SALINES.

NOTES ON THE QUATERNARY LAKES OF THE GREAT BASIN, WITH SPECIAL REFERENCE TO THE DEPOSITION OF POTASH AND OTHER SALINES.

By Hoyt S. Gale.

INTRODUCTION.

The existence of extensive lakes in certain of the larger catchment areas of the Great Basin region undoubtedly had an important influence on the concentration there of saline material. From a study of the physiographic history of the region it appears that some of these catchment basins may now be considered as more favorable and some as less favorable places in which to look for large concentrated saline deposits, especially with reference to the possible occurrence of valuable potash salts. The purpose of the present paper is to suggest a distinction that may be drawn between the desert-basin areas—in effect, a certain classification on the basis of their interpreted history, from which some conclusions of practical importance with reference to saline deposits may be deduced.

LAKE HISTORY OF THE DESERT BASINS.

It is well known that certain large lakes whose waters have now receded or entirely disappeared formerly existed in the Great Basin region. The most clearly recognized of these lakes are supposed to have been coincident with the general extension of glaciation in the higher adjoining mountain ranges, so that they are referred to the glacial epoch of the Quaternary period. Geologic study of the Great Basin has led generally to the conclusion that not only during Quaternary time but throughout several epochs in the Tertiary history of this province there has been aridity of climate and possibly desert basins without exterior drainage. Thus there may have existed at various times large interior lakes which might have left a record of lacustral sediments and chemical deposits resulting from their desiccation. Such records are indeed referred to in the literature on this region as showing lake history of epochs preceding the

Quaternary. The determination whether the Tertiary lakes were simply reservoirs for the accumulation of water that eventually found an outlet into the sea or whether they dried up after long periods of concentration of salines in their waters involves problems of great complexity. The changes in the earth's surface during the Tertiary and Quaternary periods have been so extensive that it seems as if the search for possible final concentration areas of those ancient lakes must be a random enterprise, with little evidence to guide it except the accidental discovery of the salts themselves. For these reasons in the present investigations attention has been directed primarily to the deposits of comparatively recent origin, in which the geologic record is exceptionally complete.

QUATERNARY LAKES OF THE GREAT BASIN.

A classification of the desert basins based on their lake history is suggested in the following descriptions of the major and minor Quaternary lakes that have been recognized in that region. A third member of that classification would include those basins in which, for reasons to be explained, it seems probable that no such lakes have existed.

The monographic studies of Gilbert and Russell on the Quaternary Lakes Bonneville, Lahontan, and Mono have reviewed in detail the evidence by which the existence of these former extensive water bodies has been established. For the discussion of lacustral deposits, shore phenomena, and similar details reference should be made to these reports. Besides the three lakes mentioned others assumed to be of approximately the same period have been recognized, as in the Owens basin, the former Searles Lake, and a deep lake that occupied the Panamint Valley. Although the three last mentioned have received less study, their former existence is considered to be just as firmly established as that of Lakes Bonneville and Lahontan. The shore lines of the ancient lakes at their more persistent levels are still distinctly preserved, and from these and other evidences the history of the lakes has been interpreted.

Still other prehistoric lakes supposed to be of Quaternary age have been recognized elsewhere in the desert basins. For several reasons these have not been classed with the major lakes above enumerated. These include the former lakes in Railroad Valley and at Columbus Marsh, Nev.; those of southern Oregon; and Lake Le Conte, a former body of water occupying the basin of the Imperial Valley or Salton Sink in southern California. Doubtless there are others, as similar lakes have been reported in New Mexico and Texas. Except Lake Le Conte, which may have had a history somewhat different from the others, these minor lakes of the Great Basin are supposed to have had much the same sedimentary and chemical record as the major lakes that have been named, on a scale proportionate to the size and duration of their water bodies.

A belief has gained rather wide acceptance that Quaternary lakes contemporaneous with Bonneville and Lahontan were generally distributed throughout the Great Basin. Gilbert states that vestiges of similar lakes had been found by various observers in many of the valleys of the Great Basin and expresses the belief that all the minor basins of which that area is composed had been partly or wholly filled with water.[1] This idea seems to have generally prevailed to the present day. It was with some surprise, therefore, that in traveling from one of these desert basins to another the present author noted differences in the physiographic records which were not at first clearly understood. Even if lakes once existed in all the desert basins alike, certainly the traces they left, such as ancient shore lines and tufa deposits, are now markedly different even in adjacent valleys. After further observation the author reached the conclusion that few even of the larger basins have in reality contained extensive lakes of Quaternary age. It will be seen that the demonstration of this conclusion as a fact must have an important bearing on the probability of finding valuable saline deposits in the desert-basin region generally.

As noted above, undisputed evidence of a former lake period is found in a few of the desert basins. Conversely, recent observations in the field have seemed to indicate that no traces of such a former lake period are to be found in most of the inclosed drainage areas of the desert basins. Furthermore, the enumeration of the known lake areas makes it evident that mere size of catchment area is not the criterion which determined the existence of a Quaternary lake in a given basin. This should be made clear by the following illustrations:

Death Valley is the "sink" or final point of accumulation for the waters of Amargosa River, which with its tributaries constitutes one of the large independent drainage systems of the Great Basin. Mohave River, which may be considered a tributary of Death Valley or Amargosa River, now empties its flood waters into Soda Lake, an ephemeral body of water, which if it had ever filled its shallow basin to overflow the low divide to the north would have joined the Amargosa. In spite of the immense drainage territory tributary to Death Valley there is no evidence that the waters from these streams ever accumulated in it to a sufficient extent to form more than a shallow inconstant lake. A search for traces of any upper shore lines around the slopes leading into Death Valley has failed to reveal evidence that any considerable lake has ever existed there.

[1] Gilbert, G. K., The glacial epoch: U. S. Geol. Surveys W. 100th Mer., vol. 3, 1875, p. 103.

The Panamint Valley, just across the Panamint Range west of Death Valley, shows a marked contrast in its lake history. In other respects, including general climatic conditions, the Panamint is at first sight wholly comparable to Death Valley. Its lowest part lies at an elevation of 1,050 feet above the sea and it was submerged to a depth of 1,200 feet or more. Thus the water in Panamint Valley stood at a height of some 2,300 feet above the supposedly dry floor of Death Valley. Certainly no generally effective climatic change can alone account for such distinctions.

A similar contrast is afforded by Dixie Valley, which lies east of the former shores of Lake Lahontan, just across the narrow and steep intervening divide of the Stillwater Range. Dixie Valley had no connection with Lake Lahontan, although its bottom now lies 400 feet lower than the lowest part of the Carson Desert. In spite of this difference in elevation and the fact that Dixie Valley is the lowest part of an extensive drainage area, there is no evidence to show that a large or deep lake ever existed in Dixie Valley, and it is believed that no such lake was ever formed.

Other examples may be cited, the contrasts noted demanding an explanation as to why certain drainage areas accumulated lakes in their lowest depressions while other similar and immediately adjacent areas did not. The fact that a simple and adequate explanation may be offered serves to substantiate the original conclusion that was reached from negative field evidence, namely, that most of the minor bolsons[1] in the Great Basin have not contained lakes of any considerable size in the Quaternary period.

If the areas of the major Quaternary lakes and the outlines of their drainage basins are indicated on a sufficiently complete map, it will be noted that all the major lakes have been fed by streams that are even now perennial. These tributaries are the streams which derive their waters directly from the higher summits of the Sierra in Nevada and California, and of the Wasatch Mountains in Utah. Thus the basin of former Lake Bonneville is fed by Bear River and numerous smaller perennial streams. The basin of former Lake Lahontan receives the water of Carson, Truckee, and Walker rivers. Mono Lake lies high in the Sierra and is also fed by perennial waters. Owens River supplies Owens Lake, and here is to be found an explanation of the formation of the ancient Searles and Panamint lakes by overflow from the shallow Owens Basin. Considered by itself Owens Valley would not have been classed with the major Quaternary lake basins. Its abundant water supply was passed on to other reservoirs.

[1] Bolson (Spanish bolsón, large purse) is a term used to designate a constructional detritus plain occupying a structural trough in an arid region. It is therefore a convenient name for the flat valley floor of a desert basin.

A slight increase in the humidity of the climate might easily account for increased flow in all these perennial streams, whose waters rose to correspondingly higher levels than those of the Carson, Pyramid, Winnemucca, Mono, Owens, and Great Salt lakes of to-day. That the increase of humidity may have been but slight is determined by other considerations. The water by which these lakes were filled was probably derived mainly from the snow-capped summits of only the highest mountain ranges on the extreme borders of the Great Basin area.

On the other hand, it is necessary to consider those drainage basins which include only the desert plains or bolsons, and the desert mountain ranges—even the more lofty mountains of the interior Great Basin region. To-day these basins are fed by intermittent streams which are incompetent to flood the lowest bottoms. By analogy with the climate of the present day, a slight increase of humidity of climate probably did not greatly alter the character of this typically desert-basin drainage. Desert conditions, possibly with slight modifications, such as greater frequency of periodic storms, may logically be assumed never to have suffered the establishment of a full, continuous flow in the typically desert-basin drainage areas. This is believed to be true of such streams as Mohave and Amargosa rivers and of many lesser drainage systems. Therefore, the periodic lakes of the typical desert basins probably never filled their basins deeply or for long periods.

Evidence bearing on the slightness of the climatic change required to produce the major lakes of the Great Basin has already been reviewed by Gilbert and Russell. In brief, the failure of Lakes Lahontan and Mono to overflow is believed to have an important bearing. Lake Lahontan is known to have risen to a height of 500 feet over the extensive areas of the Carson and Blackrock deserts. Although a rise of 200 feet more would have established an outlet northward into Columbia River, the balance between evaporation and inflow was maintained below the overflow point. Mono Lake in former high levels approached a point of overflow at 670 feet above its present level, but Russell states that it did not overflow. Increased precipitation in a single year is known to cause a rise of several feet in such a lake as Owens at the present time. A continued slight increase in the same degree might cause a great expansion of this lake without marked difference in climatic conditions.

SALINE DEPOSITION IN THE DESERT BASINS.

The origin of saline deposits in the desert basins is readily explained. By definition these basin areas are independent drainage systems, without external outlet, so that their surface waters flow toward an interior depression or lower part. The Great Basin is made up of many such independent basins.

