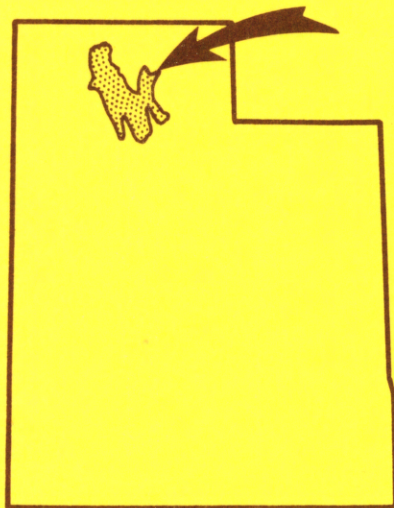


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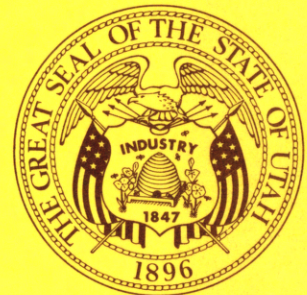
UTAH GEOLOGICAL AND MINERALOGICAL SURVEY
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THE COLLEGE OF MINES AND MINERAL INDUSTRIES
University of Utah, Salt Lake City, Utah



GREAT SALT LAKE, UTAH:

Chemical and Physical Variations
of the Brine, 1963-1966

Prepared by
The United States Geological Survey
in cooperation with
The Utah Geological and Mineralogical Survey



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GREAT SALT LAKE, UTAH.

Chemical and Physical Variations of the Brine, 1963-1966

by D. C. Hahl and A. H. Handy
U.S. Geological Survey



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GREAT SALT LAKE, UTAH:

Chemical and Physical Variations of the Brine, 1963-1966

by *D. C. Hahl and A. H. Handy*
U.S. Geological Survey

ABSTRACT

Great Salt Lake is a shallow, closed-basin lake in northern Utah. Its surface area and concentration of dissolved solids vary in response to both annual and long-term climatic changes. The lake gains water mainly as streamflow from mountains to the east and loses water through evaporation. In 1965, at a lake-surface altitude of 4,194 feet, the surface area was about 1,000 square miles, and the maximum measured depth was 27 feet.

Studies to define the variations in chemical and physical characteristics of the brine began in 1963, and detailed sampling of the lake at 29 sites was made in October 1965 and May 1966. Data resulting from concurrent sampling of the 29 sites indicated that four types of brine coexist in the lake.

The concentration of dissolved solids in the Great Salt Lake brine has always varied from place to place and with depth. Inflow, evaporation, currents, wind, and density differences resulted in brine stratification in the deep parts and brine concentration in the shallow, isolated parts of the lake.

Completion of a railroad causeway by the Southern Pacific Co. in 1957 divided the lake into two parts and altered the movement of brine. The northwestern part of the lake was essentially cut off from direct fresh-water inflow by the causeway, and as a result it was saturated and well mixed from 1963 to 1966. During the main evaporation season (June-October), a layer of salt crust was precipitated on the lakebed north of the causeway. Near Rozel Point the salt crust contained 99.6 percent sodium chloride.

The southern two-thirds of the lake receives over 90 percent of the surface inflow and since 1957 has rarely reached saturation. The southern part of the lake is not well mixed, and three types of brine have been identified by their location, concentrations of specific ions, and concentrations of dissolved solids. These brines are located (1) in a zone from the surface to a depth of about 16 feet, (2) in the zone below 16 feet south of the causeway, and (3) in the zone below 16 feet in the south end of the lake¹.

The shallow zone of brine in the southern part of the lake varies in concentration of dissolved solids from

1. Data collected by the Utah Geological and Mineralogical Survey during 1967 and 1968 indicate that the more dense brines occurred at depths of about 20 feet or more.

season to season because of the interplay between inflow and evaporation. Brine in this zone is usually the most dilute of any brine in the lake.

The two deep brines in the southern part of the lake contain almost the same concentration of dissolved solids, which is greater than that of brine in the shallow zone but not quite as great as that of brine north of the causeway. The concentrations of dissolved solids of the deep brines also vary seasonally.

Brine in the deep zone near the south side of the causeway is maintained by a density current that flows at depth from the northern part of the lake through the causeway.

Brine in the deep zone at the south end of the lake is distinguished from the three other brines in the lake by its high concentration of sodium ion and its low concentration of sulfate ion. This brine might result from the inflow of ground water through a zone of sulfate reduction at the lakebed.

Brine north of the causeway is reddish-brown and visibility of an object placed in it is limited to about 2 feet, whereas brine south of the causeway is green and bottom features 15 feet below the surface can often be clearly seen.

Studies describing the relations among the interchange of brine through the causeway, the thickness of the salt crust, the concentrations of dissolved solids in the brine, and identifying the source of deep brine at the south end would provide information needed for future lake management.

INTRODUCTION

This report gives the results of an investigation of the chemical and physical characteristics of the brine in Great Salt Lake, Utah, by the U. S. Geological Survey in cooperation with the Utah Geological and Mineralogical Survey from 1963 through 1966. The purpose of the investigation was to determine the seasonal and annual variations in the characteristics of the brine and the variations from place to place and at various depths in the lake. Such variations in the characteristics of the brine had been noted in prior studies under the same cooperative program. (See Hahl and Mitchell, 1963, and Hahl and Langford, 1964.)

None of the previous studies of the lake provided much information on the chemistry of the brine. Investigations of the chemical and physical characteristics of

