficiently long period to make possible any adequate investigation of the ordinary fluctuations, but the bench marks established and the data obtained (pp. 117–121) furnish a basis for further observations. In the NW. ¼ sec. 22, T. 13 S., R. 24 E., the water level was found to stand about 2 feet lower on December 9, 1910, than on September 12 of the same year, while at the northeast corner of sec. 1, T. 14 S., R. 24 E., the lowering of the water level from September 23 to December 10 was only about one-tenth as great. In general, the fluctuations appear to be greater near the mountains than near the alkali flat. The water level at Allaire's ranch was, according to Mr. Allaire, about 7 feet lower in 1910 than in 1884, and a similar lowering of about 7 feet is reported by W. H. Newell on the "44" ranch between 1886 and 1910. A rise in the water level was noted by Mr. Allaire after the unusually heavy rainfall of 1905.

WATER ABOVE THE MAIN BODY.

GENERAL RELATIONS.

Ground water is, in general, found near the surface in the center of the valley and at greater depths up the slopes toward the mountains. Shallow water is, however, also found in many localities on the upper parts of the slopes, especially in or near the principal draws (Pl. II). This distribution of ground water has controlled the location of the cattle ranches, and, somewhat less rigidly, the location of the homesteads of recent settlers. Most of the ranches were established in the low central parts of the valley, where water could be procured without fail by sinking shallow wells; but a few were located where shallow water was found on the upper parts of the slopes and in certain shallow-water areas among the mountains. (See p. 18.) The wide, monotonous expanses that lie between the central shallow-water belt and the high-level shallow-water tracts have remained the most thinly populated, the least developed, and the most unpromising parts of the valley.

Where the stream deposits of the upper slopes are porous enough to allow free percolation, the flood waters that enter the ground sink rapidly. A well drilled in such an area remains dry until it reaches the water table of the main body of ground water, far below the surface.

In some places near the mountains impervious bedrock lies only a short distance below the surface, and water is found in the porous deposits that rest on this rock. More commonly, however, shallow water is found where there is no indication of bedrock, and in several high-level shallow-water tracts a great thickness of valley fill has been demonstrated by drilling.

In many wells shallow water is struck above a layer of valley fill that has been rendered nearly waterproof by a firm calcareous cement. In most localities the relation of the high-level waters to the main body of ground water could not be ascertained, because few wells that extend to the main body are found far enough up the slopes. At a few points, however, in or near areas of high-level waters, deep wells have been drilled, and these show that ordinary unsaturated valley fill may occur below the cemented floor that holds up the shallow water and that the deep water to which they extend is not under much pressure, but remains in the wells, far below the level of the shallow water. These conditions are in contrast to those found in the center of the valley, where the main body of ground water is near the surface, where every porous bed below the first water-bearing stratum is saturated, and where the deeper waters invariably rise in the wells to at least the level of the first water.

Most of the high-level shallow-water tracts occur along the draws that conduct the floods discharged by the principal canyons, and they obviously obtain their waters from these floods. The draws that drain the most extensive mountain areas, such as Bonita Draw and Turkey Creek, have the largest and most reliable shallow-water tracts. The interstream areas and the draws that lead from small canyons either have no shallow-water tracts or have only small tracts that do not extend far from the mountains, yield only very meager supplies, and in seasons of drought contract greatly or become wholly dry.

In general, the shallow-water tracts yield most freely near the mountains and gradually decrease in yield downstream. In general, also, they are least affected by the dry seasons near the mountains and are very sensitive to drought at their lower ends. They do not have fixed boundaries but are continually expanding or contracting in response to the rainfall, or, more precisely, in response to the floods that flow through the draws, the greatest expansion and contraction commonly being at the lower ends.

Along some draws reversed conditions are found, as along Fivemile Creek and Ash Creek (of the Chiricahua drainage). At certain points on these stream courses "ciénegas" and very shallow wells occur far from the mountains, while farther upstream there are stretches where no ground water has been found. The dry areas probably occur where the underlying deposits are porous enough to allow the ground water to sink, the water-bearing areas farther down the valley receiving their supplies directly from the floods that reach them. The springs and shallow flowing wells apparently exist where the impervious beds that hold up the water come near the surface.

The level of these upland bodies of shallow water fluctuates more rapidly and through a wider range than does the water level of the main body, which is vastly greater and receives its supplies with more regularity and from a much larger number of sources. In the 36-foot dug well at the Bonita store, for example, the water is said to be

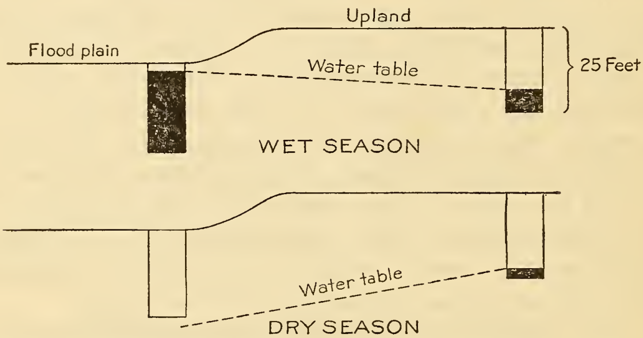


FIGURE 20.—Section on Turkey Creek showing differential fluctuation of water table. (Vertical scale exaggerated about fivefold.)

usually only about 12 feet below the surface, yet in September, 1910, it stood 32 feet below the surface.

An interesting fluctuation occurred in 1910 in the two shallow wells of A. D. Rand, in the NE. ¼ sec. 8, T. 18 S., R. 28 E. As shown in figure 20, both wells are 18 feet deep, but one is situated on the flood plain of Turkey Creek and the other on adjacent ground several feet higher. In the rainy season the lower well was nearly full of water, whereas in the upper well the water stood much farther below the surface and at a distinctly lower level. Later in the season, when dry weather returned, the water level in the lower well sank rapidly, and the well became entirely dry at a time when the upper well still had 2 feet of water. The lower well is evidently sunk into more porous gravel than the upper well and it is also nearer the source of supply. Hence, it filled more rapidly when the floods came and was more quickly drained when it received no new supplies.

NORTH END OF VALLEY.

At the north end of Sulphur Spring Valley shallow water occurs in the following localities: (1) The draw of Taylor Canyon; (2) Bonita Draw, from Bonita post office probably to its junction with Hookers Draw; (3) Hookers Draw, from the spring 5 miles above the ranch to a point at least 1 or 2 miles below the ranch; (4) land adjacent to High Creek, near the point where this creek leaves the mountains; and (5) certain tracts along Oak and Ash creeks.

The draw of Taylor Canyon, which extends from the mountains southward to Bonita post office, has for many years been inhabited by a few settlers, who dug wells and generally found water within 50 feet of the surface. The water level in this draw varies greatly, as is shown by a 50-foot well in sec. 28, T. 9 S., R. 23 E., which in the rainy season was filled within 18 feet of the surface but later became entirely dry.

In the vicinity of the post office Bonita Draw is nearly 2 miles wide and has very shallow water. In certain localities, as on the farm of M. L. Wood, the underflow is at some seasons so near the surface that it serves as a natural subirrigation supply. In September, 1910, the water had sunk lower than usual, but it stood between 20 and 30 feet in most of the wells examined. The depth to water gradually increases downstream and is reported to average between 50 and 60 feet 2 miles below the post office. Bonita Draw is rather thickly populated and is inhabited by some of the earliest settlers in the valley.

Hookers Draw contains several localities in which the water comes to the surface or stands only a very few feet below the surface. The most important locality of this sort is the ciénega in sec. 6, T. 11 S., R. 23 E., just below the junction of Bonita Draw and Ash Creek with Hookers Draw. A so-called spring occurs in the axis of the valley less than 2 miles from the Arivaipa divide. A dug well about a mile below the ciénega had water within 30 feet of the surface in December, 1910, but no shallow wells were observed farther down the valley. In this draw, as in the Taylor and Bonita draws, the water level fluctuates rapidly and through a wide range. The ciénega was the site chosen by Mr. Hooker for the Sierra Bonita ranch, one of the oldest ranching establishments in the valley.

A spring occurs where High Creek leaves the mountains, and water has been found in a well about 60 feet deep in the NW. ¼ sec. 20, T. 10 S., R. 22 E., and in several wells in the vicinity of Ash Creek. Some of these wells obtain their water from a stratum immediately above bedrock, but in others the rock is probably far below the water level. Most of the wells have failed in dry seasons, thereby causing serious inconvenience to settlers that depended on them.

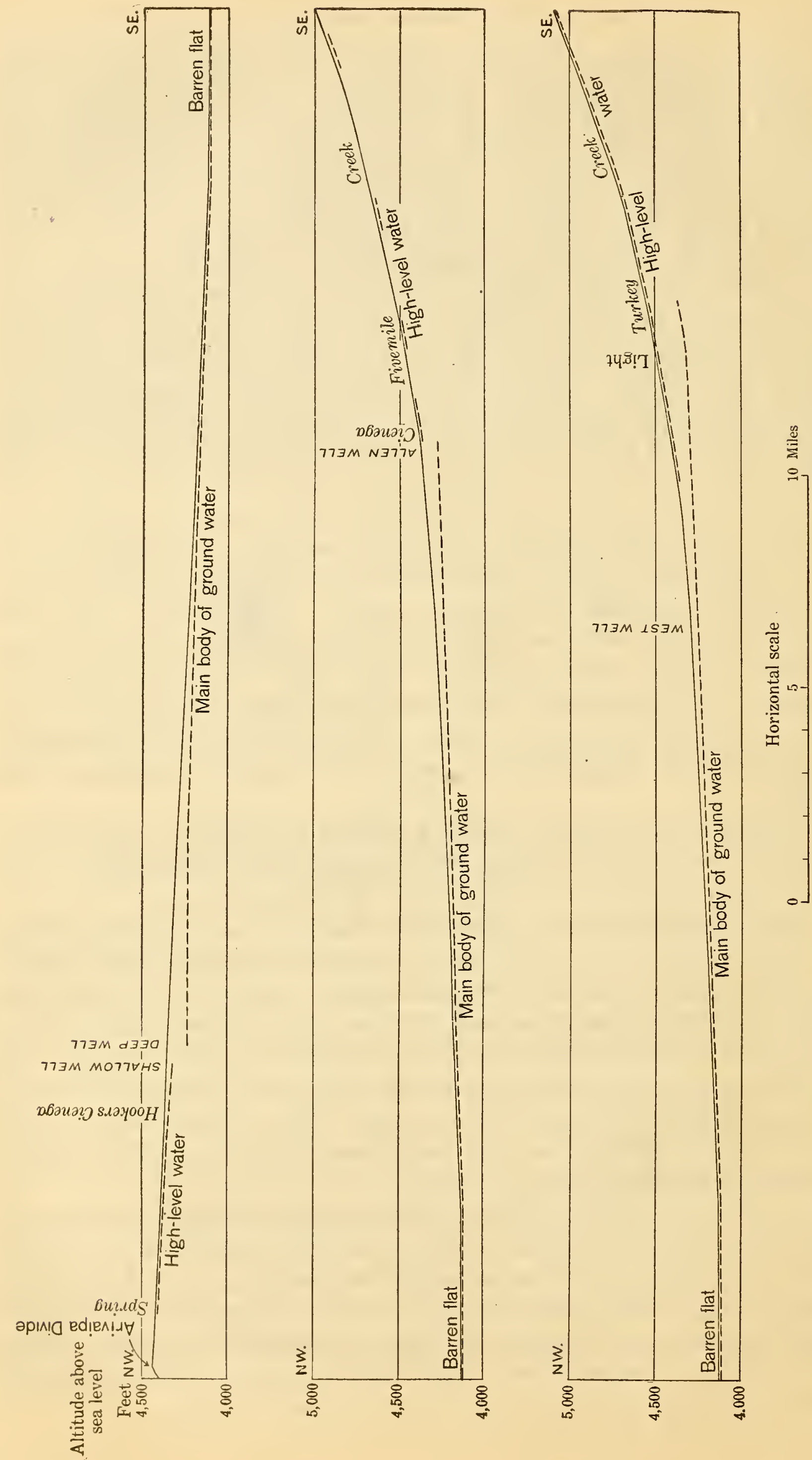


FIGURE 21.—Sections showing relation of high-level water to main body of ground water. Continuous lines show surface of land; broken lines show water table.

The shallow water near the north end of the valley stands above the level of the main body of ground water. In going from the barren flat to Hooker's ranch, the depth to water increases continuously and the slope of the water table becomes gradually more slight, until at only a short distance from the ranch water is encountered near the surface and at a level entirely discordant with the water table farther south. Thus, in a well at the south margin of sec. 7, less than 2 miles south of Hooker's ciénega, the water level is 136 feet below the surface and only 4 feet above the water level at a point 3½ miles farther down the valley; but in a well in the northern part of the same section the water level is only 30 feet below the surface and fully 100 feet above the water level in the first well. The abrupt character of this change is shown in Plate II (in pocket), and also in figure 21. In a number of wells sunk at some distance from the draws either no water was found or it was found at a lower level than in the draws.

The shallow water supply in the draws obviously comes from the run-off of the mountains which is directed into these draws. The supply in Bonita Draw is larger and more reliable than the supplies along High, Oak, and Ash creeks, because the drainage basin which furnishes the supply is larger and better watered.

SLOPE ADJACENT TO CHIRICAHUA MOUNTAINS.

Shallow water is found in the following localities on the slope bordering the Chiricahua Mountains: (1) Along Pinery Creek and its branches; (2) at a number of points in T. 17 S., Rs. 27 and 28 E., on both sides of Fivemile Creek; (3) along Turkey and Ash creeks and their tributaries; and (4) along Whitewater Draw.

The draw of Pinery Creek as far down as the Star ranch is a broad meadow with a good growth of grass and some trees; above this ranch it is joined by several tributaries which also form broad meadows. At the Star ranch a well about 25 feet deep yields a small supply of water, and farther up the draw there are other shallow wells which are said to yield more freely. Shallow water is found along this creek and its branches for at least 6 or 7 miles above the ranch. The Riggs ranches and the Riggs settlement were established in this shallow-water area at an early date in the valley's history. The portion of the draw below the Star ranch appears more arid, and no wells were reported in it.

Fivemile Creek has a smaller drainage area than Pinery and Turkey creeks, and its ground-water supplies appear to be more localized. Water is found above rock at the ranch of J. T. Porch, in the SW. ¼ sec. 14, T. 17 S., R. 28 E.; in the NW. ¼ sec. 23; and in a deep tributary ravine in sec. 11. Shallow water has been struck at a number of localities farther down the slope (Pl. II). Some of these are near the draw of Fivemile Creek; others are several miles from it. The local character of these supplies is shown by the fact that a number of rather deep holes have been sunk in the same region without striking water. The farthest down the slope that shallow water has been found is at a spring, or ciénega, in the NW. ¼ sec. 20, T. 17 S., R. 27 E., 9 miles from the mountains.

The water of this ciénega and of the 8-foot wells of S. R. Holdeman in the quarter section next north is far above the main body of ground water and is brought to the surface by an impervious layer of valley fill, as is definitely proved by the drilled well of C. M. Allen in the NE. ¼ sec. 19. The Allen well, situated less than half a mile from the ciénega and on slightly lower ground, is 146 feet deep, and its water level is 116 feet below the surface. In this well the drill passed through a few feet of clay and loose gravel, then penetrated a compact cemented clay with embedded pebbles and rocks to a depth of more than 100 feet, then passed in succession through beds of sand, red clay, and sand and gravel, the well being finished in gravel. The seepage that supplies the ciénega and the Holdeman wells is evidently in the loose gravelly material above the cemented pebbly clay. (See fig. 21.)

The shallow supply is very sensitive to the irregularities in the rainfall and fails entirely in some of the wells during periods of protracted drought. The Holdeman wells are reported to have overflowed from December, 1909, till June, 1910, after which the water subsided until the latter part of July, when it stood 6 feet below the surface. After the summer rains the water level rose, but at the end of September it still stood below the top of the wells. The yield of the shallow wells is generally too small to supply a windmill continuously. The yield of the Allen well is larger and is not known to be affected by drought.

The valley of Turkey Creek is broad but shallow, and in some places it is practically at the general level of the upland. It contains a scattering growth of trees for about 10 miles beyond the mountains. Shallow wells yielding small and variable supplies are found at short intervals along this so-called creek from the vicinity of Wilgus to about sec. 6, T. 18 S., R. 27 E., approximately 13 miles below Wilgus and 11 miles from the edge of the mountains. The shallow wells are also found along Rock Creek and along the smaller tributaries of Turkey Creek. A meager yield of water can in some seasons be obtained in the NE. ¼ sec. 6, T. 18 S., R. 27 E., at a depth of 12 feet, but no shallow wells were reported farther west.

The relation of the shallow water to the main body of ground water is well shown along Turkey Creek, a number of deep wells having been sunk in localities that have shallow dug wells. The drilled wells have sections that are similar to those of the Allen well.

The water level in them (Pl. II and fig. 19) accords with the water table of the main body of ground water, but is 100 to 200 feet below that of the shallow-water bodies. The supply of the drilled wells is permanent and large, especially as compared with that of the shallow wells. The deep well of O. S. Pratt, in the NE. ¼ sec. 6, T. 18 S., R. 27 E., for instance, is pumped by an engine at the rate of 50 gallons a minute, whereas most of the shallow wells will probably not yield as much water as a windmill can pump.

Water has been struck in a number of shallow wells along Ash and Pridham creeks and elsewhere in the southern part of T. 18 S. (Pl. II), but in other localities in the same region water was found only by drilling to depths of several hundred feet. On Ash Creek, about 3 miles from the mountains, a drill hole is said to have been sunk 386 feet without encountering a supply. One of the well-known sources of water supply in this region is the so-called ciénega near the center of sec. 25, T. 18 S., R. 27 E., where a 17-foot dug well sometimes overflows and seldom or never goes dry. On December 1, 1910, the water in this well stood only 2½ feet below the surface. There is a shallow well in the SW. ¼ sec. 23, T. 18 S., R. 27 E., in the valley of Ash Creek, and a spring in the quarter section next west. This spring is 8 miles from the mountains—the farthest point on Ash Creek where evidence of shallow water was observed.

Whitewater Draw, above the point of the Swisshelm Mountains, is a broad, deep valley with many trees. At the Rucker ranch, in the NW. ¼ sec 29, T. 19 S., R. 28 E., two wells had water 44 feet below the surface in November, 1910. About 1½ miles down the valley from Rucker's there are wet-weather wells about 10 feet deep and more reliable supplies are said to exist at 40 to 100 feet. At the Whitehead ranch three wells 145 and 150 feet deep are filled with water in wet seasons within 10 or 15 feet of the surface, but in dry seasons yield little water. Formerly there was a shallow well in the NW. ¼ sec. 22, T. 19 S., R. 27 E., where the floods of Whitewater Draw have cut into a small porphyry butte. No wells were observed for 3 miles downstream from Whitehead Ridge, but below that point there are many wells, all of which extend to the main body of ground water. (See Pl. II.)

SLOPE ADJACENT TO SWISSHELM MOUNTAINS.

Small supplies of water have been struck in several wells near the channel of Leslie Creek at depths of less than 100 feet. These wells are near the group of buttes shown in Plate II, and the water of at least some of them lies immediately above the rock. These supplies are evidently above the true water table, as is shown by the well of W. A. Murphy, in the NE. ¼ sec. 29, and the Double Rod well, in the SW. ¼ sec. 16, in which the water stands about 215 feet below the surface.

SLOPE ADJACENT TO PERILLA MOUNTAINS.

Two dug wells furnish a supply for the farm of C. A. Gardner, in T. 22 S., R. 28 E. The deepest of these wells was sunk 47 feet, and the water level in both was reported to be about 32 feet below the surface. In a drilled well on the premises of D. H. Watson, 3 miles west of the Gardner wells and on ground more than 100 feet lower, the water is reported to stand about 200 feet below the surface.

The well of William Maddox, in lot 1, sec. 4, T. 24 S., R. 28 E., is about 40 feet deep and yields only meager supplies. The well of R. H. Davidson, in lot 2 of the same section, was originally 90 feet deep and yielded little water, but it was later drilled to a total depth of 280 feet, with the result that the water level fell to about 200 feet below the surface, but the yield was greatly increased. The well of Frank Doan, in the NW. ¼ sec. 15, about 90 feet deep, and other wells east of Douglas apparently also draw from supplies that have not yet sunk to the main body of ground water.

SLOPE ADJACENT TO DRAGOON MOUNTAINS.

Shallow water has been struck in or near several draws in the vicinity of the Cochise Stronghold. As in most other localities, the largest and most dependable supplies are found near the mountains. The deep wells of W. E. Ellison, in the SW. ¼ sec. 9, T. 17 S., R. 24 E., and the deep well of G. H. Dean, in the NE. ¼ sec. 15, are 1 or 2 miles farther from the mountain border than the shallow dug wells. (See Pl. II.) In sinking these deep wells a seep that was too weak for practical use was noted by the drillers 40 or 50 feet below the surface and immediately above a cemented bed. After piercing this bed the drilling was continued through apparently dry sediments till true waterbearing beds were struck at depths of 275 and 200 feet. The water in the deep beds was under slight pressure, but remained 258 feet below the surface in the Ellison well and 194 feet below in the Dean well.

A 38-foot dug well with water 32 feet below the surface is situated in sec. 16, T. 19 S., R. 25 E., a short distance northeast of Courtland. It is near the mountains and appears to have been sunk into decomposed rock. Other attempts to find shallow water in the same locality have been unsuccessful. A similar well, 80 feet deep and with very small yield, is situated near the Arizona Eastern Railroad, southeast of Courtland.

The ranch of William Cowan, situated on the high land between the Dragoon and Mule mountains, has two wells, neither of which has a large supply. One is a dug well about 100 feet deep and the other a drilled well about 300 feet deep. The dug well extends through valley fill, which is cemented for the most part below the depth of 30 feet and which ends in impervious clay or shale. Most of the water comes from the less firmly cemented parts of the fill near its contact with the clay. Soon after the beginning of the rainy season the well begins to fill, and the water level may rise within 40 feet of the top; in this season the well can not be pumped dry by continuous use of the windmill. Later the water level sinks, and in the spring the daily supply may become reduced to an amount that can be pumped in one hour.

SLOPE ADJACENT TO MULE MOUNTAINS.

A few shallow wells are found along the draw near the international boundary. The supply on Christianson's ranch (Pl. II) is obtained from a dug well that was sunk 60 feet deep, apparently all in a caliche conglomerate, and is filled with water within 20 feet of the top. This well differs from most of the high-level wells in that its water level is said to be nearly constant and the supply is abundant and permanent. Another dug well situated in the same draw about 2 miles east of Christianson's ranch has a water level 28 feet below the surface. About 5 miles east of this well several wells reach the main body of ground water at about 100 feet, but in the intervening belt only dry holes were observed and unsuccessful borings of considerable depth are reported.

WATER IN MINOR ROCK BASINS.

CHARACTER OF BASINS.

Shallow ground water is found in many localities in the mountainous areas bordering Sulphur Spring Valley. It occurs in basins formed of rocks that are sufficiently compact and unfractured to hold it. The basins are partly filled with porous rock waste, which receives the rain that falls upon them and the storm waters that drain into them from adjacent higher land. Because of the waterproof character of the basins this water does not readily escape, but collects in the rock waste or layer of upper weathered rock and may produce seeps or furnish supplies for shallow wells. These small basins differ from the valley itself in size rather than in character. They are most abundant in areas of igneous rock, but some of them are formed, at least in part, by quartzite or other compact sedimentary beds.

PINALENO MOUNTAINS.

Shallow water is found near the mouths of some of the canyons in the Pinaleno Mountains. For example, a shallow well, a seepage spring and a cottonwood tree are found near the mouth of the canyon in which the old Bar X ranch was situated; a little farther down the draw there is an outcropping ledge of rock that apparently causes these shallow-water conditions. Below the ledge there is no indication of ground water, and the depth to water may be great. At the old Hayse ranch, in another canyon, a shallow well is evidently supplied by water which seeps through the sediments above the rock floor of the valley.

DOS CABEZAS MOUNTAINS.

The Dos Cabezas Range is flanked on the southwest by hard Paleozoic quartzites and limestones that dip toward the southwest at a steep angle and, because of their resistant character, form a sharp conspicuous ridge. Back of the ridge is a broad, relatively low basin which is underlain by granitic rocks covered with coarse rock waste and which drains into a canyon cut through the ridge. The upturned quartzite bed forms a dam which impounds the water in the sediments of the basin, thereby providing an abundant shallow-water supply for the village of Dos Cabezos, which is situated in the basin. (See fig. 22.) The depth to water in the

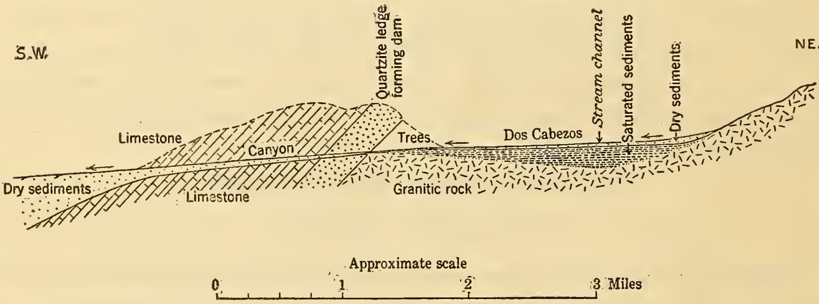


FIGURE 22.—Geologic section showing shallow-water conditions at Dos Cabezos.

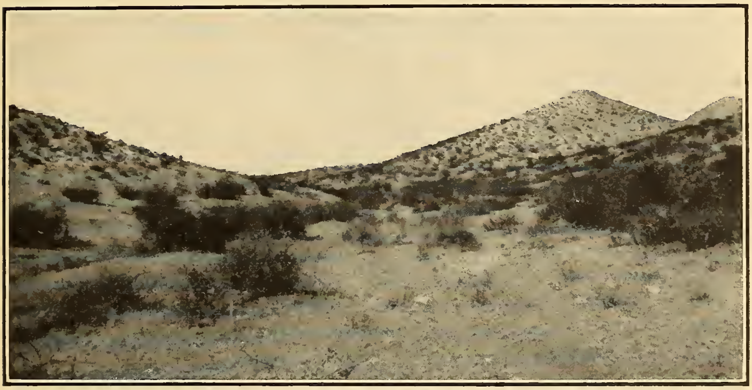
basin decreases downstream, and near the canyon and in its upper part ground water is virtually at the surface. At the Busenbark ranch the water is brought to the surface by a siphon that leads from a shallow well at the entrance of the canyon to lower ground farther down the canyon. Where the water is shallow, trees of different kinds, including cottonwood, ash, walnut, hackberry, and willow, grow luxuriantly. Below the quartzite ledge there is no evidence of ground water, and the canyon has a barren aspect which is in striking contrast to the verdure of the upper tree-covered portion. This contrast is to some extent shown by the two views in Plate XII, *B* and *C*.

CHIRICAHUA MOUNTAINS.

The Chiricahua Mountains consist largely of porphyritic rocks which are impervious except where they are decomposed. At many places veins or dikes of resistant granitic rock run through the more readily weathered formation and form dams behind which small

A. MUD SPRING.

Showing relation of shallow water to porphyry ledge.



B. VALLEY DOWNSTREAM FROM DOS CABEZOS.

Showing barren aspect below quartzite ledge.

C. VICINITY OF DOS CABEZOS.

Showing evidences of shallow water above quartzite ledge.

quantities of water are ponded. Where these small reservoirs overflow they produce seeps or springs. Igneous rock occurs a short distance below the surface in the vicinity of Fivemile Creek near the mountains. In the SW. ¼ sec. 14, T. 17 S., R. 28 E., water is found by sinking about 50 feet to this rock, and in sec. 11 of the same township water is brought to the surface by an outcrop of this rock in a deep ravine some distance from the edge of the mountains.

SWISSHELM MOUNTAINS.

In the vicinity of Leslie Canyon the Swisshelm Mountains consist of eastward-dipping limestones covered with acidic lavas, back of which is a basin comparable to that in the Dos Cabezas Range. Leslie Canyon cuts through the lava and limestone series, and leads from the basin to Sulphur Spring Valley (fig. 23).

The lava is relatively resistant and impervious, and therefore constitutes a dam behind which the water that has seeped into the

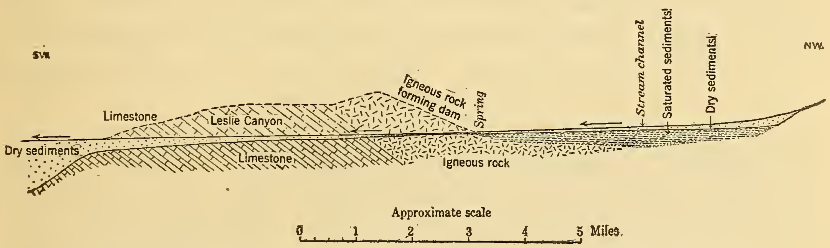


FIGURE 23.—Geologic section showing shallow-water conditions at head of Leslie Canyon.

sediments of the basin is impounded and can be recovered by means of shallow wells. At the entrance into the canyon the underground reservoir overflows, forming a good spring. The water from the spring flows down the canyon, either at the surface or through the gravels near the surface, until it reaches the limestone, where it disappears, apparently through the crevices of this rock. Trees are growing near the spring and in the part of the canyon that passes through igneous rock; but in the lower part of the canyon, which is cut through limestone, only a few willows are found.

PERILLA MOUNTAINS.

An elevated shallow-water basin exists in the vicinity of Tufa and the area north of that station. It is composed chiefly of igneous rocks, upon which rests a layer of granular and poorly assorted sediments. A number of shallow wells are supplied with water held in these sediments. Water is also found seeping through the gravels in the valley of Silver Creek, which drains southeastward into San Bernardino Valley.

Mud Spring is situated on sec. 16, T. 22 S., R. 28 E., in a stream valley that drains westward into Sulphur Spring Valley. The spring, a shallow well, and a clump of trees are found on the upstream side of a ledge of resistant red porphyry (Pl. XII, *A*). The ledge apparently extends underground across the valley and obstructs the water that seeps downstream through the valley gravels.

GALIURO AND WINCHESTER MOUNTAINS.

A number of seeps and springs occur in the mountains northwest of Sulphur Spring Valley. So far as known they resemble in character and origin the mountain springs already described. No extensive shallow-water tract was found in this region.

LITTLE DRAGOON MOUNTAINS.

The eastern part of the Little Dragoon Mountains consists chiefly of limestone and overlying conglomerate and accordingly is devoid of ground-water supplies. West of a line connecting Johnson and Dragoon station there is an extensive upland area underlain by granite mantled with rock waste. Depressions in the granitic surface, probably due to differential weathering, entrap the rain and storm waters that soak into the rock waste and thus form small reservoirs whose supplies are readily tapped by shallow wells. Johnson, which is situated in the conglomerate and limestone area, has no wells nor springs but depends for its water supply on the well of Robert Mackay, situated in a ravine southwest of the village. An outcrop of granite immediately below this well indicates that the supply of water is due to the impounding of the underground seepage by this impervious rock. In the granite area west and south of the Mackay well there are several ranches, all of which are supplied by very shallow dug wells.

DRAGOON MOUNTAINS.

In the main Dragoon Range, as in the Little Dragoon Mountains, the limestone areas are generally destitute of water, but several areas underlain by igneous rocks supply springs or shallow wells. The entire water supply for the villages of Courtland and Gleeson is obtained from shallow wells. The Courtland Water & Ice Co. has two dug wells about 2 miles northwest of the village of Courtland, one 32 feet and the other 35 feet deep. These wells are situated in the mountains, in a ravine bordered by porphyritic lavas and an upturned quartzite bed. The wells pass through rock waste and end in greatly decomposed crystalline rock. In October, 1910, the porous formations were saturated within 15 feet of the surface, but the water level no doubt fluctuates with the rainfall. In June and July, 1910, before the rainy season, the combined yield of the two wells is reported to have been only 15,000 gallons per day, but soon after the summer rains their capacity increased and in October they were being pumped at the rate of 3,200 gallons an hour. The water is pumped into an elevated tank and thence distributed through a system of mains. The water supply for the Calumet & Arizona Mining Co. is obtained from a well near the water company's wells. Several other shallow wells have been dug in this gulch.

MULE MOUNTAINS.

Small quantities of water are obtained from shallow wells sunk into the rock waste at the bottom of some of the gulches in the Mule Mountains, and the entire water supply of Bisbee was formerly derived from this source. Many of the shallow wells are still in use, though the principal supply is now pumped from wells near Naco and delivered through a pipe line to the towns in the Mule Mountains. The shallow water is found chiefly in the areas of metamorphic and igneous rocks, but is not confined to these formations. The supply at Forrest's ranch, for instance, is obtained from a spring in Cretaceous sandstone.

WATER PROSPECTS.

The shallow-water areas in the mountains owe their existence to the fact that they are underlain by compact rock through which the water can not percolate. This compact rock holds the water in the upper weathered layer of rock and in the overlying débris, but it is itself practically destitute of water. Deep drilling in these areas is therefore likely to result in failure. To develop a large supply the surface from which seepage is received should be made as extensive as possible. To this end wells of large diameter should be dug, and from the bottoms of the wells tunnels or infiltration galleries should be extended through the water-bearing materials. Gangs of shallow drilled or driven wells may be practicable in some localities but can not be successfully sunk where there are many bowlders. Small supplies for irrigation can probably be obtained in a few places, and valuable domestic and mine supplies can be developed in many localities where irrigation is not economically practicable.

WATER IN CREVICED ROCKS.

Shallow water is seldom found in mountainous areas underlain by limestones because the limestones generally contain crevices through which the water sinks. Mines in this kind of rock are usually dry until great depths are reached. Below a certain level, however, the crevices of the limestone are filled with water, and when a mine is developed below this level heavy pumping may be necessary. This condition is illustrated at both Tombstone and Bisbee. The rich mines at Tombstone were dry to a depth of 500 or 600 feet, but deeper workings could be kept accessible only by pumping great quantities of water. The mines at Bisbee are likewise dry to great depths, but heavy pumping is required from those which have been sunk deepest. Ransome reports that in the Lowell mine the water level was encountered about 1,100 feet below the surface (somewhat more than 4,200 feet above the sea) and that pumping was necessary after this depth was reached.[1] In 1910 the Calumet & Arizona mine was pumped at the rate of 2,400 gallons a minute, the water being used for irrigation on the Warren ranch, situated several miles south of Bisbee.

Evidently the water level in the limestone and other creviced rocks has no relation to that in the shallow-water basins. At Bisbee, for example, it is fully a thousand feet lower. Owing to the great depth to water, drilling into limestone would in general be as futile as drilling into the impervious igneous rocks.

Sulphur Spring Valley is itself several thousand feet above sea level and, as has been explained, it may be losing large quantities of water by leakage through the rock walls and floor. The copious quantities of water yielded by the mines at Bisbee and Tombstone suggest the possibility of heavy losses where the valley floor consists of limestone. On the other hand, the water in limestones of the mountain areas may to some extent pass through underground openings into the main body of ground water in the valley, as is suggested, for instance, by the fact that the water in the Lowell mine at Bisbee, although far beneath the surface, is several hundred feet above the water table in the central part of the valley.

TABULATED DATA.

The following table, prepared by F. C. Kelton, gives detailed information in regard to all the wells at which a bench mark was established. It states the location, owner or name, altitude of bench mark, altitude of the surface of the ground, depth of the water below bench mark, depth of the water below the surface, and the date when the measurements were made.

[1] Ransome, F. L., Bisbee folio (No. 112), Geol. Atlas U. S., U. S. Geol. Survey, 1904, p. 16.

Altitude of surface and depth to water at various wells and springs in Sulphur Spring Valley, Ariz.

[By F. C. Kelton.]

Owner or designation.	Location.		Altitude above sea level.		Depth to water.		Date when depth to water was measured. [b]
	Section.	Quarter.	Bench mark. [a]	Ground.	Below bench mark. [a]	Below ground.	
			Feet.	*Feet.*	*Feet.*	*Feet.*	
T. 11 S., R. 23 E.							
Miss Busbee	27	NW.	4,327.8	....	98.8	....	Oct. 29
—— Thurman	7	SW.	4,371.6	4,369.2	138.8	136.4	Oct. 30
T. 12 S., R. 23 E.							
—— Bittocks	10	SE.	4,291.1	4,287.0	....	....	Oct. 28
J. H. ranch (house well)	24	SE.	4,254.7	4,252.6	47.6	45.5	Oct. 26
J. W. L. Cook	1	SE.	4,281.4	4,281.0	63.0	63.0	Oct. 28
T. 12 S., R. 24 E.							
—— Bartsdale	8	NE.	4,290.4	4,289.6	77.4	76.6	Oct. 28
E. Cook	8	SW.	4,266.0	4,266.0	53.9	53.9	Oct. 26
P. C. Cunningham	34	SE.	4,225.0	4,224.4	34.9	34.3	Oct. 19
—— Lewis	20	NW.	4,254.5	4,254.5	47.1	47.1	Oct. 26
—— Marley	8	NW.	4,285.4	4,283.4	71.2	69.2	Oct. 28
C. O. Miller (windmill)	33	SE.	4,228.7	4,228.1	35.1	34.5	Oct. 24
—— ——	29	SE.	4,235.7	4,234.1	37.8	36.2	Oct. 26
T. 13 S., R. 23 E.							
—— Taylor	1	NW.	4,272.2	4,272.2	70.0	70.0	Oct. 22
T. 13 S., R. 24 E.							
J. E. Casner	8	NE.	4,218.6	4,218.6	29.6	29.6	Oct. 22
—— Comer	32	SE.	4,200.9	4,200.9	13.6	13.6	June 3
—— Doam	2	NE.	4,232.0	4,228.4	45.1	41.5	Oct. 19
—— Gardenhire	4	SE.	4,219.7	4,219.7	30.7	30.7	Oct. 22
Capt. Harris	34	SE.	....	4,180.4	....	13.8	Oct. 18
Miss Lipscomb	12	NE.	4,208.6	4,208.0	27.1	26.5	Oct. 27
D. N. Misenhimer	14	NW.	4,202.5	4,202.1	24.1	23.7	Oct. 19
G. M. Misenhimer	15	NE.	4,203.6	4,201.7	26.2	24.3	Oct. 19
—— Morgan	6	SW.	4,229.4	4,228.7	34.0	33.3	Oct. 22
—— Sands	10	NE.	4,211.2	4,211.1	28.0	27.9	Oct. 19
L. Stull	2	SE.	4,211.7	4,211.7	30.5	30.5	Oct. 27
—— Utterback	8	NW.	4,222.6	4,222.6	31.9	31.9	Oct. 22
J. Valentine	27	NE.	4,192.8	4,192.8	22.8	22.8	Oct. 18
T. 13 S., R. 25 E.							
—— Bazaurc	Willcox.		4,168.6	4,166.3	12.0	9.7	Oct. 18
—— Clark	4	SW.	4,257.7	4,256.7	66.2	65.2	Oct. 27
C. B. Currier	21	SE.	....	4,203.1	....	36.4	Nov. 28
C. A. Housel	5	SW.	4,244.6	4,244.0	55.1	54.5	Oct. 27
—— Martin	35	SE.	4,187.7	4,187.0	18.5	17.8	Nov. 27
R. L. Owen	32	SE.	4,182.6	4,182.0	28.0	27.4	Oct. 21
George Rapp	5	NW.	4,292.5	4,292.5	101.0	101.0	
Rufus Ricketts (west well)	27	NW.	4,198.1	4,198.1	30.4	30.4	Nov. 28
—— Wallace	32	SW.	4,166.5	4,166.5	12.0	12.0	Oct. 21
T. D. Ward	21	NW.	....	4,204.5	....	35.0	Nov. 28
T. 14 S., R. 24 E.							
—— Cox	5	SE.	4,192.7	4,190.3	19.5	17.1	Oct. 20
					19.2	16.8	June 3
Miss E. Crow	2	NE.	4,175.9	4,173.4	13.7	11.2	Oct. 18
					13.3	10.8	June 3
C. J. Drake	4	NE.	4,183.3	4,183.3	13.2	13.2	Oct. 20
—— Holman (pitcher pump)	30	SE.	4,184.3	4,182.8	....	....	Nov. 12
—— Holman (windmill)	30	SE.	4,183.7	4,183.7	17.9	17.9	Nov. 12
—— Kemp	5	NW.	4,209.9	4,208.9	20.0	19.0	Oct. 20
—— Marion	29	NW.	....	4,171.9	....	7.0	Nov. 12
—— McMillan	19	SE.	4,185.9	4,184.6	17.4	16.1	Nov. 12
O. T. ranch	5	NE.	4,192.2	4,192.2	11.4	11.4	Oct. 20
Riley Springs	29	NW.	....	4,163.8	....	00.0	Nov. 12
—— Severance	1	NE.	4,167.9	4,167.9	9.7	9.7	Oct. 18
					8.9	8.9	May 18
—— Taylor (6-inch casing)	5	SW.	4,238.9	4,237.7	46.5	45.3	Oct. 20
					46.4	45.2	June 3
—— Taylor (house well)	5	SW.	4,219.7	4,219.7	30.7	30.7	Oct. 20
—— ——	20	NW.	4,209.1	4,209.0	37.2	37.1	Nov. 26

[a] The bench mark is generally indicated by three notches cut into the wood of well curb or platform.
[b] Dates between October, 1910, and June, 1911.

