SALINES.

THE SEARCH FOR POTASH IN THE DESERT BASIN REGION.[1]

By Hoyt S. Gale.

AUTHORITY FOR INVESTIGATIONS RELATING TO POTASH.

Acts authorizing investigations looking to the possible development of commercial sources of potash salts in the United States were passed by Congress as follows (Stat. L., vol. 36, pt. 1, pp. 1256, 1418):

> Chapter 285. An act making appropriations for sundry civil expenses for the fiscal year ending June thirtieth, nineteen hundred and twelve, and for other purposes.
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> * * * * * * *
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> *United States Geological Survey.*—For chemical and physical researches relating to the geology of the United States, including researches with a view of determining geological conditions favorable to the presence of deposits of potash salts, forty thousand dollars. * * * [Approved Mar. 4, 1911.]
>
> Chapter 238.—An act making appropriations for the Department of Agriculture for the fiscal year ending June thirtieth, nineteen hundred and twelve.
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> * * * * * * *
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> *Bureau of Soils.*—For exploration and investigation within the United States to determine a possible source of supply of potash, nitrates, and other natural fertilizers, twelve thousand five hundred dollars, two thousand five hundred dollars of which shall be immediately available. * * * [Approved Mar. 4, 1911.]

Field and laboratory investigations to be conducted by both the Geological Survey and the Bureau of Soils are thus provided for. In recent years the annual appropriation for the work of the chemical and physical laboratories of the Geological Survey has been $20,000, so that the addition of $20,000 to this item in the current appropriation was made with an understanding that the amount of the increase should be devoted to the geologic investigations relating to potash in this country.

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[1] Revision of report published Dec. 11, 1911, as Bulletin 530-A.

SCOPE OF POTASH INVESTIGATIONS.

The investigations of the Geological Survey with a view of determining geologic conditions favorable to the presence of deposits of potash salts have been concentrated during the fiscal year 1911–12 along the followng lines:

1. The exploration by deep boring for deposits of buried salines in Nevada and in other localities in the western public-land States, by a drilling party in charge of James H. Hance, under the direction of Hoyt S. Gale.
2. The investigations of the salt deposits and the brines and bitterns in the United States east of the Rocky Mountains, carried on by W. C. Phalen, under the supervision of David T. Day.
3. The investigation of the occurrence of certain rich potash-bearing rocks and minerals, described in short reports.
4. A small amount of general field investigation in the Western States by Hoyt S. Gale.
5. Prospecting with a hand-drilling apparatus for the purpose of testing the salt and upper ground waters or brines to a depth of 50 feet or more in the Silver Peak Marsh, Nevada, by a party in charge of R. B. Dole, assisted by Charles E. Watson.

Naturally work on such a subject as this has not been concluded within a single year, but the following preliminary reports have been issued:

The search for potash in the United States; a report of progress, by Hoyt S. Gale: Advance chapter A of Bull. 530, issued in December, 1911.

The occurrence of potash in the bitterns of the eastern United States, by W. C. Phalen: Advance chapter B of Bull. 530, issued in December, 1911.

Alunite, a newly discovered deposit near Marysvale, Utah, by B. S. Butler and Hoyt S. Gale: Bull. 511, issued in January, 1912.

Potash-bearing rocks of the Leucite Hills, Sweetwater County, Wyo., by A. R. Schultz and Whitman Cross: Bull. 512, issued in January, 1912.

Alunite in the San Cristobal quadrangle, Colo., by E. S. Larsen: Advance chapter F of Bull. 530, issued in January, 1912.

Potash salts, summary for 1911, by W. C. Phalen:. Advance chapter from Mineral Resources of the United States for 1911, issued in March, 1912.

Nitrate deposits, by Hoyt S. Gale: Bull. 523, issued in October, 1912.

It is the main purpose of the present report to review briefly the evidence on which the project of drilling for potash in the desert basins is based and the reason for the selection of the preliminary site in the Carson Sink, Nevada. This is the hypothesis which assumes that soluble potassium salts may be found segregated in layers or in mother-liquor solutions in the Carson Desert and elsewhere in the desert-basin region.

The discovery of one important example of such segregation of potash salts in the brines of Searles Lake, in San Bernardino County, Cal., is considered as an important confirmation of this hypothesis. It remains to test the hypothesis in other practicable situations, and it is believed that this will generally have to be accomplished by borings.

SALINES IN THE GREAT BASIN.

SURFACE SALTS.

The surface accumulations of salines in the Great Basin are among the most characteristic features of the deserts. These deposits include the so-called dry lakes, playas or mud flats, alkali flats, salt marshes, and alkaline efflorescences in various forms. There are also alkaline lakes whose waters carry saline material in greater or lesser amounts. Springs charged with mineral matter are rather common in certain parts of the deserts.

Salt, sodium carbonate and bicarbonate, sodium sulphate, and borax have been more or less profitably worked in many parts of the region. Nitrate salts in soils and in caves and ledges have been found at a number of places, but these are not conspicuous in form and are of more exceptional occurrence.

Numerous chemical data concerning the nature of the alkaline salts in the Great Basin deserts are already available. Some of these are to be found in published form, and perhaps a larger number consist of commercial analyses so scattered that they will be difficult to assemble. Experience has shown, however, that in the general run of such analyses potash determinations on natural waters are extremely likely to be in error, often to a serious degree, even when the work has been done by an experienced chemist. The determination of potash in alkaline and saline waters is difficult and rather expensive and is subject to considerable inaccuracies unless made by a chemist who has had much experience with that particular determination and who has therefore worked out the special difficulties involved and the methods of avoiding them.

Among the first and most natural suggestions made in connection with the idea of searching for sources of soluble potash salts was that this substance would probably occur in association with other desiccated saline and alkaline-water deposits, such as are known to be abundant in the desert-basin region. The likelihood that such deposits on the surface might yield workable potash salts was pointed out, and an offer for free tests for soluble potash in samples of the desert salts was published early in the progress of the present investigations. Moreover, it was suggested that as the desert surface deposits are plainly to be seen and readily accessible to the prospector, this phase of the search might well be trusted to his activity with the expectation that he would develop anything of evident value.

BURIED SALTS.

No better statement of the reasons for assuming that immense quantities of saline material are included in the strata underlying the desert sinks of the Great Basin can here be made than by direct quotation from the writings of Russell[1] and Gilbert,[2] chiefly from the monograph on the history of Lake Lahontan. Russell does not suggest that such buried deposits will be found in commercially workable form but rather infers that the saline material is for the most part probably disseminated in the desert sands and clays. Nevertheless, the evidence that he presents is believed to be a very strong argument favoring the possible existence of such deposits, as will be seen by a review of the following quotations. It is also evident as a result of the drilling that has now been done that such salts are not disseminated to any important extent in the uppermost 800 feet or more of the Lahontan lake deposits, a result which tends rather to strengthen than otherwise the hope of ultimate success of the test in this locality.

THE DESICCATION HYPOTHESIS TO ACCOUNT FOR BURIED SALTS IN THE DESERT BASINS, WITH SPECIAL REFERENCE TO LAKE LAHONTAN.

DEFINITION OF THE GREAT BASIN.

> The major part of the North American continent is drained by streams flowing to the ocean, but there are a few restricted areas having no outward drainage. The largest of these was called by Frémont, who first achieved an adequate conception of its character and extent, the "Great Basin," and is still universally known by that name. It is not, as the title might suggest, a single cup-shaped depression gathering its waters at a common center, but a broad area of varied surface, naturally divided into a large number of independent drainage districts. It lies near the western margin of the continent and is embraced by rivers tributary to the Pacific Ocean. * * *
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> The region is occupied by a number of mountain ridges which betray system by their parallelism and by their agreement in a peculiar structure. Their general trend is northerly, inclining eastward in the northern part of the basin and westward at the south. The individual ridges are usually not of great length, and they are so disposed en échelon that the traveler winding among them may traverse the basin from east to west without crossing a mountain pass. The type of structure is that of the faulted monocline, in which the mountain ridge is produced by the uptilting of an orogenic block from one side of a line of fracture, and it has been named (from the region) the Basin Range type. Its distribution, however, does not coincide perfectly with the district of interior drainage. On the one hand the Great Basin includes along its eastern margin a portion of the Plateau province, with its peculiar structural type, and on the other the Basin Range province extends southward through Arizona to New Mexico and Mexico.
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> Between the ranges are smooth valleys, whose alluvial slopes and floors are built of the débris washed through many ages from the mountains. In general, they are troughlike, but in places they coalesce and assume the character of plains. The plains occupy in general the less elevated regions, where an exceptional amount of detritus has been accumulated. In the local terminology they are called deserts. The largest are the Great Salt Lake and Carson deserts at the north and the Mojave and Colorado deserts at the south. The Escalante, the Sevier, the Amargosa, and the Ralston are of subordinate importance.

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[1] Russell, I. C., Geological history of Lake Lahontan, a Quaternary lake of northwestern Nevada: Mon. U. S. Geol. Survey, vol. 11, 1885.

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

The southern portions of Arizona and New Mexico and the western part of Texas resemble the Great Basin in climate, and they contain a number of small interior basins. These are not so fully determined in extent as the Great Basin, but several of them may be approximately indicated.

LAKE LAHONTAN DEFINED.

[The monograph on Lake Lahontan] records the history of a large lake which flooded a number of the valleys of northwestern Nevada at a very recent geological date but has now passed away. This ancient water body is known as Lake Lahontan—named in honor of Baron La Hontan, one of the early explorers of the headwaters of the Mississippi—and was the complement of Lake Bonneville. The former, situated mostly within the area now forming the State of Nevada, filled a depression along the western border of the Great Basin at the base of the Sierra Nevada; the latter, embraced almost entirely in the present Territory of Utah, occupied a corresponding position on the east side of the Great Basin, at the foot of the Wasatch Mountains. The hydrographic basins of these two water bodies embraced the entire width of the Great Basin in latitude 41°. Lake Bonneville was 19,750 square miles in area and had a maximum depth of about 1,000 feet. Lake Lahontan covered 8,422 square miles of surface and in the deepest part, the present site of Pyramid Lake, was 886

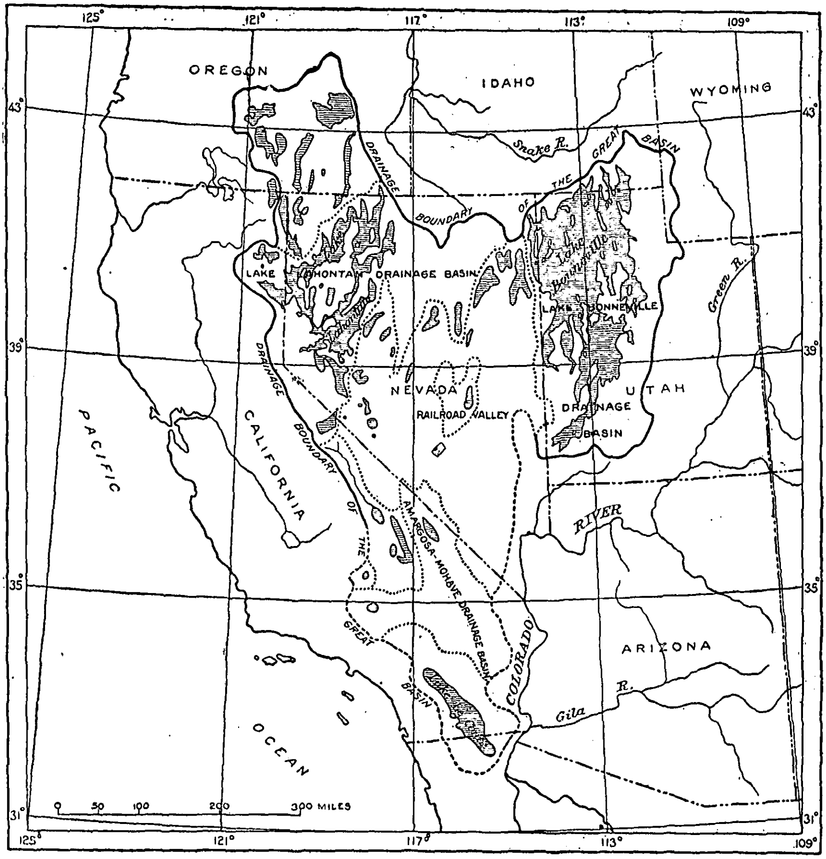

FIGURE 38.—Quaternary lakes of the Great Basin. (Revised from Pl. I of the Lake Lahontan monograph and Pl. II of the Lake Bonneville monograph.)

feet in depth. The ancient lake of Utah overflowed northward and cut down its channel of discharge 370 feet. The ancient lake of Nevada did not overflow. Each of these lakes had two high-water stages separated by a time of desiccation. In the Lahontan Basin, as in the Bonneville, the first great rise was preceded by a long period of desiccation and was followed by a second dry epoch, during which the valleys of Nevada were even more completely desert than at present. During the second flood stage the lake rose higher than at the time of the first high water and then evaporated to complete desiccation. The present lakes of the basin are of comparatively recent date and are nearly fresh, for the reason that the salts deposited when the Quaternary lake evaporated were buried or absorbed by the clays and marls that occupy the bottom of the basin.

ACCUMULATION OF SALINE MATERIAL.

It may be taken as a rule that all lakes which overflow are fresh and all lakes which do not find outlet become in time charged with mineral salts. River water is never absolutely pure but contains a small percentage of mineral matter, which is left behind when the water is evaporated. Should this process continue long enough it is evident that a lake without an outlet would in time become a saturated solution from which the less soluble mineral salts would begin to crystallize. * * *

Instances of the deposition of salts by the evaporation of inclosed lakes are common and may be illustrated by many examples in the Great Basin. The salt fields in Osobb Valley, the saline deposits left by the evaporation of the Middle Lake in Surprise Valley, Cal., in 1872, and by the broad salt field now covering the desiccated basin of Sevier Lake, in Utah, are all cases in point.

In the Lahontan Basin deposits of this character which have resulted directly from the evaporation of the former lake are nowhere to be found. The accumulations of common salt, sulphate of soda, etc., occurring in considerable quantities at certain localities have in all cases been deposited since the evaporation of the former lake. In some instances these accumulations are due to the leaching of saline clays and the evaporation of the resultant brine in restricted areas, as in the case of the salt fields in Alkali Valley; at other times saline deposits of considerable thickness have resulted from the evaporation of spring waters. Over very large areas the Lahontan beds are frequently whitened with a saline efflorescence, which also owes its accumulation to secondary causes, as will be described a few pages in advance.

Wherever the Lahontan sediments have been examined they have been found more or less highly charged with salts of the same character as those that were most common in the waters of the former lake. The total quantity of saline matter thus imprisoned is certainly very great and is assumed to represent the more soluble substances contributed to Lake Lahontan.

DISAPPEARANCE OF SALINES FROM THE SURFACE.

The apparently anomalous phenomena of the desiccation of a great lake without leaving a surface deposit of salt seems explicable in only one way. Adopting the suggestion advanced by Mr. Gilbert in explanation of some portion of the history of Lake Bonneville, the absence of saline deposits is accounted for by the hypothesis that they were buried and absorbed by lacustral clays and playa deposits during periods of desiccation.

The freshening of a lake by desiccation may be illustrated in all its stages in the various basins that have been examined in the far West. A lake after a long period of concentration becomes strongly saline and finally evaporates to dryness, leaving a deposit of various salts over its bed. During the rainy season the bottom of the basin is converted into a shallow lake of brine which deposits a layer of sediment; on evaporating to dryness, during the succeeding arid season, a stratum of salt is deposited, which is, in its turn, covered by sediment during the succeeding rainy season. This process taking place year after year results in the formation of a stratified deposit consisting of salts and saline clays in alternating layers. The saline deposits may thus become more and more earthy until the entire annual accumulation consists of clays. The site of the former lake then becomes a playa. A return of humid conditions would refill a basin of this character and might form a fresh-water lake, the bottom of which would be the level surface of the submerged playa.

The larger lakes of the Lahontan Basin, as well as a number of less importance in eastern Nevada and southern Oregon, are without outlet. They occur in basins that in almost all cases were occupied by much larger water bodies during the Quaternary, which, like their modern representatives, never overflowed. From the long period of evaporation that has taken place one would expect the existing lakes to be dense mother liquors. The fact is, however, that they are but slightly charged with saline matter and in some instances are sweet to the taste and sufficiently fresh for all culinary purposes. In many localities the lacustral beds surrounding and underlying the present lakes are highly charged with soda salts, which rise to the surface during the dry season as efflorescences. As these lake basins were never filled to overflowing, we are forced to conclude that influx was counterbalanced solely by evaporation, and that during periods of extreme desiccation the saline deposits became buried and absorbed by the marls and clays which accumulated in the valleys. * * *

POSSIBILITY OF BURIED SALINE DEPOSITS.[1]

As shown by the average composition of river water, about one-half of the total solids carried in solution by surface streams is calcium carbonate. This is the most difficult of solution of any of the salts ordinarily found in such waters, and the first to be precipitated when concentration by evaporation takes place. The more soluble salts consist mainly of sodium sulphate, sodium carbonate or bicarbonate, sodium chloride, magnesium, potash, iron, etc.