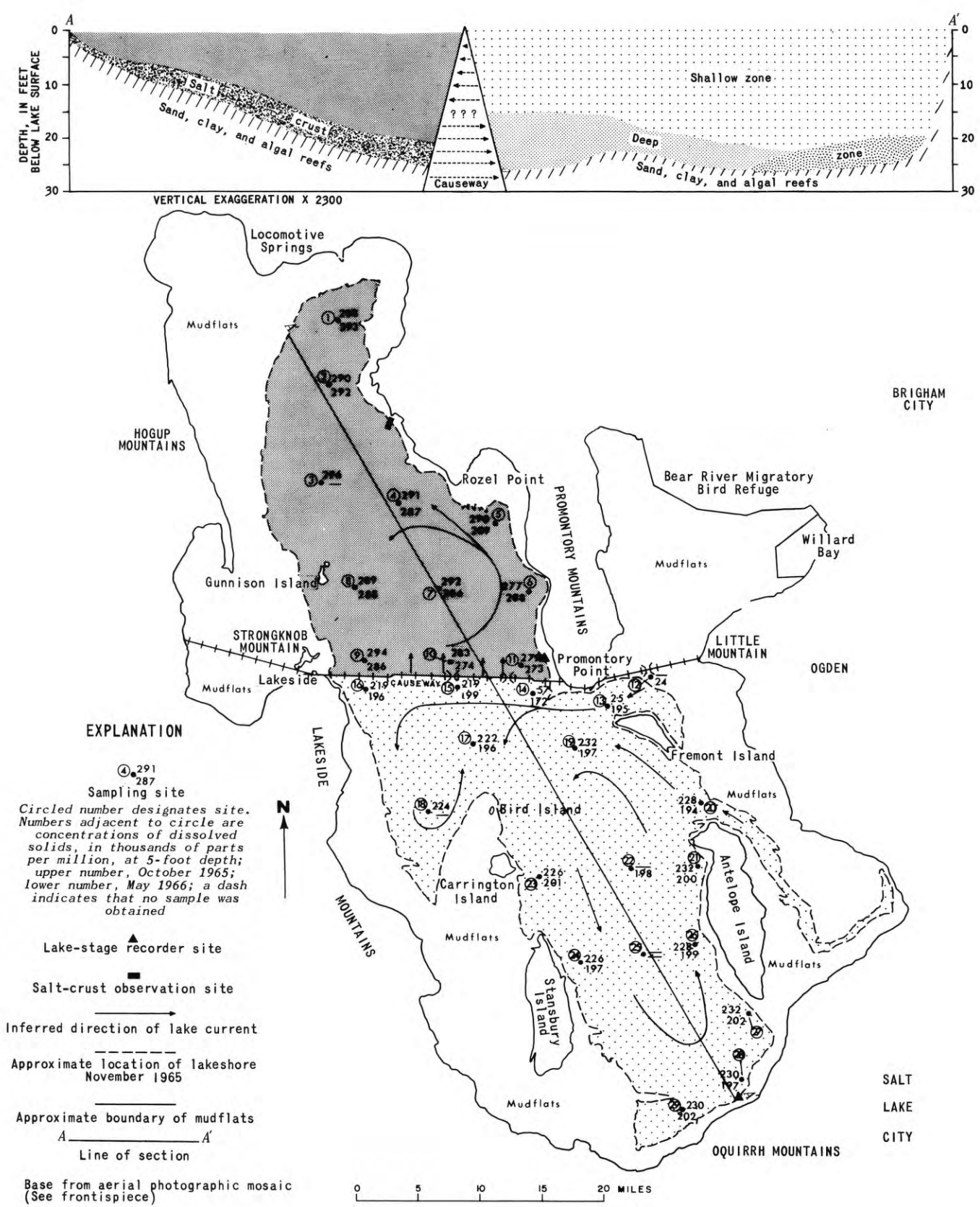


Figure 1. — Locations of sampling sites, concentrations of dissolved solids, and inferred direction of currents in Great Salt Lake during October 1965 and May 1966, and diagrammatic longitudinal section of Great Salt Lake indicating locations of the four brines (stippled patterns).

the brine were made as early as 1845 when John C. Fremont (Miller, 1966, p. 8) determined that the evaporation of 5 gallons of brine yielded 14 pints of salt. Subsequent information on the chemistry of the brine was limited by the small amount of miscellaneous sampling, which, from 1845 to 1962, was apparently only at the surface and near the shore of the lake. Numerous publications on Great Salt Lake are listed in Woolley and Marsell (1946), and subsequent pertinent studies are cited in this report.

During 1963 and 1964 the study of the variations in the chemistry of Great Salt Lake was greatly facilitated by the Southern Pacific Co. Geological Survey personnel were permitted access to the railroad causeway and taken on the lake in the company's tugboats. Data were obtained from surface and bottom points in the deeper parts of the lake. The data obtained indicated that the concentrations of dissolved solids increased with depth and that chemical characteristics varied from place to place. These data were useful in designing the sampling program that was carried out during 1965 and 1966.

During 1965 and 1966, 29 sites (fig. 1) were sampled using a boat owned by the Utah Geological and Mineralogical Survey. Sampling trips were made in October 1965 and May 1966, and during each trip the sites were sampled in less than 4 days to obtain concurrent data. At most sites samples were taken at the surface and at the bottom and at intervening 5-foot intervals. The accuracy of the measurement of the sampling depth was ± 0.5 foot.

The samples were collected in the 2-liter sampling device described in the appendix of this report. The device was specially built because most commercial depth-sampling devices contain too many metal parts to permit trouble-free sampling of brine. Two samples were collected at each sampling point. The first sample was used to determine the water temperature and to rinse the sampling bottle, the second sample was poured into a 1-liter polyethylene bottle for eventual analysis. Sampling always proceeded from surface to bottom at each sampling site to avoid agitation of the unsampled brine.

The dissolved ions in the brine samples were determined using an adaptation of chemical methods used in the analysis of fresh water (Rainwater and Thatcher, 1960). The headings in table 7 in the appendix of this report list the ions determined. A few analyses of strontium, bromide, and iodide and some spectrographic analyses also were made. Brine analysis is not as precise as fresh-water analysis because of the necessity to dilute the brine prior to analysis. Dilution alone may introduce as much as a 2 percent error in the quantitative determination.

Data collected between December 1963 and June 1966 are given in table 7. However, data collected infrequently since 1930 were used in an attempt to relate observations made about the brine during 1965-66 to brine conditions in other periods. The available data

for the period March 1930 through November 1961 are reported in Hahl and Mitchell (1963, p. 38-40).

The authors were assisted in data interpretation by B. F. Jones of the Geological Survey, who suggested the probable sequence of chemical reactions that occur in the south end of Great Salt Lake.

During the period of investigation of Great Salt Lake, aerial photographs were made for control in planned topographic mapping, for experimental purposes, and for delineation of the shoreline. Study of the photographs, which include panchromatic, infrared, color, and infrared-sensitive color, yielded information that was useful to the authors in the interpretive phase of this investigation. The frontispiece in this report is a copy of an uncontrolled mosaic compiled from about 1,000 photographs. The photographs were matched without controlling lineal distances in order to avoid prohibitive expense, but the positions of all features shown on the mosaic are virtually correct. Comparison of the distances between points shown on the Brigham City and Tooele Army Map Service maps, scale 1:250,000, with the distances between the same points on the mosaic, indicate less than 5 percent deviation in scale. On the plane of the page, the deviation is about the same in all directions.

Supplementary information on the physical characteristics of Great Salt Lake were obtained from salt gages and two water-stage recorders, the latter maintained in cooperation with the Utah State Engineer. A set of three salt gages was installed near Rozel Point (fig. 1) to measure variations in the thickness of precipitated salt on the lake bottom and shore. A water-stage recorder was installed at Little Valley Harbor on the west side of the Promontory Mountains (fig. 1) to provide data on the lake level in the northwestern part of Great Salt Lake. Data collected at this site, when compared with data which have been obtained from the recorder at the south end of the lake at the Salt Lake County Boat Harbor since 1938, provides information on differences in lake-surface altitude between the two parts of Great Salt Lake.