It is a recognized fact that all natural drainage waters collect and carry onward the soluble constituents of the soils and rocks over which they pass. These constituents become soluble by the process of weathering, a slow but ever-acting surface decomposition, in which the more complex mineral combinations break down to simpler forms, some of which are soluble in water. These soluble constituents find their way toward the lowest part of each of these drainage systems, are accumulated there, and by ultimate evaporation of their solutions are deposited in saline residues. The lowest part of each basin thus becomes an area of concentration for the soluble constituents of its drainage waters as well as an area of accumulation for the sediment washed in by its flood waters. These areas of concentration are variously termed playas, dry lakes, mud flats, and salt marshes if they are usually dry, and saline or "alkaline" lakes if they remain flooded, Most of these areas are now essentially dry. At times of exceptional precipitation these playas are wholly or partly covered by water and fine sediment in suspension is carried out over them. Sand and dust swept across in the more or less frequent wind storms settle and become mixed with the deposits. With the evaporation of the water the dissolved salts are deposited as a saline crust.

Salts and sediments laid down in the beds of periodic lakes of the type described have accumulated in immense deposits. Generally, however, the deposits are much intermingled, consisting of an alternating succession of clay, sand, and salt layers. The muds, as soon as they settle, are quite impervious to the further circulation of the water and form an effective seal against the re-solution of much of the salts once deposited. Thus the deposits of such a lake contain thin salt crusts intercalated between mud strata, and only a small part of the salt is continuously redissolved and so carried on up to the surface of each succeeding deposit. For this reason lakes of relatively dilute water may stand for long periods over deposits of playa muds carrying large quantities of crystalline salt.

Each temporary flooding deposits but a thin crust of salts upon its evaporation. A lake of larger size and longer duration may accumulate a correspondingly greater quantity of salts. While these salts remain in solution sediment which is washed into the lake settles and thus the salts are concentrated in the water and separated from the sediment. If such a lake persists for a long time it may accumulate a vast quantity of dissolved salts and if it ultimately dries up may deposit these salts in a single massive crystalline layer. An excellent example of a deposit formed in this way is that at Searles Lake, in California.

From the foregoing discussion it is evident that saline residues in massive crystalline deposits are to be naturally expected only as the result of the final evaporation of an extensive and deep saline lake, one which represents the continuous accumulation of the dissolved salts during a very long period of time. As the former existence of such lakes has been demonstrated in only a few of the desert-basin areas, it appears evident that salt deposits of this type are to be expected in only a few localities.

Potash is one of the normal constituents of most natural saline deposits. The common soluble salts of such deposits in the Great Basin are the chlorides, sulphates, carbonates, bicarbonates, and borates of sodium and potassium. Magnesia and lime are present as very minor constituents. In nearly all the deposits the sodium salts very greatly predominate. In the average of a large number of representative American river waters the ratio of potash to soda in the dissolved salts is as 1 to a little more than 4—that is, potash is about one-fifth of the total alkalies (soda and potash together). In the waters of saline lakes in the Great Basin region the ratio of potash to soda is perhaps even smaller. Analyses of saline residues in the Great Basin commonly show from 1 to 4 or 5 per cent of potash in the soluble constituents.

Potash salts in a solution containing other salts will be deposited with the rest when that solution is evaporated. If in such a solution potash is present in very much smaller quantity than soda, it is naturally to be expected that during the evaporation of the solution the potash will reach saturation later than the soda. Therefore the potash salts of such an evaporating solution have a tendency to remain in the residual brines while a portion of the sodium is crystallized out. The potash is thus partly segregated in the brine or "mother liquor" of the crystallizing salt body. Such segregation can take place on a large scale only when it acts in a single massive deposit of crystallizing salts. In this fact lies a further reason why important segregation of potash should be expected only as the result of the final evaporation of an extensive and deep saline lake, representing the continuous accumulation of dissolved salts during a very long period of time. Again the reasoning points to the elimination from practical consideration, as a favorable site for the occurrence of potash, of most playa deposits, dry lakes, mud flats, or salt marshes, unless it can be shown that the basins in which they lie have at some time contained large lakes.

The only important example now known of a massive deposit of salines resulting from the evaporation of a Quaternary lake is that at Searles Lake, Cal. Here the salts lie at the surface of the ground and the natural situation of the deposit has prevented its becoming covered and concealed by later inwash of sediment. Such saline deposits may also exist in the low parts of other Quaternary lake basins, where they have become covered and concealed by sediments. It was on the theory that such a deposit might be discovered near the center of Carson Sink, Nev., that a well was sunk there to a depth of 985 feet by the Geological Survey. The first trial has failed to locate the saline deposits sought and it may be that the estimate as to the site of a former area of concentration was not correct. It is also possible that the well did not go deep enough, but these are matters that deserve further discussion.

CONCLUSIONS.

As a result of the considerations that have been presented, it is believed that most of the saline crusts, dry-lake areas, salt flats, "sinks," or playas in the desert-basin region offer little promise for the development of commercial sources of potash salts. Potash locations are still being reported from many parts of the desert-basin country, and it is thought that in many, perhaps in most cases, the cost of staking these claims and other expenses involved in such work are incurred without a distinct understanding of the natural limitations implied in the theory of saline deposits from desiccated lakes. Most playa muds contain soluble salts, some of them in considerable quantity. These salts when analyzed usually show 1 per cent or more of potash. A small percentage of potash in such a mixture is probably not commercially extractable, and there is no good reason for the belief that such salts found at the surface indicate any richer deposits in depth.

Saline muds, even if they contain relatively high percentages of potash salts, are of doubtful value for the extraction of potash. A mud which contains 5 per cent of total saline matter would require the digging, mixing, and draining of 20 tons of raw material for a theoretical total extraction of 1 ton of crude salts. In practical operation this efficiency could never be even approached. From these crude salts the potash must then be extracted if it is to be marketed as potash. The low value of the final product appears to make such an undertaking impracticable.

Potassium-bearing brines, derived from massive beds of crystalline salts, however, may offer greater promise. The chemistry of extracting the potash seems to present some difficulties that have not yet been overcome in practical tests on a large scale. Such an enterprise doubtless must involve costly equipment and technical skill if it is to be successfully developed. Similar problems have been solved elsewhere, and there are assurances from various sources that practical methods have been found for the extraction of the potash here.

On the supposition that large deposits of buried salines exist in certain areas of concentration in the Great Basin, it still remains to be proved whether or not the potash-enriched portions of such deposits can be found. The hypothesis that these portions can be found is based principally on the assumption that the important segregation will be in the form of a residual brine, which, if free to flow, may be tapped and pumped from any point within the saline deposit and would therefore be easily found by random drilling, which might fail to strike local concentrations in solid form.

PROSPECTING FOR POTASH IN DEATH VALLEY, CALIFORNIA.

By Hoyt S. Gale.

INTRODUCTION.

In accordance with one of the first plans suggested under the governmental search for domestic sources of potash salts, a preliminary examination and test of the saline deposits in the floor of Death Valley was made during the winter of 1912–13. Four wells were drilled, three in the area of smooth salt in the lowest depression of the valley and the fourth about 20 miles north of the others. These borings are believed to have furnished the first information that has been obtained concerning the character of the deposits underlying the valley.

Reports state that practically the entire area in Death Valley has lately been located in "potash" claims, presumably as association placers, but in blocks of very large area. It is said that a single tract of 17,120 acres, known as the Kali property, was located in May to July, 1912, on the lowest part of the valley. Other groups both north and south of this tract have subsequently been taken up.

SALINE DEPOSITS IN DEATH VALLEY.

A vast amount of saline material is accumulated on and beneath the floor of Death Valley. A central area of crusted salt lies in the lowest part of the valley, extending for many miles from north to south. At the very lowest part of the valley, or so-called sink, there is an irregular area several miles across which is usually a smooth field of snowy white salt. Occasionally this is flooded by storm waters, which subsequently evaporate and again leave the surface crusted with white salts. Beyond the smooth salt to the north and south are the fields of rough salt. These differ from the area of smooth salt principally in the fact that the salt crust, not having been recently flooded and wholly redissolved, has been gradually broken into cakes and tilted at various angles, probably by expansion due to the growth of crystallization, thus producing a surface so rough that it is extremely difficult to traverse. A rim of soft mud lies between the main salt fields and the valley margin, this part also being occasionally flooded by storm waters and kept wet by the seepage of ground water from the marginal slopes. Beyond

