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POTASH BRINES IN THE GREAT SALT LAKE DESERT, UTAH

BY

THOMAS B. NOLAN

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By Thomas B. Nolan

INTRODUCTION

During and immediately after the war the brines of the Salduro Marsh, in the Great Salt Lake Desert, were a source of considerable potash for the domestic supply. Although no potash has been produced from these brines in the last few years, a continued interest in the area has been shown by a large number of filings, in different parts of the desert, under the potash law of October 2, 1917 (40 Stat. 297), and the regulations issued under that law by the Department of the Interior on March 21, 1918, in Circular 594 (46 L. D. 323).

As the basis for appropriate action on these permit, lease, and patent filings the Department of the Interior required information concerning the mode of occurrence, distribution, and general characteristics of the potassium-bearing brines in this region. Field investigation was accordingly undertaken for the primary purpose of satisfying these requirements.

The work was done by the Geological Survey and the General Land Office in cooperation with the Bureau of Mines. The Bureau of Mines furnished an autotruck and a mechanic, who also assisted in the field work, and, for a period of a month, a mine rescue car, which permitted the establishment of headquarters in parts of the desert far from sources of supplies and water. The General Land Office surveyed the boundaries of townships over the desert and located the drill holes from which samples of brine were taken.

The writer directed the work for the Geological Survey, and the analyses of the samples of brine were made in the Survey's chemical laboratory.

The greater part of the field work was done between April 17 and July 7, 1925, and the work was finished during the two periods August 17–26 and September 30 to October 2. Adverse weather throughout the season hindered the work.

LOCATION AND SETTLEMENT

The area tested for potassium is the nearly flat barren stretch of country in northwestern Utah known as the Great Salt Lake Desert. This name has been loosely used, at times referring only to the central flat and at times including also the surrounding brush-covered gravel slopes. In this report, unless otherwise specified, the Great Salt Lake Desert, or simply the desert, will be used in the restricted sense—that is, it will be applied only to the flat. Almost all this territory is included between latitude 40° and 41° 31′ and longitude 113° and the Nevada-Utah boundary line, approximately at longitude 114° 2.5′. The greater part lies in Tooele and Boxelder Counties, Utah, with small overlaps into Juab County, Utah, and Elko County, Nev.

The area is traversed by the Southern Pacific main line near its north end, the Western Pacific Railroad and the Victory Highway near the center, and the Lincoln Highway near the south end. Wendover, a division point on the Western Pacific near the Nevada line, is the chief town of the area. Lucin, on the Southern Pacific, and Gold Hill, the terminus of the Deep Creek Railroad, are other noteworthy towns. The only other settlements are section points on the two railroads, only one of which, Salduro, has other inhabitants than railroad employees.

Fresh water is totally lacking on the desert and is very scanty along its borders. The two railroads have built pipe lines from springs in the mountains to supply their needs and will furnish it in tank cars to consumers.

HISTORY OF DEVELOPMENT

According to Gale,[1] the salt beds of the Great Salt Lake Desert were brought to attention in 1907 by the engineers who were building the Western Pacific Railroad. The beds were soon covered by claims, and the owners of these claims organized the Montello Salt Co., of Ogden. After several years of unsuccessful work the property was leased to the Capell Salt Co., of Salt Lake. This company erected a small mill and for a few years gathered, ground, and shipped the crystalline salt.

During the country-wide search for potassium salts after German shipments had been stopped by the war, the area was visited by H. S. Gale, of the Geological Survey. He bored several holes and took samples of both the salt and the brine included within the salt. Analyses in the chemical laboratory of the Geological Survey showed

[1] Gale, H. S., Potash in 1916: U. S. Geol. Survey Mineral Resources, 1916, pt. 2, p. 98, 1917.

the presence of considerable amounts of potassium in the brine. This discovery was announced by the Geological Survey in Press Bulletin 271, published in May, 1916.

In the fall of 1916 the Solvay Process Co. obtained control of the Montello Salt Co. and commenced construction of a plant to produce potassium salts. Production began in 1917 and increased rapidly until in 1920 the Utah-Salduro Co., the subsidiary operating company, was the largest single producer in the country. In 1921 the plant was closed, and operations since then have been restricted to the production of salt.

The Bonneville Co., which holds patent rights to considerable land south of Wendover, has done a large amount of prospecting and some experimental work but has not produced any potassium salts. Two other companies holding groups of claims north and south of Arinosa have been active, but neither of them in December, 1925, had received patents to any of the land claimed.

ACKNOWLEDGMENTS

The writer wishes to acknowledge the cordial cooperation of Mr. Thomas Varley, Mr. G. D. D. Kirkpatrick, and Mr. V. C. Heikes, in charge respectively of the Salt Lake offices of the Bureau of Mines, the General Land Office, and the Geological Survey. Mr. Andrew Nelson, cadastral engineer of the Land Office, was of continual assistance throughout the field work, and the completion of the work was expedited by his aid. Officials of the Southern Pacific Co. and the Western Pacific Railroad freely furnished maps and well logs.

The manuscript of the report has been read by Messrs. G. R. Mansfield, O. E. Meinzer, Kirk Bryan, R. C. Wells, and R. K. Bailey, of the Geological Survey, and the writer is glad to acknowledge their helpful criticisms.

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Short notices in other potash chapters of the Mineral Resources of the United States give further details.

METHOD OF PROSPECTING

The area was prospected by 405 shallow test holes, from which samples of brine were taken. Most of these holes were put down at section corners along township and range lines, and the series on a single line was extended from the margin of the flat toward the center until a brine whose chloride content exceeded 100 grams per liter was reached. These samples were supplemented by three series of samples taken at mile intervals across the desert. The location at which each sample was taken is shown on Plate 3.