The amount of these more soluble substances carried into Lake Lahontan must therefore have been about equal to the amount of calcareous tufa precipitated.[2] As the lake never overflowed, these salts must still exist in its now nearly desiccated basin; yet in riding through the valleys that were formerly flooded no deposits of the salts referred to can be found at all commensurate with the vast quantity of calcium carbonate that attracts one's attention. The disappearance of the salts referred to seems to be satisfactorily explained in the following hypothesis:

After the last great rise of Lake Lahontan there was a long-continued episode during which its basin was more arid than at present. Evaporation during that time is thought to have been equal to precipitation, and the residual lakes were reduced to the playa condition—that is, the remnants of the great lake gathered in the lowest depressions of its basin were annually or occasionally evaporated to dryness, and their contained salts were precipitated and either absorbed by the clays, etc., deposited at the same time, or buried beneath such mechanical deposits. This process may be observed in action in many of the valleys of Nevada in which ephemeral lakes occur. The broad, naked playas of Black Rock, Smoke Creek, and Carson deserts, as well as the level floors of the basins occupied by Pyramid, Winnemucca, and Walker lakes, are in support of this hypothesis. Should the lakes just mentioned be evaporated to dryness, playas would be left similar to those in neighboring valleys of less depth.

It is beneath the level floors of these valleys and lake basins that the more soluble salts once dissolved in the waters of Lake Lahontan are buried.[2] Borings at certain localities might reveal the presence of strata of various salts, but in most cases they are probably disseminated through great thicknesses of clay, sand, and other mechanical sediments.

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[1] Russell, I. C., Present and extinct lakes of Nevada: Mon. Nat. Geog. Soc., vol. 1, No. 4, 1895, pp. 101-132.

[2] The italics are added.

SELECTION OF CARSON SINK FOR PRELIMINARY TEST BY DRILLING.

The physiographic history of the basins of Lakes Bonneville and Lahontan is thus probably more completely studied than that of any other part of the Great Basin. The monographs from which the foregoing quotations are made afford a wealth of maturely digested data on which to base the proposed plan of operation. A review of this material and the maps that accompany the reports leads to the conclusion that no better test of the hypothesis of possible buried salines in concentrated form could be made than to drill somewhere in the low portions of the Lahontan and Bonneville basins. Accordingly it was decided to make a practical test of this hypothesis by the selection of a drill site in one of these two basins.

For two reasons the Lahontan Basin was thought to offer the more favorable opportunity. First, it has been shown that Lake Lahontan never overflowed. This is important, as lake waters are freshened by overflow and the more soluble constituents of their waters are drained away. Lake Bonneville is known to have overflowed at least during a portion of its history, though there may have been desiccation periods preceding the overflowing. However, another factor appears to favor Lake Lahontan as a source of potash-bearing salt deposits, and this is concisely stated by Russell:[1]

> Surface waters derive their chemical impurities mainly from the rocks over which they flow and consequently vary in composition with the geological character of their hydrographic basins. When draining a granitic or volcanic area they are usually rich in potash and soda; when flowing over limestone they are frequently saturated with calcium carbonate. This is illustrated in the far West by the streams entering the Bonneville and Lahontan basins. In the former they have their sources in the Wasatch Mountains, where limestones occur, and are usually rich in calcium carbonate; potash is commonly absent, and soda, if present, is comparatively small in amount. In the Lahontan Basin volcanic rocks predominate and the streams contain a higher percentage of potash and soda than is usual in a region underlain by sedimentary rocks.

A summary of the low points in the Lahontan Basin narrows the selection of the drill site to a relatively small number of localities. The most extensive drainage is probably accumulated in the present Carson Sink. Humboldt Lake is really tributary to Carson Sink and, in effect, possibly always has been. The deep parts of Pyramid and Winnemucca lakes are lower in altitude, but they are water covered and so not as accessible, and their narrow, rock-walled valleys do not afford much opportunity for a satisfactory drill site. The Black Rock Desert and possibly also the Smoke Creek Desert lie at

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[1] Mon. U. S. Geol. Survey, vol. 11, 1885, p. 173.

approximately the same elevation as the Carson Desert, and the Lahontan Lake waters stood at approximately the same depth over them. There are perhaps no good criteria by which to judge between the Black Rock Desert and the Carson Sink as promising fields in which to prospect. The existence of nearly saturated solutions of sodium chloride, containing large percentages of sodium sulphate and sodium carbonate, in the Soda Lakes near Fallon may be of some significance as to the derivation of these salts from buried salines that may exist beneath.

However, the selection of the general locality for the first trial was determined, other things appearing approximately equal, by accessibility to water, fuel, and other supplies. Carson Sink being selected, the particular site was picked, first, on vacant public land; second, as near the center on the assumed axis of lowest depression of the sink as feasible; and third, along as convenient a road for transportation of outfit and supplies as could be found within the limits of the other two controlling factors.

THE TIMBER LAKE WELL NEAR FALLON, NEV.

The site selected is in sec. 30, T. 21 N., R. 30 E. The well is situated at the north end of Timber Lake, on the bank of Old Carson River near the point where that stream joins the standing water in Carson Sink. Timber Lake, now a dry basin covering an area of about 100 acres in the SE. ¼ sec. 30, was formerly filled by overflow from the main channel of Carson River. This lake has been drained by the cutting of a ditch for the purpose of straightening the course of the main river channel and is now growing up into a jungle of willows and small cottonwood trees.

The successful completion of a well on this site may prove, within the limit of depth attained, the existence and depth of any accessible saline deposits, and even if potash is not found in this first attempt, this boring will be a valuable guide in the selection of a site for further work.

The record of drilling for the year ending July 1, 1912, includes two periods of drilling amounting to a total of 135 days, or about 4½ months. The funds provided for this part of the work did not permit continuous operation and consequently the work was taken up during such periods as best conformed to the other arrangements involved in the general plans of the investigation. As stated in the preliminary report of progress on the Timber Lake well,[1] the drilling equipment

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[1] Bull. U. S. Geol. Survey No. 530-A, 1911.

was delivered at Fallon, Nev., on September 19, 1911. A summary of the periods and rate of progress attained is as follows:

Progress in drilling Timber Lake well, near Fallon, Nev.

	Time.	Amount drilled.	Average rate drilled.
	Days.	*Feet.*	*Feet per day.*
Oct. 6, 1911, to Jan. 11, 1912, inclusive	98	555	5.6
Jan. 12 to Apr. 19, inclusive	99	Drilling suspended.	
Apr. 20 to May 26, inclusive	37	280	7.6
May 27 to June 30, inclusive	35	Drilling suspended.	
		835	6.2

These unconsolidated caving and flowing sands and beds of sticky clay are perhaps as difficult to drill with standard drilling tools as any other materials that might be encountered. It is possible that by other methods of drilling, such as the use of the rotary, a more rapid rate of boring might be attained, but some factors of these other methods seem to prohibit their use for the purpose of obtaining the desired samples of soluble salts.

The work at the Timber Lake well has been under the general management and supervision of James H. Hance, who has kept the log of the well and taken the samples and made qualitative and approximate quantitative tests of the amount of potassium contained in the samples. The chemical record to date is negative so far as showing anything like commercially extractable percentages of soluble potash. The log shows an alternating series of unconsolidated sands, bearing much water and generally yielding artesian flows intercalated with beds of more or less compact clay that is impervious to the flow of water. The artesian waters are comparatively fresh and, although they have a smell and taste of hydrogen sulphide, are sufficiently good for use in camp. Analyses of these waters are in progress. As greater depth is reached, however, the volume of the lower flows encountered has diminished, or it may be that they have been in part cut off by the continuous heavy driving on the casing required to keep the hole from caving.

The negative tests for potash to the present depth (835 feet) in no way indicate the failure of the project nor invalidate the assumptions of the hypothesis on which the project is based. The very existence of large bodies of relatively fresh waters in the uppermost strata of the Lake Lahontan sediments serves to set at rest the chief doubt that has been seriously entertained concerning the probability of concentrated deposits of buried salines at greater depth in these beds. There can be little doubt that vast quantities of saline material exist within these desert basins and that a great part of this material has been carried by water in solution and concentrated in the lower parts of the basins. It has been argued that these salts may not be concentrated in well-defined stratified beds. Russell himself has already been quoted as preferring to believe that in most localities the salts are probably disseminated through great thicknesses of clay, sand, and other mechanical sediments. However, it has now been shown that for a depth of 835 feet near the lowest part of the sink of the Carson Desert these salts are not disseminated in much more than normal soil conditions or amounts for this general region. It remains to be seen whether drilling can be carried to a sufficient depth in this particular basin to strike the concentrated salines that are even more probable now that the saline material has not been found disseminated throughout this overlying thickness of the lake-bed deposits.

The log of the well at the Timber Lake site, in sec. 30, T. 21 N., R. 30 E., is shown in figures 39 to 44.

The record of progress on the boring now being made as a private enterprise in Railroad Valley, Nev., in the search for buried salines is interesting for comparison with that of the Timber Lake well. Although Railroad Valley is a narrower and smaller basin, the strata encountered are similar, being alternating layers of clay and sand or quicksand, and many of the latter bear large artesian flows of relatively fresh water.

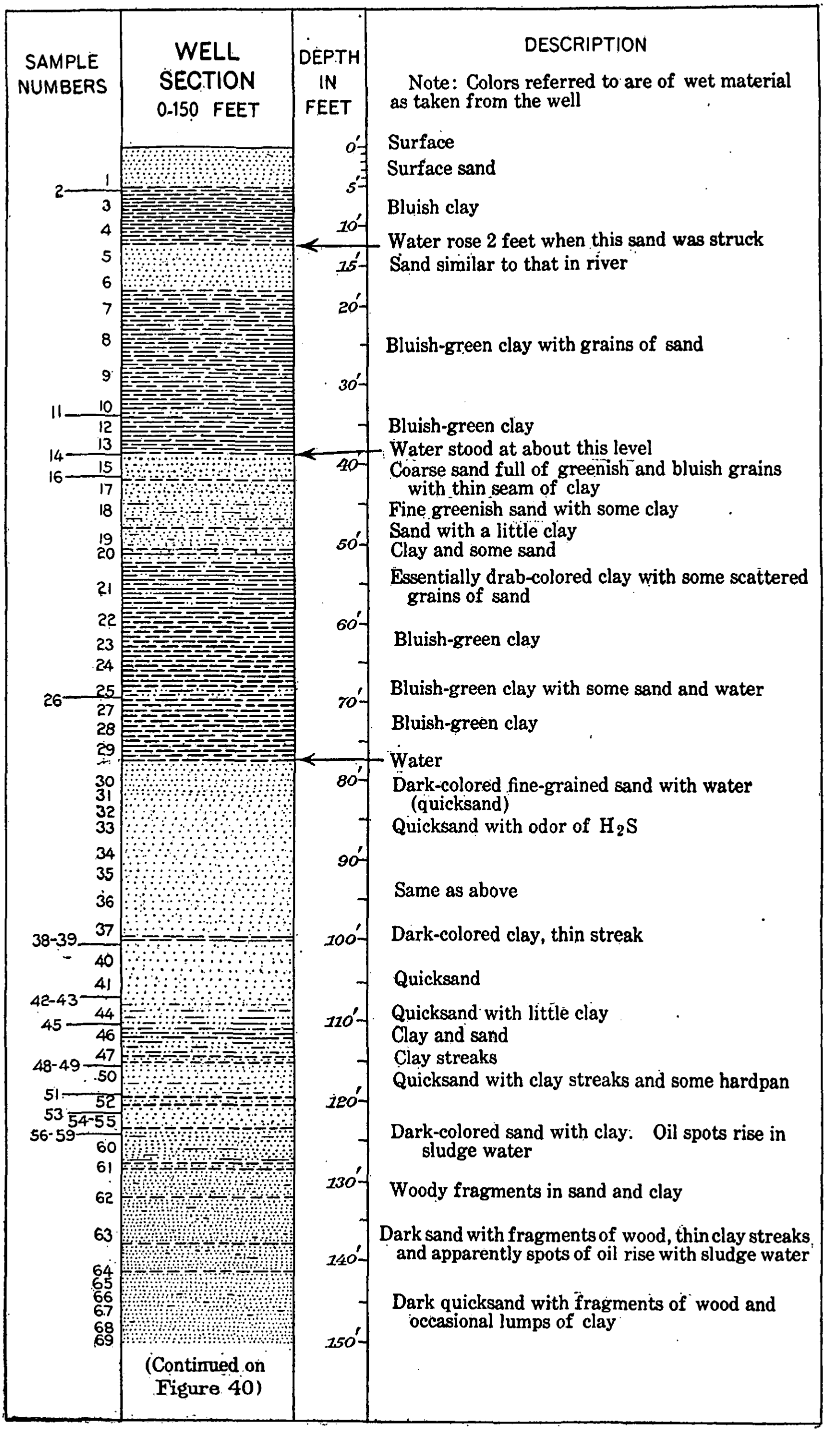

FIGURE 39.—Section of strata in Timber Lake well, near Fallon, Nev.—I.

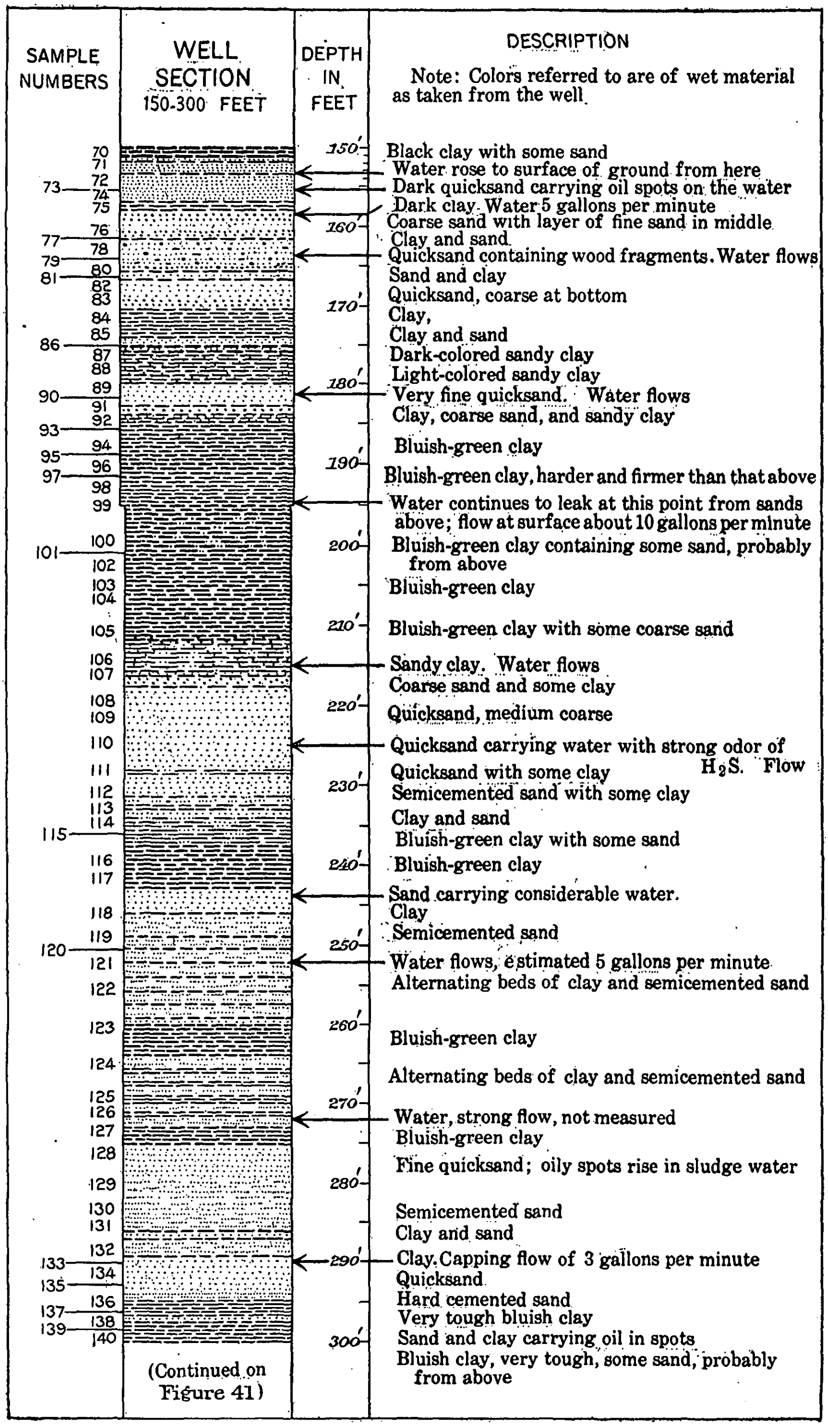

FIGURE 40.—Section of strata in Timber Lake well, near Fallon, Nev.—II.