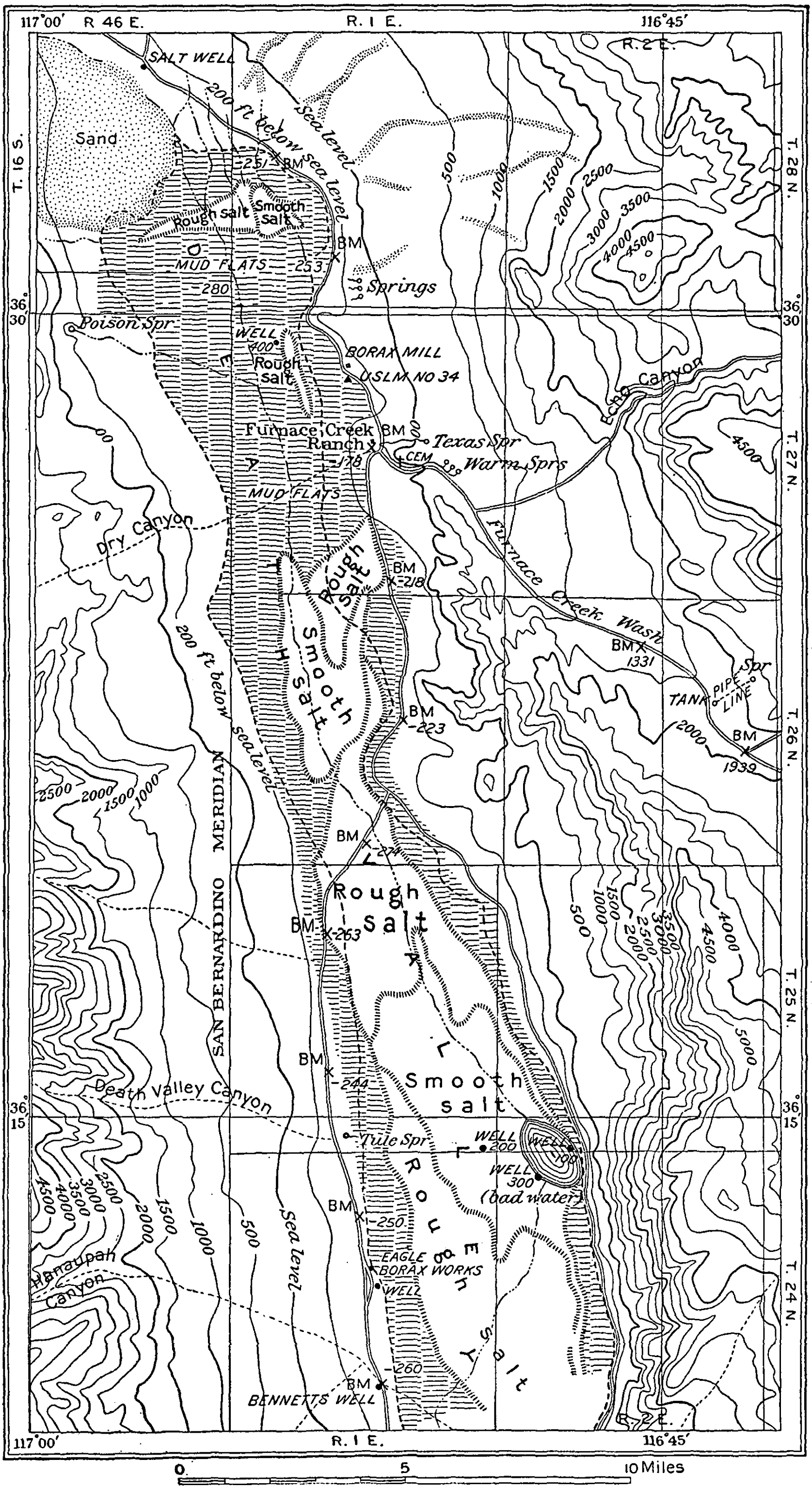

FIGURE 37.—Map showing salt deposits in Death Valley, California, and location of four wells drilled by the Geological Survey.

the mud rim are sand dunes and alluvial slopes of rock débris such as characterize these desert regions generally.

The outlines of these types of surface deposits are represented in the accompanying map of a portion of the valley (fig. 37), which is based on data collected by Charles E. Watson for the Geological Survey at the time the wells were being drilled. The location of the wells is also indicated.

SOURCE OF THE SALTS.

The salt deposits on the floor of Death Valley are believed to be explainable as the natural accumulations of salines from the normal drainage waters of country of this character and so do not differ in any essential respect from saline deposits in other desert basins in this general region. The fact that Death Valley is the final area of concentration for a very extensive drainage system is thought to explain the large extent and supposed depth of the deposits. Death Valley is known as the "sink" of Amargosa River, as it receives the periodic flood waters of that large drainage channel as well as numerous lesser tributaries. It appears, however, that Death Valley has also received similar flood-water drainage from Mohave River, for the present terminus of the Mohave drainage system lies in Soda Lake, a shallow evaporation pan separated from the Amargosa only by a very low divide. It has been suggested by several investigators that a part or all of the salines accumulated in Death Valley may have been derived from bedded saline deposits which are known to exist in at least one place in the adjacent Tertiary formations. These Tertiary beds, having been uplifted and exposed to erosion, are supposed to have contributed to the salines that found their way into the bottom of the valley. Doubtless a deposit of bedded salt, such as is known to exist, may have furnished a portion of the accumulated salines in Death Valley, but certainly it does not appear necessary to invoke such an explanation for this one occurrence, in view of the fact that deposits similar in type to those of Death Valley, on scales more or less proportionate to the present or former drainage areas of the respective basins, are common throughout the Great Basin region. The salts deposited on the floor of Death Valley are therefore assumed to be chiefly the accumulation and concentration of the salines dissolved in natural drainage waters that have evaporated there.

ANALYSES.

Prior to the present work the only published analyses of the salt in Death Valley, so far as the writer is aware, were one made by Oscar Loew[1] from a sample collected by Lieut. R. Birnie, jr., and a second made in the Geological Survey laboratory[2] from a sample collected by M. R. Campbell.

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[1] Wheeler, G. M., Ann. Rept. U. S. Geog. Surveys W. 100th Mer., 1876, p. 176.

[2] Campbell, M. R., Reconnaissance of the borax deposits of Death Valley and Mohave Desert: Bull. U. S. Geol. Survey No. 200, 1902, p. 18.

They are as follows:

Analysis of salt from Death Valley, Cal.

["Deposit 1 to 3 inches deep and covering many square miles."]

NaCl	95.49
Na_2SO_4	2.78
$CaSO_4$	.27
$MgCl_2$	Trace.
	98.54

In the analysis the sample was freed of its moisture in order to facilitate the comparison with other similar analyses.

Analysis of surface salt from Death Valley, Cal.

[George Steiger, analyst.]

NaCl	94.54
KCl	.31
Na_2SO_4	3.53
$CaSO_4\ 2H_2O$	.79
Moisture	.14
Insoluble residue	.50
	99.81

The sample collected by Campbell came from the middle of the area of the rough salt crust on the road between the Furnace Creek ranch and Bennett Wells, where the crust is nearly 3 miles wide.

During the recent explorations by the Geological Survey 83 samples, chiefly of the brines and deposits underlying the surface, have been taken, and some of these have been analyzed. The results available refer particularly to the potash content and are as follows:

Analyses of potash in natural brines from Death Valley, Cal.

[W. B. Hicks and R. K. Bailey, analysts.]

Sample.	Depth at which sample was taken (feet).	Total salts (ignited residue) (percentage of original sample).	Potash (K_2O) in total salts expressed as percentage of ignited residue.	Potassium expressed as percentage of KCl in original solution.
Ground water in the salt crust at the "sink"	0.5	28.19	3.43	1.53
Water in open "pothole"	.5	27.47	1.20	.52
Do	9.5	27.48	1.18	.51
U. S. G. S. well No. 100	6.0	27.87	2.85	1.27
Do	24.0	28.64	2.22	1.01
Do	29.0	28.96	2.35	1.09
Do	52.0	28.66	2.01	.91
U. S. G. S. well No. 200	32.0	28.33	1.54	.69
Do	38.0	29.16	1.78	.82
Do	70.0	29.96	2.48	1.18
U. S. G. S. well No. 300	1.0	27.78	2.05	.90
Do	30.0	27.91	1.68	.74
U. S. G. S. well No. 400	32.0	28.77	2.23	1.02
Do	38.0	28.73	2.12	.97
Average		28.42	2.08	.94

These are all essentially saturated brines, the principal dissolved constituent being sodium chloride. The potash content is not unusual in any way, being about the average generally found in natural brines or saline residues in the desert basins.

More complete analyses were subsequently made of several of the brines in the foregoing table, showing the general composition of the saturated brines in the lowest part of these deposits.

Analyses of brines from Death Valley, Cal.

[R. K. Bailey, analyst.]

	Depth (feet).	Cl.	SO_4.	B_4O_7.	Ca.	Mg.	K.	Na.	Total salts.
Well No. 200	32	53.07	7.93	0.42	0.07	0.05	1.29	37.17	28.50
Do	38	46.81	14.81	.44	....	.05	1.35	36.54	29.95
Do	70	47.91	12.67	1.01	....	.08	1.95	36.38	29.67
Well No. 300	1	55.74	5.05	.37	....	.04	1.62	37.18	27.71

Potash analyses of all the solid samples collected from one of the wells drilled in the lowest part of the valley were made in the Geological Survey laboratory are quoted in the following table. This well was selected for illustration, as its log and the preliminary tests made on the brines obtained from it and the other wells seemed to indicate that it would be fairly representative:

Potash analyses of solid samples from well No. 200, Death Valley, Cal.

[R. K. Bailey, analyst.]

Field No. of sample.	Depth (feet).	Loss of moisture on drying (per cent).	Total salts (ignited residue; per cent of original sample, dried at 105°).	Potash (per cent of total salts), expressed as—		
				K.	K_2O.	KCl.
32	0	7.79	87.21	0.18	0.22	0.35
33	2	28.85	26.45	2.72	3.28	5.20
34	8	11.49	68.60	.28	.34	.54
35	13	12.31	77.60	.25	.30	.47
36	17	17.47	17.57	1.62	2.10	3.09
37	21	18.10	40.51	.72	.86	1.37
38	24	30.72	21.47	1.87	2.25	3.56
39	30	20.76	94.42	.13	.16	.25
40	32	11.91	83.50	.15	.18	.28
41	37	17.30	76.71	.34	.41	.64
42	41	17.01	70.42	.47	.57	.90
43	43	22.72	40.60	.80	.96	1.53
44	46.5	25.53	24.67	.16	.20	.31
45	49.5	28.41	26.18	1.64	1.98	3.14
46	63	27.17	82.35	.52	.63	.99
47	70	21.41	67.90	.47	.57	.91
48	72	15.15	99.70	.08	.11	.16
49	74	15.24	79.45	.23	.27	.43
50	76	20.71	64.90	.54	.65	1.03
51	78	20.82	67.85	.48	.58	.92
52	81	23.80	76.90	.44	.53	.84
53	85	12.35	80.65	.22	.25	.40
54	87	16.33	77.90	.28	.34	.55
55	92	23.28	77.36	.42	.50	.79
56	....	15.66	81.80	.33	.39	.62
57	94	16.05	80.55	.52	.63	.99
58	96	11.65	39.45	.47	.57	.90
59	102	17.70	78.90	.31	.37	.59
Average	....	18.84	64.70	.59	.72	1.13

Thus the solid material of the deposits underlying the lowest part of the valley, exclusive of the flows in the water-bearing strata, to a depth of 100 feet may be assumed to average about 19 per cent of moisture, and after this has been dried out under conditions approximately normal for the locality, the dried material averages about 65 per cent of soluble salts. Of these soluble salts only about 0.72 per cent has been shown to be potash (or 1.13 per cent potassium chloride, the form in which the salt is doubtless present in this deposit).