The boring was done almost entirely with a 5-inch standard auger, equipped with a patent device that simplified emptying. The outfit included extension joints that permitted depths of 14 feet to be reached. It was originally planned to sink all holes to a depth of 10 feet, but this was not possible in many places. In a few holes caving sand prevented further boring, and in a great number the weight of several feet of brine caused the fine clay to slip through as the auger was pulled up. No casing of holes was attempted.

Field tests for chloride, potassium, and sulphate were made at the end of each day in order to guide the locations of the test holes. Chloride was determined volumetrically by titration with a standard solution of silver nitrate. Potassium was determined by measuring the volume of the precipitate obtained with sodium cobaltic nitrite solution, and sulphate was estimated by a volume measurement of precipitated barium sulphate. The determinations of chloride were satisfactory as to accuracy, but the results for potassium and sulphate, as later checked in the laboratory, were of qualitative value only.

The samples were sent to the chemical laboratory of the Geological Survey, and the results of the accurate analyses made in this laboratory by R. K. Bailey are used in this report. It is to be regretted that the pressure of other work did not permit the analysis of all the samples, but it is believed that a sufficient number have been analyzed to show the general character of the brines.

When field work was started it was thought that a constant relation existed between the contents of potassium and chloride in the brine, and that the content of chloride, which can be determined in the field with relative speed and accuracy, might be used as a measure of the economic value of the land. Sufficient samples were obtained to outline areas underlain by brines that contain 60 to 100 grams per liter of chloride. Although the potassium-chloride ratio was found to vary considerably as field work progressed, it is believed that the content of chloride alone is a fair indicator of the value of the brines in that the more concentrated brines have on the average not only a greater content of potassium but also smaller relative amounts of the undesirable sulphate and carbonate radicles. These features are discussed in somewhat more detail on page 42.

For transporting men and boring material over the desert a light-weight car is desirable. It should be equipped with large oversize or balloon tires, and the air pressure in the tires should be greatly reduced. Heavy tire chains are often necessary. Even with this equipment the car will be mired in many places, and for this contingency it is essential to carry a 10-foot length of 4 by 4 inch timber, blocks, and a number of 2-inch planks. An ordinary jack is of little use.

Consumption of gasoline and water by the motor is much in excess of normal requirements. It was found that the gasoline mileage was from one-half to one-third that obtained under normal conditions, and the water-cooling system used 6 or 7 gallons of water a day.

GEOLOGY

GENERAL FEATURES

At a geologically recent time the greater part of western Utah and small parts of adjacent States were covered by the waters of a lake which has been called Lake Bonneville.[2] The present Great Salt Lake may be considered as a remnant of this lake. At the time of its greatest extent Lake Bonneville covered nearly 20,000 square miles, and its maximum depth was over 1,000 feet. Both at this stage and at lower stages the waves and shore currents formed the terraces, bars, and other shore-line features that are so prominent on the mountains that formed the shores of the lake or were included within it as islands.

According to Gilbert, the basin which held the lake was formed in late Tertiary time.[3] He believed also, however, that older basins existed in the area, and that much of the material that forms the fill of the present basin was brought in during earlier periods. Very little is known of the duration or extent of these older lakes.

The history of Lake Bonneville, however, is fairly well known. There were at least two periods of expansion, separated by a period of aridity, in which the waters receded greatly or may even have disappeared. The land waste carried by the tributary rivers was deposited in the lake bottom and formed the sediments now exposed.

The second period of expansion continued until it was terminated by overflow into the drainage basin of Snake River, to the north. Later the climate again became more arid, and the waters receded for a second time. This recession, although oscillating, continued

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

[3] Idem, p. 214.

until the present level of Great Salt Lake was approximately reached. Since then there have been no noteworthy changes.[4]

The surface exposed by the retreating water was highly uneven, for the comparatively short existence of the lake was not sufficient for sedimentation to smooth the original irregularities of the bottom. The location of the higher portions was such that a number of closed basins took the place of the single Bonneville Basin. The Great Salt Lake Desert forms the central depression of one of the largest of these basins.

SURFACE FEATURES

The flat is almost completely bordered by mountainous country, gravel slopes of varying extent joining the two. Its level expansion is broken by several small groups of hills. The largest of these, the Desert Range, is a northeastward-striking spur from the Pilot Range. Other hills are completely surrounded by the desert and are locally known as islands. The Newfoundland Mountains and Wildcat Mountain are the most striking. The location of these features is shown on Plate 3.

To the casual observer the desert presents the appearance of a single basin, destitute of drainage as well as of vegetation. Indeed, over much of the surface instrumental observations are necessary to detect the changes in altitude which exist. However, it is probable that the flat really comprises several drainage basins. Their existence is suggested by the course of shallow dry washes, by the location of standing water on calm days, by the salinity and quantity of brine underlying the basins, and by areas of crystalline salt.

The highest divide separates the desert from Great Salt Lake. It probably follows the line of the low limestone hills which extend from the Lakeside Mountains to the Terrace Mountains and is shown by westward-draining washes and the presence of a brine of low salinity. There is some evidence to indicate that two smaller divides, one extending to the north and the other to the southeast of the Newfoundland Mountains, have formed a small basin on the east side of these mountains which has its lowest point and contains brine of highest salinity near the west margin.

A second basin exists in the arm of the desert included between the Desert Range and the Pilot Range. A marked divide between it and the main flat is found at the mouth of the arm in Tps. 5 and 6 N., R. 17 W. This divide is formed of sediments deposited by Grouse Creek where it flows out upon the level plain. The trenching of the sediments by eastward-draining dry washes amounts

[4] For the minor oscillations in the lake level since 1851, see U. S. Geol. Survey Water-Supply Paper 517, pl. 2, 1924.

to at least 7 feet. Here also the low point in the basin lies near the west border and is occupied by a rather thin deposit of salt.