DESCRIPTION OF GREAT SALT LAKE

Physical Description

Great Salt Lake, in northern Utah (fig. 2) and in the northeastern part of the Great Basin, is the largest lake in the Western Hemisphere which does not drain to an ocean. In 1965, it covered about 1,000 square miles and had a maximum measured depth of 27 feet. Great Salt Lake is a remnant of Lake Bonneville, a Pleistocene lake which had an area of about 20,000 square miles at its highest stage during late Pleistocene time, and which reached a depth of 1,000 feet before overflowing its basin.

The axis of Great Salt Lake trends northwestward. Mountains that form islands and peninsulas in the lake trend northward and form bays, mainly at the mouths

of tributary valleys. At a stage of 4,194 feet above mean sea level (about the mean stage during 1965-66), the lake was about 70 miles long and from 8 to 24 miles wide. The maximum depth measured during 1965-66 was 27 feet at site 15 (fig. 1), where the altitude of the lakebed is 4,167 feet. This point is midway between Promontory Point and Lakeside. The lake as a whole is saucer-shaped in cross section and has appreciable areas of very shallow water bordered by broad mudflats.

The bottom of Great Salt Lake is covered with oolitic sand, mud and clay, salt crust, and algal reef (Eardley, 1938, p. 1311). Figure 3 is an aerial photograph taken late in 1965 from an altitude of 6,000 feet above the lake surface about 3 miles east of Lakeside. Except for the causeway and the markings at A, all the features shown are under water. The feature at A is wave-generated froth on the surface of the brine. The bottom at B is salt crust that apparently covered most of the lake bottom north of the causeway during the investigation. The bottom at C consists of oolitic sand and at D of algal reefs. The reefs at D are mound shaped, and they extend as such almost to E where they are more elongated and are almost covered with sand.

The stage (lake-surface altitude) and surface area of Great Salt Lake are never constant and change cyclically in response to climatic factors. Because of the gently sloping bottom in the near-shore areas, a relatively small change in stage results in a large change in area and a significant change in volume of brine in the lake. Figure 4 is a graphic compilation of stage-area-volume relations for the period prior to 1957.

The aerial photographs used for the frontispiece were taken when the lake surface was at about 4,194 feet, and the area of the lake, planimetered from the mosaic, was 1,060 square miles. From figure 4, the surface area of the lake at a stage of 4,194 feet is about 1,050 square miles (670,000 acres). Thus the relation shown in figure 4 is fairly accurate for the altitude of 4,194 feet.

Volume relations, however, are not accurate for the period since 1957. The inaccuracies are due largely to changes in the northern part of the lake where precipitated salt seems to have partially filled the lake. Altitudes of the lakebed north of the causeway determined during this investigation differed by more than 5 feet from the altitudes determined from soundings made by the Salt Lake County Yacht Club, Howard Stansbury, and others (Ostermeier, 1947). At two locations the apparent difference is as much as 16 feet, but such large differences may be due to errors in location.

South of the railroad causeway, lakebed altitudes determined during this investigation did not differ more than 3 feet from those reported by Ostermeier (1947). Errors in site location could account for the small differences observed.

The Southern Pacific Co. causeway divides the lake into two different hydrologic environments. The railroad first spanned the lake between Promontory Point and Lakeside in 1903 by means of a trestle between short lengths of causeway extending from each shore. (See frontispiece.) In 1957, a continuous fill was completed that paralleled the trestle.

The two parts of the lake are not entirely independent, because the causeway was constructed of permeable fill and is cut by two culverts. Investigations prior to construction shows that much of the causeway is underlain by a bed of Glauber's salt (mirabilite) ($\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$). The bed (Eardley, 1962, p. 5) begins abruptly 6 miles west of Promontory Point where it is more than 50 feet thick. It thins westward and disappears 8 miles east of Lakeside. During construction, the lake sediments were dredged from atop the Glauber's salt bed and the trench backfilled with sand and gravel. Quarry-run limestone and quartzite from the Promontory and Lakeside Mountains were piled on the gravel to a level above the lake surface. This rock material is estimated to be as much as 150 feet wide at the top of the gravel-filled trench and about 50 feet wide at the top of the causeway. Two culverts were installed with their bases about 15 feet above the natural lake bottom. Each has an opening about 15 feet wide and about 20 feet deep. The permeability of the sand and gravel in the trench probably has been reduced by compaction, by movement of the dredged material into the trench, and by precipitation of salt. The causeway fill and the culverts still allow interchange of brine between the two parts of the lake, although a retarding effect is evident. Data from the two lake-stage recorders, after orthometric adjustment (described in appendix), show that the lake surface on the north side of the causeway generally is about 0.3 foot lower than that on the south side.

Inflow and Evaporation

Great Salt Lake changes volume continuously in response to the difference between the volume of water gained from inflow and the volume of water lost through evaporation.

Inflow is mainly from three surface tributaries, the Bear, Weber, and Jordan Rivers, but some water also enters the lake from springs, small streams, drains, and sewage canals, as precipitation on the lake surface, and as discharge from ground-water aquifers. Accurate measurements are not available for the volumes of inflow derived from precipitation or ground-water aquifers.

The inflow from the Bear, Weber, and Jordan Rivers and those associated canals and drains that enter the lake through the embayments east of Promontory Point and Antelope Island delivers about 1.5 million acre-feet of water during a year of average streamflow, such as 1964. This water contains about 2.0 million tons of dissolved solids (Hahl, 1967). These amounts are about 90 percent of the water and about 75 percent of