WELL LOGS.

The logs of all the wells bored are given in full below from the records kept by Charles E. Watson.

Log of United States Geological Survey boring No. 100, Death Valley, Cal.

	Thickness.	Depth.
	Feet.	*Feet.*
Salt, 1½ inches thick on surface		
Clay, light brown, containing crystals	10	10
Clay, light brown, smooth	4	14
Mud, brown, containing hard salt crystals	1	15
Salt and dark-brown clay	1	16
Clay, dark brown, containing crystals	4	20
Clay, dark green, containing crystals	3	23
Mud, soft, black, containing crystals	3	26
Salt, hard strata (required drilling with churn bit)	2	28
Clay, smooth, black	4	32
Clay, black, containing crystals (strata of salt 1 to 3 inches thick from 32 to 39 feet)	7	39
Clay, light gray and black, mixed, containing crystals	1	40
Salt, hard (required drilling)	1	41
Clay, light gray and black, containing many crystals	5	46
Clay, black, containing crystals	5	51
Salt crystals and a little clay, light	1	52
Clay, black, containing crystals (salt strata 1 to 3 inches thick from 52 to 56 feet; very hard salt, from 48 to 49 feet 2 inches)	4	56
Water or brines encountered:		
W. S. No. 1, salty, strong flow within 1 foot of surface		6
W. S. No. 2, salty, strong flow within 18 inches of surface		24
W. S. No. 3, salty, strong flow within 2 feet of surface		29
W. S. No. 4, salty, seepage water		52

Log of United States Geological Survey boring No. 200, Death Valley, Cal.

	Thickness.	Depth.
	Feet.	*Feet.*
Salt (6 inches thick on surface)	0.5	
Clay, soft, light brown, containing crystals	3.5	4.0
Salt, very hard	2.0	6.0
Mud, soft, brown, containing coarse crystals	11.0	17.0
Mud, smooth, brown	.5	17.5
Salt, in layers 1 inch thick	.5	18.0
Mud, soft, brown, smooth	3.0	21.0
Mud, light brown, sticky, containing crystals	3.0	24.0
Mud, soft, brown, containing crystals	3.0	27.0
Salt, hard	2.5	29.5
Clay, tough, brown	.5	30.0
Salt, hard, drilled	1.0	31.0
Mud, soft brown, containing crystals	.3	31.3
Salt, hard	.7	32.0
Clay, dark, containing crystals	4.5	36.5
Salt, hard	1.5	38.0
Mud, black, containing crystals and hard salt strata 1 inch thick	1.5	39.5
Salt, hard, black	2.0	41.5
Mud, black, containing crystals	1.5	43.0
Salt, hard	.2	43.2
Clay, black, containing crystals	2.3	45.5
Salt, hard, black	.5	46.0
Clay, light gray and black mixed, containing crystals	5.0	51.0

Log of United States Geological Survey boring No. 200, Death Valley, Cal.—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Salt, very hard	1.5	52.5
Clay, dark, containing crystals	.5	53.0
Salt, hard	.5	54.0
Clay, tough, dark	.5	54.5
Salt, very hard, hardest yet encountered, black	15.5	70.0
Clay, tough, dark blue, containing crystals	1.0	71.0
Salt, very hard, black	5.0	76.0
Clay, dark blue, containing crystals	2.5	78.5
Salt, hard, black	1.0	79.5
Clay, dark blue, containing crystals	6.2	85.7
Salt, hard	1.0	86.7
Clay, dark blue, containing crystals	3.8	90.5
Salt, very hard	1.5	92.0
Clay, very tough, dark blue, containing crystals	4.0	96.0
Clay, tough, black, containing crystals	8.0	104.0
Water encountered:		
W. S. No. 1, black salty water, came within 2 feet of the surface		32.0
W. S. No. 2, salty, nearly clear, came within 1 foot of the surface, strong flow; with 8 feet of section pipe on hand-pump well flowed 5 gallons in 2 minutes		38.0
W. S. No. 3, seepage water in well after standing over night		70.0

Log of United States Geological Survey boring No. 300, Death Valley, Cal.

	Thickness.	Depth.
Salt, 1½ inches thick, on surface.	*Feet.*	*Feet.*
Mud, light brown, containing coarse salt crystals	1.5	1.5
Salt, layer 2 inches thick, with flow of brine at bottom.		
Mud, soft, brown (small flow of warm water at 30 feet)	29.0	30.5
Mud, yielding seepage of water	2.5	33.0
Clay or mud and crystals of salt	1.5	34.5
Salt	.5	35.0
Mud, black, and crystals of salt	1.5	36.5
Salt	.5	37.0
Mud, black, and crystals of salt (water all shut off and auger cut without seepage)	15.0	52.0
Salt	.3	52.3
Clay, black, with occasional thin salt layers	3.7	56.0
Salt, crystalline, hard, containing layers of black clay mixed with salt crystals 1 to 4 inches thick at intervals of about 2 feet	8.5	64.5
Mud	.5	65.0
Salt, crystalline, apparently solid	13.0	78.0
Mud	.2	78.2
Salt, crystalline	3.8	82.0
Clay, black	1.0	83.0
Salt, crystalline	2.0	85.0
Clay, black, containing salt crystals (no water encountered in the lower part of the well)	10.5	95.5
Water encountered:		
W. S. No. 1, surface, salty, strong flow, 6 inches from surface to		5.0
W. S. No. 2, warm, salty, came within 1 foot of surface		30.0

The foregoing log shows the thickest bed of crystalline salts recorded.

Log of United States Geological Survey boring No. 400, Death Valley, Cal.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface, borax soda and brown mud	0.5	0.5
Mud, light brown, with a few flat crystals	7.5	8.0
Mud, tough, brown, smooth	4.0	12.0
Clay, light brown, smooth	5.0	17.0
Mud, dry, brown, smooth	9.0	26.0
Clay, light blue, containing crystals	5.5	31.5
Salt, hard	2.0	33.5
Clay, tough, blue, few crystals	1.5	35.0
Salt, hard	12.0	47.0
Water encountered:		
W. S. No. 1, salty, strong flow within 2 feet of surface		32.0
W. S. No. 2, salty, warm, strong flow within 2 feet of surface		38.0

These wells show that within the limits of depth attained (104 feet in the deepest well) the valley is underlain by alternating layers of mud or clay and rock salt. Salt brines were encountered at several horizons, but not under such pressure as to cause them to rise and flow out on the surface. The greater part of the beds passed through consist of compact, gummy clays, including salt crystals, apparently quite impervious to the flow of water. In general, the flows of brine appear to be derived from layers just beneath the beds of crystalline salts and rarely come as seepage from within the muds.

GENERAL CONCLUSIONS AS TO THE OCCURRENCE OF POTASH.

The evidence as to saline deposits and especially the possible segregation of potash in Death Valley may be reviewed as follows:

No shore markings or other evidence of former deep submergence of Death Valley have yet been discovered. It appears that the deposits laid down in this valley have been chiefly the result of temporary shallow submergences and alternate desiccations. Thus the deposits that make up the floor of this valley are supposed to have been built up layer by layer, the salts having crystallized from the water evaporated from the temporary shallow lakes and having been occasionally buried in mixtures of sand and silt, including more or less saline material swept in by floods. This process is going on at the present day.

A vast amount of saline material is accumulated in the bottom of this valley, but the mode of its deposition is probably not favorable to selective crystallization on a large scale. Segregation of potash or any other portion of the soluble constituents of the waters may have taken place to a slight extent in the individual salt-crust layers, but under the conditions described any such differentiation is likely to have been restricted to the individual layers as units and therefore has occurred on a scale so small as to be of doubtful practical importance. It seems evident that unless a vast body of saline material has been deposited at one time during a single period of desiccation there would be little chance for the various dissolved constituents to become segregated from one another on a large scale. There is no record of the drying up of a single large lake of saline waters in Death Valley. Although it is possible that the shores of such a lake might have been completely buried, the assumption that this may have happened must be purely a matter of speculation. Similar reasoning may apply to many other areas in the desert-basin region. Great interior lakes have existed in certain areas and may have dried up under such conditions that the salts they contained were deposited in a great body and the potash and other minerals in the waters were by crystallization to a certain extent segregated in some portion of the deposits. Searles Lake contains a deposit of salt evidently produced in this way, and others may be found, although they are not now exposed at the surface. It does not appear that there is much theoretical justification for the belief that such deposits are present in Death Valley. It is of course possible that the present conclusions are based on insufficient negative evidence, and for this reason any further drilling that may be carried on by private claimants in the Death Valley region should afford information of much importance and interest.

SALT, BORAX, AND POTASH IN SALINE VALLEY, INYO COUNTY, CALIFORNIA.

By Hoyt S. Gale.