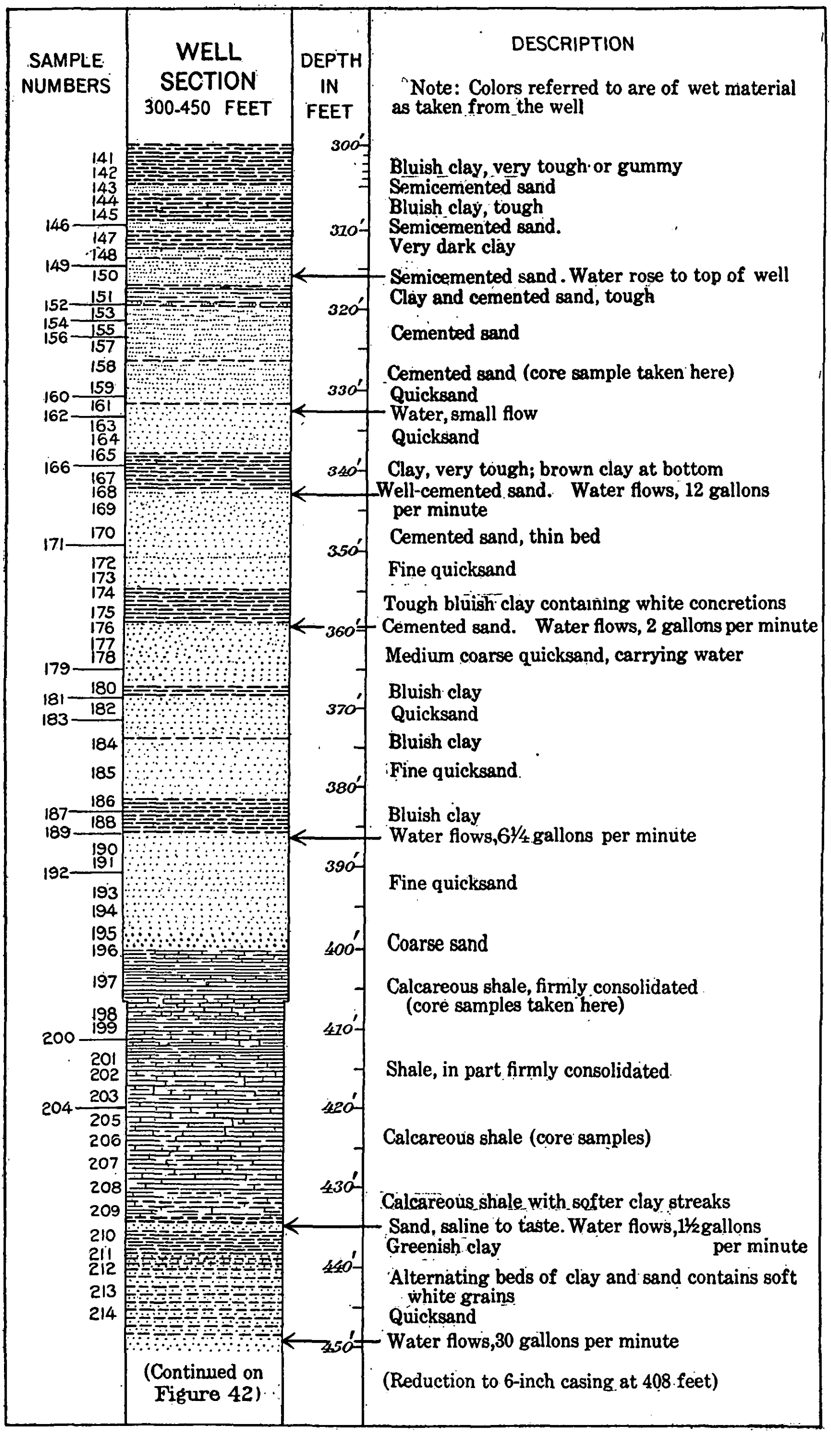

FIGURE 41.—Section of strata in Timber Lake well, near Fallon, Nev.—III.

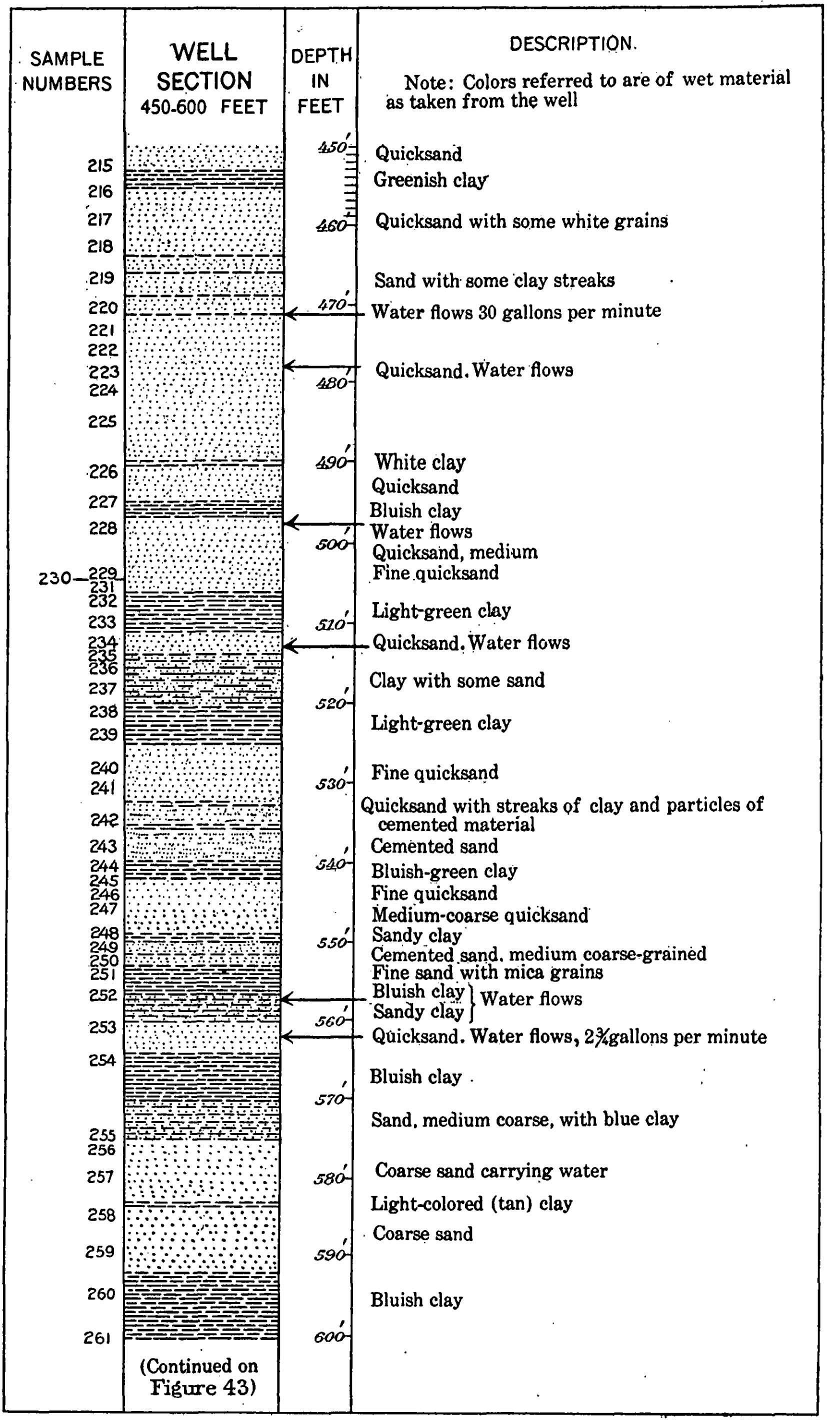

FIGURE 42.—Section of strata in Timber Lake well, near Fallon, Nev.—IV.

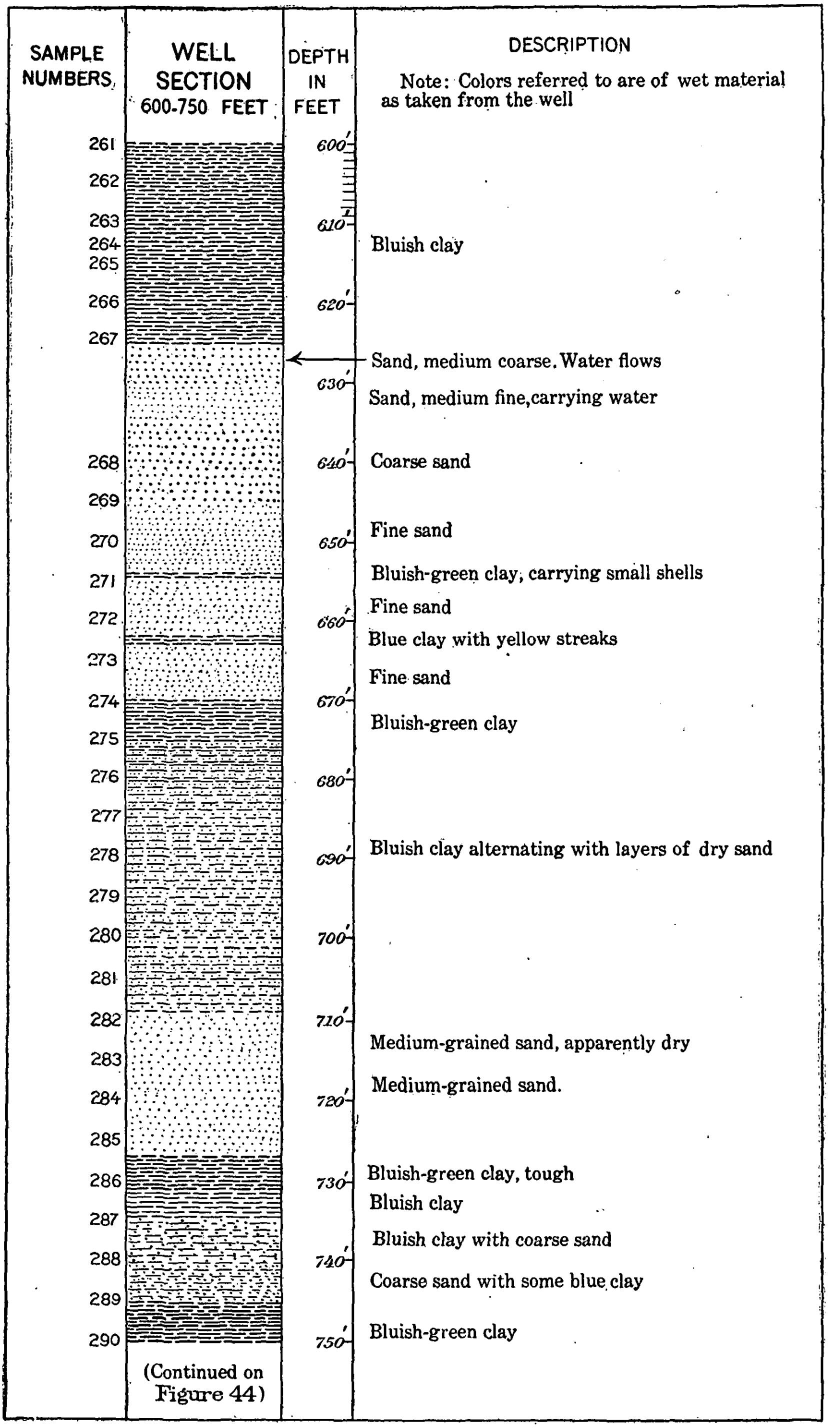

FIGURE 43.—Section of strata in Timber Lake well, near Fallon, Nev.—V.

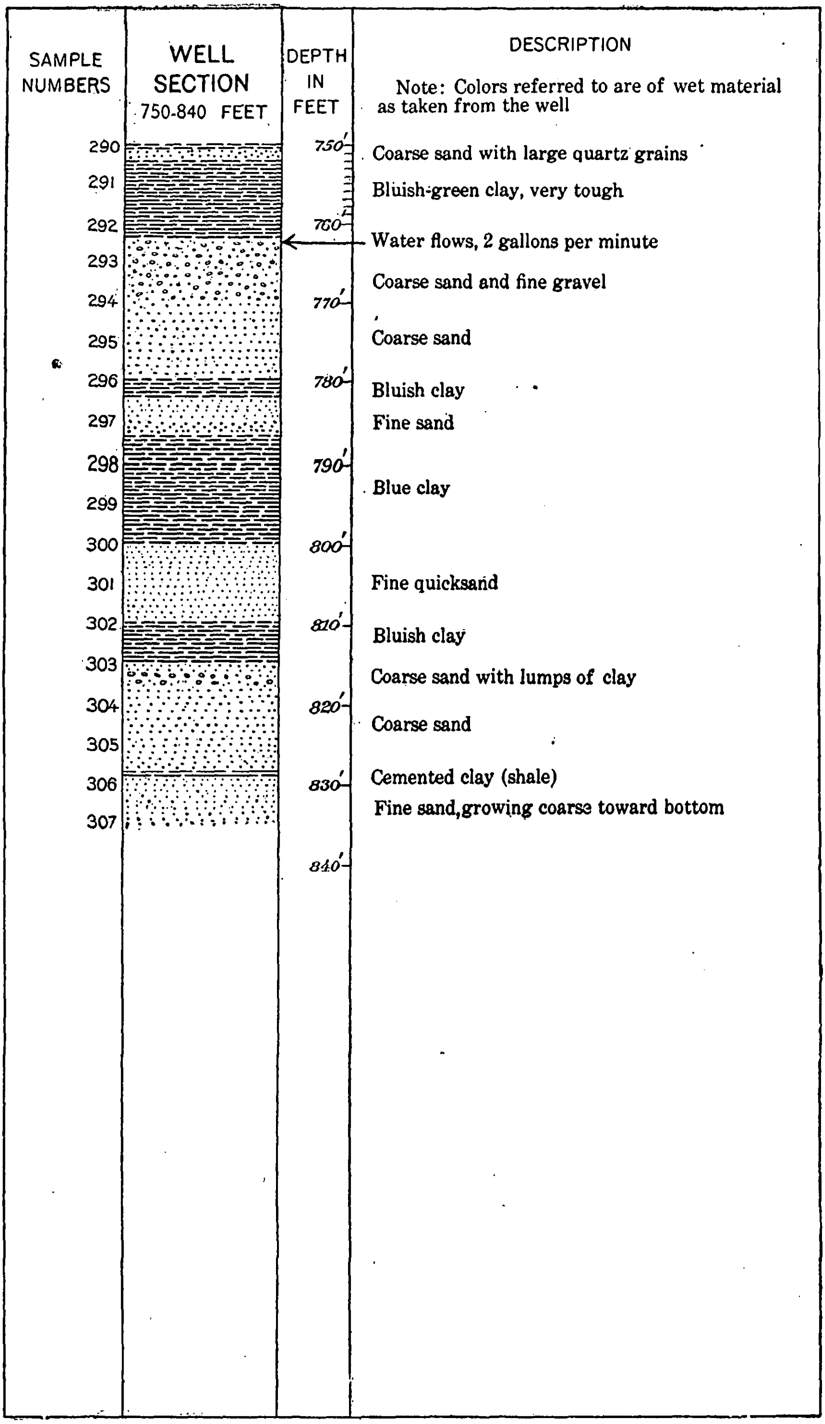

FIGURE 44.—Section of strata in Timber Lake well, near Fallon, Nev.—VI.

SUMMARY OF EXPLORATION FOR THE GERMAN SALT DEPOSITS.

In this connection it is also of interest to note the history of the explorations which resulted in the discovery of the great deposits about Stassfurt, in Germany. Possibly the analogy between that search and our own should not be urged too strongly as bearing on the present situation, but it is nevertheless significant.