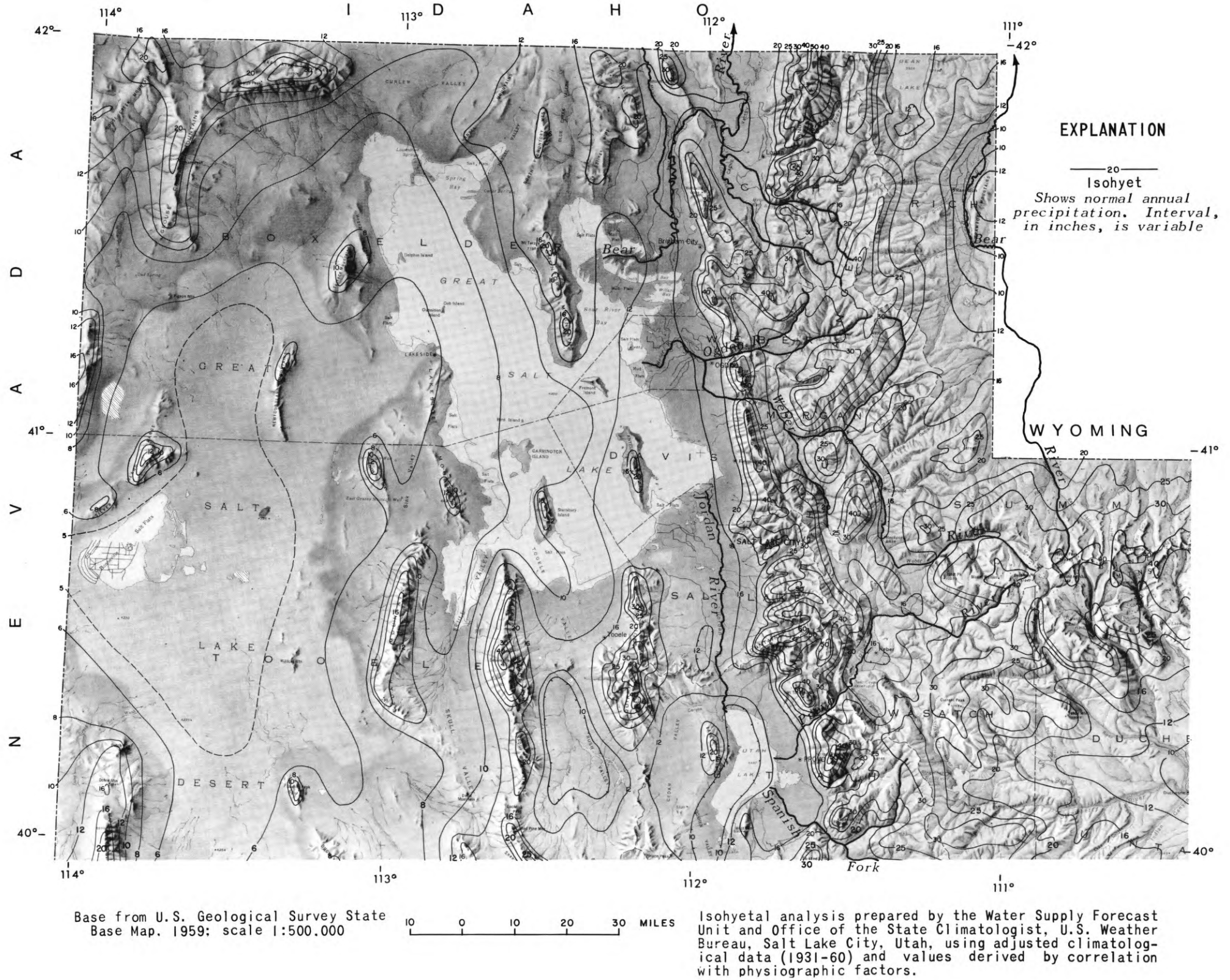


Figure 2. — Location of Great Salt Lake and its major tributaries and isohyetal lines showing distribution of normal annual precipitation, in inches, in northern Utah. (Shoreline of lake shown at altitude 4,200 feet above mean sea level.)



Photograph by Intermountain Aerial Surveys.

EXPLANATION

- | | |
|--------------------------------|---|
| A Froth on lake surface | E Sand partly covering algal reefs |
| B Salt crust | F Solution channel in salt crust |
| C Oolitic sand | G Bottom obscured |
| D Algal reef | |



Figure 3. — Features in a part of Great Salt Lake, 3 miles east of Lakeside.

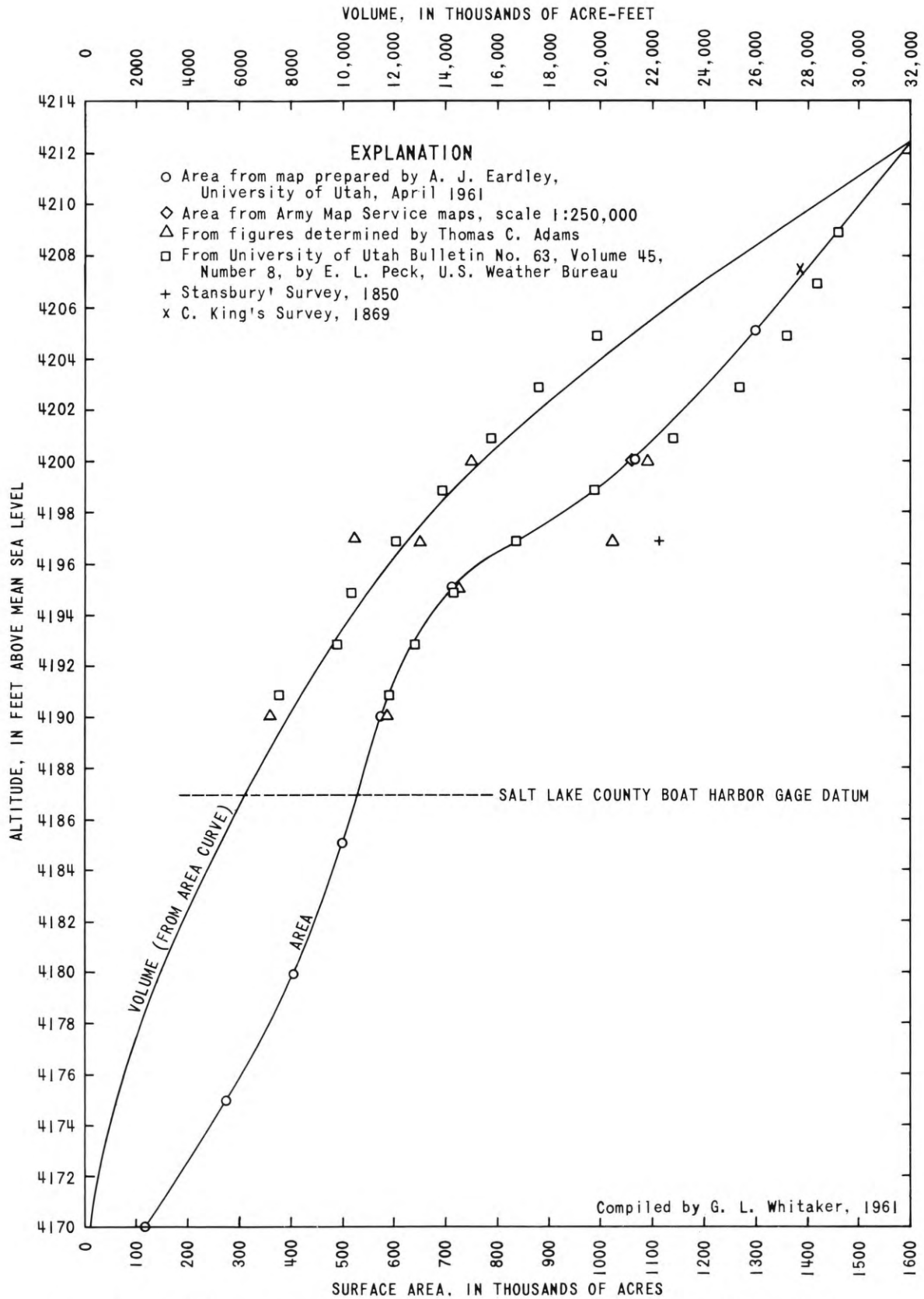


Figure 4. — Relations among surface altitude, surface area, and volume of Great Salt Lake prior to 1957.