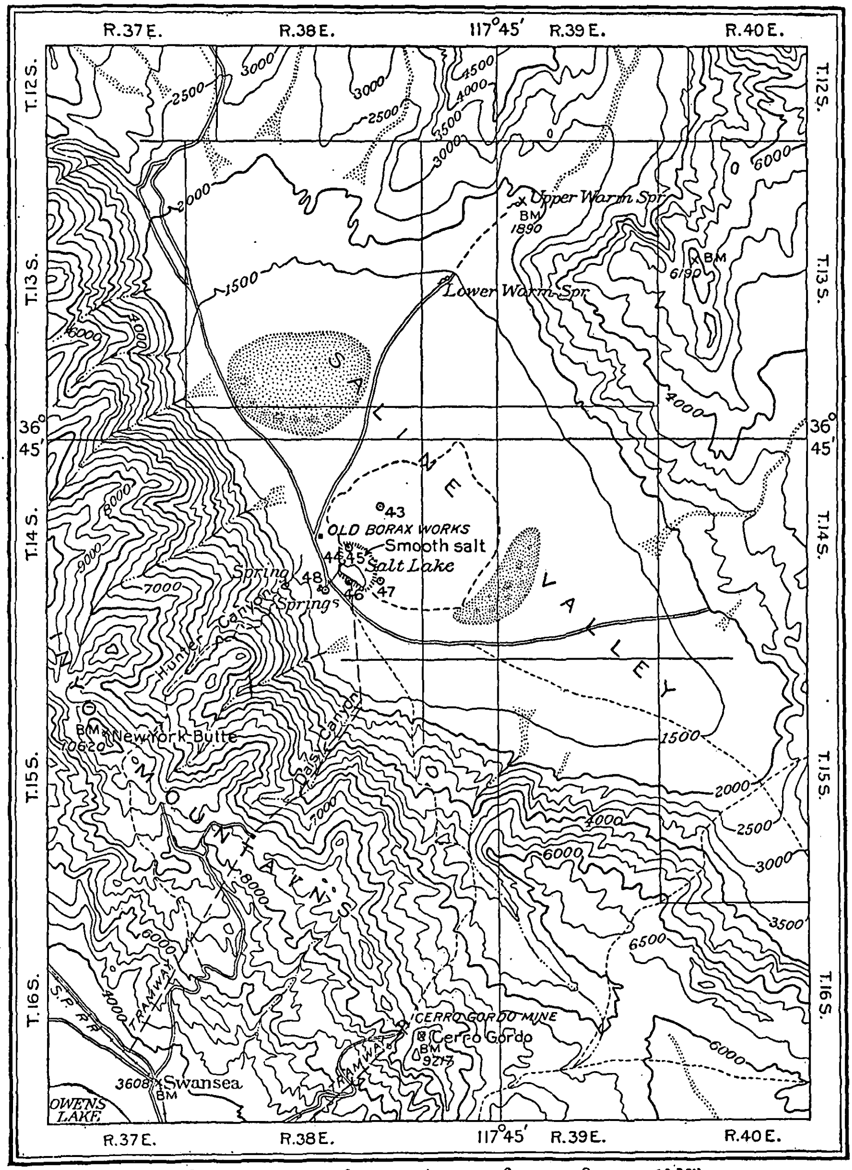
PRESENT INTEREST IN THE DEPOSITS.

A stock company recently formed to develop the salt from Saline Valley, Cal., and put it on the market has spent a considerable amount of money in building a tram which is to extend from Swansea, on the narrow-gage railroad east of Owens Lake, across the Inyo Range, and down to the margin of the salt marsh in Saline Valley. Construction on this difficult piece of engineering work was well advanced at the time of the writer's visit, and there appears good assurance that its operation will be mechanically successful. The large amount of work done for the development of this salt deposit perhaps justifies a more extended consideration of the nature of the deposit and the industrial conditions affecting its utilization than is at present feasible, but the following brief account is given from the data already at hand.

The deposit was examined by the writer October 27, 1912, for the purpose of procuring samples of the salt for analysis to determine whether or not it contains soluble potash and for such incidental data as might be obtained bearing on the deposition of desert-basin salines.

LOCATION.

The shortest route into the valley from the railroad is by trail over the Inyo Range from Keeler or, rather, from a siding called Swansea, on the Nevada & California branch of the Southern Pacific system about 3 miles north of Keeler. A wagon road crosses the range into Saline Valley from Owens Valley, to the northwest, but with an ordinary team the trip requires two days, and no water is to be had across the range. The trail from Swansea, following the route of the recently built tram, makes a climb of 5,000 feet from Owens Valley to the summit, where the tram crosses, and a descent of 7,500 feet into Saline Valley on the east side. The trip in either direction can readily be made in a day so long as the trail remains in good condition, although it is a somewhat strenuous day's work. The climb up or down the east side of the Inyo Range is over a remarkable rock-cut trail, picturesque in the extreme from its ruggedness and the precipitous



2 0 2 4 6 8 10 Miles

Contour interval 500 feet

FIGURE 38.—Map of Saline Valley and vicinity, California, showing location of salt deposits.

gorges and rocky slopes it discloses. The distance from Swansea to the camp in Saline Valley is only about 12 or 13 miles by this route.

SALT DEPOSITS.

The salt deposits of Saline Valley occupy the lowest part of the depression, which, like other desert basins, is completely inclosed by high drainage divides and has no outlet. Surface and ground waters derived from this area flow toward the central depression, which has probably been submerged, though perhaps only to shallow depths and for short epochs. No terraces or traces of upper shore marking were observed. The central or playa deposit of salts and mud, lying almost flat at the bottom of the valley, occupies approximately 12 square miles. Of this only about 1 square mile is composed of a smooth, white, salt crust containing a small pond of salt water. It is the white salt from this surface that it is proposed to harvest and ship to market. Approximate outlines of these areas are shown on the accompanying map (fig. 38), which is taken from the recently completed map of the Ballarat quadrangle. The playa surface beyond the white salt is, like that of marginal salt crusts in some other desert basins, a rough expanse of broken and tilted salt blocks which, having been partly dissolved by storm waters, now stand with an exceedingly sharp, craggy surface. The rough salt has a dirty brown color, doubtless due to the dust which is blown upon it in windstorms and which does not have an opportunity to settle out by occasional floodings and partial solution such as occur in the area of smooth salt.

The salt company's prospectus states that no refining or treatment other than grinding will be needed before placing the salt on the market, and it is assumed that in the main the product to be shipped will be gathered by scraping on the surface of the smooth salt. At the time of the writer's visit a great amount of salt had been piled in stacks ready for transfer to the tram for shipment when that shall have been completed. Samples of the undisturbed salt in these stacks were collected by the writer, with the intention of making a representative average sample of the salt on the ground. Portions were taken from the inner part of six of these stacks from various parts of the field, and these were combined and later mixed, quartered, and analyzed. The following analysis of this sample was made by R. K. Bailey, in the Geological Survey at Washington.

Composition of average salt sample from stacks in Saline Valley, Cal.

Ca	0.00		
Mg	.00		
CO_3	.00		
HCO_3	.00		
H_2O	.12		0.12
Insoluble	.17		.17
Cl	59.76	$=NaCl$	98.52
Na	39.09	$=Na_2SO_4$	1.02
SO_4	.95		
K	.11	$=K_2SO_4$	.37
	100.20		100.20

This analysis shows the salt to be of rather exceptional purity for an entirely natural product. One of the principal factors in its favor is the absence of soluble salts of magnesium or calcium, which would, if present as chlorides, tend to make the salt subject to caking on account of the attraction they have for moisture. With the exception of the small insoluble residue, which is doubtless dust blown in by the wind, the sulphate is the only impurity

Very little is known of the thickness of the deposit, as it appears from reports that no satisfactory drilling has been done. Shallow holes dug in the surface of the white salt crust for the purpose of obtaining samples of the underlying brines show a surface thickness of 4 inches of a loose-textured, porous white crystalline salt, below which is a layer of dark-greenish or almost black saline mud several inches thick. Other layers of hard salt are encountered below this mud, so that it is difficult to dig the deposit with an ordinary shovel, not only on account of its hardness but also because the pit immediately fills with the freely flowing brine.

The ground water stands so high that either the salt crust is barely submerged or water or brine will fill any hole dug in the salt almost at once, rising practically to the surface level. Thus the salt crust is not so hard as it would be on a dry surface and is readily worked. The salt on the surface of the salt flat is gathered by raking or scraping it into heaps while in a wet or slushy condition. The crystals become dry in the stacks and are benefited if washed by an occasional rain. The outer surfaces of the stacks become "sunburned" or somewhat darkened on exposure. This is probably due to the dust swept over them by the wind.

Although it is stated that the principal harvest is that of the natural salt crop, which continuously replaces itself, a series of evaporating vats have been built about the southwest margin of the salt flat and pond, where, by evaporation of the liquor of the lake or recrystallization of the less pure salt from the area surrounding the white salt, the production can be increased.

MARKET FOR THE SALT.

The total production of salt in California in 1911 was approximately 150,000 short tons, the average value of which is listed as $3.65 a ton. The price quoted for California salt is considerably higher than the average price for salt in the United States as a whole. The finer dairy salt is sold at prices higher than that given for the average, but much of the coarse solar salt is sold below that price. The market for the refined salt is of course more limited than that for the coarse. It has been estimated that 12,000 tons of refined salt from the Eastern or the Middle Western States, such as Kansas and Michigan, are shipped for use on the Pacific coast annually. Other than this the California and other western markets are now supplied chiefly by the solar evaporation plants already established on San Francisco Bay, at San Pedro, and elsewhere, and by the smaller output from natural deposits of the desert-basin type.

POTASH TESTS.

Besides the sample of surface salts, a number of samples of the ground solutions were collected at several points about the salt flat, with the special object of testing them for potassium compounds. The results of the tests were practically negative, as shown in the following tabulation of results:

Potash analyses of brines from Saline Valley, Cal.

[Nos. 43-46 by R. K. Bailey; Nos. 47 and 48-by W. B. Hicks.]

Sample No.[a]	Total salts (ignited residue).	Potassium in the total salts.		
		K.	K_2O.	KCl.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
43	29.77	1.29	1.56	2.47
44	28.10	.78	.94	1.48
45	28.05	.81	.99	1.55
46	28.77	1.29	1.56	2.47
47	28.26	.95	1.15	1.82
48	.10	.05	.06	.10

[a] For location see fig. 2.

All these samples except No. 48 are brines collected in the salt flat, the locations being shown on the map (fig. 38). No. 48 was a sample of the natural flow of lukewarm water from the large spring above the salt company's camp, taken in the center of the open stream just below the junction of the several flows. This is the water that drains into the southwest corner of the salt flat and probably supplies the pond of open water. The total flow from this spring, several hundred gallons a minute, is said to vary considerably with the rainfall in the mountains.

It appears that there is little or no evidence from these tests of an important segregation of potash in the residual solutions near the surface. There is a possibility that better results might be discovered by drilling, but from general considerations it is not now supposed likely that a segregation of the potash would be found on a sufficiently large scale to justify much expense in exploration.

BORAX FROM SALINE VALLEY.