For centuries brine springs were known in the vicinity of Stassfurt, Prussia, and it is recorded that from at least as early as the thirteenth century salt was regularly produced or manufactured from these springs. When the demand for salt began to exceed the supply that could be obtained from the springs alone, attention was directed to the opinions expressed by the mining authorities of the times, who held that these springs must derive their salt from rich saline beds below and that these beds might be reached by boring.

The first boring was done by order of the Prussian Government, commencing in 1839. The saline bed was reached in 1843 at a depth of 768 feet. The boring was continued 975 feet deeper, a total of 1,743 feet, passing through the salt beds. At first the material sought was sodium chloride, or common salt, and the presence of magnesium and potassium compounds in the salts encountered was considered an unfortunate feature.

In 1851 a shaft was begun near one of the bore holes, still in the search for beds of common salt. The success attained in these experiments aroused many private undertakings, and when the value of the associated potash salts was also recognized, the industry became of great importance.

One authoritative account relates that from 1890 to 1902 more than 150 companies were organized for prospecting these deposits by boring, and that many of them drilled several holes, while others were liquidated without accomplishing anything; also that enormous sums of money were and are still being expended in such enterprises. The total amount of such drilling was estimated to be at least 500,000 feet in 1902 and must exceed that figure many times over at the present time.

The productive mines are worked by means of shafts and are supplied with very extensive equipment.

The problems relating to the method of extraction and refining of the potassium or other salts from the crude material as it is found at Stassfurt have been very successfully worked out.

THE OCCURRENCE OF POTASH SALTS IN THE BITTERNS OF THE EASTERN UNITED STATES.

By W. C. PHALEN.

INTRODUCTION.

In connection with the potash investigations carried on by the Geological Survey in the summer of 1911, as authorized by the act of March 4, 1911 (Stat. L., vol. 36, pt. 1, p. 1256), a systematic and fairly complete study of the brines, bitterns, and rock-salt deposits of the States east of the Rocky Mountains was attempted. The study was confined to the localities that were considered the most promising with reference to the occurrence of potash salts. The investigation has but recently been completed and many of the data collected have yet to be assembled and classified before being presented in final form. Moreover, most of the samples submitted for chemical examination are yet to be analyzed, and the analyses presented below constitute but a small fraction of those to be published later. It is hoped that the complete analyses will serve for many years as positive data on the occurrence or nonoccurrence of potash salts in connection with many of the salt deposits east of the Rocky Mountains. It will be understood, therefore, that this report is purely of a preliminary nature.

In connection with the study approximately 175 samples of brines, bitterns, and calcium chloride were collected. This does not include the large number of brine samples procured through correspondence, chiefly from oil drillers throughout the country, earlier in the year. The geology of the occurrences of the brine and the salt was investigated and to this end many records of deep wells were obtained. Where possible, actual samples of the rocks passed through in making the deep drillings were collected and will be studied microscopically and chemically during the coming winter. Because so few of the samples (less than 25) collected or received by the Survey have been analyzed, a general statement of results at this time is impossible. By reference to the analyses given further on it will be seen that many bitterns supposed to be devoid of potash salts in fact contain small amounts of them. Particular attention is called to a natural bittern from northern Ohio which is known to occur over a large area and which in its content of potash salts stands out from the rest.

EXPLANATION OF THE TERM "POTASH."

To meet the numerous inquiries that have been addressed to the Geological Survey regarding the exact meaning of the terms "potash," "actual potash," "potassium," etc., the following explanation is given:

The element potassium, represented by the symbol K, is the basis of all potash salts or compounds. This substance is a metal—that is, it possesses metallic properties. To prevent rapid change it must be kept from air and water, with both of which it combines with great avidity. Combined with oxygen it forms potassium oxide, represented by the symbol K_2O, known among scientists as potassa but popularly as potash. In estimating the quantity of potassium in the different products of the Stassfurt deposits this compound, K_2O, is employed as a standard, the object being to establish a basis of comparison for all potassium salts. Among chemists as well as laymen there has grown up the practice of using for this standard the term "potash." When only the term "potash" is used in speaking of potash products, it is understood to refer to the potassium oxide (K_2O) present. As a matter of fact, potash salts are not sold in the form of K_2O, but as the sulphate or chloride,[1] etc. By the term "potassium sulphate" is meant potassium (K) combined with the acid radicle of sulphuric acid (SO_4), or potassium oxide (K_2O) combined with sulphur trioxide (SO_3), making the compound K_2SO_4. By "potassium chloride" is meant potassium (K) combined with another element, chlorine (Cl).

In the following table are given the percentages of the element potassium and the combination known as potash in or obtainable from the common potassium compounds and minerals:

Potassium and "potash" in potassium compounds.

Name.	Symbol.	Percentage of potassium (K).	Chemical equivalent in terms of "potash" (K_2O).
Element.			
Potassium	K	100	
Potassium salts or "potash salts."			
Potassium chloride (mineral sylvite)	KCl	52	63
Potassium muriate (same as chloride).			
Potassium sulphate	K_2SO_4	45	54
Potassium nitrate (saltpeter)	KNO_3	39	47
Potassium carbonate[2]	K_2CO_3	57	68
Potassium hydrate or caustic potash	KOH	70	84
Potassium cyanide	KCN	60	72
Stassfurt minerals.			
Carnallite	$KMgCl_3.6H_2O$	14	17
Kainite	$MgSO_4.KCl.3H_2O$	16	19
Sylvite (potassium chloride)	KCl	52	63

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[1] The chloride is also known in the trade by the chemically obsolete term, "muriate of potash."

[2] The term "potash" is often applied to this compound.

Other potash-bearing minerals that are found at Stassfurt are, among the chlorides, douglasite ($K_2FeCl_42H_2O$?); among the sulphates, polyhalite ($2CaSO_4.MgSO_4.K_2SO_4.2H_2O$), krugite ($4CaSO_4.MgSO_4.K_2SO_4.2H_2O$), langbeinite ($2MgSO_4.K_2SO_4$), leonite ($MgSO_4.K_2SO_4.4H_2O$), picromerite ($MgSO_4.K_2SO_4.6H_2O$), and aphthitalite ($K_3Na(SO_4)_2$). All these are of rare occurrence.

Some of the more common potash-bearing materials produced at Stassfurt consist of mixtures of potash-bearing minerals and others which do not contain potash. Among the latter may be noted common rock salt (sodium chloride) and kieserite (hydrous magnesium sulphate). Trade names have been applied to these mixtures, to which obviously no definite chemical symbol can be given. Among the trade names in common use are "sylvinite," "hartsalz," "manure salts," and "double manure salts." In a pamphlet issued by the German potash syndicate[1] these products are defined in part as follows:

Sylvinite is, in the main, a mixture of rock salt or sodium chloride ($NaCl$) and sylvite or potassium chloride (KCl), with a little kainite ($MgSO_4.KCl.3H_2O$).

Hartsalz is a mixture of sylvite or potassium chloride (KCl), rock salt or sodium chloride ($NaCl$), and kieserite ($MgSO_4.H_2O$).

Manure salts apparently consist chiefly of sodium chloride ($NaCl$) and potassium chloride with variable but small amounts of other salts.

Double manure salts consist essentially of the double sulphate of potassium and magnesium.

The table below gives the "potash" (K_2O) content and the minimum guaranteed "potash" in the products turned out by the German potash syndicate, as stated in the pamphlet just cited.

"Potash" in products of German potash syndicate.

	Crude salts (natural products).			Sulphates (nearly free from chlorides).		
				Sulphate of potassium.		Sulphate of potassium and magnesium (double manure salts).
	Kainite.	Carnallite.	"Sylvinite."	90 per cent grade.	96 per cent grade.	
Potash	12.8	9.8	17.4	49.9	52.7	27.2
Minimum guaranty	12.4	9.0	12.4	48.6	51.8	25.9

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[1] Stassfurt industry, published by the German Kali Works.

"Potash" in products of German potash syndicate—Continued.

	Salts containing chlorides.				
	Chloride of potassium.			Manure salts.	
	90 to 95 per cent grade.	80 to 85 per cent grade.	70 to 75 per cent grade.		
Potash	57.9	52.7	46.7	21.0	30.6
Minimum guaranty	56.8	50.5	44.1	20.0	30.0

STATEMENT OF THE GERMAN POTASH SYNDICATE.

In a pamphlet entitled "The potash controversy," dated at New York January 20, 1911, A. Vogel, general representative of the German potash syndicate for the United States and Canada, makes a statement on behalf of that syndicate. This statement is the same as that submitted to President Taft and Secretary Knox later in the year, except that certain matter not of general interest has been omitted.

Certain parts of this pamphlet will be quoted here in order to convey to American readers who have not had access to the subject matter contained in it some authoritative idea of the present status of the world's potash industry from the German side and the relations of the United States to it. In this brief summary will be shown (1) Germany's monopoly of the production of potash salts; (2) the consumption of potash salts in the United States; (3) the trade in potash salts with the United States, including a classification of importers. The discussion of these different topics will at once indicate the reasons why an investigation of potash resources has been undertaken by the United States Government.

Germany's monopoly of the potash industry.—The German Empire has a natural monopoly of potash salts. Practically all of the world's known potash resources are within its territory and under its control, and substantially the whole of the world's potash consumption has always been supplied from the German mines. There are in operation in Germany at present about 69 mines, and new mines are being developed from time to time. A number of them have long been owned and operated by different German States. One of the oldest and largest of the deposits has from the outset been owned and managed by the State of Prussia, and from time to time further deposits have been acquired by the Prussian Government. Another of the largest mines has from the outset been owned and operated by the Grand Duchy of Anhalt. Another large mine has for a long time been owned and operated by the State of Brunswick. Partial ownership of three further mines has for a number of years been in the State of Sachsen-Weimar.

Consumption of potash salts in the United States.—The world's consumption of potash salts during 1909 was about 670,000 tons of pure potash,[1] of which more than half was consumed in Germany. Of the balance exported, about 150,000 tons were shipped to the United States. In 1910 the total consumption considerably increased,

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[1] Presumably reckoned as the oxide of potassium, or potassa, K_2O. The kind of ton is not stated.—W. C. P.

while the quantity exported to the United States is estimated at over 200,000 tons. These exportations by the German mines to the United States embrace various potash salts in both crude and concentrated form. The principal grades of concentrated salts are:

Muriate (or chloride) 80 per cent strength, containing 50 per cent of pure potash.
Sulphate, 90 per cent strength, containing 50 per cent of pure potash.
Sulphate magnesia, 48 per cent strength (known as "double manure salt"), containing 26 per cent of pure potash.

The principal grades of crude salts are:

Manure salt, containing not less than 20 per cent of pure potash.
Hard salt, containing not less than 16 per cent of pure potash.
Kainit, containing not less than 12.4 per cent of pure potash.

Speaking in terms of pure potash, the consumption in the United States is fairly evenly divided between the crude and concentrated salts. Muriate constitutes the great bulk of the trade in concentrated salts, kainit of the trade in crude salts.

Trade with the United States, including a classification of importers.—Practically all the potash consumed in the United States is imported from Germany, and it is devoted almost exclusively to the fertilization of farm land, either directly or else indirectly as one of the most essential ingredients of manufactured fertilizer.

Potash importers in the United States may be roughly divided into four principal classes, namely:

(1) The two large corporations engaged in the business of making fertilizers—the American Agricultural Chemical Co. in the North and the Virginia-Carolina Chemical Co. in the South. Their joint annual consumption is now, say, 70,000 tons, divided about equally between them.

(2) The less important established fertilizer manufacturers (including Armour & Co. and Swift & Co.), probably over 100 in number, known as the "independents," whose annual joint consumption is perhaps 70,000 or 80,000 tons. Most of these concerns, for their common protection, voluntarily act in harmony according to trade policies recommended by an informal association in which they are represented.

(3) Some ten or a dozen manufacturers of chemicals, whose annual joint consumption is about 10,000 tons.

(4) A very large number of smaller purchasers, including some 600 dry mixers and jobbers, hundreds of cotton-oil manufacturers who also make fertilizers, numerous farmers' unions and cooperative societies, and thousands of local dealers who distribute unmixed potash direct to the farmers for home mixing or for use unmixed on the soil. The importations to these purchasers have rapidly increased within the last year. In 1909 the quantity was comparatively insignificant. In 1910 it was probably more than 40,000 tons. The increase in the total consumption within the United States, from 150,000 tons in 1909 to 200,000 tons in 1910, is to be accounted for very largely by the additional importations of this class.

PREVIOUS WORK ON POTASH SALTS BY THE UNITED STATES GEOLOGICAL SURVEY.

Early in 1911 the Geological Survey published a summary of the latest information on the domestic potash industry and the possibilities for its future development.[1] This summary, which is still available for free distribution, contained (1) a discussion of the various uses of potash salts aside from their application to the fer-

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[1] Potash salts, their uses and occurrence in the United States: Advance chapter from Mineral Resources U. S. for 1910.

tilizer industry; (2) statistics showing the magnitude of the importation of potash salts, compiled from figures in possession of the Bureau of Statistics, Department of Commerce and Labor; (3) an account of the chemical manufactures in the United States dependent on imported potash salts and figures showing the magnitude of these industries, which include, aside from the fertilizer industry, the manufacture of potash salts for use in the soap, glass, and explosives industries, of alum, the cyanides, bleaching powder, dyestuffs, and a long list of general chemicals; (4) a section on the deposits of potash salts near Stassfurt, Germany, including an account of their discovery, the theory of their occurrence, and a list of the salts deposited; (5) notes on the German potash salts in the United States; (6) a statement of the financial results of German potash mining; (7) a discussion of the occurrence of potash compounds in the United States, including the igneous rocks, the marls of New Jersey,[1] the salines, and alunite, a mineral known to contain potash; (8) a sketch of the organic sources of potash salts, including wood ashes, beet-sugar molasses and residues, wool scourings or suint, and seaweed; (9) notes on the possible occurrence of potash salts in the United States.

IMPORTS OF POTASH SALTS.

In order to bring before the reader the magnitude of the importation of potash salts into the United States, the following table is given, the figures having been obtained from the Bureau of Statistics.

Imports of potash salts for the nine months ending September, 1909, 1910, and 1911, in pounds.

[Figures from Bureau of Statistics.]

	1909		1910		1911	
	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.
Carbonate of potash	16,512,865	$545,317	12,997,618	$415,686	16,711,935	$503,828
Caustic or hydrate of potash, not in sticks or rolls	6,163,852	258,053	6,233,583	257,250	5,332,926	216,171
Cyanide of potash [a]	....	....	....	....	[b] 1,385,275	[b] 206,348
Muriate of potash	200,045,284	3,207,214	305,108,932	4,126,955	[b] 372,909,953	5,598,420
Nitrate of potash, or saltpeter, crude	12,261,105	361,331	9,874,717	297,158	6,780,382	225,280
Sulphate of potash	37,731,363	716,431	62,769,061	983,470	90,310,434	1,666,102
All other potash [c]	[b] 375,758	[b] 51,349	2,044,188	228,238	3,760,472	377,153
	273,090,227	5,139,695	399,028,099	6,308,757	497,191,377	8,793,302

[a] Included in "All other chemicals" prior to July 1, 1911.
[b] Figures cover period since July 1.
[c] Included in "All other chemicals" prior to July 1, 1909.

The imports of kainite and manure salts for the nine months ending September, 1911, amounted to 493,066 long tons, or 1,104,467,840 pounds, valued at $2,872,065, making a total importation of potash salts for the nine months ending September, 1911, of 1,601,659,217

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[1] The Leitchfield marls (Shaler) of Kentucky, which contain appreciable amounts of potash and phosphoric acid, deserve to be mentioned in this connection.

pounds, valued at $11,665,367. In this connection the following recent statement prepared by the Bureau of Statistics is of interest:

> The importation of potash salts is now running at the rate of over a million dollars a month, and has aggregated since 1900 approximately $75,000,000. While these potash salts enter the country in various forms and thus under various titles, including muriate of potash, sulphate of potash, carbonate of potash, kainit, etc., their aggregate import value in the nine months ending with September, 1911, was $11,500,000, against about $7,000,000 in the corresponding months of 1910 and a little over $5,000,000 in the corresponding months of 1909, thus indicating a steady and rapid growth in the importation of this class of products. Taking the figures for fiscal years, the total for 1911 was $14,000,000, compared with less than $12,000,000 in 1910, less than $4,000,000 in 1900, and less than $2,000,000 in 1890.

PRESENT WORK OF THE GEOLOGICAL SURVEY.

SCOPE OF THE WORK.

In view of the obvious and urgent necessity, as indicated in the general and specific ways mentioned above, to determine if possible a source of potash salts in the United States, and thus to conserve the vast sum of American money shipped abroad for potash salts each year, the United States Geological Survey, of the Department of the Interior, and the Bureau of Soils, of the Department of Agriculture, were commissioned by the Sixty-first Congress to search for potash salts.