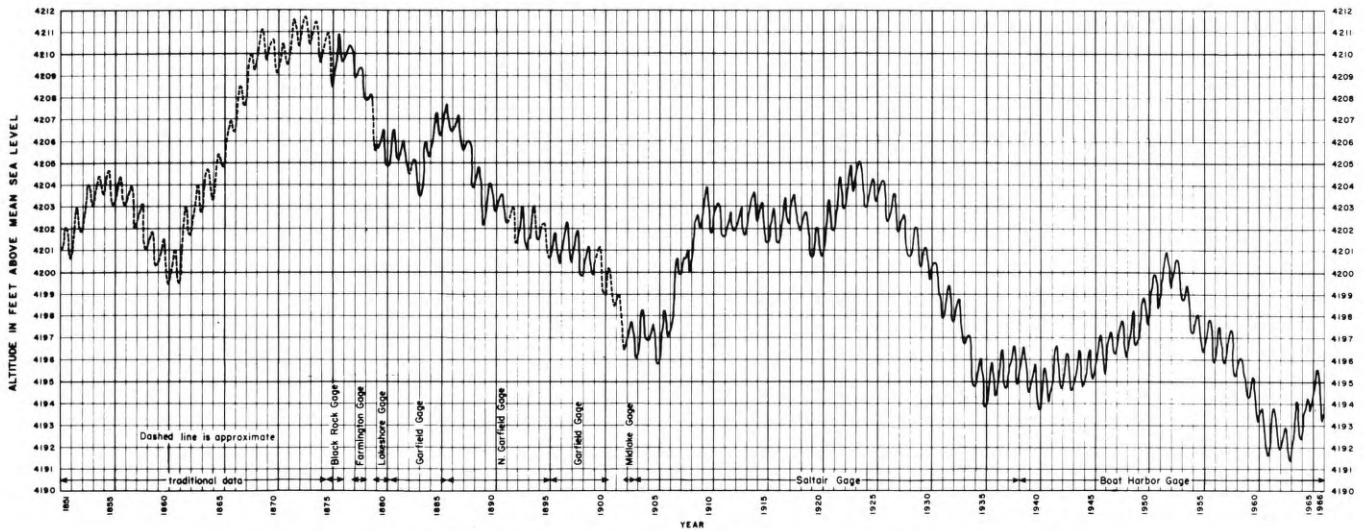


Figure 5. — Fluctuations in surface altitude of Great Salt Lake, 1851-1966.

the dissolved-solids load that enter the lake annually from surficial sources.

Springs, drains, and small streams that discharge into the lake west of Promontory Point and Antelope Island contribute annually the remaining 10 percent of the water and almost 25 percent of the dissolved-solids load from surficial sources.

The volume of water that entered the lake from surficial sources during 1964 was about 17 percent of the volume of brine in the lake, but the dissolved-solids load that entered the lake was less than 0.1 percent of the dissolved-solids content of the brine. Annual inflow thus does not appreciably influence the total amount of salts in solution in the brine but acts mainly as a diluent of the brine. In 1964 spring runoff alone increased the lake stage by about 2 feet and the volume by about 1.5 million acre-feet. (See fig. 7.)

Water leaves the lake primarily by evaporation, and dissolved solids either remain in solution or are precipitated to form lake sediments. Wind action removes some water, dissolved solids, and precipitated solids from the lake, but many of the windborne solids are redeposited within the lake basin and ultimately washed back into the lake.

The three major factors that influence evaporation rates from Great Salt Lake are (1) concentration of dissolved solids in the brine, (2) relative humidity and movement of the air mass over the lake, and (3) temperature of the brine. Other factors being equal, brine with a high concentration of dissolved solids evaporates more slowly than one with lower concentrations. Dry, strong winds carry away more water than calm humid air. For a given concentration, a warm brine evaporates more quickly than a cool one.

The northern part of Great Salt Lake is subject to drying winds (Dickson and McCullom, 1965, p. 17-18); the brine there is saturated and the observed temper-

ature is slightly higher than that in the southern part of the lake. The southern part of the lake, on the other hand, is subject to less drying action from winds, contains brine which generally is not saturated and which, during part of the year, is overlain by a surface layer of fresher water derived from surficial inflow.

Figure 5 shows yearly maximum and minimum surface altitudes of Great Salt Lake for the period 1851-1966. The annual fluctuations result from the constantly varying difference between inflow and evaporation. Periods of low evaporation in winter and high inflow in spring alternate with periods of low inflow and high rates of evaporation in summer and fall. Figure 5 also indicates long-term fluctuations of the lake surface due to variations in climate.

Brine Movement

The brine in Great Salt Lake is in constant motion that is the resultant of several forces: (1) Inertial acceleration of the brine due to the earth's spin (Coriolis effect), (2) inflow, (3) wind, (4) evaporation, and (5) density currents. No detailed study of brine movement was made; qualitative information is available, however, from notes taken by the authors during trips on the lake and from analysis of the chemical data collected during October 1965 and May 1966. The inferred directions of currents are shown in figure 1.

In the Northern Hemisphere, the Coriolis effect produces a counterclockwise circulation in large lakes (Hutchinson, 1957, p. 260-262). In the northern part of Great Salt Lake, eastward movement of brine was observed along the railroad causeway, thus indicating a counterclockwise circulation at the time of observation. South of the causeway, chemical data indicate a westward movement of brine along the causeway. The inferred general counterclockwise circulation is further supported by the location of spits along the edges of the lake. The most prominent of these are west of Carrington Island and east and southeast of Stansbury Island. (See frontispiece.)