In addition to these two basins a number of smaller and less distinct depressions occur along the east border of the desert in a zone about 12 miles wide and 30 miles long. This zone contains numerous sand dunes, which locally are continuous and have formed independent basins, some of them covering several square miles. Where the underlying lake deposits are sand or sandy clay the brine shows an increased salinity within the basin, but unlike the two basins previously described, each of these basins has its point of maximum salinity not at the west margin but near the center.

The remainder of the desert is believed to form a single drainage unit. Its lowest portion or "sink" is a salt deposit, near the west border, known as the Salduro Marsh. Precise-level lines have not been run to this marsh, but approximate figures indicate that its lowest point is about 5 feet above the present level of Great Salt Lake. The railroad grades across the flat show the extremely small differences in altitude which are found. The 10-mile stretch between Arinosa and Salduro, for example, is level, and in an equal distance from Arinosa to Barro a rise of only 2 feet is made. These grades, however, are based on the altitude of the rails on top of the fill and therefore do not exactly reflect the surface changes.

The nearly level surface of the flat is broken by dry washes and sand dunes. The washes are conspicuous only around the edge, where surface drainage has cut shallow channels, most of which are less than a foot in depth. Along these channels are narrow bands of desert bushes. Even out in the flat, where no channel exists, similar bushes mark the course of the waters from floods as they spread over the flat.

The great area of level land over which the prevailing southwest winds sweep permits large quantities of material to be transported for considerable distances. The greater part of the material carried seems to be derived from the border zone, where shallow dry washes give the advancing wind an initial face to work against. In such regions on the east side of the desert the steep banks of the streams have been removed and the interstream areas smoothly rounded. The only materials gathered from the central flat, so far as could be ascertained, are flakes of salt that were deposited at the surface by the evaporation of surface waters.

As a result of the erosion and transportation by wind, sand dunes are abundant on the east side of the desert. In places they reach heights of 100 feet and cover areas of several square miles. These larger dunes are barren of vegetation and are continually advancing. The windward sides have the lesser grade and show a char-

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acteristic rippling. Many of the lower dunes also cover large areas, but these are more or less completely covered by vegetation and are therefore essentially stationary.

Saline springs are found at the edge of the desert, particularly on the west side, where the boundary between the gravel slopes and the clay of the flat is sharp. The water of the springs is much fresher than the brine of the flats and commonly carries less than 10 grams per liter of chloride. These springs probably belong to the " border " type of Bryan,[5] owing to the fact that the impervious barrier of the desert clays causes the water within the gravel slopes to rise to the surface at the contact with the clay. The solution of small amounts of salt from the clay causes the slightly saline character. The best example of such springs is the Salt Lagoon or Salt Springs, 16 miles south of Wendover.

LAKE BONNEVILLE BEDS

Calcareous clays and sands.—The flat is underlain by fine-grained sediments that were deposited in Lake Bonneville and its predecessors. These beds, like the old lake, have a much wider distribution than the area of the desert, but only the sediments within the desert need be considered.

These sediments were studied by Gilbert at different points along the old shores and were divided by him into two groups—the white marl and the yellow clay.[6] It was not possible to make such a distinction in the material revealed by the shallow holes bored during the field season, although many of the sediments fall into the two types proposed. There is, however, no recognized segregation into two distinct groups. An apparently similar alternation at Deep or Deseret Creek in Snowsville Valley is mentioned by Gilbert.[7]

The most common sediment is a fine calcareous clay, which has in a few beds a faint lamination. The fresh material is light gray to cream-colored and is extremely plastic. On exposure the consequent drying results in the hardening and cracking of the sediments and the formation of a thin white coating of salt. Gypsum in single or grouped crystals is locally found in quantity, not only in these clays but in all other types that were cut in the borings.

Of the other types of clay found, those of yellow to olive-brown color are the most abundant. In these clays a distinct lamination is noticeable and is emphasized by a small amount of alternation of varicolored beds. Iron oxide in cubes and pseudomorphs after pyrite is common in places and is perhaps the cause of part of the brownish coloring. In the deeper holes the clay is darker. Some of

[5] Bryan, Kirk, Classification of springs: Jour. Geology, vol. 27, p. 537, 1919.
[6] Gilbert, G. K., op. cit., p. 190.
[7] Idem, p. 191.

these beds, of dark-gray to black color, have a strong odor due to decomposing organic matter. Blue-green to blue clays, however, are more general than the gray to black clays.

Sand lenses are interbedded with the clays in all proportions. They are limited to near-shore localities and are particularly common on the east side of the desert. The continuations of old stream channels are likely to have larger proportions of sand than are present elsewhere. Many of the clay beds in these areas contain more or less intermixed sandy material and are sandy clays. Variations in color, similar to those in the clay, are found in the sand.

Analyses of samples of Gilbert's white marl and yellow clay showed the presence of 25 to 75 per cent of calcium and magnesium carbonate, the remainder being silicates and small amounts of quartz.[8] The clays of the flat probably are of similar composition. One difference, however, lies in the amount of soluble salts included. The older analyses show the presence of 1 to 4 per cent, whereas clays of the desert contain from 11 to 15 per cent. The explanation lies in the fact that the buried clays of the flat have not been flushed by surface waters. The composition of the soluble salts is similar to that of the brines, except that they have a higher proportional content of the sulphate radicle.