The borax industry in Saline Valley is probably a thing of the past. It is said that borax lands were first located in the valley in 1895. Before 1907 the salt crust from certain parts of the flat which are richer in borates than the rest had been collected and dissolved in tanks of hot water and the borax crystallized from the solutions, which became supersaturated with that salt upon cooling. The following account of this process [1] has been given with special reference to Saline Valley, but the procedure was similar at many other deposits:

> All the manipulation that is required is to shovel off the surface of the marsh to a depth of 18 inches and cart the material to long hemispherical wrought-iron pans set on arches of stone, fired beneath with wood fuel obtained in the neighborhood. The pans are charged with water and the crude material thrown in and vigorously stirred with long poles, until, with the aid of heat, all of the soluble salts are dissolved. The fires are then withdrawn and the contents of the pans allowed to settle for 10 hours, when the liquor is drawn off into vats, where the borax crystallizes out. The mother liquor after six days is drawn off and the borax is taken out and packed into sacks for shipment.

For the heating of these tanks much of the grove of mesquite trees about the spring at the southwest corner of the salt flat had been cut and burned, but these trees are now replacing themselves by natural growth. The principal borax-producing plant was about a mile north of the present salt company's camp, and some of the buildings and old tanks are still there. There was another borax works on the opposite side of the valley, said to have been situated east of south from the lower hot springs noted on the map. It seems not unreasonable to assume that a part at least of the boric-acid content of these deposits is derived from the hot springs, although no analyses of these waters are known to the writer. Possibly the marked decrease in solubility of borate salts on lowering of temperature accounts for the localization of these salts reported in the saline deposits. Aside from the fact that the richer ore of borax known as colemanite has now displaced the material derived from dry lake deposits of this type, it is supposed that the richer borate-bearing portions of the salt crust have been largely worked over and exhausted.

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[1] Thorpe, Edward, Dictionary of applied chemistry, new ed., vol. 1, 1912, p. 508.

POTASH TESTS AT COLUMBUS MARSH, NEVADA.

By Hoyt S. Gale.

In February, 1913, the Geological Survey issued a press notice, giving some preliminary results of analyses of mud samples obtained in drilling on Columbus Marsh, near Coaldale, Nev. The saline muds from certain portions of the strata penetrated in the wells had been proved on testing to contain a much higher content of potash than is usually found in such deposits, and it was believed that the results were worthy of careful investigation, as they might lead to the development of a commercially important source of this material. The statements made in the press notice were in substance as follows:

During 1912 the explorations of the Survey geologists with hand-drilling apparatus were carried into Columbus Marsh, and six holes were sunk to depths ranging from 32 to 50 feet. The drilling was done by Charles E. Watson under the direction of the writer. A portion of the marsh was located for borax a good many years ago, and a very small area may have been patented, but the greater part of the playa is still public land. Prior to the Geological Survey prospecting no private interest had been shown in the possibility of developing potash deposits there.

Columbus Marsh is situated on or near the line between Esmeralda and Mineral counties, Nev. Coaldale is a railroad station at the southeast corner of the marsh, and the Tonopah & Goldfield Railroad skirts the eastern margin of the mud flat itself. The marsh covers an area of 35 or 40 square miles, roughly elliptical in outline, being about 9 miles in longest dimension from north to south and 6 miles or more in width. It is a broad mud plain with rough, lumpy surface—a typical playa, the lowest part of the basin of a distinct drainage system, a physiographic feature characteristic of the Great Basin region. Little salt shows on the mud surface except about the margins of the plain, where several borax-producing plants were located in the earlier days of the borax industry.

In the preliminary notice issued attention was directed particularly to the record of well No. 400, given herewith. The analyses of the muds sampled from this well show that the average 20-foot section from the depth of 18 to 38 feet contains 20.59 per cent of potash in the water-soluble portion of the samples. These mud samples, however, averaged only 5.96 per cent of water-soluble salts in the air-dried condition in which they were received at the laboratory. Water samples representing flows at a number of horizons associated with these high potash bearing muds had been collected during the drilling, but at the time the first press notice was issued these samples had been delayed in transit and had not reached the chemical laboratory. Naturally it was expected that the abundant water flows recorded in well No. 400 might prove to be highly charged with potash-rich saline material. From the outset, however, it has been clearly stated that "saline muds which contain only 5 or 6 per cent of total soluble material may not be commercially workable, even though 26 to 40 per cent of that total soluble portion may be potassium chloride," as had been shown in the record of this particular well. After the missing water samples were received and analyzed a second press notice was issued, giving the results.

With a few exceptions all the waters from the wells bored in Columbus Marsh were unexpectedly dilute. The compiled table of the tests is given in one of the following tables. Furthermore, the salts dissolved in these waters did not have so unusually high a potash content as the muds, showing thus a lack of correspondence to the results that had been obtained in the preliminary set of analyses. Probably the deposit warrants still further exploration, as the conditions can not be said to be thoroughly understood. The complete record of the analyses now at hand is as follows:

Analyses of mud samples from borings at Columbus Marsh, Nev.

[W. B. Hicks, analyst.]

Well No. 100, sec. 13, T. 2 N., R. 36 E.

Sample No.	Depth (feet).	Soluble (per cent of original sample).	Potash (expressed as per cent of soluble portion).		
			K.	K_2O.	KCl.
100+1	1	3.62	3.04	3.67	5.80
100+3	6½	1.67	Undetermined.		
100+5	12	1.76	Undetermined.		
100+7	16½	1.69	Undetermined.		
100+9	25	1.87	Undetermined.		

Well No. 200, sec. 12, T. 2 N., R. 36 E.

Sample No.	Depth (feet).	Soluble (per cent of original sample).	K.	K_2O.	KCl.
200+ 1	½	18.56	0.34	0.41	0.65
200+ 2	1	9.39	4.75	5.72	9.03
200+ 3	3	6.12	4.46	5.37	8.50
200+ 4	5	5.72	6.51	7.85	12.41
200+ 5	6	5.55	6.62	7.97	12.61
200+ 6	7	4.67	5.62	6.77	10.71
200+ 7	23	6.15	6.91	8.32	13.17
200+ 8	25	8.41	7.42	8.94	14.15
200+ 9	29	8.06	8.46	10.07	16.13
200+10	31	9.45	6.88	8.29	13.12
200+11	36	8.31	7.19	8.51	13.72
200+12	38	8.42	6.17	7.43	11.76
200+13	40	7.10	6.61	7.97	12.60
200+14	44	17.83	3.12	3.76	5.95
200+15	49	22.30	1.88	2.27	3.59

Analyses of mud samples from borings at Columbus Marsh, Nev.—Continued.

Well No. 300, sec. 36, T. 3 N., R. 36 E.

Sample No.	Depth (feet).	Soluble (per cent of original sample).	Potash (expressed as per cent of soluble portion).		
			K.	K_2O.	KCl.
300+ 1	1	14.10	3.79	4.57	7.23
300+ 2	3	16.02	4.65	5.60	8.86
300+ 3	5	14.70	2.93	3.53	5.58
300+ 4	10	18.80	2.82	3.40	5.37
300+ 5	15	19.64	4.14	4.99	7.89
300+ 6	20	21.60	4.69	5.65	8.94
300+ 7	23	14.74	3.81	4.59	7.26
300+ 8	27	19.83	3.78	4.56	7.21
300+ 9	31	19.44	2.40	2.89	4.58
300+10	35	20.63	3.05	3.67	5.82
300+11	40	16.01	3.67	4.42	7.00
300+12	45	26.91	2.89	3.48	5.50
300+13	50	15.13	4.34	5.22	8.26

Well No. 400, sec. 8, T. 2 N., R. 36 E.

400+1	1	17.30	1.67	2.01	3.18
400+2	3	9.07	2.55	3.07	4.85
400+3	4½	8.88	2.48	2.99	4.73
400+4	9	10.15	2.95	3.55	5.62
400+5	12	1.93		Undetermined.	
400+6	18	5.17	16.64	20.05	31.72
400+7	27	6.30	20.90	25.18	39.83
400+8	30	6.17	13.69	16.49	26.09
400+9	33-38	6.22	17.12	20.63	32.64

Well No. 500, sec. 32, T. 3 N., R. 36 E.

500+ 1	1	15.50	2.47	2.98	4.71
500+ 2	3	14.62	3.19	3.85	6.09
500+ 3	6	14.78	2.38	2.87	4.53
500+ 4	12	12.20	3.70	4.46	7.05
500+ 5	16	12.12	3.60	4.43	7.01
500+ 6	20	12.40	4.15	5.00	7.90
500+ 7	25	11.95	3.89	4.69	7.42
500+ 8	28	11.79	6.23	7.51	11.87
500+ 9	34	12.62	6.69	8.06	12.75
500+10	42	12.15	6.65	8.01	12.67
500+11	48	11.10	4.25	5.12	8.11

Well No. 600, sec. 15, T. 3 N., R. 36 E.

600+ 1	Surface.	19.12	1.37	1.65	2.62
600+ 2	4	14.48	4.57	5.50	8.70
600+ 3	10	12.83	2.41	2.91	4.60
600+ 4	17	17.50	2.69	3.21	5.09
600+ 5	20	12.61	3.37	4.06	6.42
600+ 6	25	12.30	5.16	6.22	9.84
600+ 7	29	10.51	4.44	5.35	8.47
600+ 8	32	11.85	5.18	6.24	9.87
600+ 9	37	10.60	5.94	7.15	11.32
600+10	38	15.20	5.66	6.82	10.79
600+11	46	11.04	5.80	6.98	11.05

NOTE.—Mud samples from wells Nos. 700 and 800 not yet analyzed.

Analyses of water samples obtained from borings by United States Geological Survey at Columbus Marsh, Nev.

[W. B. Hicks and R. K. Bailey, analysts.]

Well No.	Depth (feet).	Soluble (per cent of original sample).	Potassium (expressed as per cent of soluble portion).		
			K.	K_2O.	KCl.
300	17	23.73	1.57	1.89	2.99
400	10	1.86	2.87	3.45	5.47
400	16	.65	3.27	3.95	6.23
400	19	.54	3.72	4.49	7.10
400	29	.42	4.17	5.03	7.94
400	32	.44	4.93	5.96	9.41
400	38	.48	4.41	5.32	8.41
500	12	24.79	1.27	1.53	2.41
600	22	17.97	3.23	3.87	6.13
700	12	.54	Undetermined.		
700	17	.99	Undetermined.		
700	32	.68	Undetermined.		
800	6	5.23	1.74	2.09	3.32
800	16	.71	Undetermined.		
800	19	.61	Undetermined.		
800	30	.64	Undetermined.		
800	48	.82	Undetermined.		
800	74	.40	Undetermined.		