Altitude of surface and depth to water at various wells and springs in Sulphur Spring Valley, Ariz.—Continued.

Owner or designation.	Location.		Altitude above sea level.		Depth to water.		Date when depth to water was measured.
	Section.	Quarter.	Bench mark.	Ground.	Below bench mark.	Below ground.	
T. 14 S., R. 25 E.			*Feet.*	*Feet.*	*Feet.*	*Feet.*	
E. Brummet	35	NE.	4,183.8	4,182.7	15.3	14.2	Nov. 14
—— Martin (house well)	1	NW.	4,210.3	4,210.0	40.3	40.0	Oct. 21
—— Martin (southeast well)	1	NW.	4,220.5	4,218.6	49.9	48.0	Oct. 21
C. T. McGlone (house well)	5	NW.	4,163.8	4,161.8	10.5	8.5	Oct. 31
C. T. McGlone (drilled well)	5	NW.	4,160.4	4,160.0	6.0	5.6	Oct. 31
K. Riggs	23	NE.	4,190.7	4,182.8	20.3	12.4	Nov. 11
J. E. Speaks	24	SE.	4,201.5	4,199.2	26.9	24.6	Nov. 13
—— Wiley (east windmill)	24	SE.	4,216.5	4,216.0	37.1	36.6	Nov. 13
T. 14 S., R. 26 E.							
W. M. Lafevers	31	SW.	4,212.7	4,212.0	29.5	28.8	Nov. 16
—— Roberts (southeast windmill)	17	SW.	4,281.0	4,281.0	92.4	92.4	Nov. 13
T. 15 S., R. 24 E.							
—— Brown (at ranch)	7	SE.	4,184.0	4,182.0	24.7	23.0	Nov. 29
—— Brown (near Cochise)	20	NW.	4,220.9	4,217.6	57.4	54.1	Dec. 1
C. A. Cornell	32	SE.	4,206.0	4,205.0	50.4	49.0	Dec. 2
Woodson Garrard (at Cochise)	20	SW.	4,216.8	4,216.8	51.2	51.2	Dec. 1
—— Hoesch	21	NW.	4,161.7	4,161.7	11.9	11.9	Dec. 1
W. T. Muse	30	SE.	4,276.5	4,276.0	94.7	94.2	Dec. 1
P. G. Rogers	21	NW.	4,152.4	4,151.0	7.0	5.6	Dec. 1
Do	21	NE.	....	4,139.3	....	0.0	Dec. 1
—— Sarver	18	SE.	....	4,249.3	....	77.0	Nov. 30
J. F. Titsch	30	NW.	4,300.3	4,298.0	120.3	118.0	Dec. 1
—— Utterback	18	NE.	4,215.4	4,215.4	53.1	53.1	Nov. 30
T. 15 S., R. 25 E.							
Th. Allaire	28	SE.	4,171.2	4,171.2	24.6	24.6	Nov. 19
F. Arzberger	24	SW.	4,200.5	4,206.0	27.2	33.0	Nov. 17
—— Bachman	14	SW.	4,182.6	4,182.6	25.3	25.3	Nov. 15
—— Evinger	33	NE.	4,183.8	4,183.8	32.5	32.5	Nov. 19
V. H. Fross (pumping plant)	21	SE.	4,164.9	4,164.9	14.0	14.0	Nov. 19
Hope ranch	12	NW.	4,182.9	4,182.9	16.9	16.9	Nov. 15
Fred Hulsey	22	NW.	4,160.7	4,160.0	9.3	8.6	Nov. 16
—— McArthur	24	NW.	4,197.3	4,197.3	29.3	29.3	Nov. 15
—— Miller (house well)	35	NE.	4,215.9	4,215.9	41.6	41.6	Nov. 18
W. G. Sipes	2	NE.	4,173.2	4,172.0	7.1	5.9	Nov. 15
202 ranch	1	NE.	4,199.2	4,199.0	22.2	22.0	Nov. 16
——	.....	......	....	....	21.2	21.0	May 26
T. 15 S., R. 26 E.							
—— Lance	19	NW.	4,229.9	4,249.9	49.1	49.1	Nov. 17
School section	16	SW.	4,319.3	4,319.0	118.8	118.5	Nov. 17
T. 16 S., R. 24 E.							
H. T. Fitch	26	NW.	4,194.1	4,194.1	23.6	23.6	Dec. 14
Woodson Garrard (north well)	4	NE.	4,195.0	4,195.0	39.4	39.4	Dec. 2
Frank Halderman (windmill)	14	NW.	4,164.3	4,164.0	8.6	8.3	Dec. 3
J. A. Jenkins	4	NW.	4,223.1	4,222.0	47.4	46.3	Dec. 2
F. R. Masterson	23	SE.	4,180.2	4,179.0	16.8	15.6	Dec. 3
—— McCall (sun motor)	25	NW.	4,167.3	4,166.0	7.3	6.0	Dec. 14
A. Schneebeli	20	NE.	4,270.4	4,270.4	86.2	86.2	Dec. 13
J. Schneebeli	17	SE.	4,277.7	4,277.7	92.0	92.0	Dec. 13
School section	16	SE.	4,218.1	4,218.0	52.4	52.3	Dec. 13
W. Whitener (house well)	3	SW.	4,190.6	4,189.0	35.7	34.1	Dec. 2
—— Wilcox (south well)	23	SE.	4,173.2	4,173.2	14.2	14.2	Dec. 14
—— Wilcox (north well)	23	NE.	....	4,163.8	....	6.1	Dec. 14
——	22	NE.	....	4,199.4	....	34.7	Dec. 13
T. 16 S., R. 25 E.							
Peter Adling	11	SE.	4,212.7	4,212.7	35.7	35.7	Nov. 18
W. S. Bemis	25	NW.	4,236.7	4,234.0	36.8	34.0	Dec. 6
E. S. Blanke	34	SW.	....	4,199.3	....	7.4	Dec. 5
—— Chaffic	21	SW.	4,187.0	4,185.0	20.4	18.0	Nov. 21
J. W. Dunkin	25	NE.	4,243.6	4,243.6	41.8	41.8	Dec. 6
John Grafe	34	NW.	4,197.6	4,198.8	3.2	4.4	Nov. 21
Sam Grafe	27	SW.	4,197.6	4,198.0	2.6	3.0	Nov. 21
W. C. Harper	20	SW.	4,169.8	4,169.0	15.0	14.2	Dec. 14
E. S. King	12	SW.	4,220.3	4,220.0	37.6	37.0	Nov. 20

Altitude of surface and depth to water at various wells and springs in Sulphur Spring Valley, Ariz.—Continued.

Owner or designation.	Location.		Altitude above sea level.		Depth to water.		Date when depth to water was measured.
	Section.	Quarter.	Bench mark.	Ground.	Below bench mark.	Below ground.	
T. 16 S., R. 25 E.—Continued.			*Feet.*	*Feet.*	*Feet.*	*Feet.*	
J. T. McDuff (pumping plant)	2	NE.	4,212.9	4,212.9	38.8	38.8	Nov. 18
H. A. Moore	4	NE.	4,187.2	4.185.2	38.9	36.9	Nov. 19
—— Rice	26	SE.	4,231.3	4,231.3	28.7	28.7	Dec. 6
J. A. Ross	10	SW.	4,188.7	4.187.2	31.0	29.5	Nov. 21
A. J. Rosser	31	NE.	4,201.6	4,198.6	27.6	24.6	Dec. 13
B. H. Rosser	31	NW.	4,200.6	4,200.6	26.2	26.2	Dec. 13
Sulphur Springs	33	NE.	....	4,194.6	....	00.0	Nov. 21
Bob Warren	16	NE.	4,189.7	4,189.7	29.0	29.0	Nov. 21
T. 16 S., R. 26 E.							
North well	35	NE.	4,343.6	4,34 .1	113.0	111.5	Dec. 9
T. 17 S., R. 24 E.							
G. H. Dean	15	NE.	....	4,383.1	....	194.4	Dec. 11
W. A. Schofield	24	NE.	4,370.1	4,367.6	180.7	178.2	Dec. 11
J. F. Wilson	1	NE.	4,236.8	4,234.3	53.4	50.9	Dec. 10
T. 17 S., R. 25 E.							
—— Armstrong	9	NW.	4,208.6	4,207.1	29.2	27.7	Dec. 10
Mrs. Crawford	13	SW.	4,231.3	4,230.0	40.4	39.1	Dec. 7
F. M. Gibbens	15	NE.	4,218.2	4,217.0	39.5	38.3	Dec. 7
H. M. Gibbens	13	SE.	4,249.6	4,247.0	52.8	50.2	Dec. 7
Wm. Gregory	7	SW.	4,239.2	4,238.0	57.8	56.6	Dec. 10
W. J. Hansen	7	NE.	4,236.6	4,235.6	55.6	54.6	Dec. 10
Harper & Williams	Pearce.		4,378.6	4,378.0	189.4	188.8	Dec. 16
W. A. Hobson (house well)	23	NE.	4,233.2	4,231.0	42.0	40.0	Dec. 7
W. A. Hobson (northwest well)	23	NE.	4,226.6	4,226.6	40.1	40.1	Dec. 7
Frank Hughes	10	NW.	4,204.5	4,202.0	22.2	19.7	Dec. 5
—— Lacey (pumping plant)	5	SE.	4,201.5	4,201.5	24.2	24.2	Dee. 10
Dr. T. C. Lawson	2	SW.	4,215.4	4,215.0	19.3	18.9	Dec. 6
—— McBarnes	1	NW.	4,230.3	4,230.0	26.9	26.6	Dec. 6
R. F. Meachem	8	SW.	4,224.7	4,223.0	44.6	43.0	Dec. 10
R. W. Parker	1	NE.	4,242.0	4,241.0	33.6	32.6	Dec. 9
Will Purcell	22	NE.	4,234.2	4,232.0	52.6	50.4	Dec. 7
N. Siggins (northeast well)	23	SE.	....	4,238.6	....	46.6	Dec. 8
E. Webb	23	NW.	4,241.6	4,241.0	57.8	57.2	Dec. 8
H. E. Wright	4	NE.	....	4,192.2	....	10.4	Dec. 5
A. H. Young	2	SE.	4,229.5	4,228.0	27.0	25.5	Dec. 6
——	9	NE.	4,203.7	4,201.0	22.2	19.5	Dec. 5
T. 17 S., R. 26 E.							
—— Becker	19	SW.	4,243.3	4,243.3	42.4	42.4	Dec. 15
New Wheel	30	NW.	4,249.2	4,249.0	39.1	38.9	Dec. 19
A. M. Pinkerton	30	NE.	4,250.0	4,250.0	39.5	39.5	Dec. 15
West well	34	SW.	4,305.6	4,305.0	52.6	52.0	Dec. 16
T. 17 S., R. 27 E.							
C. M. Allen	19	NE.	4,378.7	4,378.7	116.0	116.0	Dec. 19
A. E. Rhodes	30	SW.	4,354.4	4,354.4	84.0	84.0	Dec. 19
T. 18 S., R. 25 E.							
Rosamond Herd	25	SE.	4,360.1	4,360.1	170.0	170.0	Jan. 28
J. V. Lambdin	24	NW.	4,351.3	4,352.6	159.8	161.1	Jan. 25
F. A. Sharkey	27	SW.	4,497.6	4,497.0	309.8	309.2	Jan. 28
T. 18 S., R. 26 E.							
J. A. Bigelow	33	NE.	4,263.1	4,261.6	67.7	66.2	Jan. 25
S. F. Burnett	32	SE.	4,270.7	4,269.0	80.0	78.3	Jan. 28
M. L. Frisbee	2	NE.	4,333.1	4,331.1	71.1	69.1	Dec. 19
Chas. Knapp	34	SW.	4,262.3	4,257.8	66.8	62.3	Jan. 23
J. V. Lambdin	20	NE.	4,271.3	4,271.3	74.2	74.2	Jan. 25
J. Neatherlin	35	SW.	4,271.9	4,271.9	73.1	73.1	Dec. 23
T. G. Owen	33	SW.	4,250.2	4,248.6	58.6	57.0	Jan. 24
H. C. Ray	28	NE.	4,272.2	4,268.0	72.9	68.7	Jan. 25
W. L. Shearer	1	NE.	4,355.9	4,354.3	85.8	84.2	Dec. 17
Southwest well	24	SW.	4,337.5	4,337.0	127.2	126.7	Dec. 22
E. C. Stevens	22	NW.	4,277.1	4,274.1	74.2	71.2	Jan. 25
C. G. Suggs	26	SE.	4,305.2	4,302.7	98.3	95.8	Dec. 22

Altitude of surface and depth to water at various wells and springs in Sulphur Spring Valley, Ariz.—Continued.

Owner or designation.	Location.		Altitude above sea level.		Depth to water.		Date when depth to water was measured.
	Section.	Quarter.	Bench mark.	Ground.	Below bench mark.	Below ground.	
T. 18 S., R. 27 E.			*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Wm. Dodd	2	NE.	4,558.7	4,557.7	199.4	198.4	Dec. 20
O. S. Pratt	6	NE.	4,383.6	4,380.0	104.4	100.8	Dec. 17
G. W. Waters	3	NE.	4,501.3	4,500.2	172.1	171.0	Dec. 20
T. 19 S., R. 26 E.							
M. L. Armstrong	28	SW.	4,186.9	4,186.6	25.2	24.9	Jan. 29
Dr. H. T. Bailey	8	NE.	4,238.4	4,236.4	53.4	51.4	Jan. 28
Mrs. Barrack	19	SE.	4,245.7	4,245.7	78.0	78.0	Jan. 27
Brophy windmill	9	SW.	4,222.1	4,222.1	39.8	39.8	Dec. 23
—— Craddock	3	SE.	4,255.3	4,255.3	66.1	66.1	Dec. 23
H. C. Dilman	4	NE.	4,251.2	4,250.2	58.2	57.8	Jan. 24
H. G. Lewis	20	NW.	4,206.3	4,206.3	33.0	33.0	Jan. 27
R. G. McBride	17	SE.	4,211.5	4,208.8	36.5	33.8	Jan. 27
—— Moore (stock well)	21	NW.	4,208.9	4,208.0	36.9	36.0	Jan. 27
Mrs. W. J. O'Brine	35	NE.	4,271.5	4,269.8	108.2	106.5	Feb. 2
W. C. Rice	30	NW.	4,267.1	4,267.0	104.3	104.2	Feb. 1
Roy Scheerer	29	SE.	4,188.2	4,186.5	25.8	24.1	Jan. 29
L. D. Shattuck	17	NW.	4,230.2	4,230.0	....	....	Jan. 27
B. Smith	1	NE.	4,325.3	4,325.0	118.9	118.6	Jan. 24
—— Tull	17	SW.	4,219.7	4,217.6	45.2	43.1	Jan. 27
J. Wilcox	29	NW.	4,200.5	4,200.0	34.6	34.1	Jan. 27
L. C. Woods	34	SW.	4,207.9	4,206.2	50.3	48.6	Jan. 31
T. 19 S., R. 27 E.							
Whitehead ranch	14	SW.	4,562.2	4,558.0	....	....	Jan. 26
	7	SE.	4,404.7	4,401.1	199.1	195.5	Jan. 26
T. 20 S., R. 26 E.							
C. M. Baldridge	13	SE.	4,194.1	4,192.5	52.4	50.8	Feb. 4
D. N. Cluff	2	NW.	4,236.3	4,231.6	80.7	76.0	Feb. 2
—— Coy	18	SW.	4,130.6	4,129.1	13.0	11.5	Feb. 3
M. A. Crawford	14	NE.	4,196.8	....	54.8	....	Feb. 2
P. A. Dilman	22	SE.	4,199.4	4,149.0	19.6	19.2	Feb. 4
D. Gibson (pumping plant)	17	NW.	4,139.2	4,139.2	11.4	11.4	Feb. 1
H. J. Hamilton (upper well)	31	NW.	4,112.7	4,110.0	17.9	15.2	Feb. 10
H. J. Hamilton (lower well)	31	NW.	4,104.3	4,104.1	9.2	9.0	Feb. 10
E. D. Harris	17	NE.	4,152.3	4,150.2	20.8	18.7	Feb. 1
J. H. Harris (house well)	4	SE.	4,191.6	4,188.9	44.2	41.5	Jan. 31
J. H. Harris (pumping plant)	4	SE.	4,189.2	4,189.2	42.6	42.6	Jan. 31
J. A. Higgins	9	SW.	4,156.2	4,155.8	23.0	22.6	Feb. 1
L. T. Jewell	9	SW.	4,167.4	4,165.1	30.4	28.1	Feb. 1
G. M. Kelley	24	SW.	4,180.5	4,177.7	43.8	41.0	Feb. 4
D. L. Martin	34	NE.	4,140.9	4,138.8	21.5	19.4	Feb. 6
Geo. Morteson	13	NE.	4,214.3	4,211.3	68.0	65.0	Feb. 4
M. Patterson	25	NW.	4,166.5	4,165.8	34.0	33.3	Feb. 4
A. Pipher	34	SE.	4,134.8	4,133.0	25.6	23.8	Feb. 6
W. H. Seaver, jr.	12	NW.	4,231.7	4,231.7	76.4	76.4	Feb. 2
J. Skinner	18	NW.	4,142.6	4,140.4	17.0	14.8	Feb. 1
Soldiers Hole	7	SE.	4,135.5	4,135.5	5.3	5.3	Feb. 1
J. A. Thomsen	12	SW.	4,214.9	4,211.2	65.7	62.0	Feb. 2
Tom Hill windmill	31	SW.	4,094.8	4,093.8	5.6	4.6	Feb. 10
R. M. Truitt	35	SE.	4,146.8	4,143.8	34.4	31.4	Feb. 6
G. I. Van Meter	21	NW.	4,130.9	4,130.9	9.9	9.9	Feb. 3
Webb schoolhouse	5	NE.	4,177.4	4,176.0	28.4	27.0	Jan. 31
T. 20 S., R. 27 E.							
T. H. B. Lovelady	7	SW.	4,239.4	4,239.4	85.0	85.0	Feb. 4
F. C. Myers	18	SW.	4,206.6	4,206.6	59.7	59.7	Feb. 4
Robt. Perrin	17	SW.	4,252.7	4,252.7	91.8	91.8	Feb. 4
T. 21 S., R. 26 E.							
Mrs. Beaumont	33	SE.	4,100.2	4,098.1	56.1	54.0	Feb. 7
John Burrows	34	SW.	4,108.4	4,107.3	62.4	61.3	Feb. 7
John Hornig	25	NW.	4,175.2	4,175.2	109.5	109.5	Feb. 13
Gus Johnson	31	NE.	4,067.4	4,065.2	23.5	21.3	Feb. 8
T. E. Latimer	1	NE.	4,171.9	4,169.0	59.3	56.4	Feb. 6
Miles McNeal	11	SE.	4,167.6	4,163.9	74.9	71.2	Feb. 13
Schoolhouse	32	SW.	4,061.0	4,061.0	21.1	21.1	Feb. 8
B. F. Silvey	31	NE.	4,069.6	4,065.8	26.3	22.5	Feb. 8
Lee Wyatt	33	NE.	4,098.1	4,095.6	50.5	48.0	Feb. 7
————	3	NW.	4,114.6	4,112.8	14.5	12.7	Feb. 10

Altitude of surface and depth to water at various wells and springs in Sulphur Spring Valley, Ariz.—Continued.

Owner or designation.	Location.		Altitude above sea level.		Depth to water.		Date when depth to water was measured.
	Section.	Quarter.	Bench mark.	Ground.	Below bench mark.	Below ground.	
T. 22 S., R. 25 E.			*Feet.*	*Feet.*	*Feet.*	*Feet.*	
J. M. Byrns	12	NE.	4,100.4	4,097.3	64.2	61.1	Feb. 11
R. B. Fulcher	12	SW.	4,113.2	4,113.0	74.0	73.8	Feb. 11
T. 22 S., R. 26 E.							
Isaac Bailey (house well)	7	NE.	4,077.9	4,076.1	44.4	42.6	Feb. 8
W. H. Dietzman	2	SE.	4,150.5	4,147.7	111.7	109.0	Feb. 7
Double Dobe schoolhouse	34	SW.	4,004.5	4,003.5	15.1	14.1	Feb. 14
J. P. Emery	4	NW.	4,083.1	4,082.6	44.2	43.7	Feb. 8
Mrs. M. Francis	6	NW.	4,084.6	4,084.3	46.3	46.0	Feb. 8
R. Humphrey	33	SW.	4,016.3	4,016.3	20.9	20.9	Feb. 15
Schultz windmill	8	NE.	4,051.1	4,051.1	21.7	21.7	Feb. 11
F. H. Spaulding	7	SW.	4,081.2	4,081.2	50.6	50.6	Feb. 11
——	13	NE.	4,130.6	4,130.6	107.1	107.1	Feb. 14
T. 22 S., R. 27 E.							
S. Feeney	30	SW.	4,075.8	4,075.8	89.8	84.8	Feb. 6
Wm. Wildman	31	SW.	4,056.0	4,053.8	77.3	75.1	Feb. 9
T. 23 S., R. 26 E.							
R. A. Campbell	2	NW.	3,999.2	3,997.4	21.6	19.8	Feb. 15
—— Clayburn	24	NE.	4,002.8	4,000.4	49.0	46.6	Feb. 22
F. C. Frusch	1	NW.	4,015.1	4,011.4	45.1	41.4	Feb. 14
J. T. Gardner	13	SW.	4,003.2	4,003.2	45.1	45.1	Feb. 22
J. F. Green	27	SE.	4,067.5	4,066.0	98.2	96.7	Feb. 20
O. F. Hicks	26	SE.	4,041.7	4,041.0	79.5	78.8	Feb. 20
J. C. Moffet	13	NW.	3,987.3	3,987.3	28.4	28.4	Feb. 22
N. W. Stevenson	5	NW.	4,042.9	4,042.9	42.5	42.5	Feb. 15
——	2	NE.	4,008.9	4,007.8	37.5	36.4	Feb. 14
T. 23 S., R. 27 E.							
H. J. Fox	11	NW.	4,093.6	4,092.6	139.7	138.7	Feb. 19
John Imsland	19	SW.	3,995.9	3,995.9	46.8	46.8	Feb. 20
T. A. Lagerfeldt	10	SW.	4,052.8	4,052.5	99.9	99.6	Feb. 19
C. A. Peckinpaugh	34	NE.	4,004.2	4,001.6	81.7	79.1	Feb. 22
Mrs. Pierce	35	SW.	3,985.2	3,982.3	64.7	61.8	Feb. 22
C. Ramsett	6	NW.	4,036.5	4,033.0	65.8	62.3	Feb. 9
G. H. Sharland	5	SW.	4,052.9	4,048.5	85.1	80.7	Feb. 9
J. Wellgehausen	18	SE.	3,987.0	3,987.0	34.0	34.0	Feb. 22
——	27	SW.	3,972.1	3,971.2	43.7	42.8	Feb. 23
——	28	SE.	3,957.6	3,954.6	28.1	25.1	Feb. 23
——	33	SE.	3,953.5	3,952.2	32.8	31.5	Feb. 23
T. 23 S., R. 28 E.							
Andrew Pallay	32	NE.	4,095.5	4,093.8	183.5	181.8	Feb. 21
T. 24 S., R. 26 E.							
C. B. Holden	12	NW.	4,058.7	4,057.7	100.1	99.1	Feb. 17
W. D. Pierce	2	NW.	4,080.5	4,080.5	113.6	113.6	Feb. 20
——	13	NW.	4,064.2	4,063.0	104.0	102.8	Feb. 17
T. 24 S., R. 27 E.							
A. H. Green	10	NW.	3,925.5	3,922.6	20.7	17.8	Feb. 23
C. A. Taylor	1	NW.	4,016.0	4,013.0	107.1	104.1	Feb. 22
——	3	SE.	3,928.4	3,925.0	30.4	27.0	Feb. 23
——	4	NE.	3,931.2	3,928.9	14.5	12.2	Feb. 23

ARTESIAN CONDITIONS.

By O. E. Meinzer.

Most of the flowing wells in both basins of the valley were drilled by ranchers long ago, and, according to a legend associated with practically all of them, they were found to flow strongly, but were plugged or in some other way obstructed by the owners through fear that a successful artesian well would attract settlers and break up the grazing monopoly. Concerning no well, however, was this legend verified.

THE NORTH BASIN.

FLOWING WELLS.

Flows have been struck in at least four wells in the north basin of Sulphur Spring Valley, but their yield is so small that they are almost valueless. Moreover, with possibly one exception, they are situated on low alkaline tracts where their water could not be used advantageously for irrigation.

Well at O. T. ranch.—A flowing well is situated 5 miles we t of Willcox, near the abandoned buildings of the old O. T. ranch, in the NE. ¼ sec. 5, T. 14 S., R. 24 E. (Pl. II in pocket). It is near the base of the slope and only a few feet above the very gently inclined plain that extends between the O. T. ranch and Willcox. The top of the well is 4,192 feet above sea level and about 60 feet above the barren flat. In a shallow dug well in the same locality the ground-water table is 11 feet below the surface, 4,181 feet above sea level, and about 50 feet above the barren flat. The flowing well is cased at the top with a heavy iron pipe about 7 inches in diameter. According to the best information, the history of the well is as follows: A flow was struck about 166 feet below the surface and the well was at first finished at this level. Later the flowing water was cased out and the drilling carried to 560 feet; but as no flow of consequence was found between 166 feet and 560 feet, the casing was drawn back and the water from 166 feet was again admitted. According to some reports, the original flow was stronger than the flow after the deep drilling had been done and the casing was drawn back. According to other reports, the flow was originally no stronger than it is at present. The water now discharges through an underground pipe into a reservoir that is used as a watering place for range cattle. The natural flow is adequate for this purpose except sometimes in the summer, when the supply may run short. A windmill, which was at one time erected over the well, is said to have drawn down the water to a level 6 feet below the surface. The analysis given on page 155 shows that the water is not highly mineralized, but contains a small amount of black alkali. It resembles the water in the shallow dug well at the same place, except that it contains a little more alkali.

Paul Roger's well.—A well that has a small natural flow and is said to be 40 feet deep is situated on the premises of Paul Roger, near the center of sec. 21, T. 15 S., R. 24 E., about a mile east of Cochise (Pl. II). This well is on low alkali ground, 4,137 feet above sea level, and only a few feet above the barren flat. It is in a locality of springs and water holes, and the ground-water table is practically at the surface.

Frank Halderman's well.—A flow was struck in a well on the premises of Frank Halderman, in the NW. ¼ sec. 14, T. 16 S., R. 24 E., about 1½ miles southwest of the barren flat and the same distance north of Servoss station (Pl. II). This well is at the foot of the ancient strand, on ground 4,164 feet above sea level, and about 30 feet above the barren flat. The ground-water table is about 10 feet below the surface. The well has a 6-inch iron casing at the top and extends to a depth of about 190 feet, where it is said to have entered a "dry" clay. The water overflows at the rate of a small fraction of a gallon a minute, and the length of time required for the casing to fill after water has been drawn out shows that the yield would be small if the well were pumped. The water was not analyzed, but does not appear to be highly mineralized.

E. Brummet's well.—The only flowing well on the east side of the flat is a 6-inch cased well on the premises of E. Brummet, in the NE. ¼ sec. 35, T. 14 S., R. 25 E. It is situated between the ancient strand and the barren flat, at a point where a seepage spring is said to have previously existed. The top of the well is about 25 feet below the strand and about 20 feet above the flat. Indefinite reports say that a light flow was struck at about 150 feet and a "dry" clay entered at 200 feet. This clay is said to have been penetrated by the drill to the depth of 513 feet, but to have yielded no water. A small amount of sulphureted water still flows from the well.

NONFLOWING DEEP WELLS IN THE NORTH BASIN.

Most of the wells in the north basin were sunk only short distances below the ground-water level, but a few besides the flowing wells were carried to sufficient depths to give some information in regard to artesian conditions. In nearly all the deeper wells the water from lower sources rises at least to the ground-water level and in several it rises notably higher.

The wells showing the most pressure were found southwest of the barren flat. The well of J. B. Cupp is situated near the southwest corner of the SE. ¼ sec. 1, T. 17 S., R. 24 E., about one-fourth mile west of the railroad that leads from Cochise to Pearce, on ground 4,264 feet above sea level, or 130 feet above the barren flat. The driller reports that this well is 125 feet deep; that the first water was struck at 70 feet and remained at that depth; that the second water was struck at 100 feet and rose within 40 feet of the surface; and that the third water was struck at 124 feet and rose within 20 feet of the surface. When the well was visited, on October 20,1910, the depth to water was only 14 feet and a few weeks later it was 15 feet. The water appears, therefore, to be lifted by artesian pressure to about 4,250 feet above sea level—that is, to 115 feet above the barren flat and 55 feet above the normal water level in the locality of the well. It rises fully to the level of the railroad and therefore higher than the surface of the land east and northeast of the railroad.

The following wells in the same vicinity are more typical of the conditions that are usually found. All except the first were reported by G. H. Dean, the driller. In the well of W. M. Jenkins, in the NE. ¼ sec. 34, T. 16 S., R. 24 E., the first water was struck at 78 feet, the drilling was carried to 125 feet, and the water rose in the completed well to a level 73 feet below the surface. In the well of G. H. Dean, in the NE. ¼ sec. 15, T. 17 S., R. 24 E., water was struck at 200 feet, the drilling was carried to 224 feet, and the water rose within 196 feet of the surface. At the time of examination the water was found to stand 194 feet below the surface, or 4,189 feet above sea level. In the well of W. E. Ellison, in the SW. ¼ sec. 9, T. 17 S., R. 24 E., the first water was struck at 275 feet, a second water-bearing bed was struck at 298 feet, and the water in the completed well stands 258 feet below the surface. In the well of W. H. Scofield, near the southwest corner of the NE. ¼ sec. 24, T. 17 S., R. 24 E., water was struck at 194 feet, a second water-bearing bed was struck at 208 feet, and the water in the completed well stands 178 feet below the surface, or 4,190 feet above sea level.

The water in the 480-foot well of C. T. McGlone, at Willcox, was found by leveling to stand 4,154 feet above the sea, or about 20 feet above the barren flat, 3½ miles south of Willcox. It stands only 1 foot higher than the water in the shallow dug well on the same premises.

A well 674 feet deep was at one time drilled for the Southern Pacific Co. about 400 feet west of the depot at Cochise and 125 feet south of the track. According to Robert Benzie, superintendent of railroad water supplies, clay containing small rocks was found in the upper 60 feet, below which a cemented deposit consisting of clay, pebbles, and bowlders—some of them a foot in diameter—was penetrated. Water was struck at about 60 feet and was found at many lower horizons. Near the bottom the drill passed through 5 feet of yellow clay and discovered water that was too salty for use in locomotives. An unsuccessful attempt was made to shut out the salty water by plugging the hole 180 feet below the surface, after which the well was abandoned. The water rose within 40 feet of the surface and was lowered only 4 feet when pumped at the rate of 150 gallons a minute.

THE SOUTH BASIN.

FLOWING WELLS.

Between Soldiers Hole and Four Bar ranch.—Along Whitewater Draw from Soldiers Hole to Douglas, a distance of over 25 miles, the ground-water table is nearly at the surface, and the water from the deeper sources will everywhere rise within a few feet of the top of drilled wells. Several flows have been struck between Soldiers Hole and the Four Bar ranch, but the information obtained in regard to most of them is indefinite and conflicting.

Soldiers Hole is situated in the SE. ¼ sec. 7, T. 20 S., R. 26 E., at the west margin of the southern alkali flat and at the base of a rather steep stream-built slope. The story is that a troop of United States soldiers crossing this part of the valley in the early days and finding themselves without water dug a hole here and discovered a good and adequate supply at the depth of 4 feet. In 1884, according to the report, the hole was sunk to a depth of 35 or 40 feet, and a flow was struck that rose 18 inches above the surface and supplied a watering trough. In 1888 or 1889 the well, it is said, ceased flowing, the loss of artesian pressure being attributed by the old settlers to an earthquake that occurred about that time. At present there is nothing but a small gully to identify the spot, which was formerly a well-known landmark.

A similar flowing well is said to have existed at one time a few rods south of Soldiers Hole, and still another to have been sunk about 1½ miles south. The arrangement at the watering place a mile north of the Four Bar ranch indicates that the well there once overflowed into the troughs, but it is at present pumped by a windmill.

One of the deepest holes in the valley was drilled on the Van Meter farm, in sec. 21, T. 20 S., R. 26 E., where the water level is about 10 feet below the surface. This well was not a success, but no reliable information was obtained in regard to it. According to current report the drilling was carried to the depth of about 1,050 feet. It is said that a flow was struck at about 450 feet, but that the water stopped flowing when the drill reached greater depth.

Wells at Douglas.—According to the records of the Copper Queen Co. flows were struck in two wells at the company's smelter west of Douglas. This smelter is at the axis of the valley a short distance north of the international boundary and is, therefore, on nearly the lowest ground in the valley. The flowing wells are near Whitewater Draw (Pl. II) where the surface altitude is about 3,890 feet above the sea, and are 316 and 1,095 feet deep; their sections are given in Plate IX (p. 52). In the 316-foot well the first flow was struck in the bed of clay and gravel lying 146 to 187 feet below the surface;

when 191 feet was reached the natural flow amounted to about 25 gallons a minute. In the 1,095-foot well the natural flow was about 75 gallons a minute at a depth of 396 feet and about 150 gallons at 434 feet. The strata at greater depths contributed little water, however, and the supply was shut off entirely when the casing was driven into the clay to 958 feet. The water in these two wells was not under much pressure and rose little if any higher than the water in the other smelter wells, which were drilled on slightly higher ground and in which the water stands about 10 feet below the surface.

NONFLOWING DEEP WELLS IN THE SOUTH BASIN.

A number of rather deep wells have been drilled in the vicinity of Douglas, but they are all on higher ground than the Copper Queen wells, and none of them flow. The deepest of the nonflowing wells at the Copper Queen smelter is 559 feet deep and has a normal water level about 9 feet below the surface, or about 3,900 feet above sea level. The well at the Calumet & Arizona smelter, a short distance west of Whitewater Draw, is 296 feet deep and its water level is 37 feet below the surface. In the city well west of Whitewater Draw, which is reported to be 287 feet deep, the water stands 27 feet below the surface, or about 5 feet below the level of the stream channel. In the drilled city well on the east side of the draw the water stands 17 feet below the surface. In the 884-foot drilled well at the old Douglas waterworks the depth to water is reported to be about 120 feet or practically the same as in the shallow wells at the same place. During 1910 and 1911 a test well was being sunk at the county hospital in the NW. ¼ sec. 3, T. 24 S., R. 27 E., on the flood plain of Whitewater Draw, where the depth to water is 10 feet. In the abandoned hole, 325 feet deep, the water stood considerably below the 10-foot level, and in the second hole no new supply had been struck when the drilling had been carried to 510 feet. (See Pl. IX, p. 52.)

A well 314 feet deep was drilled in 1910 on the premises of S. J. Robb, in the NE. ¼ sec. 21, T. 22 S., R. 26 E. The water rose within 29 feet of the surface, or about 9 feet higher than the water level in the shallow well at the same point. On the James Brophy ranch, at the southern margin of the same section, a hole was sunk to 510 feet, but only nonwater-bearing clayey deposits were found below 90 feet.

The railroad well at Kelton Junction is 650 feet deep and is lined with perforated casing to the bottom. The ground-water level is about 135 feet below the surface, and, according to F. O. Mackey, the driller, the water from the deep beds rises to approximately this level, indicating no essential increase in artesian pressure.

HIGH-LEVEL FLOWS.

Several of the very shallow wells that tap the waters lying above the main body of ground water overflow in wet seasons. The ciénega well, in sec. 25, T. 18 S., R. 27 E., and the Holdeman well, in the SW. ¼ sec. 17, T. 17 S., R. 27 E., are examples. These wells, of course, give no indication of the head of the deeper waters.

FLOWING WELLS IN ADJACENT BASINS.

SAN PEDRO VALLEY.[1]

Many flowing wells have been struck in San Pedro Valley. They are found in the vicinity of Benson, between Benson and a point about 11 miles above that city, and in an area nearer the head of the valley. The Southern Pacific Co. has two 10-inch wells at Benson, 707 and 808 feet deep, in which water from a depth of about 500 feet rose to the surface and overflowed at the rate of 42 gallons a minute. (See fig. 9, p. 61.) A 4-inch well, 590 feet deep, in sec. 27, T. 18 S., R. 21 E., is reported to flow about 80 gallons a minute, but the natural yield of most of the flowing wells is only a few gallons a minute, and only a small total area is irrigated with water from these wells. The well at the State school at Benson has a depth of 1,505 feet and is reported to be the deepest well in the valley, but owing to its high elevation its water level is 8 feet below the surface. All these wells apparently end in valley fill, but it is not possible to determine from the well logs what portion of this fill is ordinary stream deposit and what portion may consist of lake sediments.

SAN BERNARDINO VALLEY.

San Bernardino Valley consists in the main of stream-built slopes partly overlain by beds of lava, but along its axis a broad, flat-bottomed stream valley has been carved. Near the Mexican border this stream valley has been sunk practically to the ground-water level, and consequently springs issue from the valley sides, and flows are obtained by drilling into the deposits beneath the valley floor. Nine flowing wells have been drilled on Slaughter's ranch, some of them on the valley bottom and others on low terraces. They pass through valley fill interbedded with lava, and range from 340 to 675 feet in depth, flows having been struck in several beds below 200 feet. The water is warmer than the normal for this region, its temperature ranging between approximately 83° and 90° F. It is used for irrigation even in the winter season.