The depth to which the sediments extend is unknown for the greater part of the desert. At Salduro a drill hole more than 400 feet deep was sunk in lake beds, including, it was believed, a bed of salt at 300 feet. Several other holes, 200 feet deep, have been put down without striking bedrock. At the north end of the desert, along the Southern Pacific Railroad, three deep wells were drilled in a search for fresh water. Only one of these, at Lemay, reached hard rock, and this occurred at a depth of nearly 1,500 feet. The lower 200 feet may represent some earlier (Tertiary) deposits, but the material in at least 1,300 feet of the beds seems definitely to be similar to the material now exposed. The log of the well as furnished by the Southern Pacific Co. shows interstratified blue clay, sandy clay, and sand, in which the sandy clay and sand form about one-quarter of the total thickness. The sandy beds are distributed throughout the section, and many of them are but a few feet thick. The blue clay, particularly from 100 to 200 feet below the surface, contains gypsum, which locally seems to occur in considerable amount, although no quantitative statement is furnished.

The presence of a fairly definite line of demarcation between darker unoxidized beds below and brownish oxidized beds above is essentially universal throughout the desert. The depth at which the change occurs is 5 feet or more, depending upon the altitude of the

[8] Gilbert, G. K., op. cit., p. 202.

surface, the deeper occurrences being found in holes started on relatively higher ground. The upper surface of the blue clay, therefore, more nearly approaches a plane than the land surface and apparently represents a level of oxidation, developed when the lake waters retreated.

Except after recent rains the surface of the clay is covered by a network of sun cracks, approaching but never attaining the theoretically probable hexagonal pattern. The hexagons as a rule are of rather large diameter, 2 to 3 feet, and are characteristically shallow. During periods of rain the whole surface becomes a sea of soft mud, and the sun cracks disappear. Another feature of the clay worthy of mention is the presence of certain areas, particularly on the west side of the flat, which contain numerous moist zones. There is no relation between the moist zones or " soft spots " and surface depressions, surface drainage, or the presence of vegetation, all of which in other places within the desert cause local treacherous zones. Although most of the spots are irregular in outline, a few are distinctly linear, extending unbroken for a hundred yards or more, with a maximum width of only a few feet. The only suggestion which may be offered for their origin is that the surficial soft spots and lines are determined by intersecting systems of joints in the compacted clays beneath, possibly similar to those described by Gilbert,[9] along which may occur a rise of brine, caused either by capillarity or by hydrostatic pressure, or both.

Salt.—Two areas of crystalline salt occur. The larger, near the west-central border of the desert, covers an area of nearly 150 square miles that extends about 9 miles along the Western Pacific Railroad. Salduro station lies at about the center. The smaller deposit lies in the northwest corner of the embayment between the Desert Range and Pilot Mountain. Here the area covered by salt is somewhat less than 25 square miles.

The salt is a white, coarsely crystalline aggregate and is extremely porous. The pore space, except for a few inches at the surface, is entirely filled with a saturated brine. Notwithstanding this porosity the material is hard and rigid, so that it can support heavy trucks even when the surface is covered with water. It is extremely difficult to bore with the ordinary hand auger. The surface is marked by large sun cracks, the edges of which are somewhat elevated above the general level. A typical analysis of the soluble portion of the salt is quoted from Gale.[10]

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[9] Op. cit., p. 211.

[10] Gale, H. S., Eng. and Min. Jour., vol. 102, No. 18, p. 780, Oct. 28, 1916.

Analysis of the soluble portion of the salt crust about 1¼ miles southeast of Salduro station

[Analyst, R. K. Bailey]

K	0.07
Na	36.85
Ca	1.20
Mg	.10
SO_4	2.88
Cl	58.90
CO_3	None.
	100.00

Total soluble salts, 96.20 per cent of the sample.

The salt is reported to reach a maximum thickness of 5 feet near the central portion of the deposit. The greatest amount found during boring, however, was 3½ feet, near Salduro station. From the maximum it thins rather gradually to zero at the edge.

The border zone between the salt and the surrounding clay beds is a soft muddy mixture of salt and clay, which is extremely difficult to cross by wagon or automobile, even in the dryest season. The surface of the thin salt coating in this area is rather rough, through the development of miniature thrust faults during the expansion attendant upon crystallization.

BRINES

In addition to the nearly saturated brine found in the salt beds, saline waters of lesser concentration are found throughout the desert within the clay. The brines in the crystalline salt were the first to be exploited and were the source of the potassium salts produced by the Utah-Salduro Co. During the trenching operations of this company it was found that the underlying muds also contain brine at different horizons and, further, that these brines extend beyond the limits of the salt flat. These brines within the clay are attracting the most attention at the present time, in part because the clay offers easier trenching, but mainly because the area covered by the thicker portion of the salt is almost completely in private hands.

The brine in the porous salt is evenly distributed throughout the deposit, and a rough estimate puts the amount of brine at one-fourth of the total volume. The brine is struck at depths that range from half an inch at the center to 4 inches near the margin of the salt.

The composition is fairly constant throughout and shows a range, expressed in grams per liter, as follows:

Cl	186–200; average, 192.0.
K	8.7–12.5; average, 10.6.
Mg	4.8–7.3; average, 6.3.
SO_4	4.9–5.7; average, 5.2.

In every sample analyzed the ratio of potassium to magnesium is greater than unity. For a distance of about a mile from the edge of the salt the concentration is somewhat lower; the chloride drops to about 160 grams per liter and the other constituents decrease in proportion. This decrease in concentration is probably due in part to mixture with the less concentrated clay brines and in part to dilution with rain water, which tends to collect in the peripheral zone.

A similar brine is found in the thin salt deposit in the arm of the flat between the Pilot Range and the Desert Range. The quantity of brine in this area is small.