In the previous publication of the Geological Survey alluded to above, it was stated in general, with reference to the possible occurrence of potash salts in the United States, that to make a thorough and complete investigation of the occurrence of potash salts, every known salt deposit should be tested, for ordinary rock salt may overlie soluble potash salts as well as underlie them. Both these conditions exist at Stassfurt. The normal occurrence of salt is, however, at the base of a series of soluble salines deposited from the evaporation of sea water. The brines of Midland, Saginaw, Bay, and Isabella counties, Mich., are of interest in this connection, inasmuch as they contain bromine in commercial quantity, a fact which indicates partial desiccation of sea water and the occurrence of mother liquors. The brines of Malden, Kanawha County, and of Mason and Hartford, Mason County, W. Va., and across Ohio River from Mason, in Meigs County, Ohio, likewise contain and are worked for bromine. Bromine is also obtained from brine in Pittsburgh, Pa.

The "Red Beds" of the southwestern part of the United States, in Texas, Oklahoma, Kansas, Colorado, New Mexico, and possibly other States, contain deposits of gypsum and salt and are worth notice as possible sources of potash salts. These beds might profitably be explored in those places where structural conditions seem to favor the accumulation and retention of the salines.

The Geological Survey has concentrated its investigations of the possibilities of finding potash salts in commercial quantities along the following lines: (1) The exploration by actual deep drilling for deposits of potash salts in Nevada and in other localities in the far West, to be selected later, under the direction of Hoyt S. Gale, whose report of progress has already been published; (2) the investigation of the occurrence of certain rich potash-bearing rocks and minerals, to be described in short reports; and (3) the investigation of the salt deposits and the brines and bitterns in the United States east of the Rocky Mountains, carried on by the writer under the supervision of David T. Day.

INVESTIGATION OF THE BRINES.

COLLECTION OF SAMPLES.

The work in connection with the investigation of the brines, primarily, was begun in April, 1911, by sending a circular letter to all the salt producers in the United States and to many drillers of oil wells, to procure samples of brine. This circular letter is in part as follows:

> The Geological Survey is desirous of making a comparative study of the different brines characteristic of the different salt-producing regions of the States east of the Missouri River. I shall be very glad if you will therefore send a sample of your brine and a sample of the mother liquor in as concentrated a form as possible, and also give an idea as to the amount of original brine which the mother liquor represents. These will be examined, and a copy of the final report will be sent to you as promptly as possible. In this examination particular account will be taken of the occurrence of potash in these brines. I am sending, under separate cover, cans in which these samples may be sent. These cans are labeled ready to be returned. * * *

Accompanying each bottle sent out was another circular letter describing the objects of the work and giving explicit directions as to the brine samples. The form of this circular letter addressed to oil producers is as follows:

> The United States Geological Survey is making a systematic examination of crude petroleum from all the pools in the United States. In connection with this investigation it is advisable to make comparative analyses of the salt water found in each pool. This feature of the investigation is receiving particular attention at this time on account of the demand for potash salts and in the hope that these analyses may lead to the discovery of salt deposits containing potash in commercially valuable quantities.
>
> Accompanying this circular you will receive a bottle or can, which you are requested to fill with brine from your well and send by mail to the United States Geological Survey.
>
> In filling the bottle please observe the following precautions:
>
> 1. Remove the bottle from the mailing case and take care not to stain the mailing case with oil.
> 2. Rinse the bottle with the brine before filling.
> 3. Fill the bottle with the brine as it issues from the well, if possible. If this is not practicable, take it from the settling tank. A slight amount of oil in the sample will do no harm.

4. Wipe the bottle dry, close it tightly, and fill out each item of the label legibly and as carefully as possible.

5. Replace in mailing case, screw on the cap tightly, see that the mailing case is clean, and place it in any post office. The mailing case is properly labeled and does not require postage.

A copy of the analysis will be furnished you if asked for.

The responses received were very satisfactory, and many brines from all parts of the United States have been received. These will be investigated by the Bureau of Soils, as a result of a cooperative agreement between that bureau and the Geological Survey.

FIELD WORK.

At the beginning of the field season the writer was detailed to make a systematic examination of all the salt deposits and the salt industry in the United States east of the Rocky Mountains, with special reference to the occurrence of potash salts.

Accordingly, visits were made to practically all the salt plants in the eastern United States where there seemed any likelihood of procuring material that would prove of value in the present investigation. During the early part of 1911 it was rumored that potash salts had been found near Goderich, Canada, and this locality also was visited and samples obtained. The age of the beds near Goderich in which salt occurs, it is thought, will prove identical with that of the beds around Detroit and along St. Clair River, and there is no more reason to suspect the occurrence of potash salts in western Ontario than in the State of Michigan. The rumor proved to be entirely unfounded.

During the early part of the work the writer was accompanied by J. W. Turrentine, of the Bureau of Soils. The field work extended over the western portion of New York and included visits to the operating plants in Wyoming, Livingston, and Genesee counties, by the writer, and to points in Tompkins County, by Dr. Turrentine. Every active salt plant in the Lower Peninsula of Michigan, in northern and southern Ohio, West Virginia, and western Pennsylvania was visited. The Kansas field was gone over, and a trip was made to Louisiana. Samples of rock salt were carefully collected in the mines visited, and where the evaporative process was used samples of the brine and of as old a bittern as possible were collected in order to secure the maximum concentration of the mother liquor salts—that is, those salts remaining in the brine after the removal of the sodium chloride. In every case care was taken to obtain a bittern from which the maximum amount of salt had been removed, for there, if anywhere, would potash salts occur, if any were present in the original brine. The amount of bittern going to waste daily from the different plants was ascertained where practicable, for these data, together with a knowledge of the composition of the bittern, would show the amount of potash salts now going to waste in different parts of the country. In addition to collecting samples of rock salt, brines, and bitterns, the investigators obtained samples of calcium chloride, which represents the final concentrated product from the evaporation of the bittern after the sodium chloride and bromine have been removed. The geology of the brines was also studied, and to this end records of deep drillings were collected. In Michigan, both in the eastern part of the State near Detroit and in the western part near Manistee and Ludington, samples of these drillings were obtained. They will not only serve as a guide to the stratigraphy of the regions whence they come, but, when examined both microscopically and chemically, they may show the presence of potash salts. A bulletin on the salt industry is planned for issue in the spring of 1912, which will summarize the results of the last season's work and include sections on the geology of the brines, the chemistry of brine in general, the salt-making processes in the United States, the occurrence of potash salts in the brines, together with a quantitative statement of the aggregate amount going to waste at the plants visited, and a bibliography of the most important publications relating to the occurrence of salt and the salt industries in general.

It is believed that there is need of such a publication at the present time, for the results of work along this line in the United States are scattered and inaccessible. Moreover, the chemical work connected with the present investigation is being done with extreme detail and care on samples that have been collected under circumstances as closely similar as possible. The results should be strictly comparable.

GEOLOGY OF THE BRINES.

NEW YORK.[1]

The salt beds of the State of New York occur almost exclusively in the Salina formation, or, as it has sometimes been called, the "Onondaga Salt group" of the Silurian system. According to Vanuxem,[2] this important formation contains all the gypsum masses of western New York and furnishes all the salines of Onondaga and Cayuga counties.

The Salina formation was described by James Hall [3] as follows:

> Succeeding the Niagara group is an immense development of shales and marls with shaly limestones, including veins and beds of gypsum. The general color is ashy, approaching drab, with some portions of dark bluish green. The lower part is of deep red, with spots of green. Succeeding this, where protected from atmospheric influences, the rock is blue like ordinary blue clays, with bands of red or brown. This portion

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[1] See also Merrill, F. J. H., Bull. New York State Mus. No. 11, 1893.

[2] Report on the geology of the third district of New York, 1842.

[3] Geology of the fourth district of New York, 1843.

and that succeeding it are often green and spotted and contain seams of fibrous gypsum and small masses of reddish selenite and compact gypsum. From this it becomes gradually more gray, with a thin stratum of clayey limestone, which is sometimes dark, though generally of the same color as the surrounding mass. The formation terminates upward with a gray or drab limestone called by Vanuxem the "magnesian deposit." The red shale forming the lower division of the group is well developed, but in the third district has not been found west of the Genesee River. It appears in the eastern part of Wayne County, as indicated by the deep-red color of the soil which overlies it.

In their studies of the surface Hall and Vanuxem found no rock salt, because this mineral, being soluble, can not remain at the surface; but from various wells put down since their time sections of the Salina formation have been obtained, showing the position and relation of the salt beds.

Throughout the Oatka-Genesee district, which was visited by the writer, the salt is usually found at levels varying from 550 to 750 feet below the surface of the Onondaga limestone. Exceptions to this are few in number. The upper surface of the Onondaga has been taken as the datum plane to determine the relative position of the salt beds, because it is invariably recognized by the driller. Its persistent character and the abundance of chert scattered through it contrast strongly with the overlying soft shales and thin limestones.

The dip of the strata in western New York is approximately southeast, at the rate of about 60 feet to the mile, and the section between Le Roy, in eastern Genesee County, and Gainesville Creek shows that the beds do not slope uniformly to the south, but undulate in that direction. Extraneous evidence seems to point to the fact that many of the wells and shafts of New York have penetrated only little more than halfway through the salt masses.

MICHIGAN.

The rock salt of Michigan is found in the Monroe formation, consisting of Silurian rocks, which have sometimes been called "Salina," but which are not known to be the same as the Salina formation of New York. The brines in the Saginaw Valley occur in the sandstones of the Marshall formation (lower Carboniferous), whose base lies from 750 to 1,000 feet below the surface along Saginaw River. It is these sandstones that yield the brines which are utilized so extensively in the manufacture of salt, bromine, and calcium chloride.

OHIO.[1]

The salt produced in Ohio comes from two distinct districts—the northeastern district, comprising Cuyahoga, Medina, Summit, and Wayne counties, and the southeastern district, comprising Meigs and Morgan counties. In southeastern Ohio Meigs County is by far the

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[1] Bownocker, J. A., Salt deposits and the salt industry in Ohio: Bull. Geol. Survey Ohio, 4th ser., No. 8, 1906.

larger producer, and Pomeroy is the center of the industry. The salt horizon of the northeastern part of the State is in the Monroe formation of the Silurian. The surface rocks in the Ohio Valley near Pomeroy, Ohio, and Mason, W. Va., lie near the top of the Conemaugh formation, formerly known as the "Lower Barren Coal Measures." The depths of the wells in this region have undergone great variation. At first the wells were very shallow, but later they were extended to greater depths as the supply of brine near the surface became exhausted. When the supply from these deeper wells became inadequate they were sunk to still greater depths. At present salt works both in Ohio and in West Virginia are pumping brine from depths of 1,100 to 1,350 feet. The brine-bearing strata dip toward Pomeroy from the northwest, and as the brine has been removed from the wells the supply has been renewed from the rocks lying at higher levels in that direction. The brine was doubtless once a part of the ocean, and as the sand or gravel now constituting the salt-bearing rocks was deposited on the ocean floor, sea water filled the spaces between the grains and pebbles and has since remained in that position. It must be borne in mind that the Pomeroy brines were formed very near the shore, probably within a landlocked sea, and hence might vary considerably from those in the open ocean. This fact explains the presence of the relatively large quantities of bromides and iodides, as these substances are contained in certain marine plants. It is possible that the conditions were very favorable for these plants in the early sea in the vicinity of Pomeroy. The wells along Ohio River procure their brine chiefly from a horizon approximately near the base of the Salt sand of the Carboniferous.

WEST VIRGINIA.

The geology of the brine beds at Mason, W. Va., is similar to that at Pomeroy, on the opposite side of Ohio River. On the Ohio side the geology has been worked out by J. A. Bownocker and published in Bulletin 8 of the Ohio Geological Survey and in "Mineral resources of the United States" for 1907. It has been given above under Ohio and will not be repeated here.

Brines occur near Malden, W. Va., which is located on Kanawha River a few miles above Charleston. The record of a gas well on Cool Spring Branch of Burning Springs Hollow, about 3 miles from Malden, throws some light on the geology of the beds from which the brine is obtained. The record of the well, which is known as the Edwards well No. 1, has been published in a report by I. C. White.[1] According to White, the sandstone known to the oil men as the Salt sand furnishes the brine in the Kanawha Valley. This sandstone belongs to the Pottsville formation and lies very near the base of the coal measures.

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[1] West Virginia Geol. Survey, vol. 1, p. 272.

KANSAS.

The salt industry in Kansas depends on the rock salt found in Permian strata and includes the mining of this salt and the evaporation of artificial brines from wells drilled to it. By far the larger part of the salt is obtained by evaporation. The subject of salt mining in Kansas is very fully described in two papers, one by Samuel Ainsworth and the other by C. M. Young, referred to in the chapter on salt and bromine in "Mineral resources of the United States" for 1909.

In 1887 and 1888 the important salt beds of Kansas were found while wells were being drilled for oil and gas. They have been developed in an area located in the south-central part of the State, in Rice, Reno, Kingman, and parts of the adjoining counties, including Ellsworth, Saline, McPherson, Harvey, Sedgwick, Sumner, Harper, Barber, Pratt, Stafford, Barton, and Russell. In the early history of the industry numerous shafts were sunk to the salt deposits, but from lack of experience and of funds to carry on the work many of them proved failures. Only four important operations may be listed among the plants mining rock salt in recent years, and one of these plants was destroyed by fire late in 1908 and has never been rebuilt. Only three other salt mines in Kansas have ever produced salt to any extent and these have been described by Ainsworth.[1]

Young[2] discusses the evaporated-salt industry, which has its center at Hutchinson. He describes the manner of obtaining the brines from the wells, the various processes—direct heat, grainer, vacuum pan—of converting the brine into salt, the methods of handling the salt, and the productive capacity of the district.

LOUISIANA.

In Louisiana the salt mined on Weeks and Avery islands, so called, belongs in Quaternary strata. Weeks Island is on the east shore of Weeks Bay, an eastern lobe of Vermilion Bay. It is sometimes called Grande Côte on account of its size, though it is scarcely 2 miles in diameter. Salt is also mined on Avery Island, in Iberia Parish, 10 miles southwest of New Iberia. The details connected with the mining of salt in Louisiana have been published in the chapter on salt and bromine in "Mineral resources of the United States" for 1909, as obtained from a recent publication by G. D. Harris, State geologist of Louisiana.[3]

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[1] Ainsworth, Samuel, Eng. and Min. Jour., Sept. 4, 1909, pp. 454-456.

[2] Young, C. M., Eng. and Min. Jour., Sept. 18, 1909, pp. 558-561.

[3] Rock salt; its origin, geology, occurrence, and importance in the State of Louisiana: Bull. Geol. Survey Louisiana No. 7, 1908, p. 259.

ANALYSES OF THE BRINE.

The samples whose analyses are given below represent only a very small part of those submitted for examination. The care with which the work is being done requires a great deal of time, consequently the work has to proceed slowly. The chemical work thus far has been done by R. F. Gardner and A. R. Merz, of the Bureau of Soils, Department of Agriculture.

Composition of certain of the New York bitterns. [a]

Sample No.	Source.	Description of sample.	Constituents, in grams per liter.								Percentage of KCl in total solids.
			K.	Na.	Ca.	Mg.	Cl.	SO_4.	Total.	Content of KCl.	
2	Worcester Salt Co., Silver Springs.	Bittern from grainer	2.8	100.3	19.9	1.8	197.2	0.5	322.5	5.34	1.7
[b] 4	Remington Salt Co., Ithaca.	Bittern from vacuum pan.	1.0	109.1	10.3	1.6	191.1	.6	313.7	1.91	.6
5	Rock Glen Salt Co., Rock Glen.	Bittern 10 days old.	1.9	106.7	13.5	1.5	193.5	.8	317.9	3.62	1.1
7	Star & Crescent Salt Co., Salt Vale.	Bittern from grainer	1.8	93.7	25.2	2.6	197.5	.4	321.2	3.43	1.06
11	Genesee Salt Co., Pifford.	Bittern, 36 hours old, from grainer.	1.3	114.2	6.4	1.9	192.8	1.2	317.8	2.48	.8
18	Le Roy Salt Co., Le Roy.	Bittern going to waste outside plant.	.2	72.7	5.3	.7	122.8	1.1	[c]202.8	.38	.2

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[a] These analyses constitute but a fractional part of those to be submitted in the final report.

[b] Collected by J. W. Turrentine.

[c] Diluted with water.