The logs of the wells show little of distinctive character in the deposits.

Well No. 100, drilled July 6 and 7, 1912, reached a depth of 32 feet, mostly in mud, more or less sandy, showing a layer of fine gravel at a depth of 25 feet. Water was encountered from 7½ feet down, samples being taken at 12, 17, 23, and 27.5 feet. At times sand flowed into the casings like quicksand.

Well No. 200, drilled July 8 to 10, 1912, started on a dry saline-mud surface, encountering a hardpan of cemented sand at a depth of 1 foot. Below this was found a moist, sticky mud containing some sand, from which there was a seepage of water. This had a disagreeable odor, like decaying swamp matter. At 18 feet a hard layer was encountered, light gray and sandy, without water, and this continued to 25 feet. Below this was a dark sticky mud yielding seepage water, containing crystals, in part very abundantly. Water continued to seep at intervals to the total depth of 50 feet 6 inches.

Well No. 300, drilled July 11 to 12, 1912, passed through light-colored to yellowish-green clay with some sand to a depth of 20 feet. Below this the record shows a continuous section of black clay, containing salt crystals in places. A 13-inch stratum of limestone was reported at 17 feet. The only water found was a very small seepage obtained at 17 feet. The total depth reached was 50 feet. This well was sunk by augering without using casing.

Well No. 400, drilled July 13 to 18, 1912, gave more trouble than any of the other wells put down. It was cased at all times, the augering and drilling being done in the casing and the casing being driven ahead as fast as it could be moved. The material passed through was mostly very wet, flowing in and filling up the casing from the bottom, like soft quicksand. After filling the casing this material packed very tight, requiring much labor to extract it. From a depth of 28 feet water rose in the casing within 4 feet of the surface. This water contained less than 0.5 per cent of dissolved salts. A coarse sand and fine wash gravel was reported at 32 feet, underlying which, according to the log, is "tough light clay, and below that 1.5 feet of rock, then tough clay and rock again; water rising within 2 feet of the surface. At a depth of 41 feet very hard rock was struck, in which an hour of drilling made no advance." The casing was then pulled. The mud samples obtained from the lower part of this well were those that have been reported to show on analysis exceptionally high results in potash. A number of water samples were collected at various depths, all of which proved on testing to be comparatively dilute, and the salts dissolved failed to show very exceptional potassium analyses.

Well No. 500, drilled July 19, 1912, reached a depth of 49.5 feet, showing almost entirely clay, generally moist, yielding but little water. A sample of water was collected at 12 feet and a seepage was noted from the depth of 15 feet.

Well No. 600, drilled July 20 to 22, 1912, reached a depth of 49 feet. This was sunk by augering mostly in clay, light colored in the upper 10 feet, the rest dark gray to black. Water was collected only at 22 feet.

Subsequent to the drilling of the first six wells, two wells of greater depth have been drilled by the Geological Survey in the vicinity of well No. 400. The following are the complete logs of wells Nos. 700 and 800, the analyses of the solid samples from which are not yet finished.

Record of United States Geological Survey boring No. 700, Columbus Marsh, Nev., in the southeast corner of sec. 5, T. 2 N., R. 36 E.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface, salt crust, formerly worked for borax	0.3	0.3
Sand, light brown, moist	2.7	3.0
Sand and gravel, light brown, fine gravel, wet	1.0	4.0
Clay and sand, dark blue, wet	2.0	6.0
Clay and sand, black, containing crystals	6.0	12.0
Sand, black, soft muck, pumped	2.0	14.0
Sand, black, soft, full of fine crystals	3.0	17.0
Sand and gravel, fine, full of crystals	9.0	26.0
Quicksand	6.0	32.0
Water encountered:		
Water sand No. 1, black, stinking water, not salty		4.5
Water sand No. 2, seepage water, nearly fresh		12.0
Water sand No. 3, black, stinking, came within 4 feet of the surface, strong flow		17.0
Water sand No. 4, stinking, not salty, seepage		32.0

NOTE.—This well was in running sand from 3 to 32 feet.

Record of United States Geological Survey boring No. 800, Columbus Marsh, Nev., in the center of sec. 5, T. 2 N., R. 36 E.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface, salt crust like that formerly worked for borax	0.5	0.5
Sand, light brown	1.5	2.0
Sand and clay, light yellow, dry	4.0	6.0
Clay, dark blue, smooth	1.0	7.0
Mud, black, smooth, sticky	5.0	12.0
Mud, black, smooth, wet	4.0	16.0
Sand, black, wet	3.0	19.0
Gravel, fine, containing crystals	1.5	20.5
Sand, fine, containing crystals	3.0	23.5
Clay and sand, light blue, containing hard, coarse particles	7.5	31.0
Clay, light gray, containing hard, coarse particles	4.0	35.0
Clay, black and yellow, containing hard, coarse particles	3.0	38.0
Clay, dark blue, containing hard, coarse particles, soft and wet	6.0	44.0
Clay, black, containing hard, coarse particles, soft and wet	3.0	47.0
Clay, light gray and black, smooth, soft, and wet	1.0	48.0
Clay and mud, black, pumped, containing coarse, hard particles, wet	5.0	53.0
Clay, smooth, black, dry	4.0	57.0
Clay, smooth, black and yellow, dry	4.0	61.0
Clay, smooth, light yellow, dry	4.0	65.0
Clay, smooth, dark bottle-green, dry	4.0	69.0
Clay, smooth, yellowish green and black, dry	5.0	74.0
Sand, quicksand, fine running sand	8.0	82.0
Water encountered:		
Water sand No. 1, salty, small flow		6.0
Water sand No. 2, black, not salty, medium flow within 4 feet of the surface		16.0
Water sand No. 3, little salty, clear, strong flow within 1 foot of surface		19.0
Water sand No. 4, seepage, black and foul		48.0
Water sand No. 5, little salty, medium flow within 3 feet of the surface		74.0

NOTE.—Water encountered at 19 feet was a very strong flow and fresh enough for horses to drink.

On January 16, 1913, the President withdrew from location and entry all the lands in Columbus Marsh that are supposed likely to contain valuable potash deposits. The withdrawal was made under the authority of the withdrawal act as amended on August 24, 1912. This amendment makes it effective as against all forms of entry under the mining laws of the United States except those that apply to metalliferous minerals. The withdrawal will enable the Government to proceed in due course to make further examination of these deposits or to prevent undesirable title complications in case Congress sees fit to provide a new and adequate law governing the disposal or lease of properties of this character.

SODIUM SULPHATE IN THE CARRIZO PLAIN, SAN LUIS OBISPO COUNTY, CALIFORNIA.

By Hoyt S. Gale.

The deposit of sodium sulphate in Soda Lake, in the Carrizo Plain, San Luis Obispo County, Cal., was briefly described by Arnold and Johnson[1] in 1909 shortly after the erection of a plant for the commercial development of the soda. The locality was examined by the writer in October, 1912, to determine whether or not soluble potassium salts are associated with the soda. The results of the tests made are negative as regards the occurrence of commercially important amounts of potash, but it seems desirable to publish a description of the deposit including in some detail the results of the recent tests.

There is at present no considerable market for sodium sulphate, or what is known in the trade as "salt cake," which is the product of the first step in the Leblanc process for the manufacture of sodium carbonate from sodium chloride. In this process salt cake is produced by the decomposition of sodium chloride with sulphuric acid, hydrochloric acid being a valuable by-product. At present, however, the Leblanc process has been almost entirely displaced by the ammonia process for the manufacture of soda, at least in the United States. Sodium sulphate is also used in glass making, for ultramarine, in dyeing and coloring, and to some extent in medicine (Glauber's salt). A use in paper manufacture has been suggested. Quotations on sodium sulphate in current trade journals range from 55 to 65 cents per 100 pounds for glassmaker's salt cake and 60 to 90 cents per 100 pounds for Glauber's salt in barrels. This is equivalent to $11 to $18 a short ton.

It seems hardly likely that natural sodium sulphate will be largely mined and used for the manufacture of either sodium carbonate or other sodium salts so long as extensive deposits containing the

[1] Arnold, Ralph, and Johnson, H. R., Sodium sulphate in Soda Lake, Carrizo Plain, San Luis Obispo County, Cal.: Bull. U. S. Geol. Survey No. 380, 1909, pp. 369–371.

carbonate and bicarbonate in large amounts are available. Therefore it is probably reasonable to assume that the utilization of such a deposit as that at Soda Lake depends on the demand or market for sodium sulphate as such or the evolution of some new processes requiring the soda in the form of sulphate. The possibility of such a demand may be sufficient to give to the deposit in the Carrizo Plain a certain potential value.

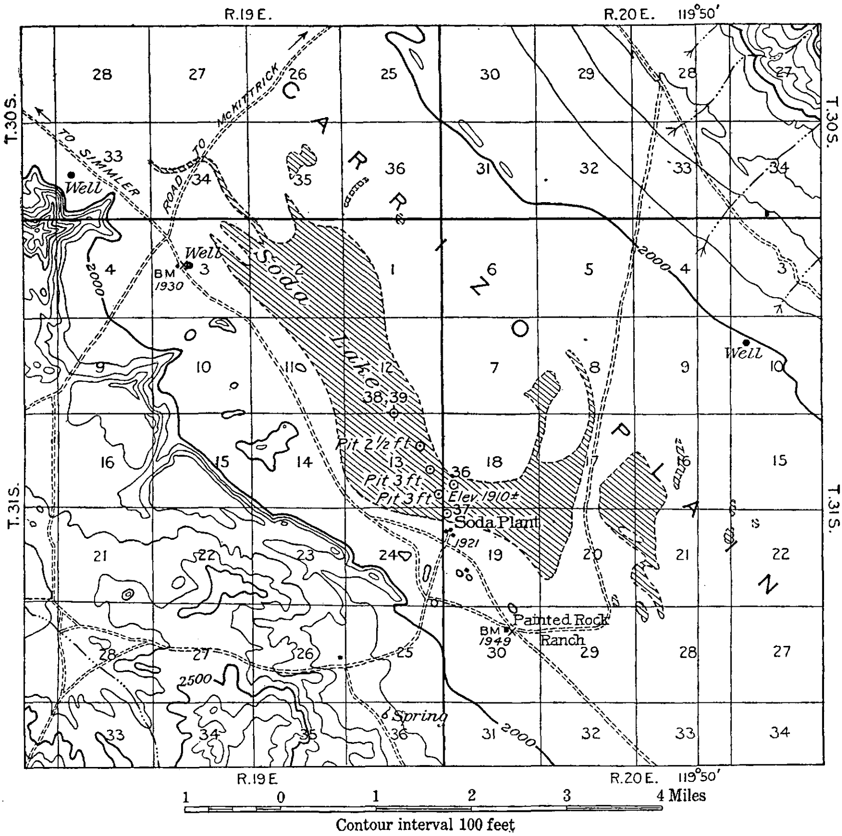

FIGURE 39.—Map of Soda Lake, San Luis Obispo County, Cal. From map of McKittrick quadrangle, U. S. Geological Survey.