The brines in the clay differ in many respects from those described above. Perhaps the most notable difference is that the composition is far less regular, single constituents varying not only absolutely but relatively. Furthermore, the brine is not uniformly distributed throughout the sediments but is found in thin horizontal zones within them. A few of these zones are determined by sandy beds, but by far the larger number are restricted to thin layers of salt-impregnated clay, which commonly are only a fraction of an inch thick. The upper limit of the brines is marked in many places by an accumulation of caliche, consisting of layers of clay or sand well cemented by evaporation products, probably in most part calcium and magnesium carbonates with some gypsum. This caliche ranges in thickness from less than an inch to more than a foot.

The depth to brine differs greatly in different places, although in general the brine is nearer the surface at the center of a basin. Near the borders of the flat, however, brines are locally found higher than might be expected. Almost all the uppermost brine of a salinity greater than 100 grams per liter of chloride will be found within 5 feet of the surface. The only exceptions are in a few regions of scant flow.

In a few holes brine was struck at more than one horizon. This condition could be proved only when the higher flow was weak and the lower one stronger. In such holes the two or, more rarely, three flows seem to represent a single zone, for near-by holes may fail to show similar occurrences. The deep holes at Lemay and Salduro, however, are reported to have struck at different depths several brine flows, which must be of independent origin.

One of the 200-foot holes at Salduro, for example, showed well-defined brines at depths of 26 and 42 feet. The records for lower depths are less exact, but several more flows seem to be present. Some of these occurrences are apparently similar to those described above—that is, several small flows belong to a single main zone.

Significant also are the variations in the quantity of brine at different localities. In some areas the flow was exceedingly scanty, and it was necessary to allow from half an hour to two hours to elapse before sufficient brine had seeped in to furnish a sample. Such brines show a rather high salinity and locally an unusual concentration of potassium. The two most extensive of these areas lie on the west side of the desert. The larger of the two includes an area 10 miles in width, measured from the margin of the flat, and extends from the middle of T. 5 S. to the middle of T. 9 S. The second area includes the northeast quarter of the embayment between the Desert Range and the Pilot Range. It is significant that the adjacent highlands in both areas are without springs of any size and furthermore represent very small drainage basins in a portion of the desert which has the scantiest rainfall.

In most of the holes away from the edge of the flat the brine flow, if plentiful, was under a small hydrostatic pressure, as shown by a rise of brine in the bore hole amounting to several inches and rarely to a foot. In no place was the pressure sufficient to cause the brine to rise to the surface. In a few holes the noise of the inrushing water revealed the presence of the brine before the auger was lifted.

Chemically the brine in the clays resembles that found in the salt only in the dominance of chloride. Chloride, except for relatively much smaller amounts of sulphate, is the only acid radicle present. The amount of chloride present varies directly with the distance from the edge of the flat—that is, the nearer to the edge the smaller the content of chloride. The degree of dilution is dependent directly upon the size of the drainage basin tributary to the inflowing stream channel and the rainfall within it. Such dilution is best illustrated at the mouth of Government Creek and to a less degree by Deep Creek, Salt Springs, Grouse Creek, and the drainage from Snake and Fish Springs Valleys. The dilution as a whole is greater on the east side of the desert, where the rainfall is about double that on the west. A generalization that seems to hold over most of the area is that land which is barren of brush is underlain by brine that contains more than 100 grams per liter of chloride.

Potassium and magnesium are both present in the clay brines in different amounts. Unlike the salt brine, the clay brine does not invariably have potassium in excess of magnesium, and furthermore the ratio between either potassium or magnesium and chloride is far from constant. The absolute content of both magnesium and potassium is independent of the total salinity. It tends to range between 1½ and 4 grams per liter of each for brines whose content of chloride is greater than 40 grams per liter. Only within a mile or so from the margin of the flat is there a tendency, by no means universal, for amounts of potassium and magnesium to decrease with lowered salinity. The average content of potassium in 199 samples containing more than 60 grams per liter of chloride was 2.89 grams per liter, and 97 samples of similar salinity had an average content of magnesium of 2.05 grams per liter.

The ratio of potassium to magnesium in different parts of the flat seems to be related to the character of the bedrock in the neighboring drainage area. This relation is most marked in brines adjacent to areas where masses of rocks rich in potassium are exposed. In these brines the ratio of potassium to magnesium rises to 3 or 4 to 1. Perhaps the best example of this dominance of potassium over magnesium is the area halfway between Salt Springs and Wendover, where the hills adjoining the flat are made up largely of rhyolite and the brine below contains but little magnesium. A ratio of potassium to magnesium less than unity is not so common. One area in which it occurs, however, is found around Wildcat Mountain, which is formed in large part of lower Paleozoic dolomites. Dolomitic rocks are of wide extent in several other mountain areas that border the flat, but in many places the brines near by have a ratio of potassium to magnesium about equal to or slightly less than unity. The probable reason for the absence of an excess of magnesium is considered on page 42.

The sulphate radicle shows no relation whatever in its distribution to the amount of chloride present. It is much more comparable to potassium and magnesium, although not as variable in its range, but tends to be equally high in all parts of the flat or even somewhat higher near the margin. In a few areas, however, the concentration is unusually high, especially in the areas to the west of the Newfoundland Range and on the east edge of the desert from Knolls to Wildcat Mountain. The sulphate content of 111 brines which carried more than 60 grams per liter of chloride was 4.36 grams of SO_4 per liter.