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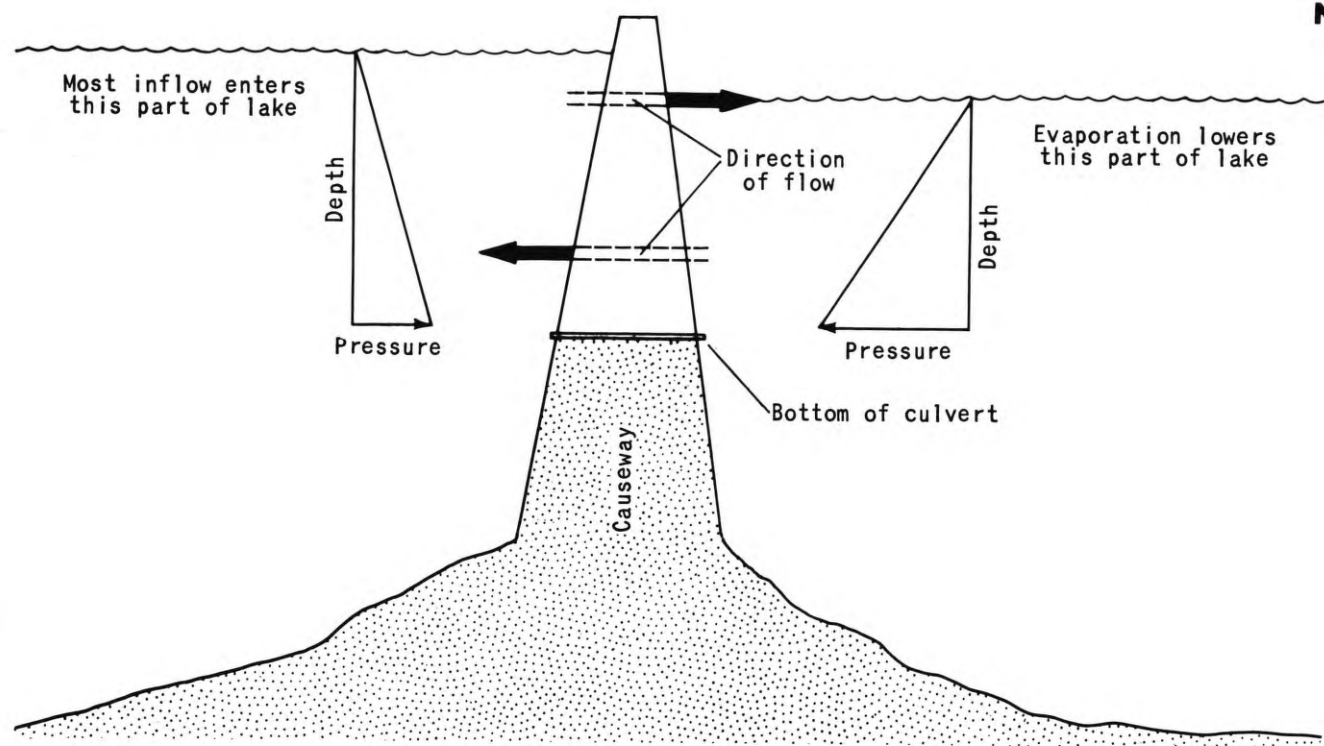


Figure 6. — Diagrammatic cross section of the railroad causeway showing observed directions of brine movement through the culverts.

The Coriolis effect apparently is reinforced by tangential entry of surface inflow south of Promontory Point. Water from the Bear and Weber Rivers is directed toward the west as it flows through the gap between Fremont Island and Promontory Point. The fresh water does not readily mix with the brine, and when sampled during October 1965, there was little evidence of dilution at 5 feet or greater depths at site 13 (fig. 1 and table 7). A surficial layer of diluted brine was traced approximately 27 miles westward toward Lakeside and thence southward along the west shore as far as site 18 near Bird Island.

Superimposed on the general circulation pattern are effects due to the wind. Winds produce wave action and seiches that may temporarily shift or interrupt the direction of shallow currents. Storm winds follow the general alinement of the lake, and the stage of the lake temporarily is affected by wind action which pushes the brine up on the downwind shore. The downwind rise in lake stage averages 1.5 feet above the mean lake stage. With cessation or reversal of the wind, the brine drains back into the lake and causes a small wave (seiche) that surges rhythmically from one end of the lake to the other. The viscosity of the brine damps the seiche. In the undivided lake, prior to 1957, the period of a seiche was about 9 hours; since 1957, the period of a seiche in the southern part of the lake is about 6 hours. Chemical data indicate that the upper 16 feet of the brine usually is well mixed by wave action and seiches, and that mixing extends deeper only during severe storms.

Density currents resulting from evaporation of the brine creates a convection-like movement in the brine. During the generally calm summer, brine in bays and in the large shallow areas of the lake becomes concentrated more rapidly than brine in the open lake. The more concentrated brine in the shallow areas moves downward along the gently sloping bottom to deeper parts of the lake and is replaced by brine from the open lake.

The same type of exchange occurs on a much larger scale between the northern and southern parts of the lake because most of the inflow to the lake enters the southern part, whereas the northern part receives little direct inflow from adjacent uplands.

During the season of maximum inflow, the lake stage south of the causeway rises rapidly, but the stage north of the causeway responds more slowly. The head difference is due to the retarding effect of the causeway, and it results in an observable flow through the causeway fill and culverts from the southern part to the northern part through most of the year. High waves and seiches only occasionally reverse the head difference and thereby reverse the flow. Evaporation in the northern part of the lake concentrates the brines that flow from the southern part, and a part of the concentrated brine returns to the southern part as a density current through the lower parts of the causeway fill and culverts. It is inferred to occur along the entire length of the causeway because the causeway is permeable and flow has been observed through it at the lake surface.