The extent of the deposit is indicated in figure 39, from which it is estimated to be 2,800 to 3,000 acres. The lake is said to remain dry on the surface during the greater part of the time, although occasionally flooded to a shallow depth after storms. Its surface normally presents a broad, flat plain of white crystalline salts, ranging from a thin sheet about the margins to a deposit a few inches thick in the deeper parts, except that there is reported to exist a still deeper "channel" of solid salts, an example of which was noted at the outer terminus of the tramway leading to the flat. At the time of visit a number of pits had lately been dug on the salt crust, and several of these remained open, being filled with a saturated solution from which crystals of salts were being deposited about the margins. In these holes long, glassy, prismatic crystals form in the solution with chilling overnight, and these were assumed to be mirabilite (Glauber's salt), the sulphate of sodium crystallized with 10 molecules of water. On removal from the solution, however, these crystals rapidly effloresce and, losing their water, crumble to a fine white powder. The natural anhydrous sodium sulphate is thenardite, which has a crystal form distinct from that of mirabilite and is not so subject to alteration on exposure to the air. This has not yet been noted in crystalline form in this deposit.

The mass of the material underlying the surface crust or cake of salts is a soft mud of dark-greenish or grayish-black color, containing more or less of crystal salts and saline matter in solution. Numbers of large, blunt, distinctly terminated and double-ended crystals of a flat tabular form were noted about some of the excavations that had been made on the lake bottom. These had been found embedded in the mud under the salt crust. The crystals consisted of clear glassy material, containing an irregularly distributed dark, almost blackish, coloring matter, supposed to be included mud. They do not alter on exposure to the air like the crystals of hydrous sodium sulphate. A number of them were collected by the writer and determined by W. T. Schaller, of the Geological Survey, to be bloedite, a hydrous sulphate of sodium and magnesium. Schaller[1] describes the crystals as follows:

> The larger crystals have a dark, almost black appearance when the superficial covering of gray mud is removed, though the small crystals are nearly colorless, the black appearance being due to impurities. In places the larger crystals are likewise nearly colorless and translucent and in small pieces transparent. In fact, selected fragments are clear and glassy and, with the lack of cleavage, greatly resemble quartz fragments. * * * An analysis of selected pure material gave the following:

Analysis of bloedite from Soda Lake, Cal.

H_2O	21.37
MgO	11.93
Na_2O	18.26
SO_3	48.11
	99.67

The accompanying figure of a bloedite crystal (fig. 40) was drawn by Schaller from the specimens collected at this deposit.

[1] Schaller, W. T., Bloedite crystals, preliminary note: Jour. Washington Acad. Sci., vol. 3, No. 3, February, 1913, pp. 75, 76.

The only other occurrence of bloedite in the United States of which a record has been found is that in the Estancia Valley, N. Mex.[1]

The surface salt crust collected by Arnold and Johnson was analyzed by George Steiger, of the Geological Survey, as follows:

Analysis of saline crust from Soda Lake, Cal.

Insoluble	0.40
Al_2O_3	.04
MgO	1.66
CaO	.45
Na_2O	40.50
K_2O	.28
H_2O	3.65
CO_2	None.
SO_3	46.12
Cl	9.27
	102.37
Less oxygen	2.09
	100.28

A combination possible from the above composition may be calculated as 81.86 per cent of anhydrous sodium sulphate with 8.97 per cent of sodium chloride. A much purer sodium sulphate readily separates by crystallization as mirabilite from the saturated solutions of these salts, as is shown in the pits of open ground waters on the deposit. Little can be added to the geologic statement of the occurrence or manner of accumulation of these salts contained in Arnold and Johnson's description:

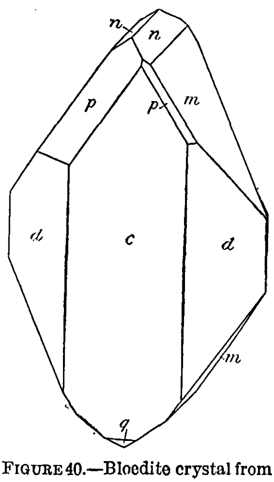

FIGURE 40.—Bloedite crystal from Carrizo Plain, Cal.

> The Carrizo Plain is a structural depression which has been faulted down between the Caliente and Temblor ranges and has been sufficiently covered by Pleistocene and possibly earlier débris to mask its real character. Faults, some of them very recent geologically, bound the plain along its northeast and southwest margins. The amount of folding and faulting which has taken place in this region is very great. This intense deformation has, in conjunction with denudation, exposed large areas of soft conglomerate, sandstone, and shale, particularly in the adjacent ranges, to the solvent action of rain, and thus through the agency of running water the soluble salts of these rocks have been transferred, in part, to the lowest portion of the plain. There they have been deposited, through evaporation of the solvent, in a series of saline beds, the chief constituent of which is sodium sulphate.

The basin has the appearance of having formerly belonged to the drainage basins of San Juan and Salina rivers. The lack of present

[1] Jones, F. A., Mines and minerals of New Mexico, 1904, p. 226.

outlet is doubtless due to tilting of this portion of the valley in fault blocks so that a former outlet to the northwest has been cut off, and as evaporation exceeds the rainfall the basin does not appear to have ever been filled to overflowing. A rise of water level of less than 200 feet at the present time would establish an outlet to the northwest. No terraces more than a few feet above the present flat were observed. The cut banks and terracelike margins of the dry lake bottom suggest the alluvial filling of a former stream channel without great modification of the original topography. Even the deeper channel in the salt deposit itself suggests a former continuous drainage channel passing across this area. If this is so, the saline and playa deposits may be of comparatively recent geologic age. The front of the Temblor Range, to the northeast, is apparently terraced, but the terraces are clearly the offsets of faulted blocks, the evidence of recent movement in places being quite distinct.

The following are the results of tests for potash salts in this deposit made in the United States Geological Survey laboratory at Washington. As has been stated, these results are of negative import, so far as a valuable content of potash is concerned.

Potash analyses of samples from Soda Lake, Cal.

[W. B. Hicks, analyst.]

Sample No.[a]	Material.	Soluble portion (ignited).	Potassium in the soluble portion.		
			K.	K_2O.	KCl.
31	Concentrated brine	29.02	0.40	0.49	0.77
34	Bloedite crystals	78.10	.10	.12	.19
35	Salt crust, average sample	89.66	.05	.06	.09
36	Concentrated brine	29.16	.63	.76	1.20
37	.....do	26.39	.36	.43	.68
38	Salt crust, average sample	88.12	.06	.08	.13
39	Concentrated brine	30.19	.29	.34	.54

[a] For location see fig. 39.

Sample No. 31 was a 1-quart sample of the natural ground-water solution found standing in a 4-foot hole that had previously been dug in the dry-lake flat at a point near the end of the tram track extending out from the soda plant. In this pit clear, transparent, needle-like efflorescent crystals had formed with chilling of the solution overnight. No. 34 was a collection of the isolated crystals afterwards determined as bloedite. No. 35 was an average sample of the surface crust of white salts collected from many places within a radius of 100 to 200 feet near the locality of sample 31. No. 36 was a 1-quart sample of natural ground-water solution from an open pit in the salt crust at the end of the tram line. This is a wet place, said to be about the lowest point in the dry lake and the last point to dry when the whole deposit has been flooded. It is evidently a low point in the channel of the salt, if such a channel exists, although it is situated near the shore on the north side and not in the center of the lake. No. 37 was a 1-quart sample of natural ground water from a pit dug in the dry-lake surface near the tram track and nearer the soda plant than the pit sampled in No. 31. No. 38 was a sample of the surface salt crust made up of many portions collected about the four posts marking the south quarter corner of sec. 12, T. 31 S., R. 19 E. The salt crust was about 2 inches thick at this place. No. 39 was a 10-ounce sample of natural ground water which trickled into a hole dug at the locality of sample 38.

In the foregoing table the figures given in the third column indicate the percentage of the original sample represented by the soluble portion after ignition at low red heat. This eliminates both the waters of the solutions and, in the salt-crust samples, the water of crystallization. The potassium content is expressed in different forms for the convenience of the reader who may have used one or the other form as a basis of comparison, and represents percentages of the soluble ignited residue only and not of the original sample.

Several other pits 2 or 3 feet deep dug in the lake bottom yielded little or no available samples of ground water within half an hour or more. Water was said to have been more plentiful on other occasions when such holes had been dug. The lake bed underlying the surface salt crust was found to be everywhere essentially a fine dark wet mud to the depth examined.

In summary it may be stated that so far as tested the sodium sulphate in the relatively thin saline crust that covers the surface of the dry-lake bottom is all that appears to be available for commercial development. At present the mineral bloedite has no commercial value. The probability of the presence of deeper saline crusts is not considered very strong, but there is, nevertheless, a possibility that such crusts may exist. The available supply of saturated ground waters is believed to be limited to the surficial salt crust. The brine can not be expected to flow readily or replenish itself rapidly through the heavy, difficultly permeable muds in the lake bottom. Free flows, probably of fresher waters, possibly even under artesian head, might be encountered by boring in the lake bottom. Estimating the specific gravity of the salt crust as 1.75 and its average depth as 2 inches over the entire surface area of 2,800 acres would give a gross weight of over a million short tons of crude salts on this deposit, and this is believed to be a warrantable and moderate assumption.

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