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[1] Information furnished by W. T. Lee, of the U. S. Geological Survey, and by F. O. Mackey, driller.

SAN SIMON VALLEY.

San Simon Valley lies in a great rock trough, and most of its surface consists of stream-built slopes that descend from the mountain borders toward the central axis. A stream valley carved along the axis descends toward the Gila with a grade of approximately 15 feet per mile. A well recently drilled at San Simon station is 850 feet deep and has a diameter of 10 inches at the top and 6 inches at the bottom. The drill first passed through 145 feet of clay, sand, and gravel; then through 430 feet of homogeneous dense blue clay or shale, and then through 275 feet of clay, caliche, and sand. (See fig. 8, p. 59.) Flows were struck in strata of sand, the highest of which lie immediately below the 430-foot clay bed. This well is situated near the depot, about 3,612 feet above the sea and about 60 feet above the ground-water level. It is at the base of the stream-built slope but near the brink of the upland that overlooks the axial draw or stream valley. (See fig. 24.) The water is said to overflow

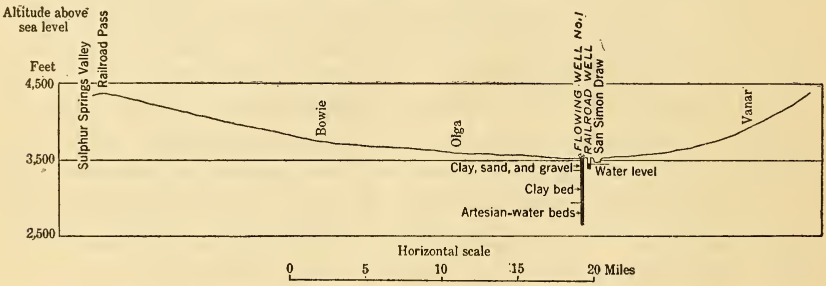

FIGURE 24.—Profile across San Simon Valley along railroad and sections of wells at San Simon station.

at the top of a pipe 24 feet above the surface. When the well was visited in December, 1910, it had been sunk to only 710 feet and the flow was small, but the yield of the completed well was estimated by the driller to be at least 150 gallons a minute. Other flowing wells have been drilled more recently.

Flows have been struck in a valley leading from the Pinaleno Mountains northeastward toward Gila River. About 15 flowing wells reported in this valley, in the southwestern part of T. 8 S., R., 26 E., and adjacent parts of the township next south, range in depth from 210 to 672 feet and in yield from 5 to 80 gallons a minute, with the exception of one well 350 feet deep, in the NW. $\frac{1}{4}$ sec. 32, which was reported to yield about 500 gallons a minute.

PROSPECTS IN SULPHUR SPRING VALLEY.

FLOWS FROM ROCK FORMATIONS.

To permit flowing wells the rock formations must have a certain definite arrangement and structure. With certain exceptions the following conditions are necessary: The rocks must include porous or creviced strata through which the water can pass, and these strata must be sufficiently exposed in the high areas to imbibe rainfall. The water-bearing strata must dip toward the valley, but their dip must be so gentle that they are still within reach of the drill in the lowest parts of the valley. Above the water-bearing strata there must be a bed of water-tight material which is so extensive, so continuous, and so free from faults and fractures that it will confine the water below, allowing it to accumulate under sufficient head to raise it to the surface in wells that puncture the confining bed in the low areas. These relations are shown in figure 25.

The mountains bordering Sulphur Spring Valley are composed in large part of igneous rocks that do not bear much water. The Pinaleno, Chiricahua, Perilla, Galiuro, and Winchester mountains consist chiefly of igneous rocks, and rocks of this class occur over large areas in all of the other ranges. Some water is carried in the crevices of hard limestones and quartzites that occur extensively in the Dos Cabezas, Swisshelm, Little Dragoon, and Mule mountains

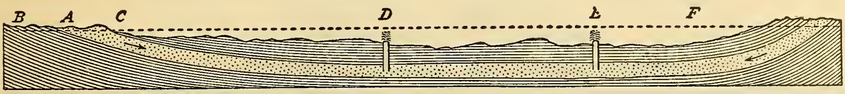

FIGURE 25.—Ideal section of an artesian basin in stratified rocks. *A*, Water-bearing stratum; *B*, *C*, confining beds; *D*, *E*, flowing wells; *F*, level to which the reservoir formed by the water-bearing bed is filled. After M. L. Fuller.

and to a less extent in other ranges, and water also exists in the more porous Cretaceous sandstones, found chiefly in the Mule Mountains.

The beds of limestone, quartzite, and sandstone dip at all angles and in many directions. Along the southwestern flank of the Dos Cabezas Range they dip sharply toward the valley; farther back in the mountains they stand almost vertical. In a large part of the Dragoon and Little Dragoon ranges the formations dip steeply toward the valley, but in some places they dip in the opposite direction. Moreover, the angle of dip changes radically within short distances and locally the strata are vertical or overturned. In the Swisshelm Mountains the stratified beds for the most part dip steeply away from the valley. In the Mule Mountains there is a great variety of dips, but the main body of the Cretaceous beds inclines toward the valley at a high angle. Nowhere were the rock strata seen to descend from the high lands toward the valley with a continuous gentle gradient such as would indicate artesian conditions.

The strata that might bear water are not generally covered with competent confining beds, and the rocks, both Paleozoic and Cretaceous, are so generally fractured and so extensively faulted that there is practically no hope that they anywhere form an artesian system. The unfavorable conditions will be more fully realized by comparing the actual structure (see fig. 26) in a portion of the Mule Mountains with the ideal artesian basin shown in figure 25. Of course the rocks are not everywhere so badly deformed as in the area shown in figure 26, yet this section is representative of the rock structure of the region.

The flowing wells in this valley and in San Pedro, San Bernardino, and San Simon valleys are all supplied from the valley fill. Drilling into the rock formations would generally be very expensive and there is no indication that it would anywhere result in finding a flow.

If bedrock of any kind is struck in a test well, the prospects are poor for obtaining a flow by drilling deeper, and if granite, schist, or porphyry is encountered the drilling should be stopped. However, the younger basaltic lava, frequently called mal pais, found in deep drilling near Douglas (see p. 68), is interbedded with the valley fill and is not an unfavorable indication. Indeed the flowing wells in San Bernardino Valley are supplied from beds below such lava.

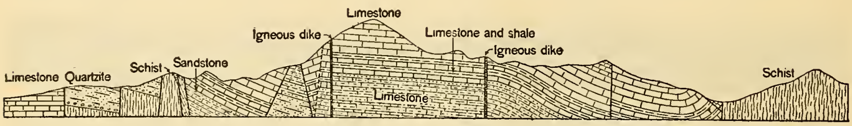

FIGURE 26.—Section of rocks near Bisbee, Ariz., showing faulting and absence of artesian structure. After F. L. Ransome, Bisbee folio (No. 112), Geol. Atlas U. S., U. S. Geol. Survey, 1904.

FLOWS FROM VALLEY FILL.

GENERAL FEATURES.

The sediments in Sulphur Spring Valley are saturated practically to the level of the lowest parts. New supplies of water are from time to time poured into the valley and sink into the gravelly upper parts of the stream-built slopes. The water beneath the slopes has accumulated till it stands above the level of the central flats and consequently moves slowly toward these low areas where it reappears at the surface and evaporates. In the upper parts of the slopes the valley fill consists largely of gravel, but farther down in the valley the gravel gives way to alternating beds of clay and sand. (See fig. 27.) Beneath the center of the valley these beds are nearly level, but beneath the slopes they curve upward. The gravel and sand are porous and therefore allow water to percolate through them, but the clay is so dense that it is relatively water-tight. The water which sinks into the gravel in the upper parts of the slopes and travels toward the central axis becomes confined below the layers of clay, and the water which accumulates back of it places it under pressure.

This pressure may become so great that when the clay layers are punctured by the drill the confined water will escape to the surface, forming flowing wells (fig. 27). If the clay layers were perfectly impervious the head of water would probably be great enough to produce flows with strong pressure over considerable areas, but in fact they allow so much water to escape that flowing wells have been struck in only a few specially favorable localities, and in most of these the pressure is slight.

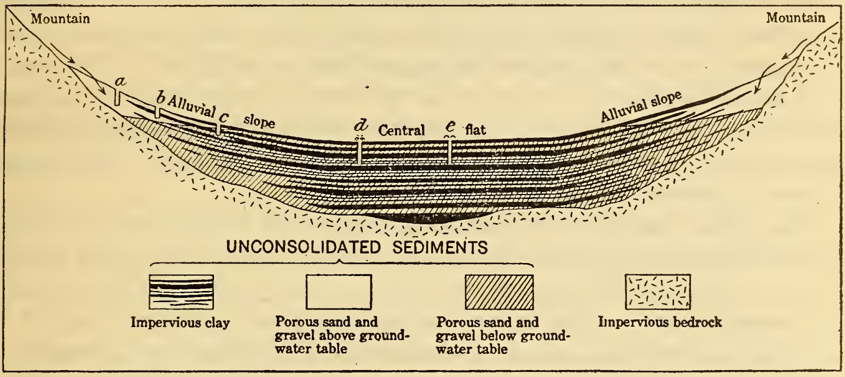

FIGURE 27.—Diagrammatic section showing artesian conditions in Sulphur Spring Valley. *a*, Dry hole which if sunk deeper would strike rock without finding water; *b*, dry hole which if sunk deeper would find water; *c*, shallow pump well; *d* and *e*, flowing wells.

SOUTH BASIN

In the south basin there is some prospect for flows along the axis of the valley from east of Kelton to the southern extremity of the region here considered. Flows are likely to be found on any part of the low flat in T. 20 S. and T. 21 S., and anywhere on the flood plain of Whitewater Draw below this flat, but the prospects are probably best on the part of the flat lying close to the steep west slope and in those sections of the draw in which ground water is nearest the surface. The flows thus far obtained have been struck relatively near the surface, and the data at hand indicate that the water in the strata reached in the deep wells is under little if any better head than the shallower water. In view of the unfavorable conditions developed by the deep wells already sunk in the south basin it is doubtful whether any more deep drilling for flowing wells would be justified in this part of the valley.

The flows that could probably be obtained in certain localities by sinking wells to moderate depths are likely to have so low a head that the yield will be small or the supply will be available only on alkali soil. Though some irrigation could perhaps be accomplished with flowing wells, the indications are that even with the utmost development of artesian supplies no important amount of irrigation from flowing wells is possible. The ground water must be recovered mainly by pumping.

NORTH BASIN.

The few flowing wells in the north basin are all supplied from comparatively shallow sources, their yield is small, and with possibly one exception they are located on low alkali soil. They are of no practical value for irrigation. Flows of this kind could probably be obtained over a considerable area surrounding the barren flat. In the Cupp well the water rises notably above the ground-water table and stands at a considerable elevation above the upper limit of alkali soil. This well and several other nonflowing wells with water under pressure, as also the flowing well at the O. T. ranch, give reason for the hope that flows of value may yet be struck in narrow tracts near the base of the slopes above the area of alkali soil.

The thick bed of dense homogeneous clay in which several of the deepest wells in the north basin end and which was penetrated to the depth of about 200 feet at Willcox (see p. 57), would, without doubt, be competent to confine water under considerable pressure, and if it is widely distributed and is underlain by water-bearing materials it may serve as the cover of an artesian system. Whether flowing wells of economic value can be obtained from strata below this clay can be determined only by drilling. The prospects are too uncertain to warrant deep drilling by any settler of ordinary means, but as the underground waters are of vital importance in the agricultural development of the region the community as a whole can afford to sink a well to a sufficient depth to make the test. Drilling should not be continued, however, after granite, porphyry, or other bedrock is reached. In order to have reasonable prospects of success the well should be put down on land where the depth to water is not very great, but in order to make the test of the most practical value it should be located outside of the zone of alkali soil.

Artesian prospects have not been as thoroughly explored in the north basin as in the south basin, but complete explorations will probably show that artesian supplies are at best only locally valuable and that pumping affords larger possibilities for irrigation

QUALITY OF GROUND WATERS.

By O. E. Meinzer.

SUBSTANCES DISSOLVED IN WATER.

The rocks which lie near the surface are exposed to weathering agencies that disintegrate and decompose them, thereby forming certain mineral compounds, some of which are more or less soluble. Water which falls as rain contains little or no dissolved mineral matter, but when it enters the ground and percolates through the earth it gradually takes into solution soluble substances with which it comes in contact, and consequently ground water always contains dissolved mineral matter. As long as this matter is in solution it is invisible, but when the water evaporates, as in a teakettle or steam boiler or on the surface of the shallow-water areas in Sulphur Spring Valley, the soluble matter is left behind and forms a crust or scale.

Ground waters differ greatly in the total amount of substances they contain in solution and also in the proportions of the different kinds of substances. Most of the mineral compounds dissolved by the water consist of two parts each: (1) A base, or positive radicle, and (2) an acid or negative radicle. When a compound is taken into solution its positive and negative radicles become partly dissociated from each other. Among the bases, or positive radicles, that occur most largely in ground waters are calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K); among the acid or negative radicles that occur most largely are the carbonate radicle (CO_3), the bicarbonate radicle (HCO_3), the sulphate radicle (SO_4), and chlorine (Cl).

Sodium and potassium are known as alkali bases, and calcium and magnesium as alkaline-earth bases. Most waters contain more calcium than magnesium and more sodium than potassium, but the relative amounts of the alkaline-earth bases and the alkali bases differ greatly. Since sodium and potassium act alike in many respects they are frequently estimated together by the analyst, and their combined mass is often reported as sodium. Water rich in calcium and magnesium is said to be hard and water containing only small amounts of these constituents is said to be soft.

When by normal evaporation the dissolved substances are thrown out of solution the negative radicles recombine with the positive radicles, again forming compounds. Some of the commonest substances thus precipitated are sodium chloride (common salt), sodium sulphate (Glauber's salt), sodium carbonate (soda, or black alkali), calcium sulphate (gypsum), calcium carbonate (limestone), magnesium sulphate (Epsom salt), and magnesium carbonate. Calcium sulphate and sodium carbonate are not likely to be precipitated from the same water.

METHOD OF INVESTIGATION.

One hundred and twenty samples of water were collected from typical wells and springs, most of which are in the valley, but a few of which are situated in the adjacent mountains. These samples were analyzed in the laboratories of the Arizona Agricultural Experiment Station, by Dr. W. H. Ross, of the station staff. The methods of analysis are those described for irrigating waters in Proceedings of the Association of Official Agricultural Chemists.[1] The

[1] Circ. Bur. Chemistry No. 52, U. S. Dept. Agr., 1910.

total dissolved solids and the chlorine, bicarbonate radicle, and carbonate radicle were determined in all samples, the sulphate radicle was determined in nearly all, and the calcium and magnesium were determined in 17 representative samples. Permanent hardness and black alkali were determined by the modification of Hehner's test given under the heading "Black alkali," in Circular 52 of the Bureau of Chemistry, United States Department of Agriculture. The permanent hardness is expressed as calcium sulphate ($CaSO_4$), and the black alkali as sodium carbonate (Na_2CO_3). The alkali bases (sodium and potassium) were not determined but their amounts can be approximately calculated. The analyses are given in the table on pages 154–159, the constituents being stated in parts per million. In addition to the analysis of samples in the laboratory a number of tests were made in the field, and several analyses were obtained from other sources.

AMOUNTS OF DISSOLVED SOLIDS.

TOTAL SOLIDS.

The smallest amount of dissolved solids found in any sample from Sulphur Spring Valley was 128 parts per million; the largest amount found in any sample was 7,154 parts per million, or more than 50 times as much. The water with only 128 parts was taken from the well at Hooker's ranch; the water with 7,154 parts, from the well on the school section 3 miles southeast of Willcox.

As shown in figure 28, waters with lowest mineralization are found near the north end of the valley; the nine samples taken north of the J. H. ranch have an average content of only 168 parts per million, and all but one have a content of less than 200 parts. Next to the waters from the north end of the valley rank those from the upper and middle portions of the slopes adjacent to the Chiricahua and Swisshelm mountains, four samples of which contained less than 200 parts per million and most of the others contained but little more than 200 parts. A few of the samples from the mountain regions contained only slight amounts of mineral matter, the water from the springs at Gabe Choate's, in Turkey Creek Canyon, having only 100 parts per million.

Thirteen samples of water contained more than 1,000 parts per million. Of these one was obtained east of Douglas, several along Whitewater Draw, several near the barren flat in the north basin, and the rest in an area that lies east of Willcox, between the barren flat and the north end of the Dos Cabezas Range. Only about one-fourth of the valley samples contained more than 500 parts per million, and these are found over comparatively small areas (fig. 28). Throughout most of the valley the ground waters are not highly mineralized.

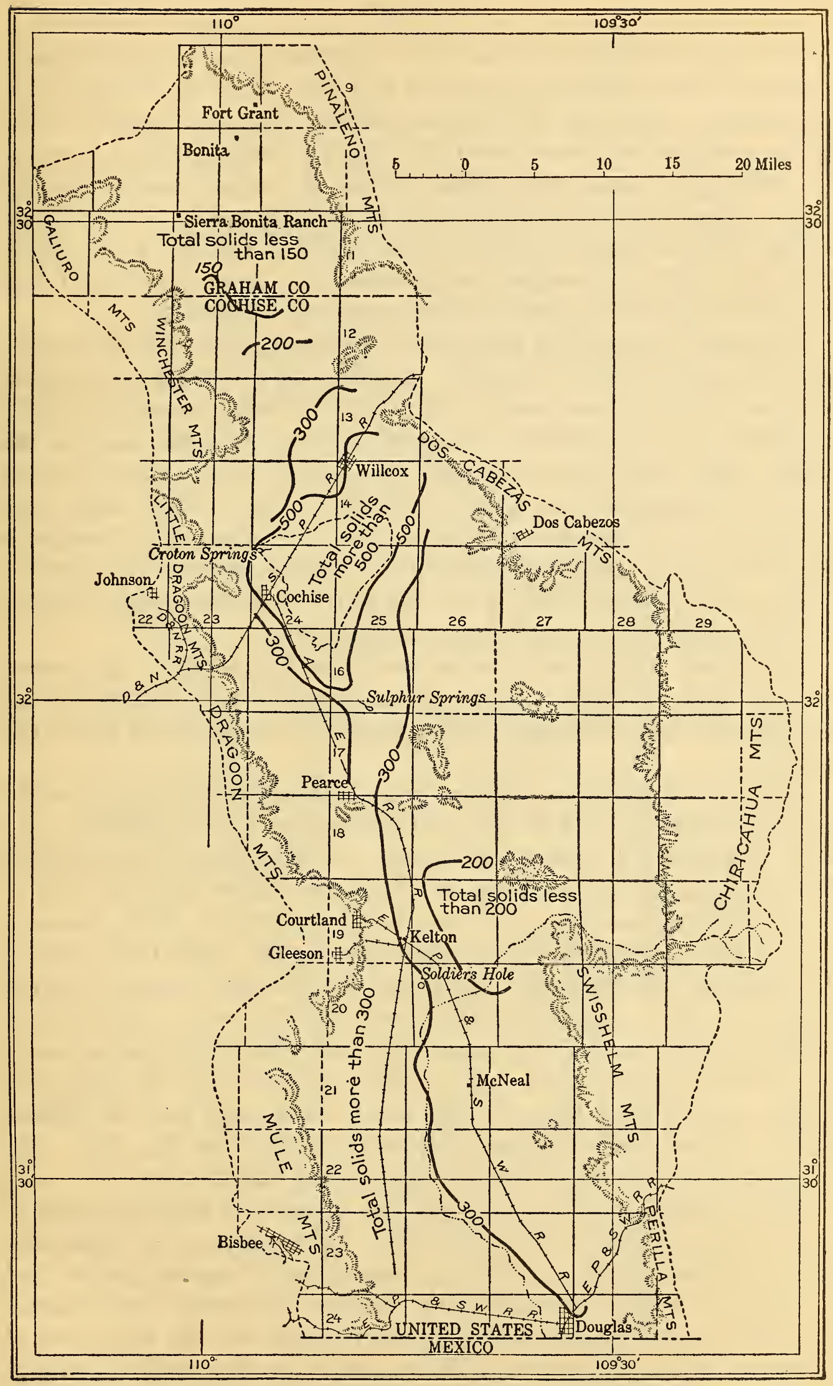

FIGURE 28.—Map of Sulphur Spring Valley, showing the approximate amounts, in parts per million, of dissolved solids in the ground waters.

CHLORINE.

For most waters the estimation of chlorine gives an approximate measure of the amount of common salt that would be deposited on evaporation, 100 parts of chlorine yielding about 165 parts of salt. In the samples that were tested the chlorine content ranged between 3.6 and 2,941 parts per million, which is proportionately nearly fifteen times as great a range as that of total solids. The sample having only 3.6 parts was taken from a well in the SE. ¼ sec. 28, T. 12 S., R. 24 E.; the sample having more than 2,941 parts was taken from the school section well 3 miles southeast of Willcox.

In general, the smallest amounts of chlorine are found in the waters near the north end of the valley. Sixteen out of a total of eighteen samples [1] from the area north of the Circle I ranch contained 10 parts per million or less, whereas among all the other samples taken in the valley only twenty-one contained 10 parts or less. Most of these twenty-one samples from the region south of the Circle I ranch were obtained on the slopes adjacent to the Chiricahua and Swisshelm mountains, but several were obtained in the area between the Circle I ranch and the barren flat, on the flat south of Soldiers Hole, and on the slope adjacent to the Dragoon Mountains.

The saltest waters occur in an area that lies north of the barren flat and east of Willcox, these being, with a single exception, the only waters found whose chlorine content exceeds 1,000 parts per million.

In the north basin the chlorine content tends to increase from the borders toward the alkali flat and the region east of Willcox. In some localities the transition appears to be gradual but in others it is remarkably abrupt. For example, the water from the well of O. H. Mayhew, near the center of sec. 11, T. 14 S., R. 25 E., contains only 11 parts per million of chlorine, whereas the water from some of the wells on the adjacent Craig farms is perceptibly saline, and the water from H. C. Martin's shallow well, a little over a mile distant, contains 1,785 parts of chlorine. The areas that yield saline water are few and small, water with more chlorine than 100 parts per million having been found in the north basin only east of Willcox and in several wells between Cochise and the flat (fig. 29). The 674-foot railroad well at Cochise also yielded saline water.

In the waters of the south basin the amount of chlorine tends in general to increase southward. The waters from the Swisshelm slope and the portions of the Chiricahua and Dragoon slopes that lie south of the divide apparently contain somewhat less chlorine than the waters from the Mule Mountain slope and the slope east of Douglas. Some of the waters that underlie the flat south of Soldiers

[1] In several of these samples the chlorine was determined by field tests.

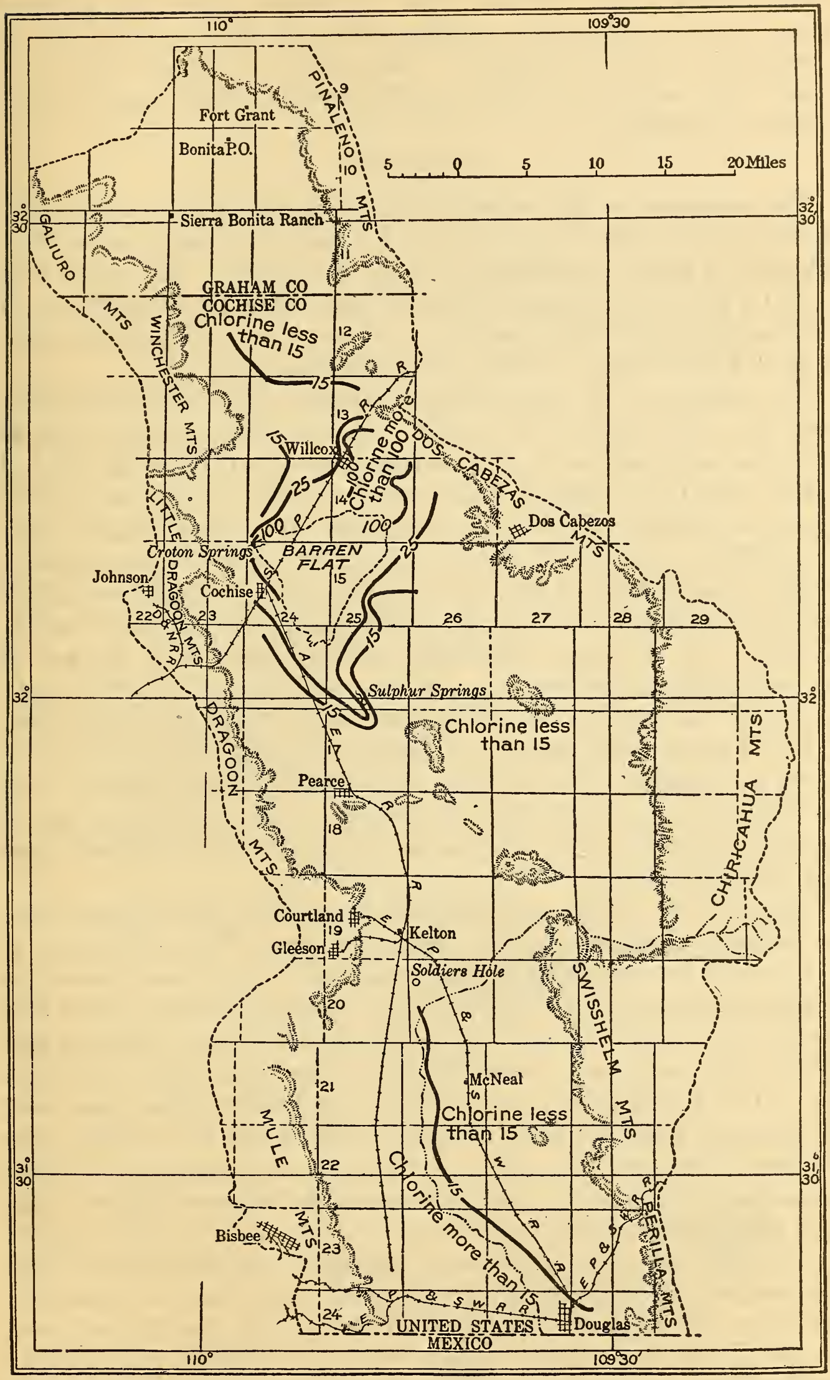

FIGURE 29.—Map of Sulphur Spring Valley, showing the approximate amounts, in parts per million, of chlorine in the ground waters.

Hole contain more chlorine than the waters below the adjacent slopes, but in most of the samples from this shallow-water district the chlorine content was small. The most saline waters found in the south basin come from wells along Whitewater Draw near the international boundary.

SULPHATES.

The amounts of the sulphate radicle found in the samples collected in the valley range between 1.4 and 1,315 parts per million, which is a range comparable to that of chlorine. The water with only 1.4 parts was obtained from the well of Minnie K. McHerron, 1 mile north of the Circle I ranch; the water with 1,315 parts from the well of Frank Doan, 3 miles east of Douglas.

The sulphates, like the chlorides, occur in the smallest quantities near the north end of the valley. The thirteen samples obtained from the area northwest of a straight line drawn from the Circle I Hills to the O. T. ranch had an average sulphate content of only 6.3 parts per million, twelve of the samples having less than 10 parts per million. Among all the other samples in which the sulphate radicle was determined only three had less than 10 parts per million of this constituent. One of these three samples was taken from the well of R. E. Sampson, near Leslie Creek, another from the well at McNeal station, and another from the well at the so-called Snake windmill—all on the slope that extends from the Swisshelm Mountains.

Six of the samples tested had a sulphate content of more than 500 parts per million. Two of these were obtained from the area west of Willcox, one near the flat east of Cochise, one on the slope east of Douglas, and two along Whitewater Draw at points relatively near the Mexican border.

Except in the gypsiferous area east of Douglas the sulphates have a distribution approximately similar to that of the chlorides, as can be seen by comparing figures 29 and 30. In the north basin the sulphates increase in general from the borders toward an area that includes the alkali flat and the region east of Willcox, the area over which they occur in considerable quantities being small. (See fig. 30.) The water below the flat south of Soldiers Hole and near Whitewater Draw for some distance south of this flat contains only moderate amounts of sulphates, although in general it contains somewhat more than the waters beneath the adjacent slopes. Samples from several wells near the axis of the valley in the vicinity of Douglas contained much larger amounts. In the area of highly mineralized water east of Douglas the sulphates are unusually abundant, although the amount of chlorine in this water is not great. In the water from Frank Doan's well, for instance, the sulphate content is 1,315 parts per million, but the chlorine content is only 21 parts.

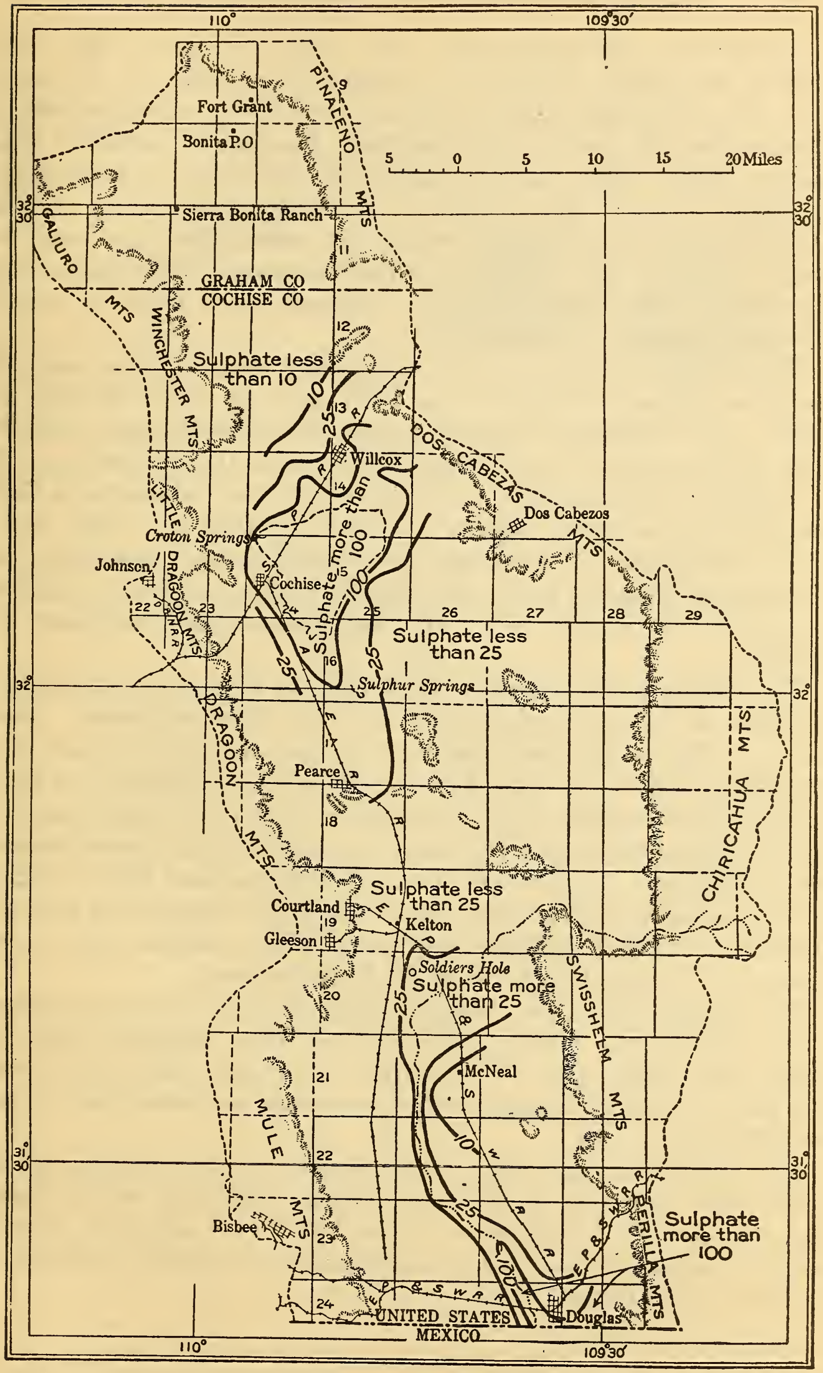

FIGURE 30.—Map of Sulphur Spring Valley, showing the approximate amounts, in parts per million, of the sulphate radicle in the ground waters.

CARBONATES AND BICARBONATES.

Carbonates and bicarbonates are readily converted into one another and should therefore be considered together. In the presence of an abundant supply of carbon dioxide the carbonate radicle changes into the more or less indefinite bicarbonate radicle. This change occurs when calcium carbonate (limestone), itself nearly insoluble, is taken into solution. If, on the other hand, carbon dioxide is removed from the water, as occurs when the water is heated or when lime is added, a reverse process takes place, the bicarbonate being converted into carbonate, as a result of which calcium carbonate is precipitated.

The smallest amount of the bicarbonate radicle found was 55 parts per million; the largest was 1,141 parts, or about 20 times as much. Less difference therefore exists in the bicarbonate content than in the content of total solids, and much less than in the amounts of sulphates and chlorides. In this respect the conditions in Sulphur Spring Valley are similar to those in other areas that have been investigated. The lowest bicarbonate content was found in the water at Hooker's ranch, and the highest in water from a shallow excavation on the farm of C. H. Cook, several miles southwest of Willcox.

The distribution of bicarbonates follows in a general way the distribution of the other constituents that have been considered. (See fig. 31.) The waters near the north end of the valley contain the smallest amounts and those underlying the slope adjoining the Chiricahua Mountains rank next. In the north basin the largest amounts are found near the barren flat and in the area of high mineralization east of Willcox. In the south basin the bicarbonates show a slight general increase toward the south, although the sample most heavily charged with this constituent was taken from a shallow well on the farm of L. J. Hamilton, north of the Four Bar ranch.

Five samples from the valley have less than 100 parts per million of the bicarbonate radicle, four of which were obtained near the north end. Only three samples from the entire valley have over 500 parts of the bicarbonate radicle and only seventeen have more than 300 parts.

The carbonate radicle (CO_3) was reported in nine samples, all of which were obtained in the north basin. The lines on the map (fig. 31) show the bicarbonate content but they would have practically the same position if they were taken to represent the carbon dioxide in both forms.

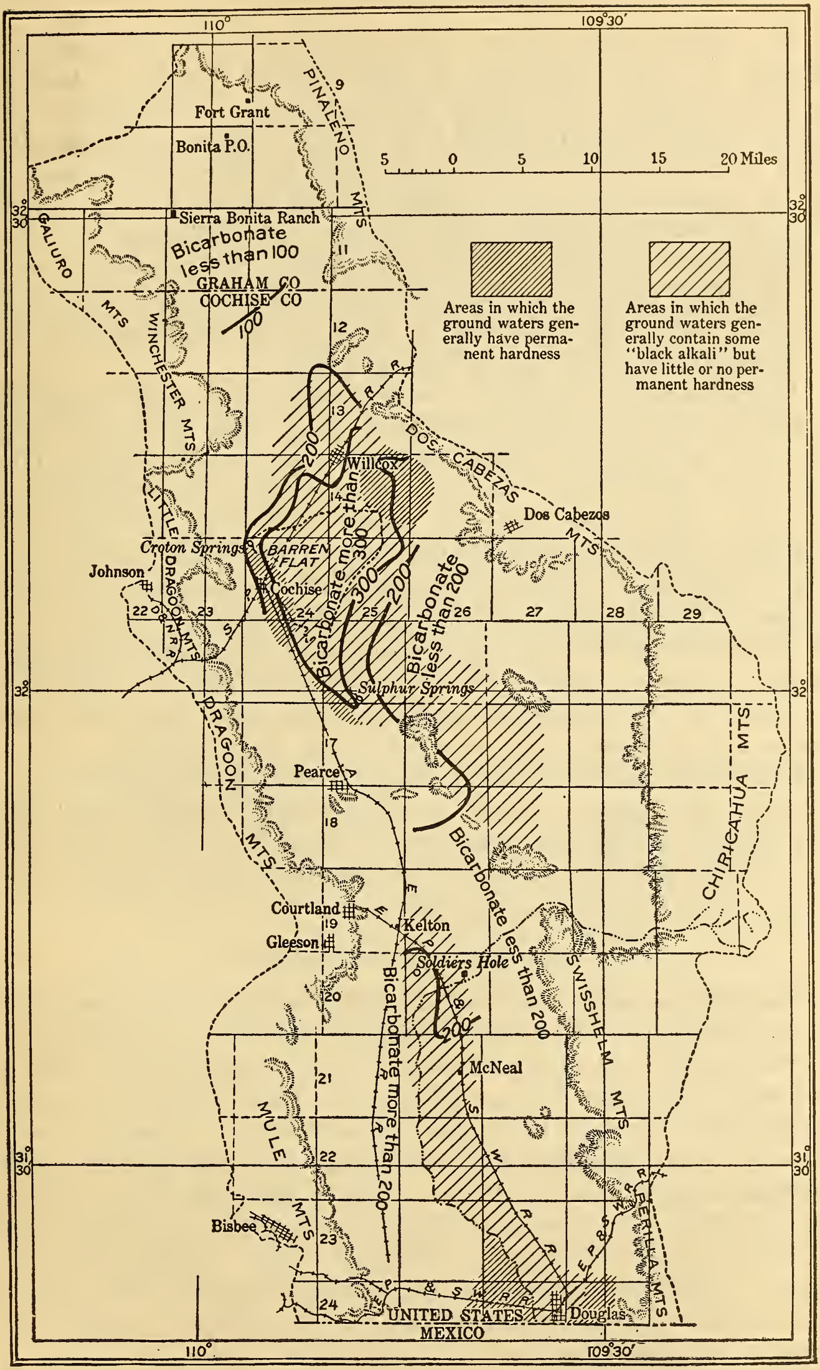

FIGURE 31.—Map of Sulphur Spring Valley, showing the approximate amount, in parts per million, of the bicarbonate radicle in the ground waters and the presence of permanent hardness or black alkali.

SODIUM AND POTASSIUM.

The alkali bases (sodium and potassium) were not determined directly but their abundance is approximately shown by Hehner's and the chlorine and sulphate determinations. A water with permanent hardness (as indicated in the column under permanent hardness, p. 154) contains enough of the alkali bases to combine with all of the chloride and sulphate radicles except that which is shown by Hehner's test as combined with calcium. A black-alkali water (as indicated in the column under black alkali, p. 154) contains enough of the alkali bases to combine with all of the chlorine and all of the sulphate radicle and also with as much of the bicarbonate or carbonate radicle as is shown by Hehner's test.

In distribution the alkali bases probably follow more closely the chlorine than any other constituent which has been considered. In some of the hard waters, such as those east of Willcox, however, the alkali bases are not as abundant proportionately as chlorine. The water from the shallow well of H. C. Martin, for instance, does not contain enough sodium and potassium to satisfy all the chlorine. This fact is shown in the analysis by the relative values of the permanent hardness and the sulphate content, and it is also shown by the fact that the residue on evaporation was hygroscopic, a property given by the chlorides of calcium and magnesium. In some of the black-alkali waters, on the other hand, the alkali bases are proportionately more abundant than chlorine. For instance, in the shallow water on the farm of C. H. Cook, southwest of Willcox, the chlorine content is not very high but the alkali bases are present in sufficient quantity to combine not only with all of the chlorine but also with all of the sulphate and carbonate and with nearly all of the abundant bicarbonate.

CALCIUM AND MAGNESIUM.

The alkaline-earth bases (calcium and magnesium) were determined in 17 samples and can be approximately estimated in the others.