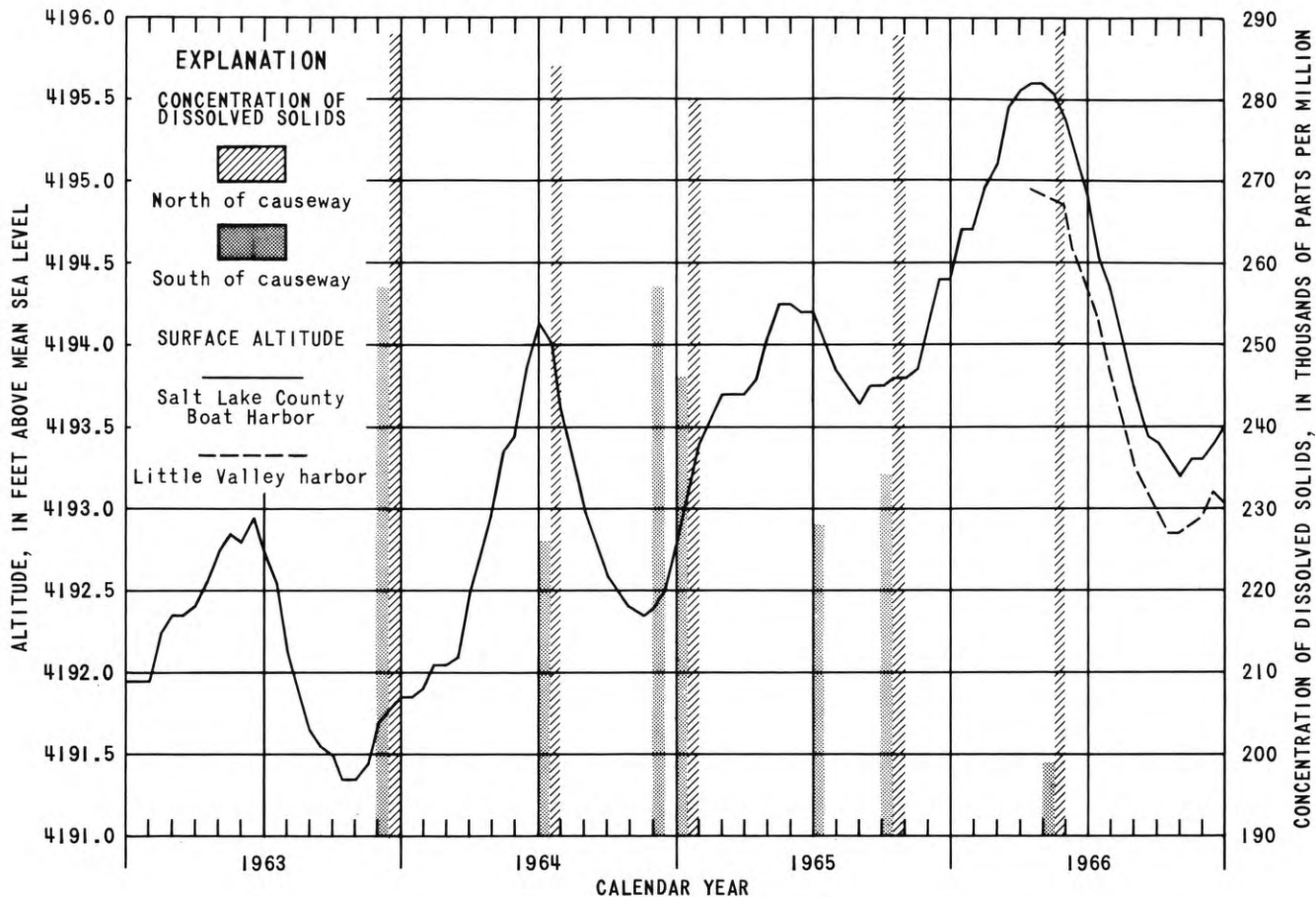


Figure 7. — Surface altitude of Great Salt Lake at Salt Lake County Boat Harbor and at Little Valley Harbor and representative concentrations of dissolved solids of the brine in the shallow zone 0-16 feet below the lake surface, 1963-66.

Thus, the upper few feet of brine move northward through the causeway fill and culverts due to head differences and the lower few feet move southward due to density differences. (See fig. 6.) This two-way flow through the causeway was observed in the culverts during the summer and fall of 1963 and 1964.

CHEMICAL AND PHYSICAL CHARACTERISTICS OF THE BRINE

Chemical Characteristics

General Discussion

The completion of the causeway in 1957 had a profound effect on the chemical characteristics of the lake water. Prior to completion of the causeway, inflow directly affected the entire lake, and the concentration of dissolved solids varied in inverse relation to lake stage. Evaporation caused brine to become saturated in many bays around the lake, and sodium chloride precipitated freely in these bays.

Since completion of the causeway, the northern part of the lake receives little fresh water and evaporation maintains the brine at saturation. By contrast, fresh-

water inflow dilutes the southern part of the lake to such an extent that the brine approaches saturation only during years of low inflow such as 1963. Figure 7 illustrates the difference between variation in lake stage and concentration of dissolved solids in the shallow zone of the two parts of the lake. Throughout the period 1963-66, despite marked changes in lake stage¹, the concentration of dissolved solids in brine in the northern part varied only from about 29 to 28 percent. During the same period, the concentration of dissolved solids in brine in the southern part varied from almost 26 to about 20 percent.

The effect of the causeway on the relation between lake stage and concentration of dissolved solids in the southern part of the lake is further illustrated in figure 8. For a given stage, the concentration of dissolved solids after 1957 has been lower than it was before 1957. For example, at a stage of 4,195 feet the concentration of dissolved solids is about 20 percent (by weight), whereas before 1957 it was almost 30 percent.

1. Although fluctuations of the stage in the northern part have only been observed since April 1966, the record since then, as shown in figure 7, indicates that the stages in the two parts fluctuate in the same general way.

Table 1. — Composition, in percentage (by weight), of the dissolved solids in Great Salt Lake brine, 1850-1966.

Computed from data reported by Richardson (1906, p. 34) for the samples obtained in 1850 and August 1892; by Clarke (1924, p. 157) for the samples obtained in 1869 and October 1913; and by Hahl and Mitchell (1963 p. 38) for the samples obtained in March 1930, April 1960, and November 1961. Data for 1963-66 are averages for all samples obtained at depths of 5 feet below lake surface.

The percentages are the ratio of the concentration of the indicated constituent to the sum of the concentrations for all constituents determined. The percentages for 1850-1892 are not altogether comparable to the percentages for 1913-66 because different combinations of constituents were determined.

Constituent						South of causeway							North of causeway			
	1850	1869	August 1892	October 1913	March 1930	April 1960	November 1961	December 1963	July 1964	July 1965	October 1965	May 1966	December 1963	July 1964	October 1965	May 1966
Silica, SiO ₂	-	-	-	-	-	0.002	0.003	0.001	0.002	0.002	0.002	0.003	0.001	0.004	-	-
Calcium, Ca ⁺⁺	-	0.17	1.05	0.16	0.17	.12	.10	.09	.10	.12	.13	.09	.09	.07	0.08	0.05
Magnesium, Mg ⁺⁺	0.27	2.52	1.23	2.76	2.75	2.91	3.49	3.29	3.32	3.31	3.61	3.80	4.66	4.35	4.52	4.38
Sodium, Na ⁺	38.29	33.15	33.22	33.17	32.90	32.71	31.55	31.02	32.25	32.58	30.90	30.56	29.08	28.58	29.22	29.67
Potassium, K ⁺	-	1.60	1.71	1.66	1.61	1.71	1.95	1.86	2.12	2.06	2.22	2.22	2.75	2.61	2.79	2.61
Lithium, Li ⁺	-	-	-	-	-	-	-	-	.02	.02	.02	.02	-	.02	.02	.02
Bicarbonate as carbonate, CO ₃ ⁼	-	-	-	.09	.05	.06	.07	.07	.08	.09	.09	.10	.09	.09	.09	.09
Sulfate, SO ₄ ⁼	5.57	6.57	6.57	6.68	5.47	6.60	8.21	9.02	7.29	7.67	7.94	7.99	7.28	8.45	9.27	8.58
Chloride, Cl ⁻	55.87	55.99	56.22	55.48	57.05	55.88	54.63	54.64	54.81	54.14	55.08	55.21	56.04	55.81	53.99	54.59
Fluoride, F ⁻	-	-	-	-	-	-	-	-	-	.002	.002	.003	-	-	-	.002
Boron, B	-	-	-	-	-	.01	-	.01	.01	.01	.01	.01	.01	.02	.02	.01
Total percent	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Concentration of dissolved solids, in percentage (by weight) of the brine	22.3	15.0	23.8	20.3	21.0	24.7	26.9	27.3	22.1	22.2	21.4	18.9	27.5	26.9	27.4	26.9