Sixteen determinations of calcium in rather widely separated brines varied but little from an average of 1.73 grams of calcium per liter. The small variation shown suggests that the calcium content is held down by the sulphate that is uniformly present. The average contents of the two substances closely approximate the proportions theoretically required for $CaSO_4$. The sum is 6.09 grams $CaSO_4$ per liter, which compares with a solubility of 6.8 (obtained by interpolating on a graph constructed from the data furnished by Seidell [11]) in a sodium chloride solution of salinity similar to that of the average brine. The conclusion drawn is that there is little if any sulphate in excess of that required to form $CaSO_4$. Such an excess is

[11] Seidell, Atherton, Solubilities of inorganic and organic compounds, 2d ed., p. 218, 1919.

undesirable in the purification of the brine, because of the relative insolubility of the monohydrated form of magnesium sulphate.

The extremely simple character of the brine is shown by the following complete analysis of a composite of 126 separate samples. The analysis was made primarily to determine whether or not there were present appreciable amounts of any of the rarer elements. The analysis shows, however, that except for a very small amount of lithium, the brine is composed of the radicles already discussed. It is worthy of note that the contents of calcium and sulphate are fairly close to the molecular proportions for $CaSO_4$—the excess SO_4 amounting to 0.46 gram per liter.

Analysis of a composite sample of brine from the Great Salt Lake Desert, Utah

[Analyst, J. G. Fairchild]

	Grams per liter		Grams per liter
Cl	96.15	Na	57.30
Br	.00	K	2.94
I	.00	Li	.002
SO_4	4.08	Ca	1.51
CO_3	.00	Sr	.00
BO_3	.00	Mg	1.91

Specific gravity at 25° C., 1.11.
Total solids at 180° C., 164.7 grams per liter.

The conditions described above are summarized on Plate 3. The location of each bore hole is shown by a small circle and number. The variations of the content of chloride in the brine are shown by the two lines marked 60 and 100 grams per liter of chloride. The samples taken in the central part of the flat are not sufficiently numerous for the construction of lines showing the distribution of brines of higher salinity.

The potassium and magnesium in this brine are so variable within the small range of these substances that it has not been possible to express them in this way. For those samples which have been analyzed in the laboratory, the figures for K and Mg in grams per liter are shown beneath the location of the bore hole, the potassium being shown above the magnesium. The potassium content has been shown as K, rather than as K_2O, which is the commercial unit not only for the sake of uniformity but also because potassium is present in the brine as KCl, which contains no K_2O. The value given for K may be converted to K_2O by multiplying by 1.204. The content of sulphate is also difficult to show graphically. Samples containing more than 6.5 grams per liter of SO_4 are indicated by a large circle around the location of the bore hole, as, for example, at bore hole 93, near the northeast corner of sec. 31, T. 7 N., R 13 W.

ORIGIN OF THE BRINES

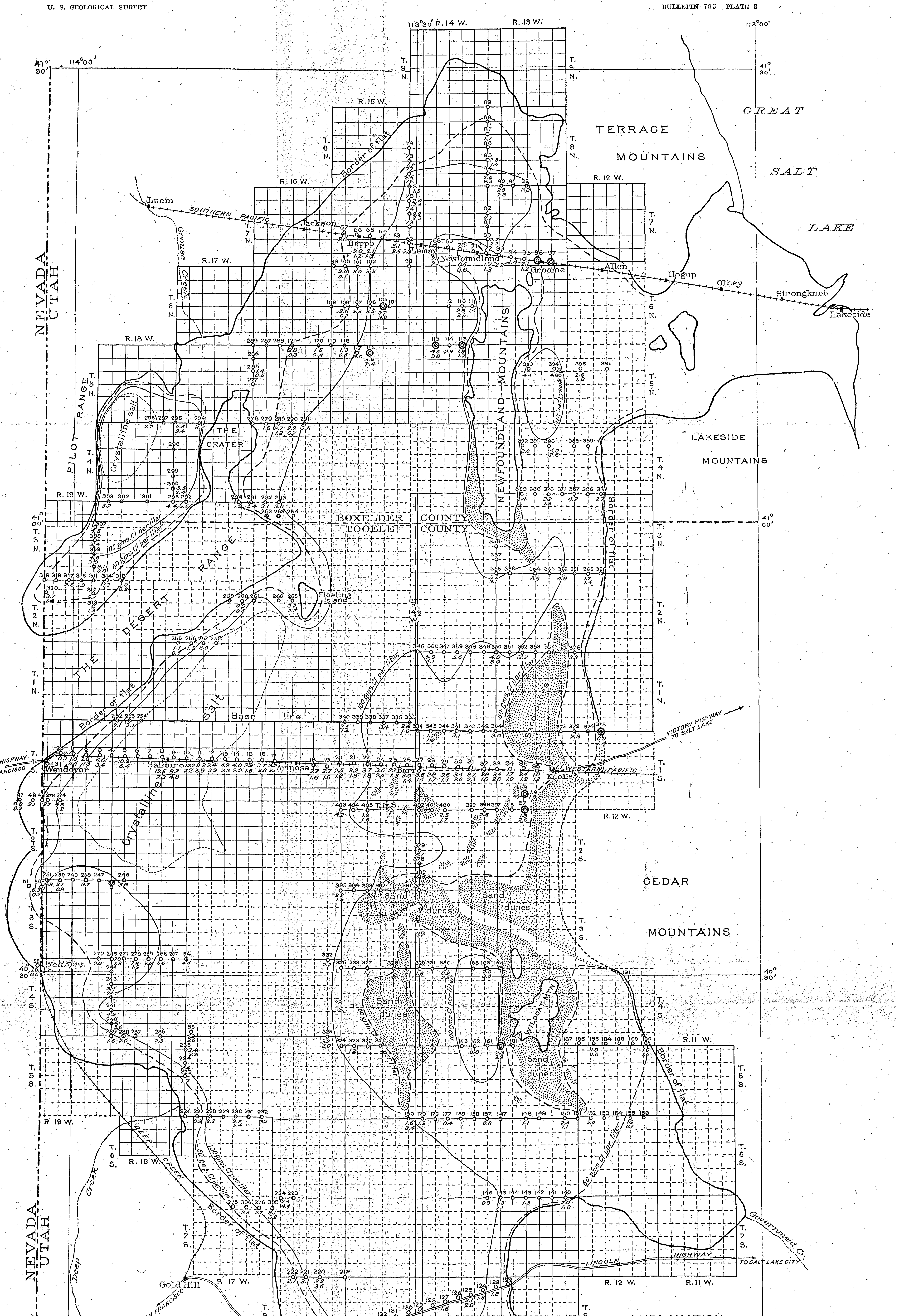
The two types of brine that have been described were formed in entirely different ways. The brine found in the salt is definitely related to the final evaporation of Lake Bonneville. It is not possible, however, to say whether it is simply a residual mother liquor, which has existed, with slight modification by rain water and mixture with the clay brines, since the withdrawal of the lake waters, or whether the evaporation of that part of the old lake in the Great Salt Lake Desert was complete and the brine in the salt represents a later solution of the more soluble potassium and magnesium chlorides, together with sufficient sodium chloride to make a solution saturated with that salt. The chemical composition in either case would be identical.