The smallest quantities of calcium and magnesium are found in the pure waters near the north end of the valley and in the strongly black-alkali waters in the shallow-water districts. Among the samples that were examined for the alkaline-earth bases, the smallest calcium content was found in the shallow black-alkali water on the farm of C. H. Cook, southwest of Willcox, and the next to the smallest was found in the water at Hooker's ranch. Waters which contain a considerable amount of the carbonate radicle (CO_3), such as the shallow water on the Cook farm, are not likely to contain much calcium or magnesium.

The alkaline-earth bases are present in the greatest quantities in the gypseous waters east of Douglas and in the highly mineralized waters east of Willcox. In the water from Frank Doan's well there are 334 parts of calcium and 61 parts of magnesium, and these two constituents are sufficiently abundant to combine with all of the bicarbonate radicle and with a large amount of the sulphate radicle. The small quantities of calcium and magnesium in the water from the well at the Douglas waterworks indicate, however, that the area of hard waters east of Douglas is small.

It should be noted that the highly mineralized waters several miles east and southeast of Willcox are radically different from the highly mineralized waters in some parts of the low region surrounding the barren flat. Thus the water from the school-section well southeast of Willcox contains 268 parts of calcium and 135 parts of magnesium, and the water from the well of Mrs. A. L. Craig contains 168 parts of calcium and 68 parts of magnesium, whereas the shallow water on the farm of C. H. Cook contains only 9 parts of calcium and 3 parts of magnesium. The radical difference between these two classes of water is shown by Hehner's test.

A similar difference exists among the highly mineralized waters in the south basin, as can be seen by comparing the water from Frank Doan's well with that from the shallow well of L. J. Hamilton. The total solids are high in both of these waters, but the calcium and magnesium are high in one and low in the other.

SUMMARY.

The waters of the valley can be divided according to their mineral contents into the following groups:

Group 1: Waters that contain only small quantities of dissolved solids. These are found chiefly near the north end of the valley, the water from the well at Hooker's ranch being typical.

Group 2: Waters that contain moderate quantities of dissolved solids. They are found beneath the upper and middle portions of most of the stream-built slopes. Northwest of Willcox and on the Chiricahua and Swisshelm slopes they generally contain small amounts of black alkali, as, for example, the water from the West well. On the slopes adjacent to the Dos Cabezas, Little Dragoon, Dragoon, and Mule mountains they are likely to have some permanent hardness, as, for example, the water from the well at Pearce.

Group 3: Waters that contain appreciable quantities of black alkali and are therefore without permanent hardness. They contain relatively large amounts of sodium but only small or moderate amounts of calcium and magnesium. They are found in the vicinity of Willcox, in the area between Willcox and the barren flat, on the low plain extending southeastward from the flat, in other parts of the shallow-water tract of the north basin, on the lowest parts of the flat that extends southward from Soldiers Hole, and in certain localities along Whitewater Draw. The shallow water on the farm of C. H. Cook is an extreme example of this group.

Group 4: Waters that have great permanent hardness but yield only small amounts of common salt. Water of this type is found east of Douglas, but does not occur over an extensive area.

Group 5: Waters that are both hard and saline and are rich in all of the constituents here considered. Water of this type occurs chiefly in the area east and southeast of Willcox, but it was also found in the well of Paul Roger east of Cochise, in George Giragi's well about 5 miles northwest of Douglas, and in a shallow well in the valley of Whitewater Draw west of Douglas.

The division of the underground waters of the region into the five groups that have been given is of course rather arbitrary, but it is helpful in setting forth general differences of great importance. There are waters of intermediate composition, and no sharp geographic boundaries can be drawn for any of the groups. Likewise the maps shown in figures 28, 29, 30, and 31 indicate general differences in the composition of the ground waters, but do not take account of small local differences. Moreover, they are based on too small a number of analyses to make great refinement possible.

RELATION OF DISSOLVED SOLIDS TO DERIVATIVE ROCKS.

Ground waters found in bolson valleys obtain part of their mineral matter by contact with the rock formations before they leave the mountains and part from the valley fill through which they later percolate. Igneous rocks yield little soluble substance except as they decompose. On the other hand, limestones are slowly dissolved by water that contains carbon dioxide, and most sedimentary rocks include a certain amount of soluble matter that was either deposited when the sediments were laid down or was precipitated later by percolating water. No doubt the valley fill derived from sedimentary rocks likewise contains more soluble matter than that derived from igneous rocks.

The quantity of mineral matter in the ground waters of Sulphur Spring Valley has an obvious relation to the kind of rocks that occur in the surrounding mountains, water of slight mineral content being found near ranges of igneous rock and more heavily mineralized waters near ranges composed largely of limestone or other sedimentary beds. The portions of the Pinaleno, Galiuro, and Winchester mountains that drain into this valley consist almost entirely of igneous rocks and agglomerates derived from igneous rocks, and this fact evidently accounts for the small amount of mineral matter in the ground waters between these ranges. The Dos Cabezas, Little

Dragoon, and Dragoon mountains contain great masses of limestone, and the Little Dragoon Mountains contain calcareous conglomerate with limestone pebbles. Consequently the water beneath the slopes adjacent to these ranges (not including the low tracts of shallow water) contains distinctly larger quantities of mineral matter than are found in the northern water.

The portion of the Chiricahua Mountains that drains into this valley consists predominantly of igneous rocks, and accordingly the water beneath the extensive slope projected from these mountains ranks next to the northern water in its mineral purity. The Swisshelm Mountains contain considerable limestone, covered to a large extent by a thick mass of igneous rocks. The water beneath the adjacent slope contains more dissolved solids than the northern water but less than the average water beneath the Dos Cabezas, Little Dragoon, and Dragoon slopes. The Mule Mountains consist largely of sedimentary rocks, and this fact probably accounts for the somewhat larger mineral content of the water of the slope adjacent to these mountains than in the water of the Swisshelm slope, on the opposite side of the valley. So far as known the rock formations in the drainage basin of Sulphur Spring Valley contain no beds of gypsum, salt, or other readily soluble substance, and accordingly the ground waters taken as a whole contain far less dissolved matter than the waters in regions where such beds occur.

The kind of soluble substance derived from igneous rocks also differs from the kind derived from most sedimentary rocks. Igneous rocks contain considerable quantities of calcium, magnesium, sodium, and potassium, but only small quantities of chlorine and the sulphate radicle. Hence, when these rocks decompose the bases can combine to only a small extent with the chloride and sulphate radicles. To a greater extent they combine with the carbonate and bicarbonate radicles derived from the carbon dioxide of the atmosphere. Thus, sodium carbonate, as well as carbonates of calcium and magnesium, is produced, and the ground water in a region of igneous rocks is likely to be black-alkali water. Whenever in its later history the sodium carbonate encounters the sulphate or chloride of any weaker base a reaction is likely to take place whereby sodium sulphate or sodium chloride is formed.

The prevailing black-alkali ground waters of Sulphur Spring Valley are no doubt causally associated with the abundance of igneous rocks in the adjoining mountains. Some of the waters of the slopes adjacent to sedimentary rocks have permanent hardness, but most of those underlying the slopes adjacent to igneous rocks are of the black-alkali type. The three most northerly samples to which Hehner's test was applied have permanent hardness, but the values are small and are probably not to be regarded as very significant.

The hard water found over a small area east of Douglas is evidently related to the gypsum deposits in that locality. It differs from other waters in the valley in containing predominant quantities of calcium and the sulphate radicle, which are the two constituents of gypsum. The deposits of gypsum are small, and hence it is not surprising that their influence over the character of ground water does not reach far. The water nearest the deposits (in the NW. ¼ sec. 15) is strongly gypseous; the waters from the two wells near the north margin of section 4 are clearly of the same type, but their permanent hardness (gypsum content) is less than one-fourth as great; and the water from the old waterworks well at Douglas appears to be completely out of the sphere of gypsum influence, for it is reported to have no permanent hardness and to contain only 39 parts of calcium.

It is not known whether the high mineralization of the water east of Willcox is in any degree caused by formations in the adjacent Dos Cabezas Range that contain unusual amounts of soluble matter. No such formations were observed, but the range was not carefully examined.

RELATION OF DISSOLVED SOLIDS TO WATER LEVEL.

The differences in the composition of the ground waters are not due entirely to differences in the derivative rocks. In the north basin both surface and ground waters move toward the low central area. (Pl. II, in pocket). The surface waters deposit a large percentage of their load of undissolved sediments before they reach the low flat, and the ground waters carry almost no insoluble suspended matter; but both the surface waters and the ground waters that reach the low flat bring with them dissolved matter. Wherever ground water lies close to the surface it is drawn up by capillary action, the soil acting in the same manner as the wick in a lamp. Evaporation, therefore, takes place over the area in which the ground water is within reach of capillary action. When water evaporates it leaves its dissolved solids, and consequently the soluble products of weathering throughout the entire drainage area of the north basin tend to become concentrated within the relatively small, low tract in which the surface waters collect and in which the ground waters come near the surface.

The analyses in the table (pp. 154–159) and the maps based on them (figs. 28 to 31) show conclusively that concentration has taken place in the low shallow-water areas. They also show that in general the differences due to concentration are greater than those due to the character of the derivative rocks.

The soluble substances left behind by the evaporating water are deposited at or near the surface where evaporation takes place, but are to some extent washed down to the ground-water level by the water of rains or floods that enters the ground. Consequently the upper layer of ground water in the shallow-water districts is likely to be highly mineralized, and purer waters are found in many places by sinking to deeper horizons and casing out the first water. This condition is shown by the analyses of the two samples collected on the farm of C. H. Cook. The samples taken from the upper layer of ground water, only 7 feet below the surface, was highly mineralized; the sample from a cased well 42 feet deep was very much better. It will be noted that the two samples differed but little in their contents of calcium and magnesium. These two bases were no doubt precipitated as carbonates, thus forming compounds which are so difficultly soluble that they were not redissolved as were the alkali salts.

Data collected from soil borings and open wells indicate that in most soils of the shallow-water areas capillary action will lift water at least 5 feet above the water table, but that it will not generally lift it as much as 10 feet, except possibly in the clay of the barren flat. These data agree in general with conclusions reached by other observers. Although the mineralized waters are, with certain exceptions, found where the water table is near the surface, yet they are not limited to the areas over which capillarity is effective nor do they have a definite relation to any specific depth to water. Moreover, mineralization is not confined to the upper layer of water but may be found in deep-seated waters, as, for instance, in the saline water tapped by the railway well at Cochise.

The north basin probably had an interior drainage and an interior underground circulation during much of the time since the rock trough came into existence, and concentration of soluble substances no doubt took place in the shallow-water areas of the past. As the basin was gradually built up by the deposition of sediments the soluble substances were, as a rule, carried upward by capillary action and were reconcentrated near the surface of the shallow-water areas. It is conceivable, however, that certain accumulations of salt may have become buried and may still remain far below the present surface to impregnate the waters that come in contact with them. Owing to a shifting of the shallow-water areas waters thus impregnated may be struck in localities where the water table is at a considerable depth below the present surface and where there are no surface indications of alkali. Such an explanation would seem to account best for the mineralized water found east of Willcox and for the deep saline water at Cochise. Another reason why accumulations of soluble substance occur beyond the present limits of capillarity may possibly be found in the fact that in the past, when the ancient lake existed, the water table stood higher and the evaporating area was much larger than it is now.

In most of the area of mineralized water east of Willcox the ground water is at present much too far below the surface to be raised to the surface by capillarity, but there is evidence, aside from the quality of the water, that this area may once have belonged to the shallow-water belt. The northern arm of the Dos Cabezas Range is very low and narrow, and it did not furnish much sediment for the valley fill. For this reason it would be expected that the alkali flat would extend near the base of this range, which, however, is not the case. The area of mineralized water is at present covered for the most part with wind-borne deposits of comparatively recent origin. These could easily have been blown into a part of the shallow-water belt, thereby covering the saline accumulations to such a depth that they can not be carried to the surface by capillary processes. Against this explanation must be set the fact that the mineralization east of Willcox is somewhat different from that of most of the waters near the barren flat, although it is much the same as that found in the water from Roger's well east of Cochise.

Concentrating processes similar to those described for the north basin have also taken place and are still taking place in the south basin, and some highly mineralized waters exist in the southern tracts of shallow water. However, owing to the surface and underground drainage out of the south basin, the evaporating area is much smaller than that in the north basin and probably has been smaller in past epochs. The analyses seem to show that mineralized waters are found over a larger area in the north basin than in the south basin, and this difference may well be due to the fact that in the south basin a large portion of the soluble salts was carried off instead of being concentrated by evaporation.

RELATION OF DISSOLVED SOLIDS TO UNDERGROUND CIRCULATION.

Plate I (in pocket) shows that in the north basin the ground waters move from the borders toward the alkali flat, and that in the south basin they have a general southward movement. It may reasonably be supposed that as the water continues in its underground course it finds new supplies of soluble matter and consequently increases its mineralization. In the north basin the mineral content increases rather gradually from Hooker's ranch to the flat, and there is a more or less gradual increase down the other slopes, but it is not possible, with the fragmentary data at hand, to determine to what extent this increase is due to normal, progressive acquisition and to what extent it is due to concentrations remaining from past times, or to some other cause. In the south basin the general increase in mineralization toward the south no doubt results partly from differences in the derivative rocks, but it may in a measure be due to the gradual acquisition of soluble matter as the water moves southward.

RELATION OF DISSOLVED SOLIDS TO USES OF WATER.

DRINKING AND CULINARY USE.

The effects of specific quantities of mineral substances dissolved in water on the health of persons that drink the water are not well understood. The effects of the same water on different persons are widely different, and many of the supposed effects, both curative and injurious, are no doubt imaginary rather than real. Water from a spring or artesian well is generally in more popular favor than water of the same quality pumped from an ordinary well. It sometimes happens that virtually the same kind of water is in one community avoided as unfit to drink and in another is prized for its medicinal properties. The effect of any mineral ingredient is generally greater on a person unaccustomed to the water than on one who has used it for a long time. Moreover, a person may at first object to a certain water because of the taste given by its dissolved minerals, but the same person after drinking the water for some time may become unable to detect any taste in it and may even prefer it to less mineralized water.

The sense of taste is a valuable though not an infallible guide to the wholesomeness of water used for drinking. Distinctly poisonous ingredients, such as salts of arsenic, lead, or copper, might be present in small but dangerous quantities without being detected by the taste, and deadly typhoid germs may exist in what appears to be excellent water, but large quantities of most of the common mineral constituents, such as might be harmful to health, are perceptible to the taste and are obnoxious to one not accustomed to the water.

Sodium chloride, or common table salt, is of course not harmful in small quantities, but water yielding more than a few hundred parts per million is unpalatable. Four hundred parts per million is perceptible to the taste, but will not generally be noticed by one habitually using the water. The water from the well of Greer Craig, in the NE. ¼ sec. 11, T. 14 S., R. 25 E., which contains about 160 parts of chlorine (equivalent to about 260 parts of common salt), is regarded by the users as "good soft water." The water from the well of Stanley Craig, in the NE. ¼ sec. 10, in the same township, which contains about 280 parts of chlorine (equivalent to about 460 parts of common salt), is regarded as usable but "only fairly good." The waters from the two wells of H. C. Martin and from the well of Mrs. A. L. Craig, which contain, respectively, 1,225 parts, 1,785 parts, and 782 parts of chlorine (see table, p. 155), are all salty to the taste and are regarded as "bad." The water containing 1,225 parts of chlorine has, however, been used for drinking and cooking when no other supply was at hand. Water yielding about 1,500 parts per million of common salt constitutes the only supply for drinking and culinary purposes at the Utah mine, Fish Springs, Utah.[1] Although this water is decidedly salty to the taste, it is not known to be injurious to the health of those who use it.

Sodium sulphate, which with water of crystallization constitutes Glauber's salt, and magnesium sulphate, which with water of crystallization constitutes Epsom salt, are laxative, and waters yielding several hundred parts per million of these salts are prized by some persons for their medicinal properties. In Minnesota it was found that waters yielding as high as 1,000 parts of sodium sulphate were used for drinking and for cooking. In Iowa the public water supplies for several cities contain from 500 to more than 800 parts of the sulphate radicle, and these waters are used widely for drinking and cooking. A rough estimate of the amount of sodium sulphate that might be yielded by the waters whose analyses are given in this report can be obtained by subtracting the permanent hardness from one and one-half times the sulphate radicle (SO_4). This computation can be expressed by the following formula:

$$\text{Sodium sulphate} = 1.5\ (SO_4) - \text{permanent hardness.}$$

For waters without permanent hardness the equation becomes simply—

$$\text{Sodium sulphate} = 1.5\ (SO_4).$$

Calcium sulphate does not possess the same medicinal properties as sodium sulphate and magnesium sulphate. In the analyses the permanent hardness is all reported as calcium sulphate, but in fact it is due in part to magnesium sulphate.

Sodium carbonate is corrosive to animal tissues if present in considerable quantity. Sodium bicarbonate (baking soda) is not as injurious as sodium carbonate (washing soda), but it may be converted into the carbonate when, by boiling or some other process, carbon dioxide is removed. The well-known Apollinaris mineral water, which contains an equivalent of about 2,100 parts per million of sodium bicarbonate,[2] is used exclusively for drinking by some persons, apparently without harmful effects.

Calcium compounds in moderate amounts are probably not injurious to most persons, although they are known to have an effect on

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[1] Meinzer, O. E., Ground waters in Juab, Millard, and Iron counties, Utah: Water-Supply Paper U. S. Geol. Survey No. 277, 1911, p. 126.

[2] Anderson, Winslow, Mineral springs and health resorts of California, 1892, p. 322.

the blood pressure and are believed by some authorities to be instrumental in producing certain diseases.

The ground waters of the greater part of Sulphur Spring Valley are of good quality for drinking and culinary uses, at least in so far as the mineral constituents tested are concerned. Objectionable amounts of chlorine were found only in waters of the small area east of Willcox and in the water from a very few wells in other localities. In general the water in the shallow-water areas does not contain excessive quantities of this constituent. Waters containing objectionable amounts of the sulphates are also confined to small areas. A large proportion of the waters of the valley are so-called black-alkali waters, but most of these yield only small amounts of soda, and only a few of them in their natural state contain the normal carbonate.

Where the water is shallow and there are evidences of alkali at the surface, it is advisable to drill or bore to some depth below the water table and to insert casing, so that the upper layer of ground water will be excluded. In the area of mineralized waters east of Willcox and east of Douglas better drinking and culinary supplies could probably also be obtained by drilling deeper than the first water.

Disease germs are found only in waters that have been polluted. On farms and ranches safety can be attained by keeping privies, cesspools, and other sources of pollution at some distance from the wells. As the ground water generally moves in the direction of the slope of the surface, structures that might be sources of pollution should be placed on the down-slope side of the well. In cities and villages without waterworks and sewers it is difficult to prevent contamination, especially if the water is near the surface, but a certain amount of protection can be obtained by drilling to some depth and inserting tight casing. Where waterworks have been installed, as at Bisbee, Douglas, and Courtland, and in other communities in which the entire supply is derived from one source, as at Pearce, it is of course important to protect the source carefully.

TOILET AND LAUNDRY USE.

Soft water is water that lathers readily, and hard water is water that consumes much soap before it will form a lather. Calcium, magnesium, and certain other bases destroy the power of soap to produce a lather because they decompose it and form curdy compounds insoluble in water, but sodium and potassium do not have this undesirable quality. Therefore the hardness of water is approximately proportionate to the amounts of dissolved calcium and magnesium. For toilet and laundry uses it is desirable to have water that will lather readily and consequently water containing large amounts of calcium and magnesium is undesirable.

Boiling decreases the soap-consuming capacity of water by causing the precipitation of a part of the calcium and magnesium, the bicarbonate radicle being converted into the carbonate radicle and the latter combining with calcium and magnesium to form insoluble compounds.

Those portions of the calcium and magnesium that can not be removed by boiling are said to produce permanent hardness, and are expressed in the analyses as calcium sulphate.

Most of the waters of Sulphur Spring Valley are either soft or only moderately hard. More than two-thirds of the samples analyzed were of the black-alkali type, which, if not naturally soft, can be softened by boiling. The worst waters for washing are the permanently hard waters east of Willcox and east of Douglas. They can be softened by means of sodium carbonate or caustic soda but not by boiling.

BOILER USE.

When water is heated and concentrated in boilers, much of the dissolved substance is precipitated, forming scale and sludge, which diminish the heating power of the fuel and may eventually ruin the boilers. Silica and compounds of calcium, magnesium, iron, and aluminum are scale-forming materials; among these, calcium and magnesium are usually present in much the largest quantities. Generally the calcium occurs in the scale either as a carbonate or a sulphate and the magnesium as an oxide. Boiler scale varies in hardness with the composition of the water, the principal precipitates that make the scale hard being calcium sulphate and magnesium oxide. If water is boiled under atmospheric pressure in a preheater before being admitted into the boiler, soft scale is precipitated, but the hard-scale ingredients are left in solution. Much of the soft scale can be precipitated by treating the water with slaked lime and much of the hard scale by treating it with soda ash.

Foaming in boilers is the forming of bubbles that do not readily break, and hence are likely to carry water out with the steam, thus interfering with the proper action of the engine. Dissolved substances of all kinds probably increase the tendency to foam, but as sodium and potassium compounds are much more soluble than most of the other substances commonly found in water they remain in solution in the boiler water after most of the other substances have been precipitated, and therefore the tendency to foam is approximately proportionate to the amount of these two elements in the boiler feed.

Water that will corrode iron is, of course, deleterious wherever that metal is used. Under the high temperatures in boilers, magnesium, iron, and aluminum may be precipitated as hydrates, and the acid thus released may cause corrosion. The carbonate and bicarbonate radicles counteract this tendency, but the sulphate, and especially the chloride radicle, increase it.

Most of the ground water in Sulphur Spring Valley is of fairly good quality for use in boilers. The highly mineralized waters east of Willcox and the gypseous waters in the vicinity of Douglas will deposit so much hard scale that they are unfit for boiler use, but the waters in other parts of the valley will, as a rule, deposit only small or moderate amounts. The waters which, according to Hehner's test, are without permanent hardness will not deposit hard scale, and, as has been shown, these waters constitute the prevailing type in this valley. Foaming, especially in locomotive boilers, may be expected with the saline waters, such as are found east of Willcox and with the strong black-alkali waters, such as are found in certain localities in the shallow-water tracts, especially in the beds nearest the surface. Foaming is also likely to occur if gypseous waters, such as those east of Douglas, are softened with soda ash. The more typical waters of the valley will not cause much trouble by foaming. Some of the highly mineralized waters east of Willcox will prove corrosive because of their high content of both magnesium and chlorine.

IRRIGATION USE.

The mineral content of water affects its value for irrigation, which is one of the most important uses that will in the future be made of the water in Sulphur Spring Valley. This subject is discussed on pages 160–171.

ANALYSES.

The analyses in the following table were made by Dr. W. H. Ross, of the Arizona Agricultural Experiment Station.

Chemical analyses of water in Sulphur Spring Valley, 1910.

[Analyst, W. H. Ross. Chemical constituents given in parts per million.]

Owner or designation.	Location. Section.	Location. Quarter.	Type.	Depth.	Depth to water.	Altitude of water surface above sea level.	Total soluble solids.	Calcium (Ca).	Magnesium (Mg).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Permanent hardness [a] stated as $CaSO_4$.	Black alkali as stated as Na_2CO_3.	Date of collection.
T. 11 S., R. 23 E.				*Feet.*	*Feet.*	*Feet.*										
Hooker's ranch	6	NW	Dug	Shallow.	[b] 16		128	12	4.9	0	55	8.9	7.9	11	0	Dec. 16
	7	NE	do	do	30		228			0	152	8.2	12	0	0	Do.
Hookers draw, about 6 miles SSE. of Hooker's ranch.				106	[b] 90		150	22	6.4	0	104	3.6	6.7	0	0	Do.
School section	36	NE	Dug		[b] 105	[b] 4,225	130			0	75	3.4	5.5	5	0	Do.
T. 12 S., R. 23 E.																
	10	SE					192			0	94	9	21	33	0	Do.
	14	SE			49		186			0	122	6.9	10	0	0	Do.
T. 12 S., R. 24 E.																
W. M. Cook	7	NW			55	4,215	142			0	91	3.5	5.5	0	0	Do.
	8	NE			77	4,213	192			0	143	4.1	7.9	0	0	Do.
Mrs. B. G. Bangs	9	SE	Bored and cased		85	[b] 4,210	160			0	128	3.8	4.8	0	8	Dec. 15
R. C. Taylor	22	SE		75	62	[b] 4,200	212			0	158	13	9.7	0	4	Do.
Minnie K. McHerron	35	NE		76	55	4,193	206			0	207	1.4	10	0	8	Do.
T. 13 S., R. 24 E.																
Mrs. M. E. Wallace	1	SE	Dug	32	29	[b] 4,185	360			0	262	20	17	0	81	Dec. 9
W. M. Utterback	8	{NW NE}	do	33	31	[b] 4,191	284			0	165	8.1	29	0	0	Do.
J. L. Lely	13	SE	Bored	23	20	[b] 4,172	340			0	213	33	20	0	21	Do.
Joseph Adling	22	NW	Dug	Shallow.	22	4,177	294	42	11	0	195	7.9	21	0	17	Do.
W. B. Dickey	25	NE		do	14	[b] 4,165	268			0	195	11	6.7	0	42	Do.
T. J. Davis	33	NE	Dug and bored	26	18	[b] 4,174	374			0	229	27	22	0	72	Dec. 16
T. 13 S., R. 25 E.																
C. A. Housel	5	SW	Dug	56	55	4,190	270			0	146	31	16	0	51	Dec. 15
R. J. Stark	20	NE	Bored	62	25	4,170	350			0	210	44	26	0	64	Do.
	29	W½			10	[b] 4,163	774			0	268	185	121	0	140	Do.

R. W. Sprinkle	29	NE		20	15	b 4,163	1,148			18	528		130	0	394	Sept. 24
L. A. Wallace	East margin Willcox.			27	11	4,154	552			0	311		42	0	153	Sept. 27
	Main Street, Willcox.						382	28	5.8	0	268	21	19	0	127	Dec. 16
T. 14 S., R. 24 E.																
	1	NE	Dug	Shallow.	10	4,158	500			0	345	32	15	0	220	Dec. 10
H. B. Faulconer	2	NW	Diameter 8 inches, cased nearly to bottom.	22	11	b 4,163	310			0	195	18	17.6	0	38	Dec. 8
Mrs. Drake	4	NE		Shallow.	13	4,170	298			0	188	16	9.7	0	110	Do.
O. T. ranch	5	NE	Dug	25	11	4,181	230			0	148	13	9.8	0	42	Oct. 11
Do	5	NE	Drilled. Iron casing. 7 inches diameter. Flowing.	166		b 4,192	256			6	146	16	10	0	118	Do.
C. H. Cook	14	SW	Diameter 5 inches. Upper water cased out.	42			356	16	1	3	195	34	14	0	119	Dec. 12
Do	14	SW	Dug	Shallow.	7	b 4,152	1,912	9	3.1	111	1,141	279	53	0	1153	Do.
W. A. Smith	17	NE	do	25	17	4,170	270			6	137	19	12	0	5.9	Oct. 13
J. C. Page	22	NE	Cased nearly to bottom.	47	6	4,145	708			69	293	99	48	0	356	Oct. 12
T. 14 S., R. 25 E.																
H. C. Martin	1	NW		63	40	4,170	3,324			0	377	636	1225	147	0	Dec. 10
Do	1	Center		48	48	4,171	4,504			0	435		1785	348	0	Sept. 27
Mrs. A. L. Craig	3	SE		40	31	4,160	2,008	168	68	0	206	184	782	653	0	Oct. 26
Earnest Trappman	7	NW	Cased to shut out first water.	31	7	b 4,150	410			0	223	30	60	0	123	Dec. 10
O. H. Mayhew	11	SE	Bored	47 b	44	b 4,165	620			0	302	72	11	0	42	Oct. 26
Jesse Moore	13	SW	Dug		38	4,174	840			0	265	149	209	185	0	Dec. 13
School section	16	NE	do	14	10	b 4,150	7,154	268	135	0	389	1157	2941	881	0	Oct. 25
Do	18	NW	Bored	20	11	4,145	424			7	259	29	41	0	203	Dec. 10
Mr. MacDonald	26	NE		Shallow.			2,290			0	165	148	1109	805	0	Dec. 12
T. 14 S., R. 26 E.																
G. L. Moore	7	SE		100	61	b 4,180	446			0	267		73	33	0	Sept. 28
Charles Roberts	17	SW		150	92	b 4,189	378			0	203	35	67	76	0	Dec. 13
F. J. Ewing	31	NE		58	49	4,185	284			0	206	24	19	0	21	Dec. 11
Wm. Cooper	Dos Cabezos	E	Dug	35	30		530			0	274		64	33	0	Sept. 29
E. M. Quirk	do		do	20	16		730			0	284		129	152	0	Do.
T. 15 S., R. 22 E.																
Robert Mackay	South of Johnson		do		31	b 4,750	354			0	230	20	35	33	0	Oct. 15

a These tests were performed by the modification of Hehner's test described in Circular Bur. Soils No. 52, Dept. Agr., 1910.

b Approximate.

Chemical analyses of water in Sulphur Spring Valley, 1910—Continued.

Owner or designation.	Location.		Type.	Depth.	Depth to water.	Altitude of water surface above sea level.	Total soluble solids.	Calcium (Ca).	Magnesium (Mg).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Permanent hardness stated as $CaSO_4$.	Black alkali stated as Na_2CO_3.	Date of collection.
	Section.	Quarter.														
T. 15 S., R. 24 E.				*Feet.*	*Feet.*	*Feet.*										
Croton Springs	6					*a* 4,145	1,350			10	271	213	400	0	161	Oct. 13
Dr. J. B. Ellis	19	NW	Drilled	97	*a* 80	*a* 4,172	548	76	32	0	195	183	50	196	0	Oct. 14
Paul Roger	21	NW	Dug		5	4,143	1,800			0	299	673	205	243	0	Oct. 13
T. 15 S., R. 25 E.																
"202" ranch	1	NE	do	Shallow.	22	4,177	536			0	366	53	63	0	136	Dec. 12
Schoolhouse well	2	NE		15	7	4,165	410			0	275	34	47	0	38	Oct. 26
David Johnson	12	NW	Dug	18	17	4,166	380			0	317		16	0	102	Sept. 30
M. C. Cowen	13	NE		47	37	4,175	322			0	226	20	41	11	0	Dec. 13
V. H. Foss	21	SE	Dug		14	4,151	294			0	213	23	9.1	0	34	Do.
Fred Arzberger	24	SW		48	35	4,173	244			0	174	24	8.5	0	21	Do.
C. C. Tilliston	27	NE			24	*a* 4,135	304			0	244	21	7.3	0	42	Do.
Thomas Allaire	28	SE		52			786			0	296	262	43	5	0	Oct. 27
Do	28	SE		45	25	4,146	464			0	290	59	46	11	0	Do.
T. 15 S., R. 26 E.																
School section	16	SW	Dug		118	4,201	260			0	189	20	16	0	4	Oct. 26
T. 16 S., R. 24 E.																
J. A. Jenkins	4	NW	Drilled	95	46	4,176	318			0	229	49	17	38	0	Oct. 15
Frank Halderman	14	NW	Dug	Shallow.	8	4,156	626			0	387	142	45	0	51	Oct. 16
T. J. Weese	21	NE	Drilled; diameter, 6 inches.	77	69	*a* 4,173	242			0	226	12	11	0	17	Oct. 21
T. 16 S., R. 25 E.																
Peter Adling, jr	11	SE	Diameter, 12 inches	50	36	4,177	436			0	232		15	0	21	Oct. 1
W. C. Harper	20	SW	Bored	65*a*	15	4,155	702			43	291	102	20	0	310	Dec. 7
Jas. Callahan	21	NW		44	18	4,167	336			0	189	52	10	0	123	Oct. 27
A. J. Rosser	31	SE	Dug	Shallow.	25	4,174	286			0	288	52	18	27	0	Oct. 20
Sulphur Springs	33	NE					336	21	2	0	145	84	16	0	72	Oct. 28
T. 16 S., R. 26 E.																
North well	35		Drilled	226(?)	118	4,201	286			0	151		11	0	17	Oct. 2

T. 17 S., R. 24 E.																
E. H. Matney	32	NE	Spring in granite				128			0	32	17	12	27	0	Oct. 20
T. 17 S., R. 25 E.																
T. C. Lawson	3	SE	Bored; cased	33	17	a 4,192	420			0	281	38	9.7	0	182	Oct. 28
H. E. Wright	4	NE	Dug and bored	19	10	a 4,182	336			0	323		7.3	0	199	Oct. 11
Do	4	NE	Bored and cased to second water bed.	23	10	4,182	312	18	3	0	189	44	9.7	0	102	Do.
Fred Lacey	5	SW		27	22	a 4,175	286			0	154	75	12	54	0	Dec. 6
Howard Hughes	9	SE			27	a 4,180	472			0	320	52	11	0	199	Dec. 4
Harper & Williams	32	SE	Dug	240	189	4,189	311	51	11	0	213	55	15	11	0	Oct. 17
T. 17 S., R. 26 E.																
West well	34	SW	do	85	52	4,253	282			0	229	11	7.2	0	8	Do.
T. 17 S., R. 27 E.																
S. R. Holderman	17	SW	do	8	(b)	a 4,385	212			0	73		14	0	4	Oct. 3
C. M. Allen	19	NE	Drilled	146	116	4,263	196			0	133		8.5	0	8	Do.
T. 17 S., R. 28 E.																
J. T. Porch	14	SW	Dug	52	29		242			0	174		11	0	8	Oct. 6
T. 18 S., R. 26 E.																
Southwest wells	24		Drilled	222	127	4,210	248	43	6.3	0	180	14	12	0	17	Oct. 18
S. L. Burnett	32	SE	Dug		78	4,191	184			0	122	12	9.7	0	0	Do.
T. 18 S., R. 29 E.																
Gabe Choate	14	NE	Spring				100			0	67		4.8	27	0	Oct. 5
Courtland waterworks	About 2 miles west-northwest of Courtland.		Dug	33	a 15	a 4,800	348			0	171	73	18	60	0	Oct. 19
Railroad well	Kelton Junction		Drilled; cased to bottom.	650	135	a 4,165	260			0	180	12	7.3	0	76	Oct. 29
T. 20 S., R. 26 E.																
D. N. Cluff	2	NW	Dug		76	a 4,165	174			0	120	30	8.5	11	0	Nov. 16
Caliente	4	NW	do	Shallow.	27	4,149	242			0	163	16	13	0	55	Do.
E. A. Crawford	14	NW	do	51	34	a 4,140	214			0	183	31	9.7	0	8	Nov. 22
Windmill	17	W. ½	Bored	35	10	a 4,125	300			0	233		10	0	127	Nov. 19
Van Meter ranch (house well).	21	SW	Dug	Shallow.	8	a 4,125	234			0	210	29	7.9	0	30	Do.
L. J. Hamilton	31	NW	do	20	17	4,095	620			0	400	99	47	0	318	Nov. 18
Do	31	NW	do	Shallow.	6	a 4,095	1,268	26	7	0	918	98	80	0	670	Do.

a Approximate.

b Near surface.

Chemical analyses of water in Sulphur Spring Valley, 1910—Continued.

Owner or designation.	Location. Section.	Location. Quarter.	Type.	Depth.	Depth to water.	Altitude of water surface above sea level.	Total soluble solids.	Calcium (Ca).	Magnesium (Mg).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Permanent hardness stated as $CaSO_4$.	Black alkali stated as Na_2CO_3.	Date of collection.
T. 20 S., R. 26 E.—Con.																
				Feet.	*Feet.*	*Feet.*										
F. C. Moore	33	SW	Drilled; cased to shut out first water.	45	12	a 4,100	184	......	......	0	154	32	8.5	0	17	Nov. 17
A. Pipher	34	SE	Dug	Shallow.	24	4,109	258	......	......	0	235	31	9.1	0	59	Do.
T. 20 S., R. 27 E.																
R. Perrin	17	SW	do	a 95	92	4,109	244	......	......	0	183	71	16	0	13	Nov. 21
T. 21 S., R. 26 E.																
4 Bar ranch windmill	7	......	do	Shallow.	4	a 4,080	290	......	......	0	210	60	17	0	81	Nov. 17
McNeal station	14	SE	Drilled	136	63	a 4,083	248	......	......	0	221	7.1	9.7	0	13	Do.
Anthony Stukel	17	SW	Dug	22	16	a 4,064	352	......	......	0	247	22	17	0	144	Nov. 1
Snake windmill	28	NE	do	......	42	a 4,060	256	......	......	0	244	8	11	0	17	Nov. 15
John J. Sullivan	29	SE	do	33	19	4,050	312	......	......	0	268	27	24	0	17	Do.
T. 21 S., R. 27 E.																
R. E. Sampson	23	SE	Drilled	83	54	a 4,370	208	......	......	0	219	5.1	6.1	0	0	Nov. 30
T. 22 S., R. 26 E.																
Isaac Bailey	7	NE	......	......	43	4,033	344	......	......	0	267	11	46	16	0	Nov. 1
School section	16	SE	Drilled; diameter 6 inches.	92	38	a 4,015	246	......	......	0	195	14	9.1	0	21	Nov. 14
James Brophy	21	South margin.	Bored	72	19	a 4,010	536	......	......	0	230	92	102	0	25	Do.
Double adobe schoolhouse.	34	SW	Dug	15	14	3,989	494	......	......	0	299	32	64	0	144	Do.
T. 23 S., R. 25 E.																
Henry Forrest	7	......	Spring	......	......	......	362	......	......	0	358	9.6	10	0	13	Nov. 2

T. 23 S., R. 26 E.																
Copper Queen ranch	12		Dug	a 40	35	3,960	372			0	221	60	36	0	8	Nov. 12
T. 23 S., R. 27 E.																
C. A. Lamb	25	NE	do	56	50	a 3,950	306	48	15	0	259	16	13	0	30	Do.
George Giragi	29	N½		35	31	a 3,940	2,324			0	252	800	491	571	0	Nov. 11
J. S. Harper	34	SE	Dug	75	64	3,915	368			0	271	35	21	0	170	Do.
T. 24 S., R. 25 E.																
Christianson ranch	15	SE	do	60	20	a 4,300	310			0	300	13	11	11	0	Nov. 4
T. 24 S., R. 26 E.																
C. B. Holden	12	NW	do	103	99	3,959	335			0	238	22	42	54	0	Do.
T. 24 S., R. 27 E.																
A. J. Cook	9	W		71	49	3,930	384			0	253		54	33	0	Do.
City well of Douglas	East of Whitewater Draw, north of railroad.		Drilled; cased to 160 feet.	a 200	17	3,900	620			0	235	180	78	0	89	Nov. 10
El Paso & Southwestern R. R. Co.	East of Whitewater Draw, south of railroad.		Dug	Shallow.	10	a 3,898	2,390			0	351	610	654	54	0	Oct. 28
T. 24 S., R. 28 E.																
Wm. Maddox	4	Lot 1	do	40			492			0	172	212	12	196	0	Oct. 26
R. H. Davidson	4	Lot 2	Dug and drilled	280	200		536			0	245	178	15	201	0	Do.
Douglas city well	East part of city		do	265	a 125		302	39	14	0	241	30	13	0	38	Oct. 25
G. O. Bohannon	Douglas		Drilled; diameter 6 inches; cased 125 feet.	152	a 105		290			0	242	28	15	0	25	Do.
Frank Doan	15	NW	Drilled	90			2,202	334	61	0	197	1315	21	930	0	Oct. 26

a Approximate.