Except sample 18, the bitterns analyzed thus far from western New York show a close similarity. Sample 18, collected from the salt plant of the Le Roy Salt Co., can not be regarded as representative, as it is contaminated with considerable fresh water. It was collected from a steady flow from a pipe outside the plant and represents waste fresh water from various sources plus bittern from the grainers.

The results given above are not strictly comparable, for most of the bitterns were taken from grainers which had been running different lengths of time. In some places salt was crystallizing rapidly and in others, where the temperature was somewhat lower, salt was making slowly. Thus the bitterns represent variable amounts of original brine and consequently some variation in the amount of total solids is to be expected. Considering the fact that the amount of total solids has not been reduced to a common standard of time and volume, the close agreement in total grams of salt per liter is somewhat remarkable. The original brines, which came from beds at the same geologic horizon, must be very closely related in chemical composition. The amount of potassium chloride in the New York brines is very small and not of commercial importance. These brines may be considered as solutions of sodium chloride (common salt) and calcium chloride, with small amounts of calcium sulphate (gypsum), potassium chloride, and magnesium chloride.

Composition of certain of the Michigan bitterns.[a]

Sample No.	Source.	Description of sample.	Constituents, in grams per liter.								Per cent of KCl in total solids
			K.	Na.	Ca.	Mg.	Cl.	SO_4.	Total.	Content of KCl.	
23	Delray Salt Co., Delray (Detroit).	Bittern from grainer.	....	121.1	1.9	0.2	187.5	3.4	314.1	....	....
98	Worcester Salt Co., Ecorse (Detroit).	Bittern, 11 days old.	....	119.5	3.0	.3	189.9	.2	312.9	....	....
53	Peters Salt & Lumber Co., East Lake (Manistee).	Bittern, 19 days old, from grainer.	0.5	115.1	3.9	3.0	191.4	2.3	316.2	0.95	0.3
56	Buckley & Douglas Lumber Co., Manistee.	Bittern from grainer, 4 weeks old.	.2	119.1	2.4	1.6	189.8	3.4	316.5	.38	.1
59	Louis Sands Lum-Co., Manistee.	Bittern from grainer, 3 weeks old.	.7	111.1	3.5	4.6	189.8	2.3	312.0	1.33	.4
61	Stearns Salt & Lumber Co., Ludington.	Bittern from grainer.	....	121.4	2.8	.3	190.4	2.4	317.3	....	....
63	Hine & Co., Bay City.	Bittern from grainer, 5 days old.	1.3	66.1	40.6	11.5	207.7	.4	327.6	2.48	.8
96	Michigan Salt Works, Marine City.	Bittern, 6 weeks old, from grainer.	2.0	104.6	13.8	2.7	194.6	.6	318.3	3.81	1.2

[a] These analyses constitute but a fractional part of those to be submitted in the final report.

The samples of bittern collected from the Delray Salt Co., the Worcester Salt Co., and the Michigan Salt Co. came from the southeastern part of Michigan and from the same geologic formation, though not necessarily from the same salt bed within that formation. In total constituents they show close agreement not only around Detroit, along Detroit and St. Clair rivers, but also with those representing brine from presumably the same group of rocks near Manistee and Ludington, in the western part of the State. Considering the fact that the two bitterns obtained near Detroit do not show even a trace of potash, the bittern from Marine City, Mich., with 1.2 per cent of potassium chloride, is rather remarkable. The bitterns from Manistee contain extremely small quantities of potash salts, that from Ludington showing none whatever.

The brines and bitterns from Saginaw Valley come from rocks very much higher in the geologic column, as indicated in the section on the geology of the Michigan brines. It is to be regretted that an analysis of an older and hence more concentrated bittern than that given in the table (No. 63) is at present not available, nor that of a sample of calcium chloride, the ultimate production of the concentration of the Saginaw Valley brine. Samples of the chloride were obtained from Saginaw, Mount Pleasant, and St. Charles. These brines are known to contain considerable amounts of bromine, and they are worked for bromine at Midland and Mount Pleasant and were formerly worked at St. Charles. The results of the analyses of the more concentrated bitterns and the end product of their evaporation—viz, calcium chloride—must be given later, as the analyses have not yet been made.

The outlook for potash in the Michigan brines aside from those in the Saginaw Valley is rather dubious. The writer is hopeful that the more concentrated brines from Saginaw Valley, and especially the samples of calcium chloride (ordinarily known simply as chloride), will show appreciable amounts of potash, but whether these will be enough to be of commercial significance can not yet be stated.

Composition of certain of the Ohio bitterns.[a]

Sample No.	Source.	Description of sample.	Constituents, in grams per liter.									Per cent of KCl in total solids.
			K.	Na.	Ca.	Mg.	Cl.	SO_4.	Br.	Total.	Content of KCl.	
112	Union Salt Co., Cleveland.	Bittern from grainer, 5 days old.	1.2	100.1	16.3	3.7	194.5	0.7	.....	316.5	2.29	0.7
117	Ohio Salt Co., Wadsworth.	Bittern accumulating 35 days.	.7	103.7	16.5	1.3	192.3	1.1	.....	315.6	1.33	.4
118	.....do..........	More concentrated bittern than No. 117; vacuum pan at boot.	1.8	97.6	12.0	2.4	187.8	1.8	.....	303.4	3.43	1.1
[b]114	Diamond Alkali Co., Fairport Harbor.	Natural bittern.	3.9	43.4	48.6	11.2	188.4	.2	.....	295.7	7.43	2.5
122	Pomeroy Salt Association, Pomeroy.	Bittern before passing to bromine plant.	3.2	2.6	145.2	42.2	360.4	5.2	11.6	570.4	6.10	1.1

[a] These analyses constitute but a fractional part of those to be submitted in the final report.
[b] Samples of this natural bittern were also obtained near Akron and Barberton, Ohio.

Composition of certain of the West Virginia bitterns.[a]

Sample No.	Source.	Description of sample.	Constituents, in grams per liter.									Per cent of KCl in total solids.
			K.	Na.	Ca.	Mg.	Cl.	SO_4.	Br.	Total.	Content of KCl.	
120	Dixie Salt Co., Mason.	Bittern from grainer before passing to bromine plant.	....	3.3	135.8	48.4	366.2	4.8	11.0	569.5	......	....
129	Liverpool Salt & Coal Co., Hartford.	Bittern before passing to bromine plant.	....	.2	143.4	43.4	358.6	3.8	12.2	561.6	......	....

[a] These analyses constitute but a fractional part of those to be submitted in the final report.

The Ohio bitterns deserve more than passing notice. The samples of bitterns collected in Cleveland and at Wadsworth are from the Monroe formation of the Silurian system. They show appreciable but not workable quantities of potash salts. The bittern from Pomeroy, Meigs County, on Ohio River, also shows an appreciable amount of potassium chloride, a fact that can not be reconciled with the results shown in the analyses of West Virginia bitterns, which though from approximately the same levels if not the identical geologic horizons and showing almost the same amount of total solids, yet show no trace of potash salts. Further analyses may explain this discrepancy and, as a check, there will be given in a later publication the analyses of several samples of calcium chloride collected from the Ohio Valley near Pomeroy, Mason, and Hartford.

Only a single analysis of a natural brine or rather bittern is available at the present time, namely, that of sample 114, collected at the Diamond Alkali Co.'s plant at Fairport Harbor, northeast of Cleveland, on Lake Erie, from a well during the process of sinking. Samples of similar natural bitterns were procured near Akron and also at Barberton. The top of this bittern stratum varies from approximately 350 to more than 400 feet above the topmost salt bed from which artificial brines are pumped in northern Ohio. One record collected shows a difference of only 250 feet, but this seems very exceptional. It will be sufficient to state here that the bittern stratum is sharply defined and is of wide areal extent. The bittern is a "bugbear" to the salt industries of this part of the State, for if allowed to get into the brines from which salt is made it renders them bitter and as a consequence plays havoc with the resulting salt. As a container of potash salts, it may prove to be the richest known in the Eastern States.

On reducing the different constituents of this bittern from their ionic state to conventional combinations, the total solids would be divided as follows:

Composition of natural bittern from Fairport Harbor, Ohio.

	Grams per liter.
Potassium chloride	7.4
Sodium chloride	110.1
Calcium chloride	134.4
Magnesium chloride	43.2
Calcium sulphate	.3
Ferric chloride	.3
	295.7

In the fractional crystallization resulting from the evaporation of such a combination of salts (which can not be far from the truth) the sulphate of calcium (gypsum) and chloride of sodium (common salt) would first separate, leaving the chlorides of potassium, lime, and magnesium, together with small amounts of iron. The potassium chloride, after the removal of the other constituents, would constitute nearly 4 per cent of the mass. Whether the removal of the lime would be commercially practicable is a problem for the industrial chemist, but it seems that these Ohio bitterns deserve careful attention and experiment to ascertain the possibilities of the sodium-free residue as a fertilizer—if not in its present condition, possibly after some cheap chemical means has been devised of precipitating its lime and magnesia. A bittern of this composition seems to offer opportunities for research which should not be neglected.

EXPLORATION OF SALINES IN SILVER PEAK MARSH, NEVADA.

By R. B. DOLE.

LOCATION AND EXTENT.

Silver Peak Marsh, comprising the lowest part of Clayton Valley, lies in Esmeralda County, Nev., about 20 miles west of Goldfield and 25 miles southwest of Tonopah, and is included in Tps. 1 and 2 S., Rs. 39, 40, and 41 E. It is about 10 miles long northeast and southwest and about 4 miles wide, its area being about 32 square miles. (See fig. 45.) It is most readily reached by means of the Silver Peak Railroad, which connects with the Tonopah & Goldfield Railroad at Blair Junction and runs south to Blair, a small mining town near the western edge of the marsh.

TOPOGRAPHY.

The marsh is a salt playa entirely devoid of vegetation and covered for the most part with a white crust of sodium chloride. Tracts 3 or 4 acres in extent rising gently 1 to 3 feet above the general level appear as rough brown sun-baked patches without a covering of salt. The most noticeable topographic features are the Goat and Alcatraz "islands," two groups of steep limestone hills near the southwest end of the playa. The marsh, when viewed from a distance, seems not unlike a shallow icebound lake having two large high islands and many small low ones. The surface of this alkali flat is usually dry, though it is sometimes covered by a foot or more of water after excessively heavy rainfall. The ground-water plane is, however, always high, and holes a few feet deep anywhere on the flat enter mud, many parts of the marsh being too soft to bear the weight of a horse. The tailings from the cyanide mill of the Pittsburgh Silver Peak Mining Co. at Blair flow into the marsh 2 miles north of Silver Peak.

Clayton Valley, the lowest part of which is about 4,340 feet above sea level, is almost completely surrounded by high mountains, one spur of the Silver Peak Range ending abruptly at the west edge of the playa. Gently sloping washes, composed of small fragments of rock interspersed with stretches of shifting sand and bearing moderate growths of sagebrush and greasewood, extend from the bases of the hills to the playa and occupy the lower divides. The present drainage basin of the valley has an area of 570 square miles.

WATER SUPPLY.

As the rainfall is less than 5 inches a year Clayton Valley is an arid region. No perennial stream exists, and the torrential discharges during the short wet season are quickly absorbed or evaporated. Enough water enters the rocks of the Silver Peak Range to furnish wells and springs at its base with a supply that is potable though hard and somewhat brackish. The largest spring, in the

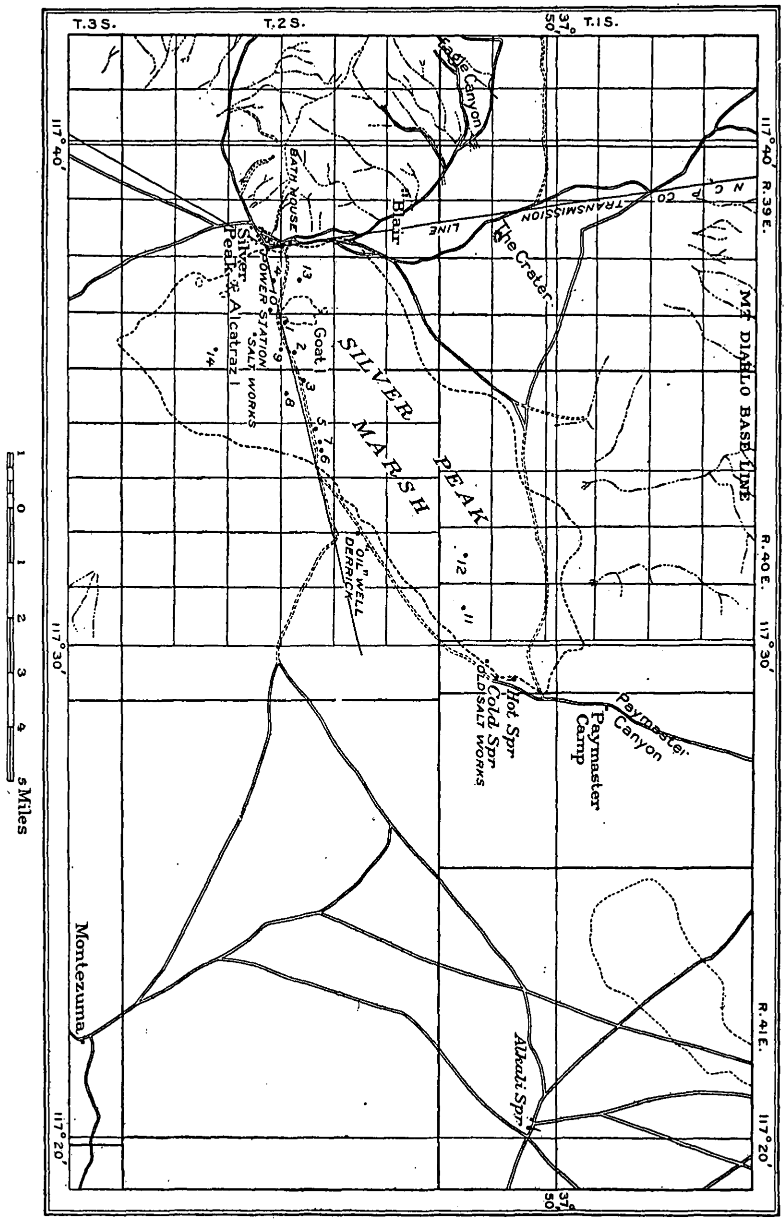

FIGURE 45.—Map of Silver Peak Marsh, Nevada, showing location of test borings.

village of Silver Peak, discharges about 350,000 gallons a day, furnishing the supply for Blair and the near-by mines, to which the water is pumped through a 3-mile pipe line. There are a few shallow dug wells in Silver Peak and Blair and one in Paymaster Canyon, 3 miles from the northeast corner of the flat, but no other potable supplies have been found except in the high gulches of the mountains. Shallow excavations on the marsh yield concentrated brines. Hot and cold springs of weak brine at the edge of the marsh near Silver Peak are used for bathing, and similar springs were found at the northeast end of the marsh.

SOURCE OF THE SALT DEPOSITS.

The geologic features of the district, including Clayton Valley, have been described by J. E. Spurr in his report on the ore deposits of the Silver Peak quadrangle, Nev.[1] The mountains are composed mostly of granitic rocks and lavas. Soft shales, sandstones, volcanic tuffs, and similar material, with interbedded layers of andesitic and rhyolitic lavas, are extensively distributed, and limestones are abundant. According to Spurr much of the material in the valley was laid down in an inclosed lake basin, within which the salt deposits have been formed chiefly by evaporation of more or less concentrated solutions. The character of the deposits makes this evident. Leachings, especially from the Tertiary stratified rocks, extensive areas of which lie in the basin, account for much of the saline residue.

It is possible that an area far greater than the present basin was formerly tributary to Silver Peak Marsh and helped to furnish the saline materials with which its clays and muds are impregnated. The lowest divide of the present watershed, 6 miles north of Blair, is at an elevation between 5,000 and 5,100 feet, or at least 650 feet above the present surface of the Silver Peak Marsh. This divide separates Clayton Valley from Big Smoky Valley, a long, large basin extending northward across Nye County. Another divide near Coaldale, however, at an elevation between 4,900 and 5,000 feet above sea level, is all that separates the drainage of Big Smoky Valley from the basin of Columbus Marsh, and it is therefore somewhat uncertain what influence this comparatively slight difference of 100 feet or less in the elevation of the divides has had on the discharge from Big Smoky Valley. Both divides may have been at the bottom of straits between divisions of a lake, if such a body of water ever filled these valleys above the level of these divides, but whether all or part or none of the discharge of Big Smoky Valley during the recession of such a lake would have come into Clayton Valley is problematic.

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[1] Prof. Paper U. S. Geol. Survey No. 55, 1906.