The location of the two bodies of salt with their included brines, near the west margin of the desert, is noteworthy as a corroboration of Gilbert's proof of a warping of the old lake bottom.[12] Gilbert showed that the beach lines of the old lake are higher near the geographic center than they are farther away. This rise was caused by progressive differential elevation of the lake bottom to compensate for the weight of the water removed by continued evaporation. It seems probable that the divide between the Great Salt Lake and the Great Salt Lake Desert was thus produced. Elevation at this point with little or no elevation at the west border would result in a tilting of the lake floor to the west, and on that side would be concentrated the products of desiccation.

The brine in the clay can not be accounted for in the same manner. The changes in quantity and the mutual relations of the contents of potassium and magnesium noted are obviously related to the quantity and quality of the surface water tributary to the desert. Such surface waters, however, would contain little chloride and relatively large amounts of carbonate and sulphate. Further, their passage from the gravel slopes, within which they flow from the higher altitudes, into the fine clays that underlie the desert, would be extremely difficult, except as they impinged upon sand lenses that would permit lateral movement. The greater part of the water on reaching the clay beds would rise to the surface and form slightly saline springs at the edge of the flat.

The restriction of the brines to comparatively thin layers within the clay seems to require that these layers shall have certain properties to distinguish them from the remainder of the sediments. This difference in character is probably due to the deposition of the beds that contain the brines at periods when the older lakes that occupied the Bonneville Basin were drying up. The beds would

[12] Op. cit., pp. 362 et seq.



MAP SHOWING THE SALINITY OF THE BRINES UNDERLYING THE GREAT SALT LAKE DESERT, UTAH therefore contain increasingly great amounts of salt and as the final deposit a thin crust of salt. When the basin again became filled with water these saline deposits would be in part dissolved, but the larger proportion would be buried by land waste, particularly if the recession and advance of the waters were oscillatory. This theory was first stated by Russell [13] to account for the lack of salinity in the lake waters now found in the Lahontan Basin, and was later applied by Gale [14] during the search for domestic deposits of potash.

Such a layer impregnated with salt would permit easy lateral movement by the inward-draining surface waters and would account for the localization of the brines at definite horizons. As each layer represents the surface of the lake floor at a particular time in the past, it would have a slight slope away from the shore of the ancient lake. Water flowing in along such a plane would therefore be under a slight hydrostatic pressure and would rise when tapped by a bore hole. The fact that such pressures exist has already been noted.

The hypothesis requires as a necessary corollary several more periods of desiccation of Lake Bonneville than are described by Gilbert, for brine was found at several deeper horizons in the deep wells of the Utah-Salduro Co. Further evidence in this regard is given by the changes in lithology and by the abundant presence of gypsum in the deep drill holes put down by the Southern Pacific Railroad along the Lucin cut-off.

The brines struck in the shallow bore holes put down in the course of the field work were probably formed in the dry period that is correlated by Gilbert with the unconformity between the white marl and the yellow clay. The accuracy of this correlation was not proved by tracing, but strong evidence is found by a comparison of the thickness of the white marl and the depths to the brine horizon. The thickness of the white marl, measured near the edge of the basin, where sedimentation would normally be at a maximum, is given as 10 feet,[15] and the depth to brine ranged from 2 to 3 feet near the center of the flat to 7 to 9 feet at the margins. The decrease in thickness of the sediments above the brine was very probably the result of diminished sedimentation with increasing distance from the source of the materials. The presence of two or three brines at this horizon perhaps shows that the desiccation was oscillatory.

Some of the puzzling features about the composition of the brine seem to be simplified by the hypothesis of such an origin. The dissolved salts would necessarily be derived from two sources—those brought in by inward-draining waters and those dissolved from the

[13] Russell, I. C., Lake Lahontan: U. S. Geol. Survey Mon. 11 p. 224, 1885.
[14] Gale, H. S., Quaternary lakes of the Great Basin: U. S. Geol. Survey Bull. 540, p. 404, 1914.
[15] Gilbert, G. K., op. cit., p. 190.

clay at the horizon of the brine. Quantitatively, the second of these sources has been the more important, as it has furnished the sodium chloride which makes up the larger part of the brine. The universal presence of this salt and the striking relations between its concentration and that of the inward-flowing drainage waters indicate strongly that it has been dissolved from beds at the horizon of the brine. In addition, a large part of the calcium and sulphate has most probably been derived in this way. The rather uniform amount present throughout the flat suggests solution in place, and the common occurrence of calcium sulphate as the initial layer of a deposit otherwise consisting of sodium chloride adds weight to this view.