ALKALI.

By O. E. Meinzer.

CONCENTRATION IN SOIL.

Soils contain various soluble substances, which are dissolved by the moisture in the soil and are absorbed with the moisture by the plants. Some of the dissolved substances are essential to plant growth, but others are injurious if present in large quantities. Soils in arid regions are less thoroughly leached than the soils of humid regions; hence they generally contain greater quantities of certain soluble materials that are of value as plant foods and may also contain undesirable amounts of injurious salts.

In some places soluble substances have been so concentrated that they have become harmful. Such concentrations may be due in part to several processes, but have been chiefly brought about by the evaporation of standing surface waters and of the ground water of shallow-water tracts, whereby the water was removed, but its load of dissolved salts was kept near the surface. As this water evaporated new supplies reached the low tracts, and these in their turn were also quietly taken into the atmosphere and made to deposit their loads of dissolved salts near the surface. By this process, continued for a very long time, the soils of the shallow-water tracts of Sulphur Spring Valley have become burdened with the minerals which the waters of the valley carry in solution. As the valley filled with sediments the accumulated salts were in part buried, but in part they were raised by the ground waters that were soaking upward and were reconcentrated in the surface soil.

Calcium and magnesium carbonates and calcium sulphate, which are the most common alkaline-earth compounds, are less soluble than the alkali salts. As ground waters are as a rule very dilute solutions, calcium and magnesium may have formed a large percentage of the dissolved matter in the original supply and yet, being the first to be precipitated, may be relatively less abundant in the concentrated soil solutions. As the alkali salts (chiefly the chloride, sulphate, carbonate, and bicarbonate of sodium) are the principal soluble constituents of the soil and enter most largely into the soil solutions, the term alkali is commonly used to include all of the constituents that are dissolved by the soil moisture.

EFFECT ON PLANT LIFE.

The subject of alkali and its effect on plant life has been extensively studied and is discussed in the publications of the Bureau of Soils, United States Department of Agriculture, in several bulletins of the Arizona Agricultural Experiment Station,[1] and in many other publications.

It is therefore sufficient in this paper to state briefly a few general facts that are essential to an intelligent discussion of the alkali problem involved in irrigating with well water in Sulphur Spring Valley.

Plants differ in the amount of alkali that they can endure. The following summary statement on this subject was made by C. W. Dorsey, of the Bureau of Soils:[2]

Of the crops usually grown in the irrigated districts of the West, Kafir corn, sorghum, sugar beets, and barley are probably the most resistant to alkali * * *. Alfalfa is also quite resistant after a good stand has been secured, but in its younger stages it is a sensitive crop. Wheat and corn are usually classed as sensitive to alkali. Rye and oats undoubtedly are quite resistant, although not as thoroughly tested as some of the crops previously mentioned.

The percentage of alkali in the soil that can be endured by any given plant depends on the texture of the soil, the methods of cultivation, and other conditions. Since clay soil can hold more water than sandy soil, a given amount of alkali in a clay soil will be dissolved in more water than the same amount of alkali in a sandy soil, and, therefore, the soil solution is more dilute. On the other hand, the alkali is less easily washed out of clay soils and the hardening effect of black alkali is greater.

The different kinds of alkali differ greatly in their injurious effects on plants. Sodium carbonate is more injurious than sodium chloride, and sodium chloride is more injurious than sodium sulphate. Magnesium chloride and magnesium sulphate are also injurious.

The effects of sodium carbonate, or so-called black alkali, are described as follows by Forbes:[3]

Black alkali, though a white substance, is so named because, in contact with the vegetable matter of wet soil, it produces the dark appearance so well and unfavorably known to the irrigation farmer. It is the same in composition as common washing soda, which resembles the caustic principle of wood ashes extracted in common lye. * * *

The limit for black alkali in a soil varies with the kind of crop and the nature of the soil. Sugar beets, for instance, are more hardy than grains, and plants from arid countries usually endure more alkali than those from humid regions. Clay soils, more than sandy ones, are injured in tilth by black alkali. In general, 0.10 per cent of black alkali in the top 2 feet of soil will prove destructive to most crops.

The injurious effects of black alkali are brought about in various ways; it destroys the tilth of heavy soils, causing them to become cloddy and difficult to cultivate. Also, in presence of water, it dissolves the humus or vegetable mold in the soil and

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[1] Forbes, R. H., Salt River valley soils: Bull. Arizona Agr. Exp. Sta. No. 28, 1898; Timely hints for farmers—Black alkali, white alkali: Idem, No. 34, 1900; The river irrigating waters of Arizona, their character and effects: Idem, No. 44, 1902; Timely hints for farmers—The rise of the alkali: Idem No. 45, 1902.

[2] Alkali soils of the United States: Bull. Bur. Soils No. 35, U. S. Dept. Agr., 1906, p. 25.

[3] Forbes, R. H., Timely hints for farmers—Black alkali: Bull. Arizona Agr. Exp. Sta. No. 34, 1900.

thus allows of its removal. But the worst effect is its corrosive action directly upon the plant at or near the surface of the ground, where, especially in hot, dry weather after irrigation, the alkali, as an effect of evaporation, collects in the form of a crust.

Sodium chloride and sodium sulphate are commonly called white alkali. The amount of sodium chloride, or common salt, that most ordinary crops can endure is generally considered to be between 0.25 and 0.5 per cent of the total soil; and the amount of sodium sulphate is regarded as about 0.5 per cent or somewhat more. Soils that contain as much as 0.5 per cent of total alkali may cause trouble, and if the alkali is largely of the black type a much smaller per cent is likely to prove serious.

METHODS OF INVESTIGATION.

As the alkali of the soil is found chiefly in the shallow-water areas where pumping is a possibility, the problem of irrigation with ground water involves the whole alkali problem and demands consideration not only of the alkali in the irrigation water but also of the alkali already in the soil. It was not feasible in this investigation to obtain as full information on the alkali in the soil as was desired, but enough data were obtained to warrant general conclusions in regard to irrigation with ground water.

Samples of soil were taken at 93 points widely distributed over the areas that show alkali symptoms. With a few exceptions they were obtained by boring with a soil auger. Usually the boring was carried to a depth of 6 feet, but at some points it was stopped before this depth was reached, either by the presence of caliche or by some other obstruction; at a few points the boring was carried below 6 feet. Generally tests were made of the soil from the first foot, of the soil from the second foot, and of all the soil obtained below the second foot. A part of the samples were tested only for total soluble salts by means of the electric bridge, but the samples from 47 points were examined in the laboratory for total water-soluble salts (reported as total soluble solids), for chlorine (reported as sodium chloride), and by the modified Hehner's test for permanent hardness (reported as calcium sulphate) and black alkali (reported as sodium carbonate). The results of the analyses are given in the table (pp. 172–181) and those for the north basin are plotted on figure 32, the values shown being the average for the entire depth to which the boring was carried.

GEOGRAPHIC DISTRIBUTION.

Alkali is found in largest quantities in the clay of the barren flat of the north basin, but it is also found in the soils of a considerable area surrounding the flat (fig. 32). North of the barren flat alkali occurs in considerable quantities over a district that extends about to the north margin of township 14 but includes a belt extending some

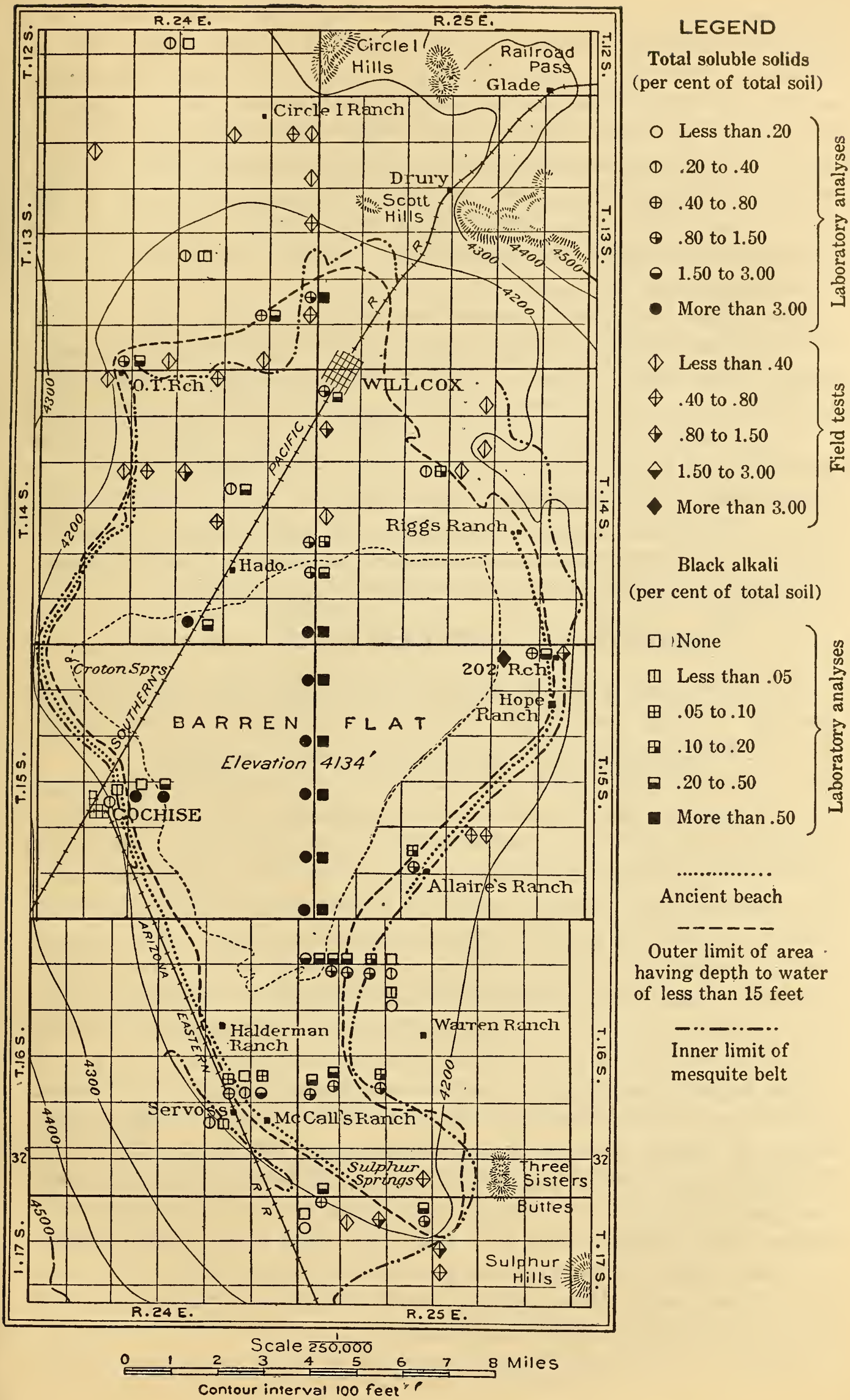

FIGURE 32.—Map showing alkali in soil of north basin, Sulphur Spring Valley.

distance north of Willcox and perhaps other small areas in township 13. It is absent, however, over much of the sandy region east of Willcox. East of the barren flat it occurs in a belt from 1 to 2 miles wide, and west of the flat in a somewhat narrower belt. Alkali is also found in a tract that lies east of the Arizona Eastern Railroad and extends from the south end of the flat for some distance beyond Sulphur Springs. As nearly as could be estimated the area in the north basin over which alkali exists in amounts that may prove injurious covers about 75 square miles, exclusive of the barren flat, or 125 square miles in all.

The alkali area lies in general inside the mesquite belt and the ancient beach ridge and within the area having a depth to ground water of less than 15 feet. A small amount of alkali soil has been found outside of these limits and some good soil within them (fig. 32).

In the south basin alkali is found on the flat that extends south of Soldiers Hole and a short distance north of that point, and on the bottom lands of Whitewater Draw from the flat to the Mexican border. The area affected by alkali in the south basin is, however, small as compared with the area similarly affected in the north basin. Altogether it does not cover much over 25 square miles.

DISTRIBUTION OF DIFFERENT KINDS OF ALKALI.

The most serious fact in regard to the alkali in the soil is that it includes a large percentage of sodium carbonate or black alkali. This undesirable substance was found at every depth in 33 out of the 44 borings examined in the laboratory,[1] and in only seven borings was its amount less than that of the calcium sulphate. Of the 37 borings which had an excess of sodium carbonate over calcium sulphate, 29 contained more than 0.1 per cent of sodium carbonate, 24 contained more than 0.2 per cent, and seven contained more than 0.5 per cent, six of the seven being from the barren flat. In 15 borings sodium carbonate comprised 25 per cent or more of the total alkali, in eight borings it comprised 40 per cent or more, and in three borings it comprised 50 per cent or more. As high as 60 per cent of sodium carbonate was found in the alkali of individual samples.

The largest percentage of sodium carbonate is found in the alkali of the area north of the barren flat. In this area were obtained eight of the 15 borings (including the boring in the NE. ¼ sec. 2, T. 15 S., R. 25 W., and the boring on the flat one-fifth mile from the north margin), whose salts contained more than 25 per cent sodium carbonate. In this area also were obtained seven of the eight borings with more than 40 per cent, and all three of the borings with more than 50 per cent. Practically all of the alkali soil obtained north of the flat was high in sodium carbonate.

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[1] Three very shallow samples are not included.

High percentages of sodium carbonate were also found in the alkali of the eastern portion of the tract south of the barren flat and in the alkali from the two borings on the flat south of Soldiers Hole.

Most of the material from the borings on the barren flat itself contains over 0.5 per cent of sodium carbonate, yet so rich is this material in the other soluble salts that the sodium carbonate forms a relatively small percentage of the total alkali.

Large amounts of calcium sulphate and sodium chloride with no sodium carbonate were found in the soil of the low land east of Cochise, and relatively small amounts of sodium carbonate were found in the borings in the western part of the tracts south of the barren flat. The meager data obtained for the southern part of the south basin indicate that the alkali along the lower course of Whitewater Draw also contains little or no sodium carbonate.

Sodium chloride forms rather more than one-half of the alkali on the barren flat, but it constitutes a very small part of the alkali north of the flat, and in most parts of the valley it is not abundant.

Although the number of analyses from which conclusions can be drawn is small, the relation of the sodium carbonate to the derivative granitic and porphyritic rocks is clearly shown. The intense concentration that has taken place on the barren flat seems to have been selective, the sodium carbonate having been to some extent neutralized or left behind and the sodium chloride accumulated.

RELATION TO WATER TABLE AND DRAINAGE.

Alkali accumulates in places where water stands at or so close to the surface that it is lifted by capillary action within the reach of the atmosphere. Hence it is to be expected that the low, poorly drained, shallow-water areas will contain the most alkali, and this is in fact the general condition in both basins of Sulphur Spring Valley. (See table, pp. 172–181, and fig. 32.)

But although capillarity is not believed to be effective for more than 10 feet, some alkali exists where the depth to water is over 15 feet, and a large amount of alkali occurs in the zone in which the depth to water is between 10 and 15 feet. It is possible that in some of these places capillarity acts through a greater height than 10 feet, or that the roots of certain native plants have drawn up alkali where it was below the reach of ordinary capillarity, or that alkali is accumulating in other conceivable ways. Probably, however, the concentrations occurring more than 10 to 15 feet above the present water level were formed chiefly in a past epoch when the water, at least in the north basin, is known to have stood higher than it does at present. Such an explanation accords with the fact that in areas having a depth to water of less than 10 feet the alkali was generally found most abundant near the surface, and in areas having a depth to water of more than 15 feet the alkali, if present in appreciable quantities, was generally found most abundant at some depth below the surface.

In the borings made in rather light porous soils at several points southwest of Willcox the alkali was found to increase downward, although the depth to water is only 6 or 8 feet. This fact, together with the alkaline character of the upper layer of water, as indicated by the sample taken on Mr. Cook's farm, suggests that the alkali, originally deposited near the surface, was later leached downward. As the ground water is at present nearly or quite within reach of the atmosphere through capillarity, there is danger that under slightly changed conditions the alkali in the subsoil and water will be returned to the surface, where it may interfere with agriculture.

On the barren flat the alkali shows no marked tendency to decrease downward. Alkali is about as abundant in the lower as in the upper part of a 6-foot boring, and a few borings carried 12 feet below the surface show virtually no decrease. In a number of borings the greatest concentration was found in the second foot, but this may be a temporary condition and not significant.

Rude estimates based on the analyses lead to the conclusion that within the upper 6 feet of soil the total quantity of alkali in the north basin is at least ten times as great as the total quantity in the south basin. This difference has no doubt resulted from difference in the conditions of drainage. In the north basin the soluble solids have for a long time been brought together and conserved in the central shallow-water area, but in the south basin they have been carried in solution beyond the international boundary both by the floods in Whitewater Draw and by the southward-moving ground waters.

RELATION TO ZONES OF NATIVE VEGETATION.

Although the character of the native vegetation may not everywhere be an accurate index to the amount of alkali in the soil, yet it is in general a guide of great value whose indications should not be ignored. Saltbush and salt grass are danger signals, and alkali sacaton (*Sporobolus airoides*) is likely to be an indication that considerable alkali is present. A healthy growth of mesquite or of grama and other upland grasses generally indicates that the soil is not overburdened with alkali, though the absence of mesquite does not, of course, necessarily imply the presence of alkali. Mesquite and grama were found growing in a number of localities where the analyses show the presence of dangerous amounts of alkali, but in these localities the plants are more or less scattered or stunted, or show other signs of distress. (See also pp. 182–187.)

EFFECT OF IRRIGATION WATER.

LEACHING ALKALI OUT OF SOIL.

The best method of reclaiming alkali land consists in washing the alkali out of the soil and thereby removing the cause of the difficulty. This is most effectively done by covering the land with water in order that the water may percolate downward through the soil and carry the alkali with it. The conditions necessary to make the method successful are (1) a porous soil and subsoil, (2) a good underdrainage, and (3) an abundant supply of water. The alkali is much more easily removed from porous sandy soils through which the water sinks readily than from heavy clay soils into which it penetrates with difficulty. Caliche and the hardpan formed by black alkali also interfere with the leaching process. In the San Joaquin Valley, Cal., it was found necessary to break up the hardpan by blasting before the soil could be effectively leached.[1] Moreover, the ground water must have opportunity to drain away, for if it accumulates and raises the water table within reach of capillary action the alkali is not permanently removed but will be drawn back when the flooding stops. Land that does not have good natural underdrainage can in many places be reclaimed by first installing a drainage system of tiles or open ditches by means of which the seepage from the irrigation water is carried away. A drainage system can of course be successful only if it can be made to discharge at a place far enough below the level of the irrigated land to allow of effective drainage.

A soil solution may contain several thousand parts per million of alkali without being injurious to crops. If the soil itself is free from alkali and is well drained, and if heavy applications of water are made, the soil solution will be not much more concentrated than the irrigation water itself; that is, the irrigation water in penetrating the soil finds but little alkali to dissolve and it leaves little of its original content of alkali when it passes out of the soil. Under such conditions water that is regarded as heavily mineralized can be successfully used. In certain oases in Sahara Desert vegetables considered sensitive to alkali are successfully grown, although irrigated with water containing as much as 8,000 parts per million of soluble salts, including in some places as much as 4,000 parts per million of sodium chloride. This is possible because the conditions for drainage are ideal and the water is used unsparingly.[2] With good drainage and a large water supply highly mineralized waters can be used not only to irrigate soil that is free from alkali but also to reclaim alkali soils, because in

[1] Fortier, Samuel, and Cone, V. M., Drainage of irrigated lands in the San Joaquin Valley, California: Bull. Office Exp. Sta. No. 217, U. S. Dept. Agr., 1909, p. 25.

[2] Means, T. H., The use of alkaline and saline waters for irrigation: Circ. Bur. Soils No. 10, U. S. Dept. Agr., 1903.

percolating through soils they retain their own load of dissolved matter, and in addition take up and carry away with them the alkali found in the soil.

The ground water of Sulphur Spring Valley is practically all sufficiently pure to be used under the ideal conditions that have been described without danger of injurious results. But this method of irrigation will find little application in this valley. The low alkaline tracts are in general poorly drained. The higher ground has somewhat more pervious soil and lies farther above the water table, but in many localities the caliche in the subsoil will to some extent hinder downward percolation. Moreover, the lavish use of water will be prohibited by the cost of pumping. On the higher ground, on the other hand, both soil and water, as a rule, contain so little alkali that vigorous leaching will not be necessary nor desirable.

CONTRIBUTING ALKALI TO SOIL.

Where it is not feasible to wash the alkali out of the soil the problem assumes a different aspect. Not only does the soluble matter already in the soil remain there, but the soluble matter introduced with the irrigation water is left in the soil when the water evaporates. Under such conditions relatively pure water may in the course of time supply a harmful quantity of alkali.

As an acre-foot of water weighs approximately 2,700,000 pounds, one part per million of any dissolved substance is equivalent to about 2.7 pounds per acre-foot. As 1 pound of chlorine is equivalent to 1.65 pounds of common salt, 2.7 pounds of chlorine is equivalent to 4.4 pounds of common salt. That is, an acre-foot of water will on evaporation deposit 4.4 pounds of common salt for every part per million of chlorine that it contains, provided that all the chlorine combines with sodium. Under the specified conditions an acre-foot of water will deposit about 110 pounds of common salt if it contains 25 parts per million of chlorine, 440 pounds if it contains 100 parts per million, and 4,400 pounds if it contains 1,000 parts per million.

An acre-foot of soil weighs approximately 4,000,000 pounds. If it is assumed that all of the mineral matter contained in the irrigation water is deposited within 3 feet of the surface, then the mineral matter deposited on each acre will be distributed through about 12,000,000 pounds of soil. It follows that where the chlorine content is only 25 parts per million a foot of irrigation water will contribute only 110 pounds of salt to 12,000,000 pounds of soil, or an amount of salt that is a little less than 0.001 per cent of the soil. Under such conditions a depth of over 400 feet of water is required in order to add 0.4 per cent of common salt, which may be regarded as an injurious amount. With similar assumptions it can be shown that 0.4 per cent of common salt will be contributed to the soil by 110 feet of water containing 100 parts per million of chlorine, by 37 feet of water containing 300 parts, by 11 feet of water containing 1,000 parts, and by less than 4 feet of water containing 3,000 parts.

It is evident that water containing less than 100 parts per million of chlorine will deposit so little salt that practically no harmful results need be feared from it even where the drainage is poor. On the other hand, it is evident that water containing over 1,000 parts per million will in the course of a few years contribute a harmful amount of salt if a large proportion of the salt is deposited in the soil and not leached out. In the low areas, where drainage is poor and the soil already contains considerable alkali, water containing several hundred parts per million of chlorine may prove injurious.

Figure 29 (p. 137) shows that the areas in which the chlorine content is greater than 100 parts per million are small and relatively unimportant. Even within these areas much of the water is not dangerously high in chlorine, but the water represented by the most highly mineralized samples may prove injurious. Of course it must be remembered that highly mineralized waters may be encountered in exceptional wells even in the areas shown on the map as having less than 100 parts of chlorine.

One-tenth of 1 per cent of sodium carbonate in a soil is generally regarded as injurious to grain crops under average conditions. With the same assumptions as have been made in the computations for common salt, it may be shown that this percentage of sodium carbonate will be contributed by 175 feet of water having 25 parts per million of black alkali, by 44 feet of water having 100 parts, by 15 feet of water having 300 parts, and by 4½ feet of water having 1,000 parts. Most of the black alkali in the water of this region is present as a bicarbonate, but in the soil some of the bicarbonate may be converted into the more injurious normal carbonate. The analyses show that most of the water in the valley does not contain dangerous amounts of black alkali, but that some supplies may under unfavorable conditions add injurious quantities of this undesirable ingredient to the soil. Water having more than 100 parts per million may be regarded with suspicion, especially where the drainage is poor and the soil is already alkaline.

Because of the wide distribution of black alkali in the soils of this region, a supply of water that has permanent hardness is especially desirable, since such water will tend to neutralize the sodium carbonate of the soil. Throughout most of the alkali tracts the ground water is of the black alkali type (see fig. 31, p. 141), but water with permanent hardness can be obtained in certain localities in which the soil contains black alkali, as for example, at Allaire's ranch, in a small area southeast of Willcox, and in a small area southeast of Servoss. Black alkali can also be neutralized by the application of gypsum. (See p. 216.)

Sodium sulphate is less injurious than sodium chloride and sodium carbonate, and, with a few exceptions, it is yielded in comparatively small amounts by the waters of this region. In general, therefore, its influence may be disregarded if account is taken of the sodium chloride and black alkali.

CHANGING THE WATER LEVEL.

Where the ground water stands at so high a level that it can be lifted by capillarity to the surface, the danger from alkali is peculiarly threatening, because the soil receives contributions of alkali both from the ground water that is pumped and applied in irrigation and from the ground water drawn up by capillarity. Temporary relief is often found by washing down the alkali, but the alkali can not in this way be permanently removed, for it is drawn back as soon as evaporation is resumed. The localities in Sulphur Spring Valley in which the water table is less than 10 feet below the surface are liable to suffer in this way, especially since they are already overburdened with soluble minerals.

A great deal of damage has resulted in irrigated areas from the fact that the water applied to the land has raised the water table and has thereby brought the ground water within reach of the atmosphere. The conditions in Sulphur Spring Valley, however, are different from those in areas irrigated with surface water. The water will be pumped from below the land that is irrigated, and it seems probable that the water table will in general be lowered somewhat when extensive irrigation is undertaken, although it may be raised in certain tracts.

CONCLUSIONS.

The conclusions in regard to the alkali in the water and soil can be briefly summarized as follows:

1. In most of the area in which the depth to water is less than 15 feet and in small tracts where the depth to water is greater the soil contains injurious amounts of alkali. The area of alkali soil covers about 150 square miles, including the barren flat.

2. In nearly all the area in which the depth to water is more than 15 feet the soil is free from injurious amounts of alkali, and the area of such soil, free from injurious amounts of alkali, in which the depth to water is less than 50 feet, covers about 250 square miles, or 160,000 acres.

3. The most harmful constituent of the alkali in the soil is sodium carbonate. It is widely distributed over the alkali area and occurs in relatively large quantities, especially north of the barren flat.

4. The ground water thus far developed is nearly all of good quality for use in irrigation. Even in the low tracts having alkali soil it is as a rule not highly mineralized.

5. Undesirable amounts of alkali are found (1) in much of the highly mineralized water southeast of Willcox, where the harmful constituents are chiefly chlorides; (2) in the water of some of the very shallow wells and a few deeper wells in the low alkali tracts, the principal harmful constituent being black alkali; and (3) in the water of a few exceptional wells in other parts of the valley.

6. In certain localities soils containing black alkali can be improved by the application of water having permanent hardness, although in general water of this type is not available where the alkali soil exists. The highly mineralized water east of Douglas is good irrigation water. The highly mineralized water southeast of Willcox will neutralize black alkali, but may deposit harmful amounts of white alkali.

SOIL ANALYSES.

The analyses set forth in the following table were made by Dr. W. H. Ross, of the Arizona Agricultural Experiment Station. They give the amounts of alkali as a percentage of the total soil.

Determinations of alkali in soil of Sulphur Spring Valley.

[Determinations in per cent of total soil. W. H. Ross, analyst.]

Location.	Situation.	Vegetation.	Depth to ground water.	Depth of soil sample.	Physical character of soil.	Laboratory determinations.				Total soluble salts.[b]
						Total soluble salts.	Chlorides expressed as common salt (NaCl).	Hehner's test.[a] Permanent hardness expressed as $CaSO_4$.	Hehner's test.[a] Black alkali expressed as Na_2CO_3.	
T. 12 S., R. 23 E.			*Feet.*	*Feet.*						
Southeast corner sec. 14	Hookers Draw	Scattered mesquite	50	0 to 1	Gray sandy loam	0.23	0.01	0.02	None.	
T. 12 S., R. 24 E.										
Near southeast corner sec. 28	Nearly level plain	Grass	[c]36	0 to 1	Light-gray, sandy loam	.21	.01	.04	None.	
				1 to 2	Whitish-gray, sandy loam					< .40
				2 to 4	Soft caliche mixed with soil.					< .40
East margin; near southeast corner sec. 1.	Gentle slope	Mesquite and grass	29	0 to 1	Reddish loam					< .40
				1 to 2	Reddish-gray gravelly loam.					< .40
				2 to 3	do					< .40
Middle south margin sec. 1	Nearly level plain	Meager growth of grass	[c]27	0 to 1	Light-gray loam with hard particles of lime.					< .40
				1 to 2	do					.40< .80
				2 to 5	Same, except more whitish					.40<1.50
Southwest corner sec. 2	do	Mesquite and grass	[c]30	0 to 1	Reddish-gray loam					< .40
				1 to 2	do					< .40
				2 to 2.3	do					< .40
Northwest corner sec. 8	do	do	32	0 to 1	Dark-gray clay loam					< .40
				1 to 2	do					< .40
				2 to 6	Same to 3 feet caliche to 3.5 feet yellow sandy loam to 6 feet.					< .40

Southeast corner sec. 12	do	Mesquite, grama, sacaton, and a little salt grass.	c24	0 to 1	Brownish-gray loam					< .40
				1 to 2	Same, except lighter color					< .40
				2 to 6	do					< .80
Southeast corner sec. 13	do	Mesquite, sacaton, saltbush (Atriplex).	20	0 to 1	Gray loam					< .40
				1 to 2	Same, except lighter gray					.80<1.50
				2 to 6	Lighter gray changing into caliche.					.40<1.50
Northwest corner SE. ¼ sec. 19	Plain; at base of slope		24	Surface crust.	Crusts of what appeared to be alkali.	9.59	.36	None.	1.97	
Southwest corner NW. ¼ sec. 22	Nearly level plain	Mesquite and grass	22	0 to 1	Reddish-gray gritty loam	.23	.01	None.	.04	
				1 to 2.5	do					< .40
Southeast corner NE. ¼ sec. 25	do	Salt grass, grama, and other grass.	14	0 to 1	Gray sandy loam	.50	.02	None.	.25	
				1 to 2	Gray loam	1.34	.03	None.	.73	
				2 to 6	White, loose-textured material; hard at bottom.	1.07	.03	None.	.63	
Southeast corner sec. 25	do	Grama and other grass; a little mesquite and salt grass.	12	0 to 1	Gray sandy loam					< .40
				1 to 2	Light-gray loam					< .80
				2 to 6	do					< .80
Southeast corner sec. 26	do	Sacaton and other grass; scattered mesquite and yucca.	12	0 to 1	Brown gritty loam	.52	.03	None.	.29	
				1 to 2	do	.65	.04	None.	.39	
				2 to 3.5	Same, except more gravelly.	.63	.04	None.	.32	
T. 14 S., R. 24 E.										
Northeast corner sec. 2	do	Sacaton and other grass; scattered mesquite.	11	0 to 1	Gray gritty loam					< .40
				1 to 2	do					< .40
				2 to 3.4	Same, except more gravelly					< .40
Northeast corner sec. 3	do	Sacaton, salt grass, and saltbush (Atriplex).	11	0 to 1	Gray loam					.80<1.50
				1 to 2	Same, except lighter color					.80<1.50
				2 to 3.4	Gray and brown loam					< .80
Northeast corner sec. 4	do	Sacaton and other grass; scattered mesquite.	13	0 to 1	Brownish-gray gritty loam					< .40
				1 to 2	do					< .80
				2 to 4.4	Grit, sand, and clay					< .40
Northeast corner sec. 5	Plain; near base of slope.	Mexican salt grass, sacaton, and other grass; scattered mesquite.	c11	0 to 1	Light-gray loam	1.34	.07	None.	.45	
				1 to 2	do	1.37	.05	None.	.61	
				2 to 6	Whitish loam with lumps of $CaCO_3$.	.87	.02	None.	.46	
Northeast corner NW. ¼ sec. 5	Slope; near base	Mesquite and grass	19	0 to 1	Reddish-gray gravelly loam					< .40
				1 to 1.5	do					< .40
Northwest corner SW. ¼ sec. 14	Nearly level plain	Sacaton, salt grass, grama, and other grass.	7	0 to 1	Dark-gray sandy loam	.18	.01	None.	.05	
				1 to 2	do	.32	.02	None.	.15	
				2 to 6	Greenish-gray sandy loam	.43	.02	None.	.25	
Northwest corner sec. 15	Nearly level plain	Sparse growth of salt grass.	c10	0 to 1	Hard, dark clay; apparently containing black alkali; alkali that tastes hot and soapy.					1.50<
				1 to 2	Dark-gray sandy loam					< .80
				2 to 6	do					.40<1.50

[a] Modified method described in Circular Bur. Soils No. 52, Dept. Agr., 1910, p. 13.
[b] Made by Meinzer with electrical bridge.
[c] Estimated.
<.40 means less than .40 per cent, .40<.80 means more than .40 per cent and less than .80 per cent, etc.

Determinations of alkali in soil of Sulphur Spring Valley—Continued.

Location.	Situation.	Vegetation.	Depth to ground water.	Depth of soil sample.	Physical character of soil.	Laboratory determinations. Total soluble salts.	Laboratory determinations. Chlorides expressed as common salt (NaCl).	Hehner's test. Permanent hardness expressed as $CaSO_4$.	Hehner's test. Black alkali expressed as Na_2CO_3.	Total soluble salts.
T. 14 S., R. 24 E.—Continued.			*Feet.*	*Feet.*						
¼ mile east of northwest corner sec. 16.	Plain below ancient beach; ¼ mile from beach.	Salt grass and sacaton.	a 10	0 to 1	Gray loam	......	......	......	......	< .80
				1 to 1.5	....do	......	......	......	......	.40<1.50
⅛ mile west and ⅛ mile south of northeast corner sec. 17.	Slope; near base. Above the ancient beach.	Mesquite	17	0 to 1	Red gravelly loam	......	......	......	......	< .40
				1 to 1.5	....do	......	......	......	......	< .40
3/10 mile south of northeast corner sec. 22.	Nearly level plain	Mexican salt grass, sacaton, and other grass.	6	0 to 1	Gray loam	......	......	......	......	< .40
				1 to 2	Same, except yellowish sand near bottom.	......	......	......	......	< .40
				2 to 6	Yellowish loamy sand	......	......	......	......	< .80
SE. ¼ sec. 24	Low wind-blown hills; ½ mile north of barren flat.	Saltbush (Suæda), salt grass, and sacaton.	a 7	0 to 1	Gray sand	1.01	.15	None.	.19	......
				1 to 2	Gray sand and clay	......	......	......	......	.80<1.50
				2 to 6	Gray sand and greenish clay.	......	......	......	......	.80<1.50
NE. ¼ sec. 25	Barren flat; ⅛ mile from margin.	Inner limit of vegetation; isolated clump of saltbush (Suæda).	4⅛	0 to 1	Brown clay; greenish near bottom.	3.62	1.64	None.	.95	......
				1 to 2	Greenish clay and sand	1.32	.53	None.	.38	......
				2 to 6	Greenish sand to 4.1 feet. Black sand to 6 feet.	.53	.15	None.	.16	......
North of Ry.; 1½ miles southwest of Hado; sec. 34.	Barren flat; ⅛ mile from margin.	No vegetation	4½	0 to 0.2	Dark brown clay	4.17	2.12	None.	.78	......
				0.2 to 0.5	Same, except lighter color and some grit.	3.13	1.13	None.	.76	......
				0.5 to 1.6	Coarse yellowish sand	1.65	.82	None.	.31	......
				1.6 to 4.3	Yellowish-gray clay	3.30	1.70	None.	.58	......
				4.3 to 8	Black clay, with odor of H_2S.	3.46	1.74	None.	.32	......

SE. ¼ sec. 36	Barren flat; 1½ miles from margin.	....do	?	0 to 1	Reddish loam, with white spots.	5.74	3.39	None.	.88	....
T. 14 S., R. 25 E.										
Southeast corner sec. 3	Level tract surrounded by wind-blown hills.	Sage; a little grass and mesquite.	31	0 to 1	Gray sandy loam	....	....	....	....	< .40
				1 to 2	....do	....	....	....	....	< .40
				2 to 6	Same, except more loamy	....	....	....	....	< .40
Northwest corner SW. ¼ sec. 6	Nearly level plain	Salt grass; also saltbush (Atriplex) and sacaton.	a 8	0 to 1	Yellowish-gray loam with grit.	.82	.04	None.	.32	....
				1 to 2	Same, except lighter color and with more grit.	.95	.08	None.	.46	....
				2 to 5.6	....do	.83	.10	None.	.44	....
Northwest corner SW. ¼ NW. ¼ sec. 7.	....do	Sacaton, salt grass, and saltbush (Suæda).	7	0 to 1	Gray sandy loam	....	....	....	....	< .40
				1 to 2	Yellowish-gray loam and coarse sand.	....	....	....	....	.40<1.50
				2 to 6	Yellow and brown sand and clay.	....	....	....	....	.40<1.50
SE. ¼ sec. 10	Top of wind-blown ridge.	Sage; a little yucca and mesquite.	?	0 to 1	Gray loamy sand	....	....	....	....	< .40
				1 to 2	....do	....	....	....	....	< .40
				2 to 6	....do	....	....	....	....	< .40
Near northwest corner sec. 15	Meadow bordered by wind-blown ridges.	Sacaton	....	0 to 1	Gray clay loam	....	....	....	....	< .40
			a 17	1 to 2	....do	....	....	....	....	< .40
				2 to 6	....do	....	....	....	....	< .40
At well near north margin sec. 16	Irregular, wind-blown surface.	Sacaton and a little saltbush (Atriplex).	10	0 to 1	Gray loamy sand	.23	.01	None.	.08	....
				1 to 2	Same, except lighter color	.24	.02	None.	.12	....
				2 to 6	Same, except more greenish	.48	.05	None.	.21	....
Near northwest corner sec. 18	Very low wind-blown ridge.	Salt grass, sacaton, and a few small yuccas.	11	0 to 1	Gray sandy loam	....	....	....	....	< .40
				1 to 2	Same, except lighter	....	....	....	....	< .40
				2 to 6	Same, except more sandy	....	....	....	....	< .40
T. 15 S., R. 24 E.										
SE. ¼ sec. 1	Barren flat; near center.	No vegetation	?	0 to 1	Reddish and greenish clay	5.16	2.90	None.	.79	....
				1 to 2	Greenish-gray clay	6.13	3.63	None.	.75	....
				2 to 6	Reddish and greenish clay	5.75	3.29	None.	.76	....
NE. ¼ sec. 13	....do	....do	?	0 to 1	Gray loam	4.24	2.43	None.	.69	....
				1 to 2	Gray clay loam	....	....	....	....	....
				2 to 6	Gray and greenish clay	....	....	....	....	....
¼ mile east of Cochise; sec. 20	Slope	Mesquite	a 40	0 to 1	....	.22	.01	None.	.02	....
¾ mile east of Cochise; sec. 21	Nearly level plain, ½ mile west of barren flat.	Salt grass	....	0 to 1	....	6.18	.30	2.46	None.	....
				0 to 1	....	9.65	2.20	3.87	None.	....

a Estimated.

<.40 means less than .40 per cent, .40<.80 means more than .40 per cent and less than .80 per cent, etc.

Determinations of alkali in soil of Sulphur Spring Valley—Continued.