Spurr suggests that the salt deposits of this and of other playas in the vicinity may have been made partly by concentration of weak brines from the hot springs around the marshes. The possibility, however, that these waters owe their content of salt to the marsh itself should not be overlooked. All the salt springs around Silver Peak Marsh emerge at the level of the salty surface and within or close to its edge. Seepages above that level are not salty but are rather hard carbonate waters, whereas all waters from any source within the playa are necessarily salty because of the ready solubility of the saline deposits. The composition of the waters from the marsh west of Goat "Island," where the ground flow is most abundant, is what might be given to limestone water by contact with salt, but the solutions farther out in the marsh are simply strong brines such as might be produced by leaching the salt muds with rainwater or by continued reaction of hard water with saline deposits. Therefore, it does not seem at all impossible that the brine springs may take their load of salt from the muds of the flat instead of adding salt to them.

METHOD OF EXPLORATION.

The exploration on which this report is based was made principally by means of a Junior Empire drill, though a few shallow holes were bored with a 2½-inch auger attached to ½-inch piping. The Junior Empire drill consists essentially of a rotatable 2½-inch flush-joint casing in 4-foot lengths, bearing a toothed shoe. The borings were started with a 2½-inch auger so constructed that it retains and protects a sample during withdrawal from the hole; this tool was used till soft mud that slumped was encountered, when casing was inserted. Various drilling tools were operated by hand within the casing. Those most frequently used at Silver Peak were a ship auger and a drill bit, operated by means of ¾-inch steel rods in 4-foot lengths, and a flap-valve sand pump 3 feet long attached to a ½-inch rope. The ship auger was used in clay, mud, and similar materials that would stay on the auger during withdrawal; the sand pump was used for removing softer materials and for taking water samples. It was customary to bore below the casing 4 feet and then to rotate in a section of casing rather than to rotate and bore simultaneously. If it was impracticable to do that the casing was advanced by rotating and driving. The casing was revolved by a burro on an 8-foot sweep. It was necessary to drill through some strata of crystals and cemented hardpan. After a boring had been completed the casing was withdrawn without special difficulty. As the casing is watertight it was possible to obtain by means of the equipment uncontaminated samples of all materials encountered and also to ascertain whether strata contained water. Many alterations in the outfit and the manner of operating it were made to fit the conditions. The boring equipment with all necessary attachments weighs about 1,000 pounds and can readily be packed in the bottom of a two-horse wagon.

LOGS OF BORINGS.

The following tables summarize the results of the exploration, locations being referred to the Mount Diablo meridian and base. Borings were made across the marsh eastward from Silver Peak. Two holes also were sunk at the northeastern end and one at the southern end of the playa. (See fig. 45.) The similarity of the materials encountered, as indicated by the records of these borings, rendered further exploration unnecessary.

Summary of records of borings in Silver Peak Marsh, Nev.

Well No.	Location.				Depth of boring.	Depths at which brine was encountered.	Total thickness of crystalline salt penetrated.
	Quarter.	Sec.	T. S.	R. E.			
					Feet.	*Feet.*	*Feet.*
1	SW.	13	2	39	29.0	4 27	None.
2	SE.	13	2	39	14.0	4	None.
3	SW.	18	2	40	55.0	4 13.5 22.5	2.25
4	NW.	23	2	39	11.5	3	None.
5	NW.	17	2	40	12.5	2	None.
6	NE.	17	2	40	52.0	21 38	7.0
7	NW.	17	2	40	17.0	4	None.
8	SW.	18	2	40	13.0	None.	None.
9	NE.	24	2	39	13.0	None.	None.
10	NE.	23	2	39	8.0	3	None.
11	NW.	35	1	40	38.3	22.5 31.5	13.2
12	SW.	34	1	40	36.0	8.5 18 22	15.7
13	SW.	14	2	39	41.0	4 15.5	None.
14	NE.	25	2	39	40.0	8 16	None.

Record of boring No. 1.

[Location, SW. ¼ sec. 13, T. 2 S., R. 39 E.]

	Thickness.	Depth.
	Feet.	*Feet.*
Brown mud containing small crystals of salt	7.0	7.0
Same, containing more clay	2.0	9.0
Stiff blue clay containing small rock fragments	18.0	27.0
Fine gravel and sand	1.5	28.5
Rock fragments	.5	29.0

Ended in small rock fragments. Water encountered at 4 feet rose slowly to 2 feet. Water plentiful at 27 to 29 feet.

Record of boring No. 2.

[Location, SE. ¼ sec. 13, T. 2 S., R. 39 E.]

	Thickness.	Depth.
	Feet.	*Feet.*
Brown mud containing small crystals of salt	10.0	10.0
Stiff blue clay	4.0	14.0

Ended in blue clay. Water encountered at 4 feet rose slowly to 2.5 feet.

Record of boring No. 3.

[Location, SW. ¼ sec. 18, T. 2 S., R. 40 E.]

	Thickness.	Depth.
	Feet.	*Feet.*
Damp sand containing salt	2.0	2.0
Brown mud containing small crystals of salt	10.0	12.0
Stiff blue clay containing small crystals of gypsum	1.5	13.5
Crystallized salt and brine	2.0	15.5
Black clay containing brine and crystals of salt	6.5	22.0
Crystallized salt and brine	.25	22.25
Black clay containing brine and crystals of salt	1.25	23.5
Brown clay	6.0	29.5
Brown clay containing small crystals of salt	9.5	39.0
Drab clay and sand	2.0	41.0
Brown clay	3.0	44.0
Gray clay and sand containing small crystals of salt	1.5	45.5
Red clay containing sand and small crystals of salt	9.5	55.0

Water encountered at 4 feet rose slowly to 2.3 feet. Plentiful supply of cold brine at 13.5, 22.5; none below 30 feet.

Record of boring No. 4.

[Location, NW. ¼ sec. 23, T. 2 S., R. 39 E.]

	Thickness.	Depth.
	Feet.	*Feet.*
Brown mud containing small crystals of salt	3.0	3.0
Brown mud containing nodules of calcareous tufa	4.0	7.0
Greenish mud containing nodules of calcareous tufa	3.0	10.0
Calcareous tufa	.2	10.2
Blue clay	1.3	11.5

Water encountered at 3 feet rose slowly to 2.5 feet.

Record of boring No. 5.

[Location, NW. ¼ sec. 17, T. 2 S., R. 40 E.]

	Thickness.	Depth.
	Feet.	*Feet.*
Damp brown sand containing small crystals of salt	2.0	2.0
Brown mud containing small crystals of salt	6.0	8.0
Blue clay	4.5	12.5

Water encountered at 2 feet.

Record of boring No. 6.

[Location, NE. ¼ sec. 17, T. 2 S., R. 40 E.]

	Thickness.	Depth.
	Feet.	*Feet.*
Crystallized salt and brown sand	3.0	3.0
Brown mud containing small crystals of salt	16.5	19.5
Blue clay	1.0	20.5
Black clay	.5	21.0
Gray clay containing brine and crystals of gypsum	2.5	23.5
Crystallized salt and some gray clay	2.5	26.0
Crystallized salt and black clay	4.0	30.0
Black clay	1.0	31.0
Gray clay	5.0	36.0
Gray clay containing small crystals of gypsum	2.0	38.0
Gray sand and clay containing brine	2.0	40.0
Gray sandy clay	7.0	47.0
Crystals of salt (no water)	.5	47.5
Gray sandy clay	4.5	52.0

Brine encountered at 21 to 29 feet rose to surface. Brine at 38 to 40 feet.

Record of boring No. 7.

[Location, NW. ¼ sec. 17, T. 2 S., R. 40 E.]

	Thickness.	Depth.
	Feet.	*Feet.*
Brown sand containing salt	2.0	2.0
Brown mud containing small crystals of salt	8.0	10.0
Blue clay	.1	10.1
Brown clay	6.9	17.0

Water encountered at 4 feet rose to 2.5 feet. Boring ended in brown clay on hardpan.

Record of boring No. 8.

[Location, SW. ¼ sec. 18, T. 2 S., R. 40 E.]

	Thickness.	Depth.
	Feet.	*Feet.*
Brown mud containing small crystals of salt	12.5	12.5
Blue clay containing small crystals of gypsum	.5	13.0

Boring ended in blue clay on hardpan. Dry hole.

Record of boring No. 9.

[Location, NE. ¼ sec. 24, T. 2 S., R. 39 E.]

	Thickness.	Depth.
	Feet.	*Feet.*
Brown mud containing small crystals of salt	12.5	12.5
Blue clay containing small crystals of gypsum	.5	13.0

Boring ended in blue clay. Practically no water.

Record of boring No. 10.

[Location, NE. ¼ sec. 23, T. 2 S., R. 39 E.]

	Thickness.	Depth.
	Feet.	*Feet.*
Brown mud containing small crystals of salt and nodules of calcareous tufa	7.5	7.5
Gray sandy clay	.5	8.0

Boring ended in gray sandy clay on hardpan (tufa?). Water at 3 feet.

Record of boring No. 11.

[Location, NW. ¼ sec. 35, T. 1 S., R. 40 E.]

	Thickness.	Depth.
	Feet.	*Feet.*
Brown mud containing small crystals of salt	13.0	13.0
Drab clay	9.5	22.5
Crystallized salt with brine and some clay	7.5	30.0
Drab clay containing small crystals of salt	1.5	31.5
Crystallized salt with brine and thin strata of black clay	5.7	37.2
Cemented hardpan	1.1	38.3

Ended in cemented hardpan. Brine encountered at 22.5 to 30 feet rose to 6.5 feet. Brine at 31.5 to 37.2 feet rose to 8 feet.

Record of boring No. 12.

[Location, SW. ¼ sec. 34, T. 1 S., R. 40 E.]

	Thickness.	Depth.
	Feet.	*Feet.*
Brown mud containing small crystals of salt	8.5	8.5
Fine sand containing brine	.5	9.0
Brown mud containing small crystals of salt	2.0	11.0
Drab and gray clay	7.0	18.0
Crystallized salt and brine	2.5	20.5
Drab clay containing salt	1.5	22.0
Crystallized salt and brine with thin strata of drab clay	6.2	28.2
Black clay containing crystals of salt	.8	29.0
Crystallized salt and black clay	7.0	36.0

Boring ended dry in black clay and salt on cemented hardpan. Water encountered at 8.5 to 10 feet rose to 1.8 feet. Water at 18 to 20.5 feet rose to 7.5 feet. Water at 22 to 35 feet rose to 8 feet.

Record of boring No. 13.

[Location, SW. ¼ sec. 14, T. 2 S., R. 39 E.]

	Thickness.	Depth.
	Feet.	*Feet.*
Damp sand	1.0	1.
Hardpan containing nodules of calcareous tufa	.2	1.
Brown mud containing brine and nodules of calcareous tufa	3.3	4.
Brown clay	5.0	9.
White tufaceous material ranging in size from particles ½ inch in diameter to powder.	4.5	14.
Same, looser and containing water	25.5	39.
Small waterworn particles of calcareous tufa and water	1.5	41.

Water at 4 feet. Water at 15.5 to 41 feet rose to 1 foot and could not be lowered by pumping.

Record of boring No. 14.

[Location, NE. ¼ sec. 25, T. 2 S., R. 39 E.]

	Thickness.	Depth.
	Feet.	*Feet.*
Brown sand and salt	3.0	3.0
Brown mud containing small crystals of salt	6.0	9.0
Gray clay	7.0	16.0
Loose, fine light-gray tufaceous material and water	2.0	18.0
Gray clay	9.0	27.0
Red clay	13.0	40.0

Ended in red clay. Water at 8 to 12 feet rose to 4 feet. Water at 16 to 18 feet rose to 3 feet.

Brown mud 5 to 20 feet deep forms the upper layer of the marsh. (See fig. 46.) Because of the intense heat the surface of this mud is usually baked dry and hard enough to support the weight of teams. Small scattered tracts have become dry enough to be pulverulent for a depth of 1 to 2 feet, but over the greater part of the playa 4-foot holes are sufficiently deep to strike soft mud. As this layer is composed of very small particles and contains a large proportion of clay, the strong salt waters in it circulate very slowly. The mud contains a great quantity of salt, though the crystals are small. The brines obtained from it are very strong, and the surface is generally covered to a depth of one-eighth to one-quarter of an inch by a white crust of salt that has crystallized from solutions drawn to the surface by capillarity.

The upper mud along the west shore of the playa, particularly west of the "islands," contains nodules of calcareous tufa, which apparently have been formed by deposition of calcium carbonate from the hard waters percolating into the marsh from Mineral Ridge. The record of boring No. 13 shows that clay under the mud west of the "islands" is underlain by white tufaceous materials, but no salt occurs at a depth less than 41 feet except that in the abundant weak brines.

Well-defined beds of clay containing crystals of gypsum were penetrated east of Goat "Island" in borings Nos. 3 and 6, and these are underlain by beds of crystallized salt containing saturated brine. Very stiff black, blue, red, gray, and brown clays underlie the beds of salt or mixed salt and clay in boring No. 3 to a depth of 55 feet, but in boring No. 6 the clays are interrupted by a stratum of gypsum-bearing clay below the salt and a 6-inch stratum of salt at 47 feet below which clay was again encountered.

Except a shallow bed of light-gray calcareous material at 16 feet nothing but clay containing weak brine was struck to a depth of 40 feet in boring No. 14, at the south end of the playa. (See fig. 47.)

Borings Nos. 11 and 12 indicate that the beds of salt in the northeastern part of the marsh are denser than those farther south. The mud is underlain by clay and that in turn by crystallized salt so hard

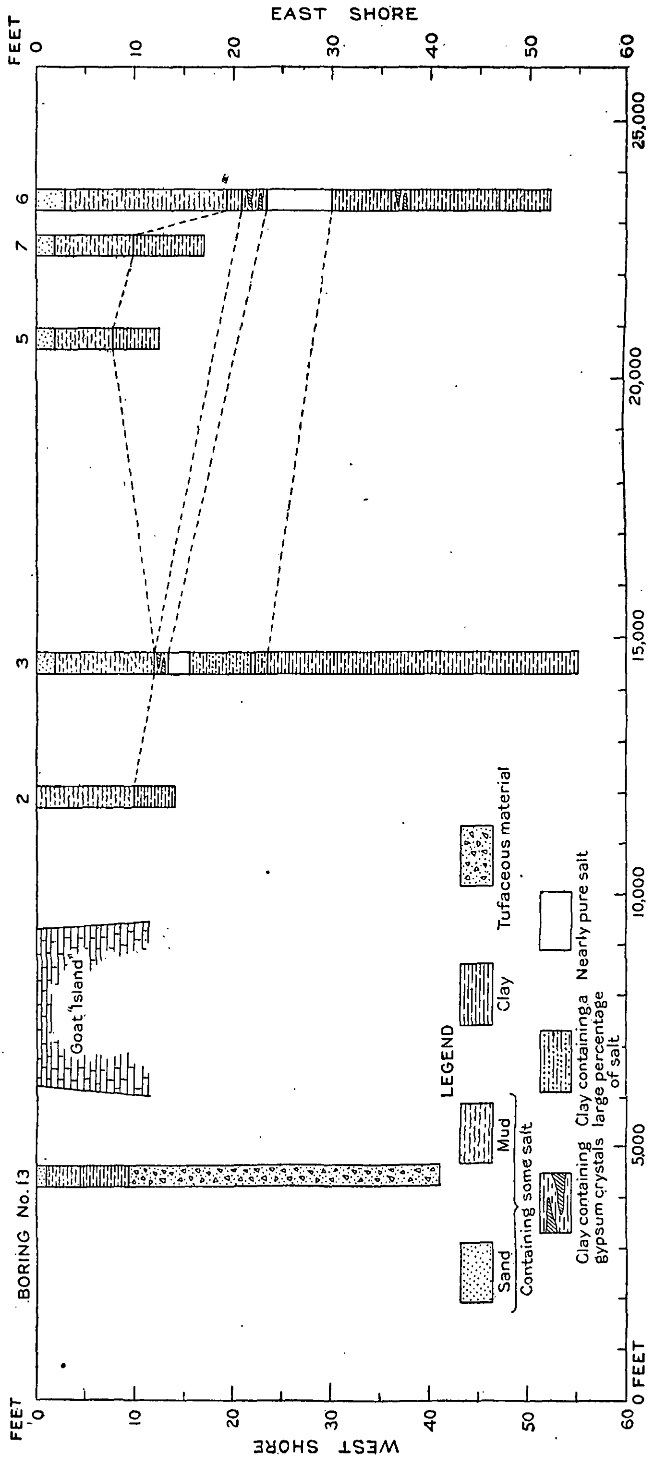

FIGURE 46.—Diagram showing beds penetrated by borings Nos. 2, 3, 5, 6, 7, and 13 in Silver Peak Marsh, Nevada.

that it has to be drilled. A much harder formation, probably calcareous tufa, was struck below the salt in both borings at a depth of about 36 feet.