The meteoric waters that drain into the flat provide the larger part of the potassium, as is clearly shown by its dependence upon the presence of adjoining areas underlain by potassium-rich rocks. Magnesium and calcium are also brought in, probably as bicarbonates. The high salinity of the brines, however, like that of the Great Salt Lake,[16] does not favor the holding of carbonates, particularly calcium carbonate, in solution, and thus most of the calcium and a large part of the magnesium are precipitated. This condition seems to account for the local failure of magnesium to be as abundant as the character of neighboring rock outcrops would suggest. The precipitated carbonates form zones of caliche immediately above the beds that contain the brine. Some sulphate is also introduced and may form areas of local high concentration, but the larger part is precipitated as gypsum, tiny crystals of which are found in the brine.[17]

Some sodium and chloride are doubtless brought in by the meteoric waters, but the quantity is very small compared to that derived from the clays by solution. The apparent anomaly of the marked difference in character between the two brines, notwithstanding the fact that their ultimate sources were the same, is explained by the fact that the salts dissolved from the clay are the concentrates of a large body of water from which the less soluble constituents, such as the carbonates of calcium and magnesium, have been eliminated, either as deposits of tufa along the shore, or to form other sedimentary beds rich in carbonate.

Buried salt beds have been postulated by Meinzer to account for the chloride-rich waters that underlie the Estancia Valley, N. Mex.[18]

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[16] Clarke, F. W., The data of geochemistry, 5th ed.: U. S. Geol. Survey Bull. 770, p. 159, 1924.

[17] Gale, H. S., Potash in Salduro salt deposit: Eng. and Min. Jour., vol. 102, p. 781, 1916.

[18] Meinzer, O. E., Geology and water resources of Estancia Valley, N. Mex.: U. S. Geol. Survey Water-Supply Paper 275, p. 51, 1911.

TECHNICAL CONSIDERATIONS

Two features of the brines of the Great Salt Lake Desert which should aid in their commercial development are the arid climate of the flat, which permits extensive use of solar heat in concentrating the brine, and the extremely simple chemical character of the brines.

Solar evaporation was successfully practiced by the Utah-Salduro Co. during the war and has since been tried on an experimental scale by two of the newer organizations. The extreme heat during the summer and the persistent southwesterly winds combine with the lack of rainfall to make the rate of evaporation unusually high. The only weather records available for the flat itself are those kept at Lemay, on the Southern Pacific Railroad. There the annual rainfall for the years 1911–1924 has averaged 3.90 inches, rather equally divided throughout the 12 months.

The character of the brine simplifies refining, particularly as a certain amount of evaporation, by which some of the sodium chloride is eliminated, will produce a brine that closely resembles the artificial brines of the Stassfurt region. The subsequent treatment may thus closely parallel that used in Germany.[10] In that country the magnesium chloride has also been recovered and has been utilized in the manufacture of metallic magnesium. If a market for this metal could be developed here the possibility of successful exploitation would be considerably enhanced.

Several unfavorable features offset these advantages to some extent. First, the low content of potassium necessitates considerable concentration before the grade of the German raw material is reached. This concentration, however, may be accomplished cheaply by solar methods. Second, the distance from present centers of consumption, notwithstanding the fact that two transcontinental railroads cross the flat, will remain a serious obstacle until the demand for potash due to increased consumption of fertilizer in the Western States has materially increased. Third, and perhaps most important, is the probable rapid exhaustion of the widespread but thin layer containing brine near the surface. Large-scale operations will require for their maintenance the development of the deeper brines, concerning which little is now known. Although the deeper brines may in general have the same chemical character as the upper brines, it is not improbable that marked local differences in both quantity and composition will be found. In this regard it is necessary to consider the possibility of the presence of completely buried rock ridges. These ridges ought to be found at no great depth along the continuations of the present "islands," such as Wildcat Mountain and

[10] A synopsis of the Stassfurt refining practice may be found in Thorpe's Dictionary of Applied Chemistry, vol. 4, pp. 342–347, London, 1913.

the Newfoundland Mountains. In addition, other completely buried rock masses probably exist, whose position and depth below the present surface can be determined only by deep drilling. The effect of such buried mountains on the brines in the surrounding lake sediments is of course unknown, but probably it would be toward a lower salinity, because of the general tendency toward dilution that is found near the margins of the flat now exposed.

SUMMARY

The following summary shows the more notable features of the uppermost brine:

1. The quantity of brine present at any place varies more or less directly with the amount of surface drainage discharged from the adjacent highland. Other things being equal, the eastern half of the flat may be expected to yield stronger flows because of the progressively heavier rainfall eastward.
2. The salinity of the brine varies roughly with the distance from the margin of the flat, except where large drainage channels enter the flat. In the line of extension of such channels lines of equal salinity are displaced away from the margin for considerable distances. The limit of stunted brush corresponds more or less closely with a content of 100 grams per liter of chloride in the brine.
3. The content of potassium and magnesium bears little or no relation to the salinity.
4. The relative amounts of potassium and magnesium present depend upon the type of rock in the adjacent highland. Thus, if the inward-flowing stream drains an area composed largely of potassium-rich igneous rocks, the potassium content of the brine will be in excess of magnesium. If, however, the drainage area contains abundant dolomite, magnesium will be more abundant; but in many places the potential excess will not be found because of the relative insolubility of magnesium carbonate in saline solutions.
5. The content of sulphate is generally low. Areas where this radicle is high, however, have been determined west of the Newfoundland Range and along the east border of the desert south of Knolls.

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