Location.	Situation.	Vegetation.	Depth to ground water.	Depth of soil sample.	Physical character of soil.	Laboratory determinations.				Total soluble salts.
						Total soluble salts.	Chlorides expressed as common salt (NaCl).	Hehner's test.		
								Permanent hardness expressed as $CaSO_4$.	Black alkali expressed as Na_2CO_3.	
T. 15 S., R. 24 E.—Continued.										
			Feet.	*Feet.*						
1½ miles east of Cochise; sec. 21	Barren flat; near margin.	Extreme limit of vegetation.	....	0 to 1	Red clay to 8 inches; green clay to bottom.	3.67	1.85	None.	0.39	....
				0 to 0.1	Dry gray crust; brittle under foot.	3.54	2.02	None.	.34	....
1¾ miles east of Cochise; sec. 22	Barren flat; ½ mile from margin.	No vegetation	....	0 to 0.1	Soft under foot	3.00	1.68	None.	.49	....
2 miles east of Cochise; sec. 22	Barren flat; ¾ mile from margin.	.....do	....	0 to 0.1	Brittle under foot	3.22	1.98	None.	.47	....
NE. ¼ sec. 24	Barren flat	.....do	(?)	0 to 1	Reddish-gray sandy loam	4.09	2.20	None.	.65	....
				1 to 2	Reddish and greenish clay loam.	4.84	2.60	None.	.83	....
				2 to 6	Greenish clay to 9 feet	....	....	....	....	3.00<
				10 to 11	Black clay to 12 feet	....	....	....	....	3.00<
NE. ¼ sec. 25	.....do	.....do	(?)	0 to 1	Reddish and greenish loam.	4.79	2.62	None.	.61	....
SE. ¼ sec. 36	.....do	.....do	(?)	0 to 1	Reddish and greenish clay	6.74	4.46	None.	.81	....
				1 to 2	Greenish clay	10.29	7.02	None.	1.08	....
				2 to 6	Same to 9 feet	7.71	5.52	None.	.69	....
				10 to 12	Black clay to bottom	....	....	....	....	3.00<
T. 15 S., R. 25 E.										
Near northwest corner NE. ¼ sec. 1	Slope; near base. Above ancient beach.	Sparse mesquite and sacaton.	22	0 to 1	Light gray loam with pebbles.	....	....	....	....	1.50<
				1 to 2	.....do	....	....	....	....	1.20<
				2 to 6	.....do	....	....	....	....	<1.20
Northeast corner sec. 2	Meadow; below ancient beach and near base of slope.	Tall sacaton	7	0 to 1	Gray loam	.52	.03	None.	.14	....
				1 to 2	.....do	1.13	.13	None.	.56	....
				2 to 6	Whitish clay loam	.71	.10	None.	.35	....

NW. ¼ sec. 2	Margin of barren flat	Scattered saltbush (Suæda).	4	0 to 1	Yellowish-gray sandy loam				3.00<
				1 to 2	....do				2.00<
				2 to 3	....do				2.00<
Northwest corner NE. ¼ sec. 27	Plain, above the ancient beach.	Mesquite and sacaton.	24	0 to 1	Gray gritty loam				< .40
				1 to 2	....do				< .40
				2 to 6	Same, except more whitish.				< .80
Northeast corner sec. 27	....do	Mesquite, sacaton, other grass.	*a* 27	0 to 1	Gray gravelly loam				< .40
				1 to 2	Reddish-gray gravelly loam.				< .80
				2 to 2.3	....do				< .80
Near southeast corner SW. ¼ sec. 28	Plain, immediately below the ancient beach.	Sacaton; also saltbush (Suæda) and salt grass.	*a* 15	0 to 1	Light-gray sandy loam	.68	0.07	None.	.15	
				1 to 2	....do	1.44	.09	None.	.11	
				2 to 6	....do	.76	.07	None.	.14	
T. 16 S., R. 24 E.										
Near northwest corner sec. 26	Slope; near base. Above the ancient beach.	Scattered mesquite; sacaton and other grass.	*a* 35	0 to 1	Dark-gray sandy loam	.31	.01	None.	.04	
				1 to 2	Gray sandy loam	.26	.01	.01	None.	
				2 to 4.4	Light-gray sandy loam	.25	.02	None.	.01	
SW. ¼ sec. 24; ¼ mile north and nearly 1 mile east of Servoss.	Plain, below the ancient beach.	Salt grass, sacaton, and bare spots. Sample taken on a bare spot.	5	0 to 1	Dark, fine sandy loam	3.82	.30	.27	None.	
				1 to 2	Dark clay loam	2.24	.20	None.	.08	
				2 to 6	Greenish-gray coarse sand; some clay.	.80	.08	None.	.13	
SE. ¼ sec. 23; about ¼ mile north and ½ mile east of Servoss.	Immediately below the ancient beach.	Salt grass and sacaton		0 to 1	Dark sandy loam	.32	.02	None.	.04	
				1 to 2	Whitish sandy loam. Caliche at bottom.	.40	.02	.02	None.	
				2 to 6	Gravel, whitish clay, and caliche.	.32	.02	.01	None.	
¼ mile north of Servoss; immediately east of Ry.; sec. 23.	Base of slope; above ancient beach.	Sacaton, salt grass, and other grass.	15	0 to 1	Gray sandy loam	.33	.02	None.	.08	
				1 to 1.7	Light-gray gravelly loam. Caliche at bottom.	.74	.06	None.	.07	
T. 26 S., R. 25 E.										
SW. ¼ sec. 6	Barren flat	No vegetation	(?)	0 to 1	Reddish and greenish clay	3.57	1.56	None.	.75	
				1 to 2	Greenish clay and a little sand.	2.22	1.02	None.	.46	
				2 to 6	....do	1.64	.89	None.	.28	
¼ mile west of northeast corner sec. 7.	Near barren flat	Sparse growth of saltbush (chiefly Suæda).		0 to 1	Yellow sandy loam	2.58	.71	None.	.75	
				1 to 2	....do	2.38	.43	None.	.49	
				2 to 6	Yellow and gray sand	.66	.13	None.	.25	

a Estimated.

<.40 means less than .40 per cent, .40<.80 means more than .40 per cent and less than .80 per cent, etc.

Determinations of alkali in soil of Sulphur Spring Valley—Continued.

Location.	Situation.	Vegetation.	Depth to ground water.	Depth of soil sample.	Physical character of soil.	Laboratory determinations.				Total soluble salts.
						Total soluble salts.	Chlorides expressed as common salt (NaCl).	Hehner's test.		
								Permanent hardness expressed as $CaSO_4$.	Black alkali expressed as Na_2CO_3.	
T. 26 S., R. 25 E.—Continued.			*Feet.*	*Feet.*						
Northwest corner sec. 8	Irregular surface near barren flat. Wind-blown ridge 20 rods west.	Sparse sacaton and stunted grama; bare spot where boring was made.	*a* 15	0 to 1	Yellowish sandy loam	1.97	0.08	None.	0.48	
				1 to 2	.....do					1.20<
				2 to 6	Same, except harder and more gray.					.80<1.50
⅜ mile west of northeast corner sec. 8.	Plain; sloping gently toward barren flat.	Sparse growth of sacaton and saltbush (Atriplex). Inner margin of mesquite belt.	*a* 25	0 to 1	Gray sandy loam	.64	.05	None.	.13	
				1 to 1.8	Greenish fine sand; hard at bottom.	1.14	.08	None.	.14	
Northwest corner sec. 9	Plain; nearly 50 feet above barren flat.	Large mesquite	*a* 30	0 to 1	Gray sandy loam	.29	.01	None.	None.	
				1 to 1.9	Same, except lighter color; changing into caliche.	.42	.01	None.	None.	
Southwest corner sec. 9	.....do	.....do	30	0 to 1	Gray sandy loam	.14	.01	None.	.02	
				1 to 2	.....do					< .40
				2 to 3	Light-gray fine sand underlain by caliche.					< .40
SW. ¼ sec. 19	Low plain	Sacaton and salt grass		0 to 1	Gray clay loam	1.24	.11	None.	.31	
				1 to 2	Yellowish-gray clay and sand.					1.50<
				2 to 6	Greenish sand and calcareous clay.					.80<1.50
Near northeast corner SE. ¼ sec. 19	.....do	Salt grass and sacaton	14	0 to 1	Reddish sandy loam	1.34	.09	None.	.29	
				1 to 2	Gray sandy loam	1.03	.06	None.	.33	
				2 to 6	.....do	.89	.05	None.	.24	
Southeast corner NE. ¼ sec. 20	Plain	Mesquite, sacaton, grama.	18	0 to 1	Reddish-gray sandy loam	.90	.02	None.	.18	
				1 to 2	.....do					.80<1.50
				2 to 3	Same; hard near bottom					.80<1.50

Several rods south of Sulphur Springs; sec. 33.	Low plain	Sacaton and salt grass		0 to 1	Gray loam and sand					.80<1.50
				1 to 2	....do					1.20<3.00
				2 to 6	....do					.40<1.20
T. 17 S., R. 25 E.										
1/8 mile north of southeast corner NE. 1/4 sec. 4.	....do	Sacaton and salt grass; sample taken on a bare spot.	10	0 to 1	Reddish sandy loam	1.67	.02	None.	.63	
				1 to 2	Gray sandy and gravelly loam.	1.24	.02	None.	.39	
				2 to 6	Whitish calcareous material.	.80	.02	None.	.39	
Southwest corner NW. 1/4 sec. 5	....do	Grass	*a* 25	0 to 1	Reddish-gray loam					< .40
				1 to 2	....do					< .40
				2 to 4.3	Same to 2.5 feet; calcareous clay and caliche to bottom.					< .40
Northeast corner SE. 1/4 sec. 5	....do	Sacaton and salt grass	*a* 16	0 to 1	Gray loam					1.20<
				1 to 2	Light-gray loam					1.50<
				2 to 4	Calcareous clay and caliche					.40<1.50
Middle west margin sec. 6	Near base of slope; above ancient beach.	Grama and other grass.	*a* 45	0 to 1	Reddish gravelly loam	.14	.01	0.06	None.	
				1 to 2	....do	.16	.01	None.	.02	
				2 to 4	Same; becoming more gravelly near bottom.	.20	.01	None.	None.	
Middle north margin sec. 6	Plain at base of slope; immediately above ancient beach.	Grass	25	0 to 1	Gray loam with gravel	.51	.05	None.	.21	
				1 to 1.5	Gray loam, changing to caliche.	.74	.08	None.	.22	
Northwest corner sec. 10	Near base of slope	Mesquite and sacaton	*a* 18	0 to 1	Reddish-gray gritty loam					.80<1.50
				1 to 2	Same, except more calcareous.					1.20<
				2 to 6	Soft caliche; sandy below 4 feet.					.80<1.50
20 rods south of northwest corner SW. 1/4 sec. 10.	....do	....do	27	0 to 1	Reddish-gray loam					< .40
				1 to 2	Reddish-gray gritty loam with calcareous particles.					< .40
				2 to 6	Same to 4.5 feet; calcareous clay to bottom.					< .80
T. 20 S., R. 26 E.										
Middle north margin sec. 14	Meadow; near Whitewater Draw.	Sacaton and other grass.	*a* 45	0 to 1	Dark clay loam					< .40
				1 to 2	....do					< .40
W. 1/2 sec. 17; 1/10 mile northwest of well.	Flat	Sparse sacaton	*a* 11	0 to 1	Brownish sandy loam	.97	.04	None.	.36	
				1 to 2	....do	.72	.03	None.	.36	
				2 to 6	....do	.66	.03	None.	.33	
Near center sec. 21	....do	Sacaton	10	0 to 1	Gray loam					.40<1.50
				1 to 2	....do					.40<1.50
				2 to 5	Same, changing into caliche					< .80
Intersection of Ry. with east line of sec. 21.	Low plain	Mesquite and sacaton	*a* 14	0 to 1	Light-brownish sandy loam with a few pebbles.					< .80
				1 to 2	....do					.40<1.50
				2 to 3	....do					.40<1.50
Middle north margin sec. 29	Flat	Sacaton and some salt grass.	*a* 5	0 to 1	Brownish-gray clay loam					.80<1.50
				1 to 2	....do					.80<1.50
				2 to 6	Same, except lighter gray below 5 feet.					< .40

a Estimated.

<.40 means less than .40 per cent, .40<.80 means more than .40 per cent and less than .80 per cent, etc.

Determinations of alkali in soil of Sulphur Spring Valley—Continued.

Location.	Situation.	Vegetation.	Depth to ground water.	Depth of soil sample.	Physical character of soil.	Laboratory determinations.				Total soluble salts.
						Total soluble salts.	Chlorides expressed as common salt (NaCl).	Hehner's test.		
								Permanent hardness expressed as $CaSO_4$.	Black alkali expressed as Na_2CO_3.	
T. 20 S., R. 26 E.—Continued.			*Feet.*	*Feet.*						
Near northeast corner sec. 30	Approximately lowest part of flat.	Sacaton and bare spots. Sample taken on a bare spot.	4 (−)	0 to 1	Brownish clay loam					1.20<
				1 to 2	Same, with grit					.80<1.50
				2 to 6	Same, with considerable sand. Dark-gray below 3 feet.					< .80
Near northeast corner NW. ¼ sec. 31	do	Sacaton and salt grass.	4	0 to 1	Yellowish-gray loam	1.04	0.07	None.	0.34	
				1 to 2	Yellowish-gray sandy loam.	1.10	.08	None.	.42	
				2 to 4	do	.49	.04	None.	.23	
About 30 rods east of northwest corner sec. 31.	Near margin of flat	Grass and bare spots. (Sacaton and salt grass?)	10	0 to 1	Brownish gritty loam					.80<1.50
				1 to 2	do					1.20<
				2 to 6	Sandy loam to 5 feet; clay to bottom.					.80<1.20
About 10 rods south of northwest corner sec. 31.	Natural levee, or stream-built ridge, at base of slope.	Mesquite	17	0 to 1	Gravelly loam					< .40
				1 to 2	do					< .40
				2 to 3	do					< .40
Northeast corner sec. 28	Near base of slope	do	42	0 to 1	Reddish gravelly loam					< .40
				1 to 2	do					< .40
				2 to 3	do					< .40
Near middle north margin sec. 29	30 feet east of channel of Whitewater Draw.	Sacaton	*a* 15	0 to 1	Whitish loam	.41	.01	None.	.08	
				1 to 2	do	.60	.04	None.	.13	
				2 to 6	Whitish-clay loam	1.86	.06	.03	None.	
About ¼ mile west of northeast corner sec. 29.	Immediately east of flood plain of Whitewater Draw. Slightly above the flood plain.	Mesquite	*a* 18	0 to 1	Yellowish loam or clay loam with some grit.					< .80
				1 to 2	do					.40<1.50
				2 to 3	do					.40<1.50
Northeast corner sec. 21	Gentle slope	Grass	38	0 to 1	Reddish gravelly loam					< .40
				1 to 2	do					< .40

Near middle south margin sec. 21	Flood plain of Whitewater Draw.	Sacaton and a little mesquite.	*a* 13	0 to 1	Dark-brownish clay or clay loam.					< .80 m
				1 to 2	do					.80<1.50
				2 to 6	do					.40<1.50
Middle west margin (?) sec. 28	Near base of slope	Mesquite	*a* 25	0 to 1	Dark reddish loam with a little fine grit.					< .40
				1 to 2	do					< .40
Near southeast corner sec. 33	Flood plain of Whitewater Draw. About 600 feet from channel.	Sacaton and scattered mesquite.	13	0 to 1	Dark clay loam					1.20<
				1 to 2	Dark clay or clay loam					1.20<
				2 to 6	do					.80<1.50
T. 23 S., R. 26 E.										
Center sec. 12	Upland near flood plain of Whitewater Draw.	Grass; a little sacaton and mesquite.	*a* 35	0 to 1	Dark-brown gravelly loam					< .40
				1 to 1.5	do					< .40
T. 23 S., R. 27 E.										
NE. ¼ sec. 29	Upland, some distance from flood plain of Whitewater Draw.	Sacaton. Inner margin of mesquite belt.	*a* 35	0 to 1	Reddish gravelly loam	.25	.01	.06	None.	
				1 to 3	do	.19	.01	.05	None.	
Near northwest corner sec. 30	Gentle slope	Grass and a little mesquite.	50	0 to 1	Reddish sandy loam					< .40
				1 to 2	do					< .40
				2 to 3	Same, except more gravelly					< .40
T. 23 S., R. 28 E.										
Near southwest corner sec. 31	do	Grass	138	0 to 1	Reddish gravelly loam					< .40
				1 to 2	do					< .40
T. 24 S., R. 27 E.										
Several rods east of northwest corner sec. 1.	do	do	*a* 100	0 to 1	do					< .40
				1 to 2	do					< .40
NE. ¼ sec. 4	Bottom of channel of Whitewater Draw.		*a* Less than 5	Surface film.	Loam with incrustations of salt.	1.07	.15	.09	None.	
Do	Flood plain of Whitewater Draw; 40 feet from channel.	Sacaton; a little mesquite.	*a* 10	0 to 1	Dark-gray gravelly loam	.37	.05	None.	None.	
				1 to 2	Dark-gray loam	1.41	.28	.18	None.	
				2 to 6	Dark-gray clay loam	2.45	.32	.33	None.	

a Estimated.

<.40 means less than .40 per cent, .40<.80 means more than .40 per cent and less than .80 per cent, etc.

VEGETATION IN RELATION TO WATER AND OTHER GEOGRAPHIC CONTROLS.[1]

By O. E. Meinzer.

ZONES OF VEGETATION.

With respect to its native vegetation, the drainage basin of Sulphur Spring Valley can be divided, from higher to lower levels, into (1) a forest zone, (2) an upland grass and brush zone, (3) a mesquite zone, (4) a sagebrush area, (5) a zone of alkali vegetation, and (6) a barren zone. The pronounced segregation of the dominant plant forms that gives rise to these zones is due to the radical differences, within this comparatively small region, in the physical conditions that control plant life. The most important of these controlling factors are soil, temperature, and water supply.

FOREST ZONE.

The forest zone includes the greater part of the mountain area, approximately 1,000 square miles, and also the upper parts of the valleys of some of the principal draws that descend the stream-built slopes. Over only small parts of the area is the forest dense or continuous; more commonly the trees are scattered or grow in clumps in sheltered places, extensive mountain areas being quite treeless. On the lofty ranges tall yellow pines predominate; on the foothills and lower ranges junipers, live oaks, and cedars are common; and in the ribbons of timber that stretch along the stream courses live oaks, sycamores, and cottonwoods prevail. The principal controlling factor in this area is its relatively abundant water supply.

UPLAND GRASS AND BRUSH ZONE.

The upland grass and brush zone occupies the higher parts of the valley adjacent to the mountains; it is bounded on its lower side by the mesquite zone, or, where the mesquite is absent, by the zone of alkali vegetation. It extends over approximately three-fourths of the valley. Most of the area is covered with a light growth of different sorts of grasses, but in the central and southern parts of the valley it includes extensive tracts of creosote and other bushes. It also includes "groves" of thrifty yucca (Pl. XIII, *B*). This rather heterogeneous zone contains much good soil but is characterized on the whole by a gravelly soil and an uncertain water supply. The greater part of it is as yet unpromising for agricultural development, especially because of the depth to ground water.

[1] The determinations of plants whose scientific names are given were made by J. J. Thornber, of the Arizona Experiment Station staff.

A. MESQUITE BELT.

B. YUCCA GROVE.

C. SAGEBRUSH ON WIND-BUILT AREA.

MESQUITE ZONE.

The mesquite zone is occupied by mesquite (*Prosopis glandulosa*) of moderate size, although small as compared with the large individuals of *Prosopis velutina* found farther west in the State. Bushes ranging from 5 to 10 feet in height are common, but those of 15 feet are rare. This zone lies on the middle and lower parts of the stream-built slopes (Pls. I, in pocket[1]; XIII, *A*). Its limits are as a rule well defined, although in some places, especially on the upper sides, they are indefinite. Exclusive of the tracts of scattered mesquite on the upper slopes, this zone covers about 250 square miles, or nearly one-sixth of the valley surface. It is wide on the broad gentle slopes that descend from the Pinaleno and Chiricahua mountains but more narrow on the abrupt slopes bordering the smaller ranges, and in some localities it wedges out entirely. Its inner limits seem, with some exceptions, to be established by the soil of the low tracts, both the alkali content and heavy clayey character of the lowland soil probably being uncongenial to mesquite. The conditions that establish its outer limits and prevent the mesquite from spreading generally to the upper slopes are not so obvious. The outer margin of the zone bears a general, though indefinite, relation to the depth to ground water.

As this zone holds an intermediate position, it includes a large proportion of the best soil of the valley and much of the area having moderate depth to ground water. Consequently it includes a large part of the area having the best agricultural prospects. Much labor is required to prepare the mesquite-covered land for cultivation, but this difficulty is not insurmountable and should not be given undue weight by prospective settlers.

SAGEBRUSH AREA.

Sagebrush (*Artemisia filifolia*), although not commonly found in this part of the country, predominates over an area of about 8 square miles, lying immediately east of Willcox (Pls. I, in pocket; XIII, *C*), and is present over an additional area of several square miles in the same general locality. It has a definite relation to the sandy soil of the wind-built area. A part of the sagebrush land has a sandy-loam soil of fairly good quality and is sufficiently level to be brought under irrigation, but a part is too sandy and hilly to be successfully irrigated or cultivated.

ZONE OF ALKALI VEGETATION.

Low tracts partly inclosed by the mesquite-covered areas support a vegetation entirely different from that found in any other part of

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[1] Note error on legend of map, Plate I.

the valley. The prevailing forms in these tracts are the saltbushes, Atriplex sp., commonly known as "chamiso," "shadscale," or "sagebrush"; the burro weed, Suæda, commonly found at the margin of the barren flat; the alkaline sacaton (*Sporobolus airoides*); and the Mexican salt grass (*Eragrostis obtusiflora*). All of these plants are alkali-resistant and for this reason occupy the soil which their more sensitive upland neighbors can not endure. The plants mentioned are to some extent segregated into subzones, the salt grass and Suæda generally occupying more alkaline land than the sacaton and chamiso. The Suæda maintains itself in clumps at the margin of the barren flat where the surface is otherwise destitute of vegetation (Pl. V, *B*, p. 33).

The tracts of alkali vegetation cover a total area of somewhat more than 100 square miles, the greater part of which lies in the north basin surrounding the barren flat. In this zone, especially in those parts in which salt grass and Suæda predominate, crops are liable to suffer from excessive alkali, and agricultural developments should therefore be made with caution.

BARREN ZONE.

The lowest part of the flat in the north basin comprises, as already stated, an area of slightly more than 50 square miles that is entirely destitute of vegetation (Pls. I, in pocket; V, *C*, p. 33). The analyses of all the samples taken from this flat show very high percentages of alkali, which condition no doubt accounts for the absence of even the plants that can endure relatively large amounts. The barren flat is of course entirely hopeless for agriculture.

GEOGRAPHIC CONTROLS.

As already indicated, the principal physical conditions that control the plant life of the region and create the well-defined zones of vegetation relate to the soil, temperature, and water supply.

SOIL.

The soils range between extreme limits, both in physical constitution and in soluble content. The valley contains very coarse gravelly soil, exceedingly dense clay soil, and all intermediate varieties. It contains soil from which practically all of the soluble mineral matter, even the calcium carbonate, has been removed, soil rich in lime and gypsum but free from alkali; and soil charged with more than 10 per cent of alkali. These radical differences are reflected in the vegetation. The sagebrush dominates over its competitors in the sandy soil of the wind-built area, but can not gain a foothold elsewhere. The creosote bush prefers the calcareous soil derived from limestone formations. The yucca and mesquite find a congenial habitat on the beach ridges but avoid the alkaline clay soil on either side. One type of grass flourishes on the heavy soil of an arroyo, another on the lighter soil of the natural levees that border the arroyo, and still another on the alkaline soil of the central flat. The saltbushes can not establish themselves in the mesquite zone, but they take possession of large parts of the alkaline tracts. Even among the saltbushes there is segregation resulting from adaptation to differing soil conditions, for one type selects the lighter and less strongly impregnated soil, and the other subsists, often without competition, on the heavier and more alkaline clay.

TEMPERATURE.

The differences in temperature within the region result chiefly from the differences in altitude, and, therefore, their effects upon vegetation are most noticeable on the mountains, where there are large and abrupt differences in altitude. In ascending a lofty range, such as the Chiricahua Mountains, one can not fail to observe the changes in the dominant tree species with increasing altitude, but one can not always be sure to what extent the changes result from reduced temperatures and to what extent from increased precipitation. However, that the changes in temperature have some influence is suggested by the fact that at the higher altitudes trees characteristic of regions farther north, such as deciduous oaks, are found. The mountains are not high enough to extend above the timber line, but near the top of the Chiricahua Range the trees are notably smaller and less prosperous than those of the same species at somewhat lower altitudes.

As a rule the temperature decreases with increasing altitude, but an exception to this rule is formed by the lowest parts of the valley, where the temperatures at night are generally lower than on the upper parts of the slopes and in the foothills. The low temperatures on the valley flats, which result from the fact that the cold, heavy air sinks to the lowest levels, have an important and well-recognized effect on fruit growing, the danger from frost being greater on the flats than in the higher parts of the valley.

WATER SUPPLY.

The three principal sources of water supply for the native vegetation are: (1) The moisture derived directly from rain or snow, (2) the freshets which occasionally flood the arroyos and spread in sheets over portions of the stream-built slopes, and (3) the ground water, wherever it is within reach of the roots of the native plants. The supply of water available for vegetation from any one of the three sources is very much greater in certain parts of the region than in others, and the influence of these differences on the character of the vegetation is so pronounced that it can not fail to be noticed.

The scanty precipitation in the valley and foothills has given rise to plants adapted to withstanding drought. On the other hand, the abundant precipitation on the lofty mountains has produced very different conditions of plant life, resulting in a very different flora, large prosperous forests taking the place of the thorny shrubs and drought-resisting grasses of the desert. Within the tree-covered area, moreover, there are differences in vegetation due to differences in the amount of rainfall. The tall yellow-pine timber on the high mountains, for instance, indicates more rainfall than the scattered cedars on the mesas and foothills.

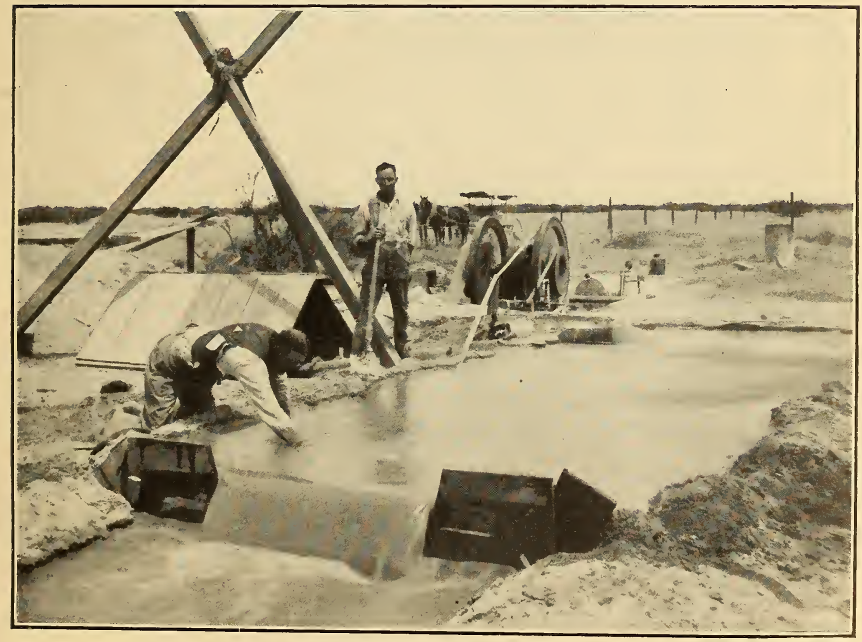
The land lying in the upper parts of the large draws, such as Bonita Draw and the draw of Turkey Creek, is frequently watered by floods emanating from the mountains; land lying in the smaller draws or in other favorable locations is occasionally, though more rarely, covered with flood water; and other extensive portions of the stream-built slopes are at present never refreshed with flood waters. The most favored draws produce a relatively luxuriant vegetation, some of them, such as Turkey Creek Draw and Whitewater Draw, being timbered with live oaks, sycamores, cottonwoods, and other trees for miles along their upper courses; the less frequently flooded areas are treeless, but produce a good crop of grass in seasons when they have been moistened by freshets; but the tracts not reached by floods produce only a sparse growth of grass or desert brush. In the fall it is not difficult to recognize the areas that were favored during the previous rainy season with one or more floods. The flooded belts commonly have grass large enough to be cut for hay, but the areas that have received no moisture except that supplied by the local rainfall have generally only a light covering of grass. The good grass that has made Sulphur Spring Valley as a whole such a valuable cattle range is largely produced by the sheet floods which at intervals spread over the smooth, extensive, and but slightly dissected slopes comprising the greater part of the valley.

Yucca will endure severe drought and accordingly is found on the poorly watered upper slopes. Yet even this plant has generally only a scattering growth on the areas that are not flooded, but is found in luxuriant "groves" in the tracts where the rainfall is occasionally supplemented by freshets.

Where the water table is near the surface the roots of plants extend down to it. The grasses and saltbushes of the low alkali tracts no doubt feed on ground water, which in these tracts saturates the soil nearly to the surface. Mesquite, which has deep roots and grows chiefly where the depth to water is not great, also no doubt depends

A. HOOKER'S RANCH.

Showing trees supported by high-level ground water.



B. PUMPING PLANT NO. 20.

in part on ground water, and its occurrence is to some extent restricted to the areas in which its roots can penetrate to this supply.

An intimate relation exists between the forested portions of the draws and the areas of high-level ground waters, suggesting that the trees may be supported by these relatively permanent supplies rather than by those obtained directly from the uncertain floods. (See Pl. XIV, *A*.) Along Turkey Creek, for example, the lower limit of trees corresponds pretty closely to the lower limit of high-level water. This relation has been observed in enough places to warrant prospecting for shallow water in the forested draws in which wells have not yet been sunk.

SUMMARY.

The geography of Sulphur Spring Valley is the resultant of a chain of natural events that are causally related to each other. The cycle was started by the deformation through which the mountains were lifted and the valley was depressed. The difference in altitude thus produced resulted in differences in temperature and corresponding differences in rainfall. Gravitation then cooperated with the rain and other agencies to dissect the mountains and to develop the smooth face of the valley with its large areas subjected to flooding, to segregate the soils of the valley into zones ranging from the densest clay to the lightest sand and gravel, to establish a water table that is practically at the surface in some places and hundreds of feet below in others, and to leach the soluble salts from a part of the land and concentrate them elsewhere. The differences in temperature, rainfall, flooding, physical constitution of the soil, depth to ground water, and concentration of the soluble salts are all consequent to the normal development of the geologic cycle begun by the deformation. They are all reflected in the native vegetation of the region, and they are controlling factors that can not safely be ignored in the agricultural conquest of the valley.

PUMPING PLANTS.

By F. C. Kelton.

DISTRIBUTION.

Scattered about Sulphur Spring Valley are about a hundred pumping plants (Pl. II, in pocket), ranging in capacity from 20 to 1,500 gallons a minute. This number does not include the numerous windmills which pump water for domestic uses, stock watering, and garden irrigation.

The pumping district is not confined to any particular portion of the valley, except as it is naturally limited by physical features, such as the concentration of alkali, which precludes the successful use of irrigating water in the lower parts, and the greater depths to water on the receding slopes. However, the region adjacent to the town of Willcox, especially the part lying to the northwest, is the most advanced in respect to pumping developments, chiefly because water is obtainable more easily there than elsewhere. As a rule each settler has been able to obtain a considerable supply by his own efforts and the use of hand tools only.

WELLS.

The common type of well consists of an open pit dug within a foot of water level and a bored hole extending down into the water-bearing strata. The boring is usually done by means of a post-hole auger operated by hand. The pump is set in the dug pit and connected through an inclined beltway to the engine at the surface. So far as observed the water level does not fluctuate appreciably throughout any one year, and the plant can therefore operate under uniform load. The pit is generally rectangular in section and may vary in size from 3 by 4 feet to 5 by 7 feet; the auger holes will average 8 or 9 inches in diameter, though some are as small as 6 inches and others as large as 14 inches. As the holes are generally left without casing, it is the opinion of the writer that they should be at least 10 inches in diameter for plants having a capacity of 450 gallons a minute (the usual rating for 4-inch centrifugal pumps) and 14 inches in diameter for plants having a capacity of 750 gallons a minute (5-inch centrifugals).

For wells of moderate depth sunk by contract the following prices prevail:

Cost of wells per foot of depth.

4 by 4 foot	$1.00
4 by 5 foot	1.25
4 by 6 foot	1.50
6-inch diameter	.75
8 or 10 inch diameter	1.00
Beltway (per cubic yard)	1.70

PUMPS AND ENGINES.

The common type of pumping plant consists of a gasoline engine belted to a horizontal centrifugal pump. The engines vary in size from 4 to 30 horsepower and the pumps from 2 to 8 inch diameter of opening. A typical plant has a 10-horsepower gasoline engine and a 4-inch horizontal centrifugal pump, with a lift of 35 feet.

SCOPE OF INVESTIGATION.

Duration.—Of the 20 representative plants selected for pumping tests, 8 had been recently installed. The remaining 12 had been installed in the previous irrigating season, but 8 of them had been delayed and had not been operated to any great extent. For this

A. PORTABLE WEIR BOX READY FOR TRANSPORTATION.

B. PORTABLE WEIR BOX IN USE.

reason reliable figures on cost of maintenance, repairs, attendance, and operation could not be obtained, and the investigation was necessarily limited to ascertaining the initial cost of plants, consumption and cost of fuel, yield of wells, and general efficiency. Long-time tests extending through a period of several days were not practicable. The tests covered three to nine hours.

Measurement of fuel.—Wherever possible, the consumption of gasoline, which at all plants was a No. 1 distillate, was measured in volume. Either the fuel tank was drained and a measured quantity of distillate put in and the time required to consume it noted, or the tank was filled at the start to some convenient and accurate measuring point and at the completion of the test the amount required to refill it to the same point was ascertained.

Measurement of lift.—At most plants the distance through which the water was lifted was measured with a steel tape. At a few falling water made the use of the tape impossible and a ¼-inch rubber tube was employed, the depth at which it entered the water being ascertained by blowing gently through the tube as it was being slowly lowered into the well. When the tube entered the water the vibration due to bubbling was very apparent.

Measurement of yield.—It was desired to measure the amount of water pumped as accurately as possible and the Cippoletti weir method was selected for this purpose. A temporary weir board set in the ditch was impracticable at many plants—for instance, at those where the soil is very sandy and porous, or where the well discharges directly into an earthen reservoir, or where the fall in the ditch is very slight. As most of the plants are equipped with centrifugal pumps ranging in size from No. 2 up to No. 5, and as the capacity of such pumps may be assumed to range from 100 to 900 gallons a minute, a portable weir box (Pl. XV), measuring 4 feet by 10 feet by 18 inches was constructed of No. 6 waterproofed duck and was found to measure with fair accuracy any quantity within these limits.

The qualities considered necessary in this box were water-tightness; flexibility, so that the box could be easily folded for transportation; durability, the material being such as to permit of frequent foldings without developing cracks or leaks; and simplicity and lightness, so far as consistent with the other requirements.

One end of the box was closed by a weir board of the standard Cippoletti type, having a crest of 15 inches, the water edge being perfected and protected by means of a plate of No. 16 galvanized iron cut to proper shape and screwed to the board. Flaps nailed to the weir board with cleats pervented leakage. The box was stiffened at the sides by galvanized-iron pipes thrust through loops and supported by strips of wood, and at the end opposite the weir board by a 1 by 4 inch board tacked to the canvas along the upper edge. The four corners of the box were supported by iron rods, which were passed through loops and driven into the ground.

For use, the box was adjusted beneath the discharge pipe of the pump, a foundation of boards being laid, where necessary, to insure a level position. A few boards were placed immediately under the discharge pipe of the pumping plant to receive and distribute the force of the falling water. An apron of scrap tin was used to prevent the falling water from causing scour. One baffle board was placed about 2 feet from the weir-board end of the box and another 3 feet from the opposite end, and the 5-foot space between the two was filled with green brush, weighted down, which permitted the water to percolate freely but quieted the wave motion and eddying, thus permitting accurate measurement of the head on the weir.

DESCRIPTION OF PLANTS AND RESULTS OF TESTS.

Plant No. 1.—Plant No. 1, located in the N. ½ sec. 29, T. 23 S., R. 27 E., and owned by Mr. George Giragi, was tested on May 14, 1911. The outfit includes a Fairbanks, Morse & Co. 4-horsepower vertical gasoline engine, with 22-inch drive pulley; an American No. 2½ horizontal centrifugal pump, with 8-inch pulley lagged to 8¾ inches; a 4-inch 4-ply rubber belt, with half turn, inclined 75° from the horizontal; a 3-inch suction pipe 17 feet long, with foot valve; and a 3-inch discharge pipe connected with a pipe line containing 36 feet of 4-inch and 830 feet of 3-inch pipe.

The well is dug to a depth of 49 feet, 4½ by 4½ feet, and is timbered with 2-inch rough lumber, with sets at 5-foot intervals. The normal water level stands at 31 feet. During the excavating the well was kept clear by a plunger pump, with a 4-inch piston and a 24-inch stroke, working 37 strokes per minute. No water-bearing sand or gravel was encountered, and no difficulty was experienced in keeping the water lowered until at 49 feet depth a 2-inch stratum of hard cemented material was pierced with an iron bar. When this cement was broken the bar is said to have sunk 3 or 4 feet into loose sand or gravel, and a strong flow of water gushed into the well.

Test of plant of George Giragi, N. ½ sec. 29, T. 23 S., R. 27 E. (plant No. 1).

Duration	hours	3.67
Water pumped	acre-inches	0.56
Maximum discharge measured	gallons a minute	115
Average discharge	do	69
Water level drawn down	feet	7.0
Average lift, static	do	40.0
Useful horsepower		0.70
Fuel used during test	gallons	1.47
Fuel used per useful horsepower-hour	do	0.58
Fuel used per acre-foot of water pumped	do	31.3

Speed of engine........................revolutions a minute..	395
Explosions per minute......................................	108 to 120
Speed of pump........................revolutions a minute..	917
Ratio of useful horsepower to rated horsepower of engine, when pumping through pipe line (practical efficiency)......per cent..	14. 8
Same, when discharging near well..........................do....	30
Cost:	
Engine..	$350
Pump, pipe, and belt (second hand)........................	65

Plant No. 2.—Plant No. 2, in the SW. ¼ sec. 24, T. 15 S., R. 25 E., is owned by Fred. Arzberger. It was installed in November, 1909, and was tested May 19, 1911. The plant is equipped with a Stover 6-horsepower horizontal gasoline engine; a Gould No. 2 horizontal centrifugal pump; a 6-inch 4-ply Gandy belt inclined 72° from horizontal, with a half turn; 18-inch and 6-inch pulleys; a 20-foot suction of 3-inch standard pipe, with foot valve; a discharge pipe of the same material, with 35 feet vertical, a standard elbow, and 3 feet horizontal. The engine and well are both in the cellar of the dwelling house.

The well was dug 33 feet to water level, after which an 8-inch auger hole was bored. The water is supplied from a 3-foot stratum of coarse rounded sand and gravel at a depth of about 51 feet. Clay was the only other material encountered below water level.

A pasteboard gasket in a flange connection of the suction pipe permitted some air leakage, thereby lessening the efficiency of the plant; and the pump did not have the speed required for the head against which it was working.