The data afforded by the six deeper borings lead to the conclusion that the northeastern two-thirds of the playa is underlain at a depth of about 20 feet by beds 5 to 15 feet thick of crystallized salt mixed with more or less clay. It is doubtful if deposits of so great extent occur west of Goat "Island" or south of Alcatraz "Island." Besides these beds practically all other strata to a depth of 50 feet contain appreciable proportions of salt that readily dissolves in water percolating through them.

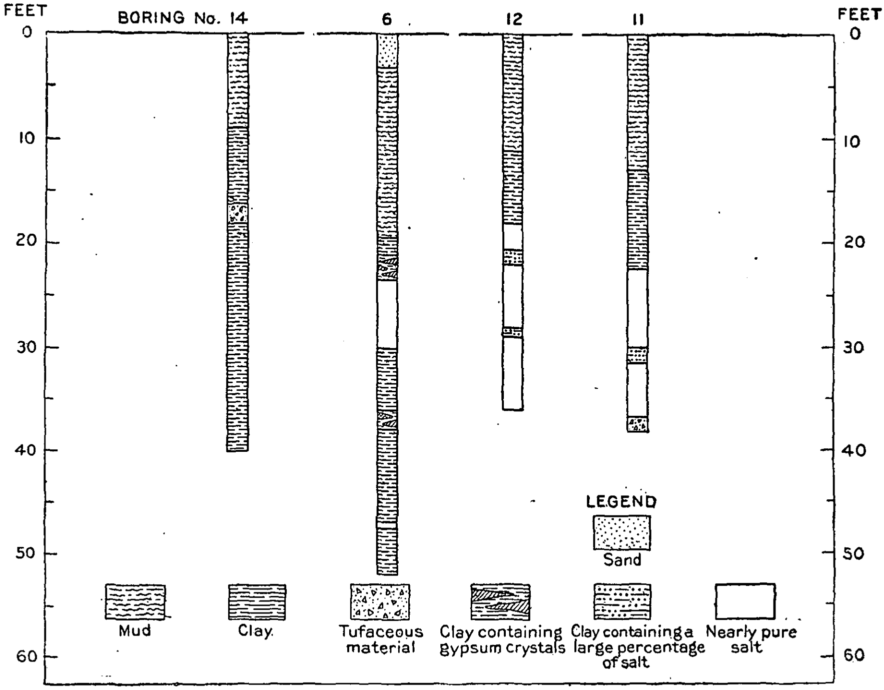

FIGURE 47.—Diagram showing beds penetrated by borings Nos. 6, 11, 12, and 14 in Silver Peak Marsh, Nevada.

COMMERCIAL POSSIBILITIES.

Practically the entire surface of the playa, 32 square miles, is covered with salt that averages in depth about one-quarter of an inch. The upper muds, averaging probably 10 feet thick, contain not less than 2 per cent of salt. It is estimated that not less than 15 square miles of the northeastern part contains a 10-foot saline bed of which at least 60 per cent is salt. It is calculated from these moderate estimates that 15,000,000 tons of salt lies within 40 feet of the surface. The high rate of evaporation, which would permit solar concentration of brines, the absence of long-continued rainfall to interfere with operations, the nearness of a railroad, and more especially the high degree of purity of the product as indicated by analyses of the brines are extremely favorable features in considering the possibility of utilizing these deposits.

Salt is now being produced on a small scale by Frank Porter, of Silver Peak, whose works are situated in sec. 24, T. 2 S., R. 39 E. Brines from pits in the upper muds or from furrows filled with rainwater that has become saturated are concentrated and crystallized by solar evaporation in shallow vats dug in the playa, and the salt thus obtained is bagged for sale. Mr. Porter states that about 150 tons has been produced in three years.

OCCURRENCE OF POTASH.

Potash was not found in sufficient quantity or concentration to be commercially valuable. Though all the clays, muds, and brines give indication of the presence of potash by the flame test, the percentage of that substance is low. Samples of all the brines were tested for potash by A. R. Merz at the Cooperative Laboratory, Mackay School of Mines, Reno, Nev.; the results of these examinations, shown in the following table, indicate the low content of potassium in the saline solutions. The figure for potassium has been expressed as the radicle (K), as the oxide (K_2O), and as the chloride (KCl), for convenience of reference. The saturated brines average a little more than 2.5 per cent in their content of potash (K_2O), a concentration much lower than that in the brines from Searles Lake, Cal. Whether more important deposits lie deeper than these explorations were carried is of course unknown.

Total salts and potassium in brines from Silver Peak Marsh, Nev., June, 1912.

[Examinations by A. R. Merz, Reno, Nev. Quantities in grams per 100 cubic centimeters unless otherwise designated.]

Boring No.	Depth of sample.	Total solids at 105° C.	Potassium expressed as—			
			Potassium (K).	Potassium chloride (KCl).	Potassium oxide (K_2O).	Percentage of potassium oxide (K_2O) in saline residue.
	Feet.					
3	15.5	33.28	0.91	1.74	1.10	3.30
6	21	33.13	.77	1.47	.93	2.80
6	40	33.75	.75	1.43	.90	2.67
11	27	32.25	.74	1.41	.89	2.76
11	35	32.05	.55	1.05	.66	2.07
12	10	26.56	.61	1.16	.74	2.78
12	20	32.90	.59	1.12	.71	2.15
12	27	32.97	.64	1.22	.77	2.34
13	16	4.15	.12	.23	.14	3.36
13	31.5	4.61	.13	.21	.16	3.43
13	40	3.38	.11	.21	.13	3.80
14	11	26.82	.66	1.26	.80	3.00
14	17	26.21	.66	1.26	.79	3.01
Average, exclusive of samples from boring No. 13	....	30.99	.69	1.31	.83	2.69

CHEMICAL COMPOSITION OF THE BRINES.

Samples of saline solutions from the borings in different parts of the marsh were tested for the purpose of ascertaining their relative purity as sources of salt. The waters of all the springs also were examined and the results of these tests are given in the following tables, the first showing partial analyses of the samples and the second complete analyses of composite samples. These analyses were made by Walton Van Winkle, assistant chemist.

Partial analyses of brines, Silver Peak Marsh, Nev.

[Milligrams per kilogram except where otherwise designated.]

Source.	Depth.	Date, June, 1912.	Specific gravity at 20° C.	Total residue.		Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Borate radicle (B_4O_7).
				Dried at at 180° C.	After ignition.				
	Feet.								
Boring No. 1	6	1	1.0281	39,330	38,620	0	532	570	....
	27	4	1.0406	57,600	56,240	Trace.	327	582	....
Boring No. 3	15.5	4	1.2103	276,800	271,600	0	38	2,475	0
Boring No. 6	21	7	1.2081	273,000	270,000	0	28	2,675	0
	40	10	1.2082	274,000	270,000	0	36	2,395	0
Boring No. 11	27	13	1.2105	274,000	271,700	0	74	4,955	0
	35	14	1.2089	272,000	270,000	0	122	4,600	0
Boring No. 12	10	15	1.1702	226,700	224,100	0	51	4,640	....
	20	17	1.2097	274,500	270,900	0	45	4,030	....
	27	17	1.2098	274,700	271,300	0	50	3,900	....
Boring No. 13	16	20	1.0284	39,950	38,860	0	803	476	....
	31.5	21	1.0321	44,900	44,300	0	840	491	....
	40	22	1.0297	41,510	40,900	0	792	477	....
Boring No. 14	11	24	1.1747	233,200	228,800	0	39	2,250	....
	17	24	1.1697	227,900	223,500	0	33	2,090	....
Hot spring at bathhouse, Silver Peak	....	8	1.0217	30,670	29,960	0	533	....	Trace(?)
Cold spring at bathhouse, Silver Peak	....	8	1.0226	31,980	31,530	Trace.	530	....	Trace.
Cold spring at northeast end of marsh	....	14	1.0124	16,830	16,620	0	274	....	0
Hot spring at northeast end of marsh	....	14	1.0177	24,430	24,180	Trace.	515	....	....
Spring at pumping station, Silver Peak	....	28	....	1,920	1,500	0	144	....	....
30-foot well at power house, Silver Peak	....	28	....	1,520	1,220	0	132	....	....

Analyses of water from Silver Peak Marsh, Nev.

Composition in milligrams per kilogram.

No.	1	2	3	4	5	6	7	8	9	10	11	12
Specific gravity at 20° C.	1.2089	1.2019	1.0300	1.1722	1.0217	1.0226	1.0124	1.0177	1.0406	1.0281	....	....
Silica (SiO_2)	0	20	50	0	80	20	30	40	40	40	....	....
Iron (Fe)	Trace.	Trace.	Trace.	Trace.	Trace.	Trace.	Trace.	Trace.	Trace.	Trace.	Trace.	Trace.
Aluminum (Al)	Trace.	Trace.	Trace.	Trace.	Trace.	Trace.	Trace.	Trace.	Trace.	Trace.	Trace.	Trace.
Calcium (Ca)	1,800	940	790	2,800	580	420	130	220	470	490	170	150
Magnesium (Mg)	650	290	1,030	100	70	70	20	40	270	190	58	56
Sodium (Na)	97,180	95,190	13,620	77,480	9,650	10,110	5,770	8,370	19,210	13,030	352	195
Potassium (K)	7,290	5,890	1,290	6,590	930	930	500	800	2,060	1,180	21	15
Carbonate radicle (CO_3)	0	0	Trace.	0	0	Trace.	0	Trace.	Trace.	0	0	0
Bicarbonate radicle (HCO_3)	40	70	700	40	533	530	270	520	330	530	144	132
Sulphate radicle (SO_4)	2,360	4,420	540	2,210	410	480	580	690	610	610	95	160
Chlorine (Cl)	159,730	153,710	23,760	134,400	17,130	18,010	9,330	13,650	33,050	22,110	[a] 858	[b] 548
Total residue dried at 180° C.	278,760	264,030	42,820	233,440	30,670	31,980	16,830	24,430	57,600	39,330	1,868	1,379
Total residue after ignition	270,990	262,670	41,610	228,440	29,960	31,530	16,620	24,180	56,240	38,620	1,672	1,209
Anhydrous residue [c]	269,110	260,570	41,440	223,660	29,120	30,310	16,500	24,070	55,890	37,920	1,630	1,195

Percentage composition of anhydrous residues.[c]

No.	1	2	3	4	5	6	7	8	9	10	11	12
Silica (SiO_2)	0.00	0.01	0.12	0.00	0.28	0.07	0.18	0.17	0.07	0.11	....	....
Calcium (Ca)	.67	.36	1.92	1.25	1.99	1.38	.79	.91	.84	1.29	10.43	12.56
Magnesium (Mg)	.24	.11	2.49	.04	.24	.23	.12	.17	.48	.50	3.55	4.70
Sodium (Na)	36.11	36.53	32.86	34.64	33.14	33.35	34.97	34.77	34.37	34.36	21.58	16.32
Potassium (K)	2.71	2.26	3.12	2.95	3.19	3.07	3.03	3.33	3.69	3.11	1.28	1.26
Carbonate radicle (CO_3)	.01	.01	.83	.01	.90	.86	.81	1.05	.29	.69	4.35	5.44
Sulphate radicle (SO_4)	.88	1.70	1.30	.99	1.41	1.58	3.52	2.87	1.09	1.61	5.83	13.40
Chlorine (Cl)	59.35	58.99	57.33	60.09	58.82	59.43	56.55	56.70	59.14	58.30	[a] 52.62	[b] 45.87

[a] Nitrate radicle 5.6 milligrams per kilogram, or 0.33 per cent.

[b] Nitrate radicle 5.0 milligrams per kilogram, or 0.42 per cent.

[c] Computed on the assumption that iron, aluminum, borates, and other radicles constitute 0.03 per cent of the anhydrous residue.

1. Composite of samples from boring No. 3 at 15.5 feet and from No. 6 at 21 and 40 feet.
2. Composite of samples from boring No. 11 at 27 and 35 feet and from No. 12 at 10, 20, and 27 feet.
3. Composite of samples from boring No. 13 at 16, 31.5, and 40 feet.
4. Composite of samples from boring No. 14 at 11 and 17 feet.
5. Water from hot salt spring under bathhouse near Silver Peak, Nev., collected June 8, 1912.
6. Water from cold salt spring at bathhouse near Silver Peak, Nev., collected June 8, 1912.
7. Water from cold salt spring at northeast end of marsh, collected June 14, 1912.
8. Water from hot salt spring at northeast end of marsh, collected June 14, 1912.
9. Water from boring No. 1 at 6 feet, collected June 1, 1912.
10. Water from boring No. 1 at 27 feet, collected June 4, 1912.
11. Water from spring at pumping station, Silver Peak, Nev., collected June 28, 1912.
12. Water from 30-foot well of Nevada-California Power Co. at Silver Peak, Nev., collected June 29, 1912.

Borings Nos. 3, 6, 11, and 12 yield nearly saturated solutions that are remarkably uniform in composition and concentration, and it is therefore practically certain that an extensive deposit of salt lies in the playa. The brines from boring No. 14 are somewhat weaker than those from the main salt body farther north, a condition doubtless due to the presence of less salt and more water in the muds at the south end of the marsh. Boring No. 13 yields a solution still lower in salt but higher in magnesium. The salt springs at Silver Peak contain about 3 per cent of saline matter, or a little less than ocean water, whereas the springs at the northeast end of the playa, emerging at somewhat higher elevations above the marsh than those at the bathhouse, are only half as strongly mineralized. The spring at the pumping station and the well at the power house, both of which are fed from Mineral Ridge, yield fresher water. Therefore, though all the ground flow is undoubtedly increasing the soluble mineral content of the playa, the striking increase of salt in the waters with decrease of elevation makes it probable that nearly all the salt in the springs is dissolved from the muds of the marsh instead of being brought from the surrounding hills.

The table giving the percentage composition of the anhydrous residues shows that the brines from the main salt body are of great natural purity. Analyses Nos. 1, 2, and 4, of waters from borings Nos. 3, 6, 11, 12, and 14, indicate that these brines contain less than 2 per cent of sulphate and 0.02 per cent of carbonate. Only traces of borate were found. These brines on evaporation would yield a mass containing about 90 per cent of sodium chloride and the character of the other ingredients makes it certain that a much purer product could be obtained by one crystallization. The differences in the amounts and proportions of the alkaline earths are especially noteworthy, as they indicate progressive steps in the concentration and deposition of those substances.

The anhydrous residues of the brines represented by analyses Nos. 1, 2, and 4 average 2.64 per cent in content of potassium (K). The average potassium content of the same brines according to Merz is 2.23 per cent of the saline residue dried at 105° C. This apparent discrepancy in estimates is, however, caused mostly by difference in unit of expression, the actual determinations of the radicle being equivalent respectively to 0.79 and 0.69 gram of potassium (K) per 100 cubic centimeters of brine.

The water of the spring at the pumping station and that of the well at the power house are the only potable waters that were analyzed. Both are very hard and distinctly brackish but are used as sources of domestic supply without any apparent deleterious effect on health. The water of the power-house well is somewhat softer and notably lower in content of alkali and tastes better.

SUMMARY.

Silver Peak Marsh is a salt playa containing a high grade of sodium chloride. No extensive deposits of potash-bearing salts were found. To a depth of 50 feet the formations are chiefly salt clays and muds with layers of crystallized salt covered irregularly by gypsum-bearing clays. It is estimated that 15,000,000 tons of salt lies within 40 feet of the surface of the playa.

SURVEY PUBLICATIONS ON SALINES, INCLUDING SALT, BORAX, AND SODA.

The more important publications of the United States Geological Survey on the natural lime, sodium, and potassium salts included in this group are those listed below.

These publications, except those to which a price is affixed, may be obtained free by applying to the Director, United States Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C.

ARNOLD, RALPH, and JOHNSON, H. R., Sodium sulphate in Soda Lake, Carriso Plain, San Luis Obispo County, Cal.: Bull. 380, 1909, pp. 369–371.

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CHATARD, T. M., Salt-making processes in the United States: Seventh Ann. Rept., 1888, pp. 491–535. $2.

DARTON, N. H., Zuñi salt deposits, New Mexico: Bull. 260, 1905, pp. 565–566. 40c.

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YALE, C. G., and GALE, H. S., Borax: Mineral Resources U. S. for 1911, pt. 2, 1912, pp. 857–866.