Test of plant of Fred. Arzberger, SW. ¼ sec. 24, T. 15 S., R. 25 E. (plant No. 2).

Duration..hours..	4. 43
Water pumped....................................acre-inches..	0. 71
Maximum discharge measured.................gallons a minute..	84
Average discharge ....do....	72
Water level drawn down...............................feet. .	10. 1
Discharge lift...do...	35. 7
Average suction lift...................................do...	9. 2
Average total lift......................................do...	44. 9
Useful horsepower..	.81
Ratio of useful horsepower to rated horsepower of engine (practical efficiency)..per cent..	13. 5
Speed of engine......................revolutions a minute..	275 to 278
Speed of pump.....................................do....	760 to 776
Cost of plant, not including well.............................	$335

Plant No. 3.—Plant No. 3, in the SE. ¼ sec. 21, T. 15 S., R. 25 E., belongs to V. H. Fross. It was tested May 20, 1911. It was installed in May, 1910, but the well was not completed until the spring of 1911. The pump, a Gould No. 2½ horizontal centrifugal, is belted to a Root & Vandervoort 4-horsepower vertical gasoline engine. The belt is of 4-inch 4-ply rubber, inclined 45°. The 4-inch suction pipe is 21 feet long; the discharge pipe is of the same diameter, and delivers the water vertically into a wooden flume. There is a check valve at the lower end of the discharge pipe, the priming being done by means of a pitcher pump.

The well pit was first dug to a depth of 12 feet, the water level standing at 13 feet. A 7-inch hole was then bored 55 feet deep, showing the following log:

Log of well of V. H. Fross, SE. ¼ sec. 21, T. 15 S., R. 25 E.

Material.	Thickness.	Depth.
	Feet.	*Feet.*
Adobe soil	2½	2½
Clay with streaks of caliche	8½	11
Clean uniform sharp sand of medium size	1	12
Clay	1	13
Fine sand, packed. No casing required	2	15
Alternating layers of clay and caliche, with clay predominating	15	30
Rounded sand and gravel with some clay. Caves	2	32
Clay	23	55

The stratum from 30 to 32 feet is the only one containing any appreciable amount of water. To tap this stratum, five additional holes were bored at intervals of about 10 feet and connected with the first well by a drift whose bottom is 5 feet below normal water level. As the water rises and flows through the drift to the pumping pit, an effective 5-foot drawdown is maintained in each of the auxiliary wells. On account of a slipping belt and an underspeeded pump, the plant did not yield nearly its full capacity. However, the water level in the main well was drawn down 9.3 feet, or to 4.3 feet below the bottom of the tunnel, and the auxiliary wells therefore gave their maximum yield, and any greater efficiency of the plant would have to depend for additional water on the main well only. The pump is rated at 185 gallons a minute. At the end of the test run, with a drawdown of 9.3 feet, the discharge was only 60 gallons a minute, showing conclusively that the water supply obtainable from the present development is entirely inadequate for the capacity of the pump. The wells undoubtedly interfere with each other; and even at its best the 2-foot water-bearing stratum tapped could be but a poor yielder. Probably the best solution of the water-supply problem in this vicinity is to sink deeper. A machine-drilled well, with a casing with suitable perforations, would be preferable to the post-auger holes now in use.

Test of plant of V. H. Fross, SE. ¼ sec. 21, T. 15 S., R. 25 E. (plant No. 3).

Duration .... hours..	3. 92
Water pumped .... acre-inches..	0. 63
Average discharge .... gallons a minute..	73
Water level drawn down .... feet..	9. 3
Average lift .... do...	18. 6

Plant No. 4.—Plant No. 4, in the NE. ¼ sec. 22, T. 15 S., R. 25 E., is owned by R. F. McHenry. The plant was installed in March, 1911, and the test was made May 21, 1911. A 6-horsepower horizontal gasoline Economy engine operates a No. 2 Gould horizontal centrifugal pump. The belt is 6-inch 4-ply stitched canvas, inclined about 55° from the horizontal. The pulleys are of 16-inch and 8-inch diameters, the latter being lagged with one thickness of belting, which increases its diameter to 8½ inches. The pump is primed by means of a hand primer on the suction. The piping is 3-inch spiral riveted. The length of suction is 20 feet. The discharge pipe is bolted 4 feet above the ground to a flume with a 2-inch plank bottom and galvanized-iron sides.

The well is dug 22½ feet, with dimensions 3 by 5 feet. Only the upper 4 feet are curbed. The 8-inch bored hole, 24 feet deep, is without casing. At 42 feet a 3-foot stratum of sand and fine gravel was penetrated.

The breaking of a bolt on the governor rod brought the test to an abrupt close sooner than was intended.

Test of plant of R. F. McHenry, NE. ¼ sec. 22, T. 15 S., R. 25 E. (plant No. 4).

Duration .... hours..	3. 33
Water pumped .... acre-inches..	0. 69
Average discharge .... gallons a minute..	104
Water level drawn down .... feet..	8. 5
Average lift .... do...	34. 3
Useful horsepower	0. 89
Fuel used during test .... gallons..	1. 5
Fuel used per useful horsepower-hour .... do....	0. 56
Fuel used per acre-foot of water pumped .... do....	26. 1
Speed of engine .... revolutions a minute..	323 to 335
Speed of pump .... do....	655 to 670
Ratio of useful horsepower to rated horsepower of engine (practical efficiency) .... per cent..	14. 8
Cost:	
Engine	$145. 00
Pump	82. 00
Belt	13. 50
Curbing, flume, etc	5. 00
	245. 50

Plant No. 5.—Plant No. 5, in the SE. ¼ sec. 3, T. 16 S., R. 24 E., is owned by Walter Whitener. The pump was installed in January, 1911, and the test was made June 9, 1911. A Stover portable 10-horsepower gasoline engine is owned jointly with a neighbor and is moved back and forth to be used in turn. The pump is a No. 4 American vertical centrifugal. The suction pipe is of 6-inch standard casing, and the discharge pipe 4-inch casing, with a short-turn elbow and 10 feet horizontal. There is a 6-inch Gandy belt drive on 20-inch and 8-inch pulleys. The pump is not submerged, but is set just above the normal water level at 23 feet.

The well is dug, about 5 feet square, to 23 feet, the upper 17 feet being curbed with 1 by 12 inch boards. An 8-inch bored hole extends to 54 feet, with the lower 20 feet cased with galvanized iron. The casing is freely perforated with hatchet-made slits about 1½ inches long, with the burrs on the outside.

Log of well of Walter Whitener, SE. ¼ sec. 3, T. 16 S., R. 24, E.

Material.	Thickness.	Depth.
	Feet.	*Feet.*
Sandy loam	4	4
Free coarse sand and gravel	9	13
Alternating layers of clay, hardpan, and fine packed sand	21	34
Loose fine sand	3.5	37.5
Clay	12	49.5
Hardpan	0.5	50
Brownish, clean, coarse sand and gravel	4	54

Test of plant of Walter Whitener, SE. ¼ sec. 3, T. 16 S., R. 24 E. (plant No. 5).

Duration .... hours..	2.83
Water pumped .... acre-inch..	0.72
Maximum discharge measured .... gallons a minute..	127
Average discharge .... do....	114
Water level drawn down .... feet..	8.3
Average lift .... do...	33.6
Useful horsepower	0.97
Ratio of useful horsepower to rated horsepower of engine (practical efficiency) .... per cent..	9.7
Cost:	
Engine (one-half interest)	$235
Pump, shafting, pipe, and belt	176
Lumber in well	10

Plant No. 6.—Plant No. 6, in the SW. ¼ sec. 20, T. 13 S., R. 24 E., belongs to L. W. Vertrees. It was installed in May, 1910, and tested May 16, 1911. The engine is a Foos Junior 4-horsepower horizontal gasoline. The pump is a Gould No. 2½ horizontal centrifugal driven by a 4-inch, 4-ply rubber belt working on 10-inch and 5-inch pulleys at about 60°. The 3-inch suction pipe is of galvanized-iron, spiral riveted, 10 feet long, and has a foot valve. The discharge pipe is of the same size and material, with 20 feet of horizontal 4-inch pipe, which discharges 3 feet above the ground.

The dug portion of the well is 4 by 6 by 25 feet, uncurbed. The first 14 feet of bored hole is 12 inches in diameter, with a galvanized-iron casing perforated with slits that are very narrow—too narrow to permit the free entrance of water. The lower 11 feet of the well is 10 inches in diameter, with no casing. The total depth is 50 feet, with water at 26 feet. The log was estimated as follows:

Log of well of L. W. Vertrees, SW. ¼ sec. 20, T. 13 S., R. 24 E.

Material.	Thickness.	Depth.
	Feet.	*Feet.*
Soil, clay, etc	28	28
"Second water." Alternating layers in equal amount of medium-sized gravel and fine sand	13	41
Clay	9	50
"Third water," in gravel.		

Test of plant of L. W. Vertrees, SW. ¼ sec. 20, T. 13 S., R. 24 E. (plant No. 6).

Duration	hours	6.23
Water pumped	acre-inches	1.97
Maximum discharge	gallons a minute	156
Average discharge	do	142
Water level drawn down	feet	7.4
Discharge lift	do	26.0
Average suction lift	do	6.5
Average total lift	do	32.5
Useful horsepower		1.17
Fuel used during test	gallons	3.0
Fuel used per useful horsepower-hour	do	0.41
Fuel used per acre-foot of water pumped	do	18.3
Speed of engine	revolutions per minute	336 to 343
Speed of pump	do	625 to 626
Ratio of useful horsepower to rated horsepower of engine (practical efficiency)	per cent	29.2

Plant No. 7.—Plant No. 7, in the SW. ¼ sec. 12, T. 12 S., R. 23 E., is the property of A. I. McAllister. It was installed in July, 1910, and was tested May 14, 1911. A Witte 12-horsepower horizontal gasoline engine is belted to an American No. 3½ vertical centrifugal pump. The belt is a 6-inch 4-ply Gandy. The engine and pump pulleys are 30 and 7 inches in diameter, respectively. The 5-inch suction pipe is 12 feet long. The 5-inch discharge pipe is bolted to the bottom of a galvanized iron barrel 5 feet above the ground.

The well pit is 3½ by 4½ feet by 62 feet, curbed all the way with 1 by 12 inch pine. A bored hole 8 inches in diameter extends 13 feet deeper, cased with galvanized iron; the lower 5 feet is perforated.

The engine was greatly overloaded and its speed was irregular and spasmodic. At frequent intervals the pump ceased to deliver water and required repriming. The engine is too small for the work. The lift at the start is 66.4 feet, and a drawdown of 10 feet should be allowed for. If the capacity of the pump is 370 gallons a minute as rated, and if an efficiency of 40 per cent is allowed for the entire plant, an 18-horsepower engine should be used.

It was impossible to measure the lowering of the water level, because the pump fitted closely over the casing of the well. The portable weir box proved particularly valuable in measuring the discharge, for the soil was loose and sandy and the fall in the ditch very slight.

Test of plant of A. I. McAllister, SW. ¼ sec. 12, T. 12 S., R. 23 E. (plant No. 7).

Duration	hours	3.88
Water pumped	acre-inches	1.25
Maximum discharge measured	gallons a minute	195
Average discharge	do	145
Discharge lift	feet	66
Average total lift (estimated)	do	73.00
Useful horsepower (approximate)		2.65
Fuel used during test	gallons	9.0
Fuel used per useful horsepower-hour	do	0.87
Fuel used per acre-foot of water pumped	do	86.4
Ratio of useful horsepower to rated horsepower of engine (practical efficiency)	per cent	22.1

Plant No. 8.—Plant No. 8, in the NE. ¼ sec. 10, T. 14 S., R. 25 E., is owned by Stanley W. Craig. The installation was made in January, 1911, and the plant was tested June 8, 1911.

A Root & Vandervoort 6-horsepower horizontal gasoline engine is belted to a Byron Jackson No. 2½ horizontal centrifugal pump. The engine has a wooden pulley 24 inches by 6 inches, and the pump a 5-inch iron pulley. The belt is 5-inch 4-ply rubber inclined about 60°. The suction pipe is 28 feet long, of 3½-inch outside diameter casing, with check valve just below the pump. The discharge pipe is 27 feet 8 inches long, of 4-inch outside diameter casing, discharging vertically into a galvanized-iron tub and flume.

The first 12 feet of the well are of 6 by 7 feet dimension, the upper 6 feet being curbed with 1 by 12 inch redwood laid vertically. The next 16 feet are 4 feet square, without curbing. The water stands at 28 feet. A 9-inch hole extends to 65 feet, having 33 feet of 8½-inch galvanized-iron casing without perforations, in 30-inch lengths, with the joints lapped 1¾ inches and riveted.

Log of well of S. W. Craig, NE. ¼ sec. 10, T. 14 S., R. 25 E.

Material.	Thickness.	Depth.
	Feet.	*Feet.*
Sandy soil	5½	5½
Lime formation, uniform and consistent	6	11½
Fine sand and silt, packed (water level at 28 feet)	16½	28
Fine sand and silt similar to above stratum, but more sandy and less earthy. Runs freely, requiring casing	9	37
Hard clay. Last 6 inches took two men half a day to bore	3	40
Fine sand, packed, but otherwise same as above 9-foot stratum	8	48
Clay with several 3-inch to 12-inch layers of fine free sand and a few streaks of caliche; the latter had to be broken with a bar	14	62
Free, coarse, clean sand	3	65
Hard clay.		

Test of plant of S. W. Craig, NE. ¼ sec. 10, T. 14 S., R. 25 E. (plant No. 8).

Duration	hours	7.05
Water pumped	acre-inches	2.36
Maximum discharge measured	gallons a minute	202
Average discharge	do	151
Water level drawn down	feet	18.4
Discharge lift	do	28.5
Average suction lift	do	15.9
Average total lift	do	44.4
Useful horsepower		1.69
Fuel used during test	gallons	5.2
Fuel used per useful horsepower-hour	do	0.44
Fuel used per acre-foot of water pumped	do	26.4
Speed of engine	revolutions a minute	304 to 310
Speed of pump	do	1,390 to 1,400
Ratio of useful horsepower to rated horsepower of engine (practical efficiency)	per cent	28.2
Cost:		
Plant, not including well		$395
Lumber for engine house and well curbing		25

Plant No. 9.—Plant No. 9, in the NW. ¼ sec. 28, T. 22 S., R. 26 E., is the property of J. E. Brophy, of Bisbee. The test was made May 26, 1911, about three months after the plant was installed.

The engine is a 3-horsepower vertical gasoline from the Union Gas & Electric Engine Co., of Los Angeles. It is in a pit 7 feet below ground level. The pump is a Byron Jackson 2½-inch horizontal centrifugal. A 4-inch rubber belt is used, set at 45°. The pulleys are of 15-inch and 6-inch diameters. The log of the well was given as follows:

Log of well of J. E. Brophy, NW. ¼ sec. 28, T. 22 S., R. 26 E.

Material.	Thickness.	Depth.
	Feet.	*Feet.*
Soil	1	1
Clay	14	15
Quicksand	12	27
Coarse rounded sand and gravel	94	121
Clay	383	504

The water level is at 19 feet. The dug hole extends to the gravel bed at 27 feet, and from it a 6-inch drilled hole, cased with unperforated black pipe, extends to a total depth of 504 feet. At first 8-inch pipe was used, with ½-inch holes for perforations. After two lengths of pipe had been sunk the upper end of the casing became battered from driving and the hole was reduced to 6 inches. In addition to the deep hole, another is drilled to a depth of 24 feet below water level and cased with 6-inch sand-screen casing.

Test of plant of J. E. Brophy, NW. ¼ sec. 28, T. 22 S., R. 26 E. (plant No. 9).

Duration	hours	6.00
Water pumped	acre-inches	2.10
Average discharge	gallons a minute	157
Water level drawn down	feet	7.3
Average lift	do	27.7
Useful horsepower		1.10
Fuel used during test	gallons	3.0
Fuel used per useful horsepower-hour	do	0.45
Fuel used per acre-foot of water pumped	do	17.2
Speed of engine	revolutions a minute	408 to 426
Explosions a minute		204 to 213
Speed of pump	revolutions a minute	1,031 to 1,080
Ratio of useful horsepower to rated horsepower of engine (practical efficiency)	per cent	36.7

Plant No. 10.—Plant No. 10, in the SW. ¼ sec. 3, T. 24 S., R. 27 E., about 2½ miles northwest of Douglas, is owned by George Turvey, who uses it to irrigate 10 acres of vegetable garden for the city market. It was tested May 25, 1911.

The plant consists of a Weber 6-horsepower horizontal gasoline engine with 24-inch pulley; a Byron Jackson No. 3½ horizontal centrifugal pump, with 7½-inch pulley; a 6-inch rubber belt, with half turn, inclined 77° with the horizontal; 5-inch suction and discharge pipes; and a foot valve.

The pump is set in a pit 20 feet deep. A machine-drilled hole extends to 306 feet and is lined with 8-inch casing without perforations to a depth of 240 feet. The log of the well was not obtainable. A small stratum of water-bearing material was encountered at 93 feet. This stratum was tested, at the time of drilling, with a 2½-inch centrifugal pump, and its supply was quickly exhausted. The present supply is obtained entirely from the 300-foot level.

Test of plant of George Turvey, SW. ¼ sec. 3, T. 24 S., R. 27 E. (plant No. 10).

Duration	hours	7.35
Water pumped	acre-inches	3.36
Maximum discharge measured	gallons a minute	261
Average discharge	do	206
Water level drawn down	feet	3.6
Discharge lift	do	21.9
Average suction lift	do	16.4

Average total lift .... feet..	38.3
Useful horsepower	1.99
Fuel used during test .... gallons..	5.8
Fuel used per useful horsepower-hour .... do....	0.40
Fuel used per acre-foot of water pumped .... do....	20.7
Speed of engine .... revolutions per minute..	316 to 375
Speed of pump .... do....	940 to 1,130
Ratio of useful horsepower to rated horsepower of engine (practical efficiency) .... per cent..	33.2
Cost:	
Engine	$275
Pump	85
Piping	25
Belt	17
Shed	30
Drilling well [1]	618
Casing	284
	1,334

Plant No. 11.—Plant No. 11, in the NE. ¼ sec. 4, T. 17 S., R. 25 E., belonging to H. E. Wright, was tested May 21, 1911. It is equipped with a McVickers automatic 6-horsepower horizontal gasoline engine and a Gould No. 2½ horizontal centrifugal pump. The 4-inch suction pipe is 22 feet long. The 2½-inch discharge pipe is 10 feet vertical and 6 feet horizontal.

The dimensions of the well are 7 by 7 by 17 feet, with an auger hole extending to a total depth of 75 feet from the surface. It was said that the first water was found at 10 to 15 feet in a coarse, loose sand, the second water from 23 to 26 feet in similar material with the addition of some small gravel, and the third water from 47 to 50 feet in gravel ranging up to 3 inches in size and containing very little sand. The hole was originally cased with 8-inch galvanized-iron pipe with small punched holes for perforations. These perforations did not yield water readily and the casing was withdrawn, after which the hole filled nearly to the bottom of the suction pipe with caved material.

The loose condition of the first water stratum necessitated its being curbed with 2 by 12 inch plank. A short length of galvanized-iron pipe extends through the second water-bearing stratum.

The capacity of the well was overtaxed in 19 minutes while pumping at an average rate of 210 gallons a minute. It is probable that this apparent deficiency is due not to a lack of water supply but to inefficient methods of development.

[1] The price charged for the drilling was divided as follows:

First 100 feet	$150
Second 100 feet	200
Third 100 feet	250
Last 6 feet	18
	618

Test of plant of H. E. Wright, NE. ¼ sec. 4, T. 17 S., R. 25 E. (plant No. 11).

Duration	hours..	0.32
Water pumped	acre-inches..	.15
Maximum discharge measured	gallons a minute..	237
Average discharge	do....	210
Water level drawn down	feet..	16.6
Average lift	do...	18.5
Useful horsepower		.98
Ratio of useful horsepower to rated horsepower of engine (practical efficiency)	per cent..	16.3

Plant No. 12.—Plant No. 12, in the SE. ¼ sec. 21, T. 13 S., R. 24 E., is owned by J. W. Ditmars. It was installed in May, 1910, and the test was made June 6, 1911. The plant consists of a Gould No. 3 horizontal centrifugal pump; an International Harvester Co. engine rated at 6-horsepower; a 16-inch driving pulley, and a 7-inch driven pulley; an 8-inch 5-ply stitched canvas belt; a 4-inch suction pipe 16 feet long, of spiral riveted pipe, with combination hand primer and check valve; and a 4-inch galvanized-iron discharge pipe, delivering the water 3½ feet above the ground.

The well is of the usual type. The pit is 4 by 6 by 22 feet, uncurbed. The 10-inch bored hole extends to 40½ feet, without casing. The log was given as follows:

Log of well of J. W. Ditmars, SE. ¼ sec. 21, T. 13 S., R. 24 E.

Material.	Thickness.	Depth.
	Feet.	*Feet.*
Sandy adobe soil	2	2
Clay interspersed with chunks of hard, white caliche	17	19
Packed coarse sand (water)	3	22
Clay	18	40
Coarse "second water" gravel	½	40½

Test of plant of J. W. Ditmars, SE. ¼ sec. 21, T. 13 S., R. 24 E. (plant No. 12).

Duration	hours..	6.00
Water pumped	acre-inches..	2.97
Average discharge	gallons a minute..	223
Water level drawn down	feet..	6.4
Discharge lift	do...	24
Average suction lift	do...	8.2
Average total lift	do...	32.2
Useful horsepower		1.81
Fuel used during test	gallons..	4.7
Fuel used per useful horsepower-hour	do....	0.43
Fuel used per acre-foot of water pumped	do....	19.0
Ratio of useful horsepower to rated horsepower of engine (practical efficiency)	per cent..	30.2
Cost of plant (about)		$510

Plant No. 13.—Plant No. 13, in the SE. ¼ sec. 27, T. 13 S., R. 25 E., belongs to A. E. Keeth, of Willcox. It was installed in January, 1911, and was tested June 4, 1911. The outfit consists of a Stover portable 10-horsepower engine belted to an American No. 3½ horizontal centrifugal pump. A 6-inch 4-ply Gandy belt works on 20-inch and 8-inch pulleys at 45°. Suction and discharge pipes are of 5-inch standard pipe. The discharge pipe is bolted to a flume made with a plank bottom and galvanized-iron sides.

The well consists of a dug pit 4 by 6 by 23 feet and a 14-inch bored hole to a total depth of 50 feet. Neither pit nor bored hole required any casing. The first 18 feet consisted of alternating layers of soil and hard clay, below which were 28 feet of hard-packed fine sand, then 4 feet of coarser sand and a little fine gravel, packed. At 50 feet a hard rocklike substance was struck, upon which no impression could be made with auger or iron bar.

Test of plant of A. E. Keeth, SE. ¼ sec. 27, T. 13 S., R. 25 E. (plant No. 13).

Duration	hours	3.78
Water pumped	acre-inches	2.16
Maximum discharge measured	gallons a minute	296
Average discharge	do	258
Water level drawn down	feet	12.4
Discharge lift	do	24
Average suction lift	do	11.7
Average total lift	do	35.7
Useful horsepower		2.33
Ratio of useful horsepower to rated horsepower of engine (practical efficiency)	per cent	23.3
Cost of engine, pump, pipe, pulleys, belt, and flume		$700
Contract cost of well and engine house (not built)		125

Plant No. 14.—Plant No. 14, in the SE. ¼ sec. 26, T. 13 S., R. 24 E., owned by J. J. Gandy, was installed in June, 1910, and was tested May 10, 1911. Some difficulty was experienced in starting the engine on account of the poor quality of the fuel oil. Twice during the test the engine stopped completely, and each time about 12 minutes were consumed in restarting. The engine is an 8-horsepower horizontal gasoline, of Witte make. The pump, an American No. 4 horizontal centrifugal, is placed in a pit 16 feet below the surface of the ground and is operated by a 6-inch rubber belt workin a tunnel beltway at 45°. Six-inch suction and discharge pipes are used, the former being 18 feet long.

The pit is 3 by 4 by 16 feet, with an 8-inch bored hole extending to a total depth of 40 feet. The water table stands at 18 feet. Neither the dug nor bored portions of the well have any curbing or casing. The tunnel beltway was made by boring with an auger at the desired inclination and enlarging.

The pump discharges into a small reservoir, necessitating the use of the portable weir box for measuring the water. A plank platform resting on a temporary timber crib was improvised and served admirably as a support for the weir box. The water stood about a foot deep in the surrounding reservoir. It was difficult to measure the depth to water in the well when the pump was running. This was finally done, however, by gradually lowering a rubber tube and blowing into it constantly. When the tube enters the water, the vibrations caused by the bubbling can be easily felt.

The 1.89 acre-inches of water pumped were used to irrigate 0.84 acre of corn to a depth of 2.24 inches.

Test of plant of J. J. Gandy, SE. ¼ sec. 26, T. 13 S., R. 24 E. (plant No. 14).

Duration	hours	3.18
Water pumped	acre-inches	1.89
Maximum discharge measured	gallons a minute	296
Average discharge	do	268
Water level drawn down	feet	10.5
Discharge lift	do	19.0
Average suction lift	do	12.0
Average total lift	do	31.0
Useful horsepower		2.11
Fuel used during test	gallons	3.18
Fuel used per useful horsepower-hour	do	.47
Fuel used per acre-foot of water pumped	do	20.2
Ratio of useful horsepower to rated horsepower of engine (practical efficiency)	per cent	26.4
Cost:		
Engine		$534
Pump		90
Belt		12
Shed		40
		676

Plant No. 15.—Plant No. 15, in the NE. ¼ sec. 33, T. 12 S., R. 24 E., belonging to C. O. Miller, was installed in April, 1910, and tested October 25, 1910. A Peerless 8-horsepower upright gasoline engine operates a Byron Jackson No. 3 horizontal centrifugal pump by means of a 6-inch 4-ply rubber belt working at about 57° from the horizontal. The pulleys are 26 and 6 inches in diameter. Both suction and discharge pipes are 4 inches in diameter, the former having a foot valve and strainer. The discharge pipe delivers the water vertically into a short length of wooden flume 1 foot wide by 1 foot deep.

The dimensions of the well pit are 4 by 5 by 34 feet, the water level being 35 feet from the surface. In the bottom of the pit an 8-inch bored hole, uncased, extends to a further depth of 18 feet.

The lower 2 feet of the bored hole were said to be caved, so that at the time of the test the depth of water in the well was 15 feet.

The engine is well protected by a house 10 feet square, and the plant is operating quite successfully. During the test, 6.05 acre-inches of water were pumped and, after being conveyed about half a mile in an open ditch, were applied to 1.06 acres of alfalfa. The depth of irrigation, not allowing for loss, was therefore 5.7 inches.

Test of plant of C. O. Miller, NE. ¼ sec. 33, T. 12 S., R. 24 E. (plant No. 15).

Duration....hours..	9.95
Water pumped....acre-inches..	6.05
Maximum discharge, measured....gallons a minute..	287
Average discharge....do....	274
Water level drawn down....feet..	7.3
Discharge lift....do...	36.0
Average suction lift....do...	8.0
Average total lift....do...	44.0
Useful horsepower....	3.06
Fuel used during test....gallons..	6.05
Fuel used per useful horsepower-hour....do....	.20
Fuel used per acre-foot of water pumped....do....	12.0
Speed of engine....revolutions a minute..	300
Speed of pump (computed)....do....	1,300
Ratio of useful horspower to rated horsepower of engine (practical efficiency)....per cent..	38.2
Cost:	
Engine....	$450
Pump, suction, and foot valve (second hand)....	75
Well, belt and discharge pipe....	100
	625

Plant No. 16.—Plant No. 16, in the NE. ¼ sec. 8, T. 13 S., R. 24 E., is owned by J. E. Casner. Originally a smaller plant was installed, consisting of a 4-horsepower engine and a 2-inch centrifugal pump, but this was replaced in May, 1911, by the present outfit. The test was made June 5, 1911. A Stover 10-horsepower horizontal gasoline engine, set upon a good concrete foundation, operates a Gould No. 4 horizontal centrifugal pump by means of a 6-inch 4-ply rubber belt working on pulleys of 22-inch and 10-inch diameters at 62°. Suction and discharge pipes are of 6-inch standard size. A wooden flume, which ordinarily delivers the water into an earth reservoir 60 feet by 150 feet, was swung around during the test and delivered the water into the portable weir box. There is no valve on the piping. Priming is done by plugging the end of the discharge pipe and exhausting the air from the centrifugal by a hand pump.

The well pit is 4 by 5 by 28 feet, without curbing. The bored hole was formerly of 7-inch diameter and was tested with a 2-inch pump when it had been bored to a total depth of 67 feet. Twelve feet of suction pipe exhausted the water in 30 seconds. The hole was then continued 3 feet deeper and a coarse gravel was encountered, after which the same pump could lower the water level only 9 feet in a day's pumping. After several days pumping, the water level could be drawn down only 5 feet 2 inches. When the 4-inch pump was purchased, the 7-inch hole was reamed out to 9 inches. The water level was reached at 29 feet, but the first good water-bearing material was a coarse gravel at a depth of 70 feet.

Test of plant of J. E. Casner, NE. ¼ sec. 8, T. 13 S., R. 24 E. (plant No. 16).

Duration	hours..	5.18
Water pumped	acre-inches..	3.50
Average discharge	gallons a minute..	304
Water level drawn down	feet..	9.5
Discharge lift	do...	30.8
Average suction lift	do...	11.4
Average total lift	do...	42.2
Useful horsepower		3.24
Fuel used during test	gallons..	7.0
Fuel used per useful horsepower-hour	do....	.42
Fuel used per acre-foot of water pumped	do....	24.0
Ratio of useful horsepower to rated horsepower of engine (practical efficiency)	per cent..	32.4

Cost:	
Engine	$400
Pump	100
Well	100
Piping	60
Housing	60
Belt	35
Flume	5
	760

Plant No. 17.—Plant No. 17, on the ranch of C. E. Ellinwood, in the SE. ¼ sec. 30, T. 13 S., R. 25 E., was installed in June, 1910, and was tested October 17, 1910. It consists of a Samson 12-horsepower horizontal gasoline engine and a Samson No. 4 horizontal centrifugal pump. The discharge pipe is 6 inches in diameter and the suction 5 inches in diameter and 10 feet long. An 8-inch 4-ply rubber belt works at about 40° from horizontal, the engine and pump pulleys being 24 and 10 inches in diameter, respectively. The cylinder of the engine is connected with the pump suction and discharge by means of a 1-inch pipe which furnishes circulating water for the cooling system.

The well pit was dug to a depth of 11 feet; then a 7-inch hole was bored 18 feet deeper. The total depth of the well is therefore 29 feet and at the time of the test the water level stood at 12.4 feet from the surface. On account of caving sand the first stratum of water was cased off with a 12-inch square cement box, 6 feet deep. At a depth of about 21 feet a 3-foot stratum of sand and gravel was encountered. At first a perforated casing was tried, extending down through this sand and gravel into clay. The perforations did not yield enough water and the casing was withdrawn. The sand and gravel then caved, limiting the possible length of suction pipe to 10 feet. In the present undeveloped condition of the well, the plant can not be run at its full capacity. The results of the test, however, indicate that a yield of 400 gallons a minute can at present be maintained under average pumping conditions. Further development of the well would undoubtedly greatly increase this amount.

Test of plant of C. E. Ellinwood, SE. ¼ sec. 30, T. 13 S., R. 25 E. (plant No. 17).

Duration	hours	3.62
Water pumped	acre-inches	3.24
Maximum discharge measured	gallons a minute	491
Average discharge	do	403
Water level drawn down	feet	6.0
Discharge lift	do	12.0
Average suction lift	do	9.0
Average total lift	do	21.0
Useful horsepower		2.16
Fuel used during test	gallons	6.0
Fuel used per useful horsepower-hour	do	0.77
Fuel used per acre-foot of water pumped	do	22.2
Speed of engine	revolutions a minute	235 to 273
Speed of pump	do	534 to 618
Ratio of useful horsepower to rated horsepower of engine (practical efficiency)	do	18.2
Cost of plant, excluding well (about)		$580

Plant No. 18.—Plant No. 18, in the NW. ¼ sec. 12, T. 13 S., R. 24 E., owned by F. M. Harris, was installed in June, 1910, and tested May 13, 1911. The plant consists of a Stover 10-horsepower vertical gasoline engine and an American No. 4 horizontal centrifugal pump. The belt is a 6-inch Gandy, with a half turn, working at 70° on 20-inch and 8-inch pulleys. The suction is of 6-inch black pipe, 12 feet long. The discharge pipe is of the same material, and has an elbow and one length of horizontal pipe, on the outer end of which is a flap valve. The water is delivered into a wooden distributing box, from which ditches lead in three directions.

Water is here struck at 22 feet and the well is 43 feet deep. A pit 4 by 8 feet was dug to water level and an 8-inch hole bored 21 feet deeper. The pit is curbed for the upper 8 feet only. The bored hole has no casing. The well was dug by a former occupant of the ranch and its log was not obtainable.

The feed pump on the engine gave considerable trouble by not feeding sufficient fuel per stroke. Occasionally it had to be worked rapidly by hand.

The water was measured on a 12-inch Cippoletti weir about 15 feet from the point of discharge.

Test of plant of F. M. Harris, NW. ¼ sec. 12, T. 15 S., R. 24 E. (plant No. 18).

Duration.........hours..	6.75
Water pumped.........acre-inches..	6.71
Maximum discharge measured.........gallons a minute..	457
Average discharge.........do....	447
Water level drawn down.........feet..	6.6
Discharge lift.........do...	26.0
Average suction lift.........do...	8.3
Average total lift.........do...	34.3
Useful horsepower.........	3.87
Fuel used during test.........gallons..	8.5
Fuel used per useful horsepower-hour.........do....	0.33
Fuel used per acre-foot of water pumped.........do....	15.2
Speed of engine.........revolutions per minute..	312
Speed of pump.........do....	750
Ratio of useful horsepower to rated horsepower of engine (practical efficiency).........per cent..	38.7
Cost of plant.........	$625

Plant No. 19.—Plant No. 19, in the NW. ¼ sec. 11, T. 13 S., R. 24 E., is owned by J. W. Baker. It was installed in June, 1910, and was tested May 12, 1911. A Peerless 12-horsepower vertical gasoline engine with a 26-inch driving pulley is connected by means of an 8-inch 4-ply rubber belt, inclined at about 60°, with an American No. 4 horizontal centrifugal pump having an 8-inch pulley. The water from the pump is elevated about 4 feet above the ground level and is delivered from a horizontal arm of the discharge pipe 18 feet from the well. The 6-inch discharge pipe is of galvanized iron and contains a check valve just above the pump. There is an 18-foot length of 6-inch suction pipe. The pump is primed by a hand pitcher pump.

The well is dug 4 by 5 feet to 25 feet. The upper 8 feet are curbed with 1 by 12 inch boards, and the remaining 17 feet are uncurbed. The well is deepened to 44 feet by a 10-inch bored hole uncased. No water-bearing material was found above 44 feet, at which depth coarse sand and gravel were struck, some of the latter measuring 1 inch. It was impossible to bring up this material with the boring apparatus used, and as enough water was yielded to supply the pump, no further development of the well was attempted. It is thought that the average yield of 461 gallons a minute obtained on the 9½-hour run was practically all supplied from the bottom of the hole.

To illustrate the irregularity of the valley fill, it may be mentioned that another well dug previously a few hundred feet away found no good water-bearing material in 70 feet of depth.

The water was measured over a 12-inch Cippoletti weir board set in the ditch near the well. The water level in the well, while pumping, was measured by noting the wetted portion of a narrow elongated weight which had been attached to the end of a steel tape and lowered into the well. In 35 minutes after starting, the water level had been lowered 10.8 feet. In the next nine hours the water fell at a fairly constant rate of about 2 inches per hour.

Test of plant of J. W. Baker, NW. ¼ sec. 11, T. 13 S., R. 24 E. (plant No. 19).

Duration ... hours..	9. 5
Water pumped ... acre-inches..	9. 72
Maximum discharge measured ... gallons a minute..	473
Average discharge ... do....	461
Water level drawn down ... feet..	12. 5
Discharge lift ... do...	28. 5
Average suction lift ... do...	14. 2
Average total lift ... do...	42. 7
Useful horsepower ...	4. 97
Fuel used during test ... gallons..	16. 1
Fuel used per useful horsepower-hour ... do....	0. 34
Fuel used per acre-foot of water pumped ... do....	19. 9
Speed of engine ... revolutions a minute..	272
Speed of pump ... do....	850
Ratio of useful horsepower to rated horsepower of engine (practical efficiency) ... per cent..	41. 4
Cost:	
Engine ...	$650
Pump, belt, and piping ...	165
Well ...	87
	902

Plant No. 20.—Plant No. 20 (see Pl. XIV, *B*, p. 186), in the NE. ¼ sec. 24, T. 13 S., R. 24 E., owned by H. L. Carnahan, was the largest irrigation outfit in the valley when the test was made—May 15, 1911, about a month after the plant was installed. The equipment consists of a Hercules 30-horsepower horizontal gasoline engine with a 36-inch drive pulley; a 10-inch 5-ply stitched canvas belt; an American No. 8 horizontal centrifugal pump with a 16-inch pulley; a suction pipe 9 inches in diameter, 19 feet of its length being of standard oil-well casing, then 7 feet of galvanized iron riveted and soldered; and a 12-inch riveted discharge pipe discharging at ground level. A ¾-inch circulating pump supplies water to the cylinder for cooling. A vacuum gage is attached to the pump suction, the connecting pipe extending up to the surface of the ground for greater convenience in reading the gage. The pump is set as low as is possible without getting the belt in the water. There is no foot valve nor check valve, but the priming is easily done by throwing several gallons of water down the discharge pipe after the pump has attained full speed.

The well is 235 feet deep. The first 20 feet were dug 5½ by 7 feet and left uncurbed. The remaining 215 feet were drilled 10 inches in diameter, and the first 82 feet were cased with double stovepipe casing, thoroughly perforated with quarter-inch slots 10 to 12 inches long. Following is the driller's log:

Driller's log of well of H. L. Carnahan, NE. ¼ sec. 24, T. 13 S., R. 24 E.

Material.	Thickness.	Depth.
	Feet.	*Feet.*
Soil	7	7
Sand and gravel, packed but not cemented	4	11
Soil (water level at 20 feet)	9	20
Sandy clay	3	23
Sticky yellowish clay	1	24
Fine quicksand, requiring casing	3	27
Clay	1	28
Coarse gravel, up to 1 inch in size	4	32
Sandy clay	7	39
Blue clay	1	40
Coarse gravel, same as above	4	44
Soft clay	16	60
Gravel	2	62
Yellowish clay	9	71
Gravel	3	74
Sticky blue clay	11	85
Main water-bearing gravel, coarse and heaving	18	103
Clay	114	217
Gravel	2	219
Blue clay	16	235

For measuring the water, a special Cippoletti weir board was made, with a crest of 42 inches. The vacuum gage was used for determining the suction lift.

Test of plant of H. L. Carnahan, NE. ¼ sec. 24, T. 13 S., R. 24 E.

Duration	hours	6.00
Water pumped	acre-inches	14.4
Maximum discharge measured	gallons a minute	1,443
Average discharge	do	1,080
Water level drawn down	feet	19
Discharge lift	do	20.0
Average suction lift	do	18.4
Average total lift	do	38.4
Useful horsepower		10.48
Fuel used during test	gallons	20.5
Fuel used per useful horsepower-hour	do	.33
Fuel used per acre-foot of water pumped	do	17.1
Speed of engine	revolutions a minute	200 to 240
Speed of pump	do	484 to 527
Ratio of useful horsepower to rated horsepower of engine (practical efficiency)	per cent	34.9
Cost of plant and well (about)		$2,000

Summary of tests.—The different elements of the plants tested, together with the results obtained, are summed up in the following table:

Summary of tests of pumping plants in Sulphur Spring Valley, Ariz.

No. of plant.	Owner.	Duration of test (hours).	Engine.	Average useful horsepower.	Practical efficiency (per cent).[a]	Pump.	Depth of well (feet).	Depth to water (feet).	Water level lowered (feet).	Average lift (feet).	Average water pumped.		Fuel used (gallons).			Cost.						
											Cubic feet per second.	Gallons per minute.	Per acre-foot of water pumped.	Per acre-foot of water lifted 1 foot.	Per useful horsepower-hour.	Well.	Plant.			Fuel.	
																	Total.	Per rated horsepower.	Per useful horsepower.	Per acre-foot of water pumped.	Per acre-foot of water lifted 1 foot (cents).
1	Geo. Giragi........	3.67	4-horsepower Fairbanks Morse & Co.	0.70	14.8	American No. 2 horizontal.	49	31	7.0	40	0.154	69	31.3	0.78	0.58	$225	$415	$104	$593	$5.75	14.4
2	Fred Arzberger....	4.43	6-horsepower Stover.........	.81	13.5	Gould No. 2 horizontal.	54	33	10.1	45	.159	72	....	....	....	75	335	56	414	....	....
3	V. H. Fross.......	3.92	4-horsepower Root & Vandervoort.	.34	8.5	Gould No. 2½ horizontal.	55	13	9.3	19	.162	73	....	....	....	....	....	....	....	....	....
4	R. F. McHenry...	3.33	6-horsepower Economy......	.89	14.8	Gould No. 2 horizontal.	46	23	8.5	34	.230	104	26.1	.76	.56	60	242	40	272	4.53	13.2
5	Walter Whitener..	2.83	10-horsepower Stover........	.97	9.7	American No. 4 vertical.	54	23	8.3	34	.254	114	....	....	....	80	646	65	666	....	....
6	L. W. Vertrees.....	6.23	4-horsepower Foos, Jr........	1.17	29.2	Gould No. 2½ horizontal.	50	26	7.4	32	.316	142	18.3	.56	.41	70	....	....	....	3.17	9.8
7	A. I. McAllister....	3.88	12-horsepower Witte	2.65	22.1	American No. 3½ vertical.	75	61	....	73	.322	145	86.4	1.18	.87	....	....	....	....	14.97	20.5
8	S. W. Craig........	7.05	6-horsepower Root & Vandervoort.	1.69	28.2	Byron Jackson No. 2½ horizontal.	65	28	18.4	44	.335	151	26.4	.59	.44	100	395	66	234	4.58	10.3
9	J. E. Brophy......	6.00	3-horsepower Union.........	1.10	36.7	.....do.............	504	19	7.3	28	.350	157	17.2	.62	.45	....	....	....	....	3.16	11.4
10	Geo. Turvey.......	7.35	6-horsepower Weber.........	1.99	33.2	Byron Jackson No. 3½ horizontal.	306	34	3.6	38	.457	206	20.7	.54	.40	904	402	67	202	3.80	10.0
11	H. E. Wright......	.32	6-horsepower McVickers.....	.98	16.3	Gould No. 2½ horizontal.	75	10	16.6	18	.467	210	....	....	....	....	....	....	....	....	....
12	J. W. Ditmars.....	6.00	6-horsepower International Harvester Co.	1.81	30.2	Gould No. 3 horizontal.	40	23	6.4	32	.495	223	19.0	.59	.43	70	510	85	282	3.30	10.3
13	A. E. Keeth.......	3.78	10-horsepower Stover........	2.33	23.3	American No. 3½ horizontal.	50	23	12.4	36	.573	258	....	....	....	100	700	70	300	....	....

[a] Ratio of useful horsepower to rated horsepower of engine.

Summary of tests of pumping plants in Sulphur Spring Valley, Ariz.—Continued.

No. of plant.	Owner.	Duration of test (hours).	Engine.	Average useful horsepower.	Practical efficiency (per cent).	Pump.	Depth of well (feet).	Depth to water (feet).	Water level lowered (feet).	Average lift (feet).	Average water pumped.		Fuel used (gallons).			Cost.					
																	Plant.			Fuel.	
											Cubic feet per second.	Gallons per minute.	Per acre-foot of water pumped.	Per acre-foot of water lifted 1 foot.	Per useful horsepower-hour.	Well.	Total.	Per rated horsepower.	Per useful horsepower.	Per acre-foot of water pumped.	Per acre-foot of water lifted 1 foot (cents).
14	J. J. Gandy	3.18	8-horsepower Witte	2.11	26.4	American No. 4 horizontal.	40	18	10.5	31	0.595	268	20.2	0.65	0.47	$50	$636	$80	$301	$3.50	11.2
15	C. O. Miller	9.95	8-horsepower Peerless	3.06	38.2	Byron Jackson No. 3 horizontal.	52	35	7.3	44	.608	274	12.0	.27	.20	70	575	72	188	2.08	4.7
16	J. A. Casner	5.18	10-horsepower Stover	3.24	32.4	Gould No. 4 horizontal.	70	29	9.5	42	.676	304	24.0	.57	.42	100	600	60	185	4.16	9.9
17	C. E. Ellinwood	3.62	12-horsepower Samson	2.16	18.2	Samson No. 4 horizontal.	29	12	6.0	21	.896	403	22.2	1.06	.77	60	520	43	241	3.85	18.4
18	F. M. Harris	6.75	10-horsepower Stover	3.87	38.7	American No. 4 horizontal.	43	22	6.6	34	.994	447	15.2	.44	.33	75	625	62	162	2.64	7.8
19	J. W. Baker	9.50	12-horsepower Peerless	4.97	41.4	do	44	27	12.5	43	1.024	461	19.9	.46	.34	87	815	66	164	3.44	8.1
20	H. L. Carnahan	6.00	30-horsepower Hercules	10.48	34.9	American No. 8 horizontal.	235	20	19.3	38	2.400	1,080	17.1	.45	.33	500	1,500	50	143	2.96	7.8

CONCLUSIONS.

Character and depth of wells.—Of the plants tested, the wells at Nos. 9, 10, and 20 were machine drilled. No. 1 was dug and curbed all the way. The other 16 were bored below water level by hand, the average depth (excluding No. 11, which is largely filled with caved material) being 51 feet.

Yield.—The plants in the above table are arranged and numbered according to the amount of water pumped, which ranged in the tests from an average of 69 gallons a minute for plant No. 1 to 1,080 gallons a minute for plant No. 20. In some tests the amount of water pumped varied greatly, as, for instance, at plant No. 20, which gave a maximum discharge of 1,450 gallons a minute at the start and a minimum of 915 gallons a minute when the speed of the pump became low because of slipping of the belt or improper regulation of the charge in the engine. The presence of air in the pump occasionally diminished the stream, and frequent trouble arose from belt slippage. Notable steadiness was shown by plants Nos. 9 and 19. At plant No. 9 the maximum discharge was 163 gallons and the minimum 154 gallons a minute, a range of only 6 per cent. At plant No. 19 the stream was even more constant, varying between 472 and 457 gallons a minute, or only about 3 per cent. At both plants the pumps delivered their full rated capacity.

Lift.—The depth to the water level at the plants tested is 10 to 61 feet; the actual lift, which includes the lift above the ground and the lowering of the water below the normal water table, varied from 18 to 73 feet, the mean value being about 36 feet.

Drawdown.—The water level in the bored wells northwest from Willcox was drawn down an average of 1 foot for every 40 gallons a minute that was pumped. Thus, in that locality a well of moderate depth pumping 400 gallons of water a minute may be expected to lower the water level about 10 feet, and this fall, together with the height to which the water is to be raised above the ground level, should be added to the depth to water when estimating the probable lift for a proposed plant of 400-gallon capacity. The water in the deep well at plant No. 20, in the same locality, lowered a foot for each 56 gallons a minute pumped.

On the east and west flanks of the barren flat each foot of drawdown corresponded to an average of about 10 gallons of water a minute pumped. In the southern part of the valley pumping for irrigation has not been tried very extensively as yet, and the three wells tested were so different that an average representative yield can not be given. In general, however, the water seems to be obtained from greater depths than in the northern part of the valley, requiring deeper and more expensive wells. Most of the water, however, is under hydrostatic pressure and rises in the wells, so that the actual lift is not excessive.

Power.—All the plants tested were of the distillate centrifugal type, 18 having horizontal and 2 vertical pumps. Many plunger pumps are in use throughout the valley, but they all deliver streams of water that are too small for much irrigation. Two steam plants have been installed, but at neither had sufficient water been developed in proportion to the capacity of the plant to justify comparison with gasoline plants. At present distillate is practically the only fuel to be considered, and will probably remain so until electric power is generated and distributed on a large scale.

Efficiency.—Of the pumps tested, the rapid-speed type appeared to be the more efficient. The belt should be placed at a high inclination and the pull should be on the lower side, thus giving a greater contact on both the upper and lower sides when there is any sag in the belt. The pulleys, besides being properly proportioned according to the speeds of engine and pump, should be of ample size. In any given plant there is a certain amount of power to be transmitted, and that power is the product of the strength of pull and the rapidity of motion of the belt; the greater the speed the less the necessary pull. A fast-running belt, therefore, can be of lighter construction and more flexible, will permit a greater sag, and will induce less friction loss by reducing the lateral strain on the shaft bearings.

The two causes which are preeminent in reducing the efficiency of plants tested are (1) the insufficient speed maintained by the pump and (2) the improper timing of the ignition in the engine. Every pump should have a center punch hole on the exposed end of its shaft, with ample room for free access to it; and every plant owner should have a revolution counter and a catalogue containing a speed table for his particular pump. The actual pumping lift should be measured and every precaution taken to insure the maintenance of the proper speed. The time of ignition may be noted by turning the flywheel of the engine slowly by hand. The spark should pass on the back stroke shortly before the piston reaches the dead-center point, preferably about one-ninth of a quarter revolution before the connecting rod and crank reach a horizontal position.

Cost.—The cost of pumping plants per rated horsepower varied from $40 to $104, with an average of $66. This is exclusive of the cost of the well and necessary buildings. The average cost per useful horsepower was $290. If an efficiency of 40 per cent is obtained, as it should be, the cost would be reduced to $165 per useful horsepower. The average fuel cost per acre-foot of water pumped was $4.39, with distillate figured at 16½ cents per gallon in the northern part of the valley and at 17½ cents in the southern part. An addition of 5 per cent was made to the fuel cost as an allowance for losses of fuel by leakage, evaporation, etc. Cost of pumping must vary with the lift; the figures vary from 4.7 to 20.5 cents, with an average of 11. 2 cents as the cost of lifting each acre-foot 1 foot. The cost of lubricating oil will bring the average up to about 12 cents. As previously stated, irrigation has been practiced in the valley for only a very short time, and reliable data concerning fixed charges, such as those for repairs, attendance, and depreciation, can therefore not be given.

The table below gives the usual percentage allowance made in the Southwest for fixed charges on gasoline-engine centrifugal-pump plants. The localities represented are the Rillito and Santa Cruz valleys near Tucson, Ariz., the Pomona district in southern California, and scattered plants at Deming, Las Cruces, and Estancia, N. Mex.

Percentage allowance for fixed charges on pumping plants.

	Arizona.[a]	Southern California.[b]	New Mexico.[c]
Depreciation	10	12 to 15	11
Interest	8	6	8
Taxes	1	1	1
Maintenance and repairs	4		
Total	23	20	20

[a] Bull. Arizona Agr. Exp. Sta., No. 64, p. 209.
[b] Bull. Office Exp. Sta., No. 181, U. S. Dept. Agr., p. 51.
[c] Bull. New Mexico Agr. Exp. Sta., No. 73, p. 15.

The short time during which irrigation has been practiced in Sulphur Spring Valley also affects estimates of cost through lack of information as to the duty of water. Possibly not more than half an acre-foot of pumped water may be required for some crops when dry-farming and supplementary irrigation methods are employed. On the other hand, 3½ acre-feet of water will probably be needed for the most successful alfalfa irrigation. The average cost of fuel and lubricating oil for these two extreme cases is found to be 6 and 42 cents, respectively, for each foot that the supply for one acre is lifted; with a total actual lift of 40 feet the cost for these items would be $2.40 and $16.80, respectively, per acre per annum.

AGRICULTURE.[1]

By R. H. Forbes.

EARLY HISTORY.

Prehistoric people have left behind them in Sulphur Spring Valley evidences of a primitive agriculture. The remains of ditches and of metates for grinding corn indicate the cultivation of the soil and the utilization of its products by ancient tribes. Many of these remains occur in localities where the present water supply is extremely scant and unadapted to agricultural operations. It is therefore not unlikely that, in accordance with the views of modern meteorologists, there was a period unknown centuries ago when the average annual rainfall of the region was considerably greater than it is now, making possible the irrigation and cultivation of tracts for which there is now no known water supply.

At the time of the Gadsden purchase, when American occupation of the region began, Sulphur Spring Valley was without agriculture, except, perhaps, a little of the crudest nature at the camps of the Apache Indians in the Chiricahua Mountains. The first American settlers in Sulphur Spring Valley were cattlemen who took little interest in cultural operations except as these were tributary to the cattle industry.

Among the earliest and most progressive of these cattlemen was H. C. Hooker, who first reached Sulphur Spring Valley with a large herd of cattle in 1867, and who in 1872 established the Sierra Bonita ranch, 22 miles northwest of Willcox.

Mr. Hooker availed himself of the flood waters in his vicinity for the growing of corn, sorghum, and Johnson grass, and for the betterment of his range. By means of diversion ditches so placed as to spread the run-off from the adjacent slopes over the grass country in the vicinity, he improved thousands of acres of grass land. Following flood-water distribution of this character new areas of perennial sacaton grass, of great value in time of drought, were established, and aided him greatly in maintaining his herds at certain seasons of the year. In the bottom of the valley he impounded water by means of transverse embankments. From the storm-water reservoirs thus created he irrigated fields of sorghum and corn, and when such reservoirs were emptied of their store of water he planted sorghum in the wet soil remaining in their bottoms. In this way considerable quantities of forage were produced which were preserved and utilized in times of scarcity. In time of extreme need he would plow his Johnson grass fields, turning up the succulent roots and stolons that were then eagerly consumed by famishing cattle, which were thus carried over a period of scarcity.

[1] The data on dry farming in Sulphur Spring Valley used in this report were furnished by R. W. Clothier, of the Arizona Experiment Station staff.

Aside from such operations as these practically no attempt at farming was made in Sulphur Spring Valley until very recently. The abundant rains of 1905, in conjunction with an increased demand for desirable farming land, led to the homesteading of large areas of land in Sulphur Spring Valley which had before been utilized exclusively as grazing range. Dry-farming theories of cultivation also had much to do with this movement, as it is popularly supposed that by means of dry-farming methods even the soils of the semiarid Southwest may be made to grow successful crops on rainfall only. This stage of agriculture in Sulphur Spring Valley and in Arizona has only just begun. Some experience has been gained and some ideas have been developed with reference to the possibilities of agriculture by dry-farming and other methods of agriculture in this region.

SOILS.

As in all the large valleys of the Southwest, the soils of Sulphur Spring Valley vary from coarse gravels on the higher and steeper slopes to fine and dense clays at lower elevations where the gradients are slight. The coarse, sandy, and gravelly soils at the higher elevations are as yet of little importance agriculturally because the groundwater supply of the valley lies so deeply beneath them as to be agriculturally unavailable under present conditions. Most of the heavier clay soils, lying for the most part in the valley bottoms, are also in large part unavailable because they are so charged with alkali salts as to make crop production impossible. The intermediate grades of soil lying between the coarse gravels of the higher slopes and the dense clays of the valley bottoms are those to which recourse must in the main be had for agricultural results.

The gradients of these intermediate portions of the valley are for the most part well suited to irrigation, varying from 8 to 40 feet per mile. The general surface of the valley is but little eroded, although it has been heavily grazed for the last 40 years. Probably most of Sulphur Spring Valley was originally grass covered. In the grass-covered tracts it costs but little to prepare land for a crop, but mesquite lands, although usually of excellent quality, require expensive clearing before farming operations are possible. The expense is in considerable part offset by the value of the posts secured, but even with this consideration is often heavy.

As in all semiarid regions, the soils of Sulphur Spring Valley are deficient in humus and nitrogen except where grass roots and decayed vegetation have formed a few surface inches of soil rich in vegetable matter. Limy hardpan, locally known as caliche, is not developed to the extent found at lower elevations in Arizona; but considerable areas of the valley are underlain by whitish deposits of soft, limy material, which may be regarded as an incipient hardpan formation.

The soils of Sulphur Spring Valley are very generally charged with sodium carbonate, commonly known as black alkali. This fact is related to the granitic character of the surrounding mountains—granite weathering to form, among other things, sodium carbonate. In many places the amount of this substance is sufficient to preclude successful agriculture. Black alkali is directly corrosive to vegetation, and it also destroys the tilth of a soil by deflocculating it, causing it to become plastic, and consequently difficult to irrigate or aerate properly. Even when present in very small amount, therefore, black alkali is very undesirable in an agricultural soil, one-tenth of 1 per cent being commonly stated as the limit endurable by crop plants.

Fortunately there are gypsum deposits in Sulphur Spring Valley, and gypsum is a chemical antidote for carbonate of soda, reacting with it to form harmless calcium carbonate and less harmful sodium sulphate. These deposits of gypsum are now developed about 5 miles east of Douglas and can be delivered on board the cars at Douglas at $1.30 a ton. It is therefore quite possible to neutralize small percentages of black alkali in a soil and doubtless, in time to come, as economic conditions permit, these deposits will be used for this purpose in the region. Aside from soils containing excessive and soils containing curable amounts of black alkali, there are, however, large areas which are sufficiently free from soluble salts to be available for general farming operations.

Small areas of white alkali (sulphate and chloride of sodium) are also found in the valley; higher percentages of these are permissible in the soils.

WATER.

With reference to its use in agriculture, the water supply of Sulphur Spring Valley may be divided into direct rainfall, flood-water run-off, and ground water. The rainfall, which ranges from as little as 6 to as much as 22 inches a year at agricultural levels within the valley (see p. 89), is sometimes, as in 1905, adequate for the production of crops by ordinary methods of farming, and at other times, as in 1900, is entirely inadequate. In average years, however, the summer rains, from July 1 to October 1, are adequate for the production of certain crops. (See pp. 78–91.) The winter rainfall is much less valuable, but by suitable methods of conservation may be made to contribute to crop results. As elsewhere in southern Arizona, the summer rainfall of the valley is patchy in character, the amount and distribution being often much more satisfactory in certain localities than in others. The winter rains, however, have the advantage of being uniformly distributed throughout the region in which they occur.

The flood-water run-off, resulting from heavy rains in the mountains adjacent to the valley, is often of great benefit to the subjacent country. These flood waters, issuing from mountain canyons, are naturally widely distributed over the valley lands below. Their distribution, especially before the country was overgrazed, was facilitated by the gentle gradients and by the dense growth of grasses with which the valley was covered. Flood waters received from the mountains were spread out in wide sheets and their progress obstructed by the heavy growth, so that they were rapidly absorbed in the soil and there utilized by growing vegetation. Similarly, by means of ditches, this flood water may be intercepted and carried onto cultivated land for future use in growing various cultivated crops. This form of water supply, however, like rainfall, is intermittent and uncertain and requires to be supplemented by some more certain supply in order to be made useful.

The underground waters of Sulphur Spring Valley, where within economical reach of pumping operations, constitute a supplementary supply of great future importance. These waters, however, being derived probably in the main from flood-water run-off from the mountains, are, unlike the rains and the surface floods, more or less charged with salts absorbed from the soil through which they move. As is to be expected from the character of these salts, the alkali contained in the ground waters is to a considerable extent black in character, about two-thirds of the samples examined being of this nature. About one-third, however, contain calcium sulphate, which is, chemically, an antidote for black alkali. It is interesting to note that in some places pumped water supplies of these two characters could probably be combined in such proportions as to render harmless the black alkali contained. It is of interest also to note that, in the main, the saltiest waters occur only at the lowest levels in connection with the heaviest and physically less desirable types of soil, whereas at intermediate and higher levels the quality of the water supply is sufficiently good to be available for irrigation without resulting damage to the soil.

AGRICULTURAL METHODS.

Several more or less successful farming methods have been adapted to the water supply described above. Among these are so-called dry farming; flood-water farming; farming by irrigation with pumped water; combinations of dry farming and flood-water farming, dry farming and supplementary irrigation with pumped water, and farming with the ranging of cattle where the land is yet unoccupied.

DRY FARMING.

Dry farming in Sulphur Spring Valley is uncertain, because of the varying rainfall from year to year and because of the possible bad distribution of a rainfall which, if timely, would be adequate for the production of crops. As ordinarily in dry-farmed regions, dry farming consists, essentially, in the storage of moisture in the soil and its subsequent utilization by crops. In Sulphur Spring Valley, however, the irregularity of the rainfall may easily interfere with a carefully planned program of operations; and the winds, the exceedingly dry air, and the heat of summer, all result in excessive evaporation of moisture and necessitate unusual vigilance and care in maintaining the soil mulch to conserve the rainfall even temporarily. Good equipment and efficient organization are consequently necessary for carrying on farming operations punctually and in the proper way. In spite of these difficulties, however, part crops of corn, sorghum, milo maize, and beans were grown on the dry farm of the Arizona Experiment Station southwest of McNeal (see Pl. I, in pocket), during the somewhat unfavorable seasons of 1909 and 1910, on rainfall only, conserved by dry-farming methods of cultivation. Beans produced an encouraging crop, and considerable yields of corn and sorghum were also obtained. In 1910 by purely dry-farming methods the following crops were grown:

Crops grown on the dry farm of the Arizona Agricultural Experiment Station, southwest of McNeal, in 1910.

Crop.	Soil.	Stand.	Yield per acre.	Damage by birds.	Corrected yield if undamaged.
				Per cent.	*Bushels.*
Sorghum	Heavy soil, fallowed preceding year, not previously cropped.	Good	3.18 tons	None.	
Do	Lighter soil, fallowed preceding year, cropped 2 preceding years.	do	2.56 tons	None.	
Do	Lighter soil, cropped 3 preceding years.	Medium	1.26 tons	None.	
Kafir corn	Medium soil, fallowed preceding year, not previously cropped.	do	2.05 tons		
Blue Aztec corn	Lighter soil, fallowed preceding year, cropped 2 preceding years.	do	8.9 bushels	15	10.4
Yellow Aztec corn	do	Good	7.3 bushels	20	9.1
White flint corn	Medium soil, cropped 3 preceding years.	Half stand	6.1 bushels	15	7.2
Yellow Tepary beans	Heavy soil, fallowed preceding year, not previously cropped.	Medium	370 pounds	None.	
Do	Lighter soil, fallowed preceding year, cropped 2 preceding years.	Less than half stand	232 pounds	None.	

Ranchers in the valley have also produced promising crops of beans, sorghum, corn, broom corn, milo, and Kafir. These preliminary results indicate that dry farming alone has a distinct but limited utility in the region, which, however, can undoubtedly be greatly increased by the use of supplementary water. (See p. 221.)

In this connection it is worthy of notice that the French in North Africa are producing economic crops of corn, wheat, wine, grasses, sorghum, and olives on lands receiving from 10 to 16 inches of rainfall a year, largely as a result of thorough cultural methods, and the choice of varieties suited to semiarid conditions. Recent crop statistics from Algeria are as follows:

Crops raised in Algeria by dry-farming methods.

Crop grown.	Yield per acre.	Total production.
Wheat	10 bushels	24,500,000 bushels.
Wine	1,000 gallons	175,000,000 gallons.
Corn	8 bushels	58,000,000 bushels.
Sheep		8,000,000 head; 1,200,000 exported.

FLOOD-WATER FARMING.

Flood-water farming, which is immediately consequent upon rainfall, is practiced to some extent in the southwestern part of the United States and adjacent portions of Mexico. The Papago Indians, especially, are very skillful in diverting storm waters at advantageous points by crude ditches which lead the water upon subjacent tracts of level land. These Indians, at the beginning of the summer rains, make preparation for planting and cultivating their summer crops by breaking the fallow ground left after harvesting preceding crops. In the loose soil thus prepared the rainfall and the diverted storm waters are accumulated. In it corn, beans, melons, pumpkins, squashes, martynias, and sorghum mature rapidly under the influence of the warm summer season, the moisture in the soil, and usually the continued rains and floods of the summer. The Papago Indians are particularly successful in the cultivation of their own quick-growing, drought-resistant varieties of corn and beans and rarely fail to obtain satisfactory returns from their operations.

Winter crops of wheat and barley are usually less satisfactory, for the winter storms are less adequate and the winter run-off is less abundant than the storms and run-off of summer. In some winters, however, fairly satisfactory crops of wheat are matured by the Indians.

Following the example of agricultural tribes of the Southwest the Mexicans and to some extent the Americans also are utilizing storm-water run-off, supplemented in many places with additional irrigating supplies. By combining the use of flood waters with the thorough cultivation incident to dry-farming methods, considerable, though not always dependable, returns are to be realized.

In some situations it is also possible to supplement rainfall and flood waters with stored water impounded behind low and inexpensive embankments thrown up at advantageous points across washes and swales leading from the mountains whence comes the major portion of the water supply. Such storage is practiced by the Indian tribes, but thus far is used by them exclusively for the watering of stock and not for the irrigation of crops. There is no reason, however, why, with higher embankments and larger reservoirs, such storage should not be increased sufficiently to be available for irrigation. To a small extent, in fact, American farmers in Arizona are already saving small stores of water from summer storms and utilizing it to bring to maturity quick-growing crops of beans, melons, and corn.

In many parts of Sulphur Spring Valley, especially in the borderland between the foothills and the open valley, numerous sites are available for storing small bodies of water and will doubtless be developed in course of time.

SUPPLEMENTARY IRRIGATION WITH PUMPED WATER.

Unlike rain and flood waters, which are intermittent and uncertain, the ground waters which may be economically reached under certain areas of Sulphur Spring Valley are permanent and dependable and may be used to supplement the cheaper supplies, thus assuring crop returns to the farmer.

Stored ground waters of Sulphur Spring Valley, indeed, will take the place of the reservoir waters available in certain other agricultural valleys of southern Arizona. In some localities where water of desirable quality comes very near the surface it may be found possible to develop and use ground waters according to ordinary methods of irrigation. Where pumping from any depth is required, however, the cost of this form of water supply renders desirable the use of as little pumped water as possible. To be most effective, it should be applied only when the starting or saving of a crop renders its use especially advantageous or necessary. The summer growing season in the valley, for instance, beginning with the summer rains in July and ending with the early frosts, is sometimes too short to mature satisfactorily corn, sorghum, kafir corn, and certain other forage and vegetable crops. These crops can be started well in advance of the summer rains by running pumped water down the planting furrows, then cultivating thoroughly to conserve moisture, and sowing seed in the moist soil. Crops thus planted will come on rapidly while the soil moisture lasts and will then be taken up by the summer rains beginning about the 1st of July. If the rains are timely and thorough cultivation is employed after each rain, no further irrigation will be necessary and fairly satisfactory crops will result.

In the winter growing season, also, fall crops of wheat and barley may be started by similar supplemental irrigation and brought up in time to utilize winter rainfall and be well advanced toward maturity by April. The scant rainfall of the spring months, however, is usually insufficient to mature grain crops, and a second supplemental irrigation is necessary. The use of supplemental pumped water is much less practicable with winter than with summer crops in Sulphur Spring Valley because of the greater amount of supplementary water required.

The use of supplemental pumped water is, however, not limited to the exigencies of planting and maturing a crop. By maintaining surface tilth in the form of a deep mulch according to dry-farming principles of agriculture, pumped water, like rainfall or storm-water run-off, may for a season be stored and conserved in the soil. At the dry farm near McNeal such storage has been made and utilized with conspicuously beneficial effects on crops six months after pumping, thus making it practicable to utilize the output of small plants for soil-water storage. To do this the ground should be irrigated through furrows as rapidly as the pumping plant will supply the water. These furrows should then be cultivated level and the mulch maintained as in dry farming. Beginning, say on the 1st of January, the farmer can thus store water in his fields for four months, until danger of late frosts is over, and can then plant his crops upon accumulated soil moisture to be supplemented by summer rains, and the crop can usually be brought to completion without further help from the pumping plant. The experiments near McNeal have shown that about 4 inches deep of water, or about one-tenth the amount required under ordinary irrigation in southern Arizona, applied in this way, is sufficient to assure a crop. Moreover, the continuous use of a pumping plant through several months of the year is more economical, considering investment, interest, and depreciation, than is the temporary use of such a plant only at critical times in the growth of the crop. Used continuously in this manner a pumping plant may be made to carry the crops, not on a few acres only, but on as many acres as can be supplied by the plant with water a few inches deep during several months of the year. Following is a table derived from Prof. R. W. Clothier's work at the dry farm of the experiment station in 1910, showing results by dry-farming methods only and by dry-farming methods with supplemental pumped water.

Dry-farm crops, with and without supplemental pumped water, grown at McNeal.

Crop.	Without supplemental irrigation.		With supplemental irrigation.	
	Forage.	Grain.	Forage.	Grain.
Sorghum .... pounds..	3,188	27	5,476	370
White flint corn .... bushels..	....	5.14	....	11.4
Milo .... do....	....	4.0	....	32.6
Tepary beans .... pounds..	....	387	....	761

The limitations under which pumping plants for supplementary water supply may be used are mainly those of cost of operation as compared with the value of resulting marketable products. The practice of the region is yet so new that no authentic figures are available. A number of profitable gardens, however, in several parts of the valley adjacent to mining markets, have been maintained with the help of pumps operated by windmills and by gasoline engines. These engines are usually operated without special skill and without the best of management in the use of water. In course of time, by means of cooperative plants organized on the principle of centralized economical production and advantageous distribution of electrically transmitted power to individual farms, supplementary pumped water should be developed in large amount in Sulphur Spring Valley.

AGRICULTURAL POSSIBILITIES.

The area within which dry-farming methods supplemented by pumped water are possible under present conditions is limited to those intermediate elevations of the valley where good soil is underlain by ground water within economical pumping distance. The area of such lands is probably not less than 200,000 acres. This leaves approximately 700,000 acres of land of good quality which is capable of supporting an abundant growth of native grasses but under which the water lies at too great a depth for economical pumping as yet. It is not at all unlikely, therefore, that it will later be found advantageous to use these lands for the grazing of cattle, to which the valley was formerly exclusively devoted, in combination with farming operations in the more favorable areas where dry farming with supplemental pumped water can be undertaken with a fair degree of success. This cultivable portion of the valley should be made to act as a balance wheel for the grazing areas. By means of rainfall, flood waters, and, when necessary, supplemental pumped water, crops of sorghum, Kafir corn, milo maize, and quick-growing varieties of Indian corn, and even alfalfa, may be grown and cured for use as forage in times of drought when the open range fails. Such supplies of forage will serve to tide over range animals, especially during the dry months of April, May, and June, when feed is most likely to be deficient and when, in some years, many cattle have starved. The losses from starvation, sometimes reaching 50 per cent or more, may in this manner, to a considerable extent, be guarded against.

By such a plan not only is productiveness secured for the areas actually cultivated, but utility is gained for large additional grazing areas.

In this connection, it is not at all unlikely that silos may come into use as a feature of the agriculture of the region. During the winter and spring seasons, when frosts and dry weather curtail the supply of green feed, a supply of fresh forage would be of great value to stock-growing industries within the valley. In French North Africa, in a semiarid region similar to southern Arizona, silos are successfully employed to preserve forage for use at times when green material is not available. Both dairying and the fattening of cattle are practiced successfully with the aid of these silos. Sulphur Spring Valley, cost permitting, would be peculiarly benefited by the installation of this feature in the agricultural practice of the region, inasmuch as corn, sorghum, and other forages, which may be grown during the summer rainy season, are of double value in connection with the output of the adjacent range when fed during the following winter and spring.

It is interesting, in this connection, to note the manner in which the Papago stockmen of extreme southwestern Arizona adapt themselves to the arid conditions which there obtain. About July 1, at the beginning of the summer rainy season, when surface flood waters may be impounded in the valley bottom lands, these people, with their cattle, horses, and agricultural implements, move from the mountains to the valleys and there remain, grazing their cattle on summer grasses and planting quick-growing crops on soil soaked with flood waters and occasionally moistened with rain. In the fall, as the rains fail and the supplies of water impounded for domestic use disappear, the Indians migrate back to their villages in the adjacent foothills, where their cattle range through the winter on the summer growth of wild-hay forage and are watered from their owner's wells. In this way, spending half the year in the mountains and half in the valley bottoms these Indians live successfully in a region where white men, with methods unadapted thereto, have repeatedly failed to establish themselves. The peculiar merit of the Indian method is that their cattle are shifted from mountains to valleys and from valleys to mountains each year, so that at no time are their ranges seriously overgrazed, as necessarily happens with the fixed watering places and grazing grounds commonly maintained by American stockmen. If it were practicable, such a system, or some modification of it, by which purely grazing ranges should be used in combination with cultivated areas, would be found well adapted to Sulphur Spring Valley.

The question of crops peculiarly adapted to the region is also most important. Quick-growing and drought-resistant varieties of corn, milo maize, sorghum, millets, beans, and other summer crops are especially desirable. Quick growth is necessary to insure maturity before the frosts of late September, and drought resistance is essential at times when the rains and the stored soil waters fail. Some native varieties of corn and beans are especially adapted to the region.

The small-eared, soft Indian corn of the aboriginal tribes produces well under conditions which would prohibit the growth of many eastern varieties, and the Indian beans of the region are especially valuable because of their ability to produce with a small and uncertain water supply. These beans have succeeded relatively well during the last two years at the experimental dry farm near McNeal and will probably become a feature of the agriculture of the region, as they bid fair to produce remunerative crops and also to aid in maintaining the fertility of soils depending in large part on rainfall and pumped ground waters.

The introduction and planting of drought-resistant trees is also important in Sulphur Spring Valley. The semiarid, subtropical parts of the world are the most promising regions in which trees of this character are to be sought. The tamarisks of Asia are examples of introduced trees which will undoubtedly prove valuable.

SUMMARY.

The foregoing discussion of the agricultural resources of Sulphur Spring Valley may be summed up as follows:

Extensive areas consist of agricultural soils, under a portion of which water lies within economical pumping distance. Adjacent valley and foothills contain much grazing country that can not at present be economically watered by pumps, and that is valuable chiefly in connection with some reliable source of forage. Water supplies are derived from rainfall, storm water run-off, and ground waters. The valley has a summer growing season beginning with the rains of July and terminating with the frosts of late September, and a winter growing season for grains beginning in the fall and carrying through the frosty months. A small but increasing list of crop plants have shown themselves adapted to the region; among them are quick-growing drought-resistant varieties of Indian corn and beans, sorghum, milo maize, Kafir corn, pumpkins, and squashes.

Several methods of culture have been or may be developed under prevailing conditions. Of these, dry farming by means of rainfall only is somewhat uncertain because of the variations in rainfall from year to year; flood-water farming, like dry farming with direct rainfall, is also uncertain because of variations in precipitation; dry farming supplemented with pumped water supply is more certain than either dry farming or flood-water farming. The preceding cultural methods may be combined advantageously with the grazing of cattle on adjacent ranges.

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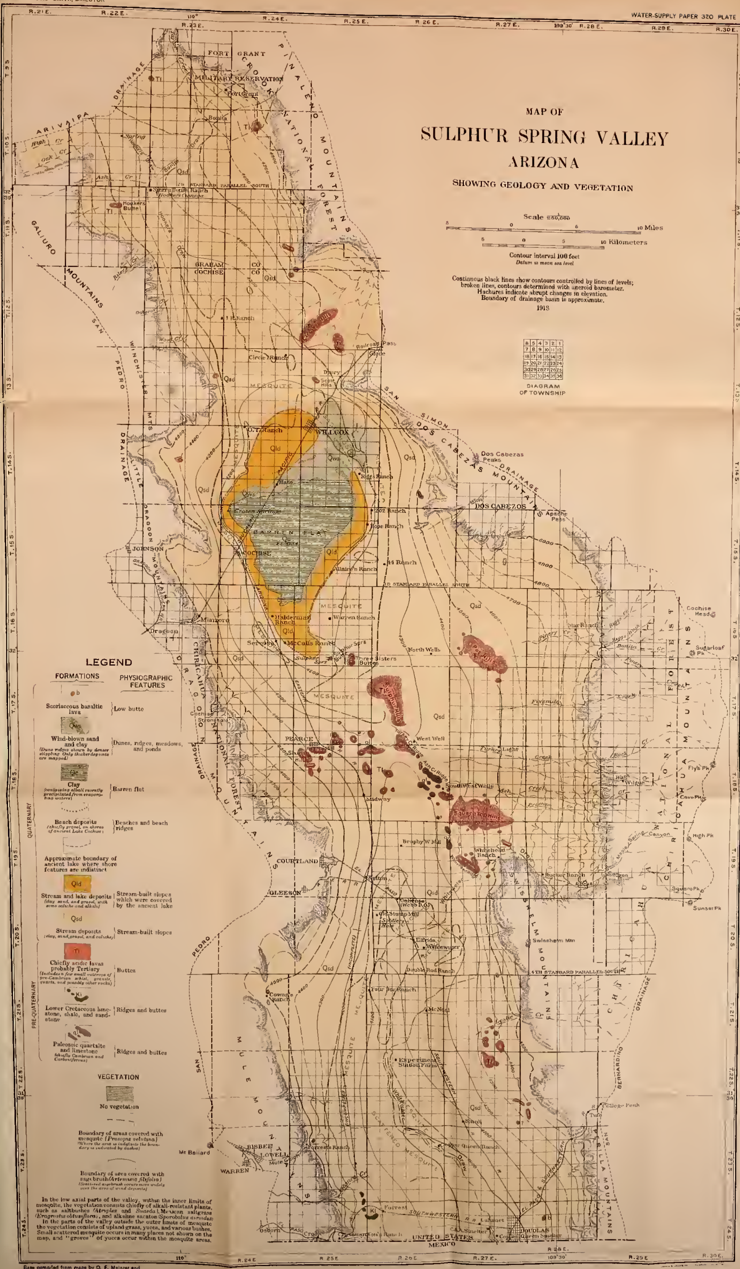
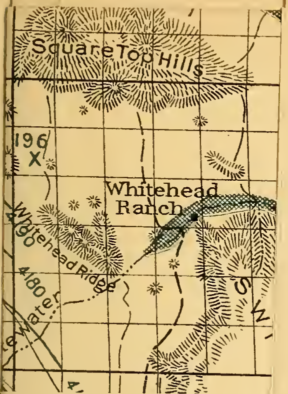
Square Top Hills
Whitehead Ranch
Whitehead Ri



Base compiled from maps by O. E. Meinzer and F. C. Kelton, General Land Office township plats, railroad alignments, and Forest Service maps. Instrumental leveling by F. C. Kelton.


Square Top Hills
196
Whitehead Ranch
Whitehead Ridge
4180

Base compiled from maps by O. E. Meinzer and F. C. Kelton, General Land Office township plats, railroad alignments, and Forest Service maps. Instrumental leveling by F. C. Kelton.