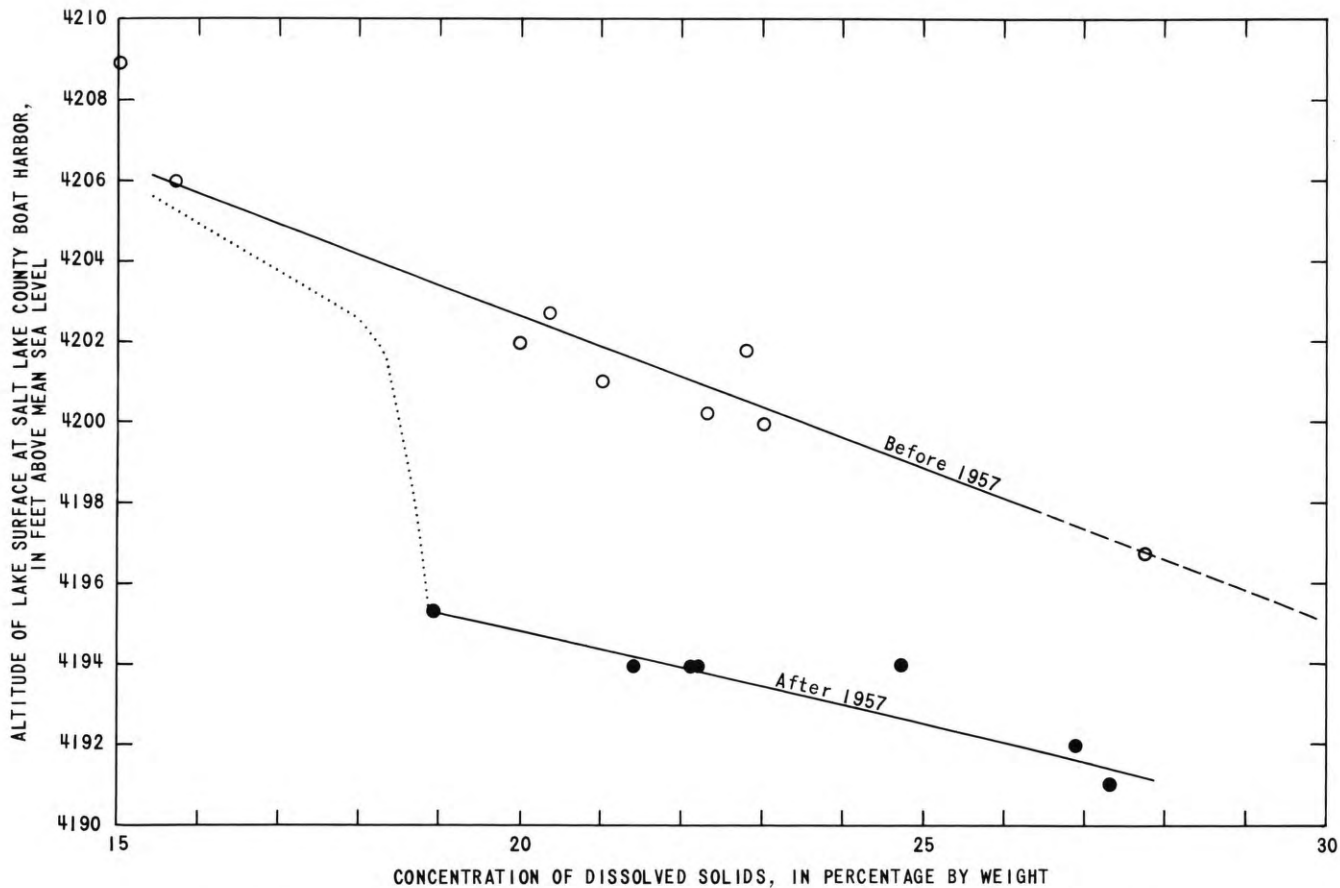


Figure 8. — Relation of concentration of dissolved solids to surface altitude in the southern part of Great Salt Lake before and after completion of the causeway in 1957.

Despite the variations in dissolved-solids concentration of the lake brine, sodium and chloride have since 1850 made up about 88 percent of all dissolved solids. Similarly sulfate made up about 7 percent, magnesium about 3 percent, and potassium about 2 percent of the dissolved solids. Completion of the causeway has, however, resulted in a slight lowering of the percentage of sodium and chloride and an increase in the percentage of magnesium and potassium in the dissolved solids of both parts of the lake.

The slight decrease in the percentage of sodium and chloride in the dissolved solids is probably due to precipitation of salt (sodium chloride) north of the causeway. There, the precipitated salt is in equilibrium with the brine and either accumulates or dissolves as the concentration of dissolved solids in the brine changes. Under climatic conditions existent during the period 1963-66, the brine north of the causeway has remained saturated with respect to sodium and chloride. If the total annual inflow to the lake increases in the future, however, brine containing fewer dissolved solids than now contained in the northwestern part of the lake would enter and some of the salt layer north of the causeway would dissolve. In this event, part of the salt dissolved in the northwestern part of the lake would return to the southern part of the lake, and the relation between lake stage and

concentration of dissolved solids for the southern part of the lake would approach the relation shown in figure 8 for the period before 1957.

Great Salt Lake contained at least four different co-existent brines during the period 1963-66 (fig. 1). The brines were identified on the basis of similarity in chemical characteristics. One type of brine is north of the causeway and the other three are south of it.

Chemical Characteristics North of the Causeway

The brine north of the causeway is well mixed, and the concentration of dissolved solids remains relatively constant from season to season. (See fig. 9.) The chemical characteristics of the brine changed little even though the stage of the lake rose about 4 feet from December 1963 to May 1966 and fluctuated as much as 2.3 feet annually. For example, the mean concentration of dissolved solids for the period was 285,000 ppm (parts per million), and the standard deviation was 7,500 ppm (2.6 percent of the mean). This lack of change may have resulted from an equilibrium that existed between the saturated brine and the salt (principally NaCl) on the lakebed, and equilibrium between inflow and evaporation, or a combination of both.

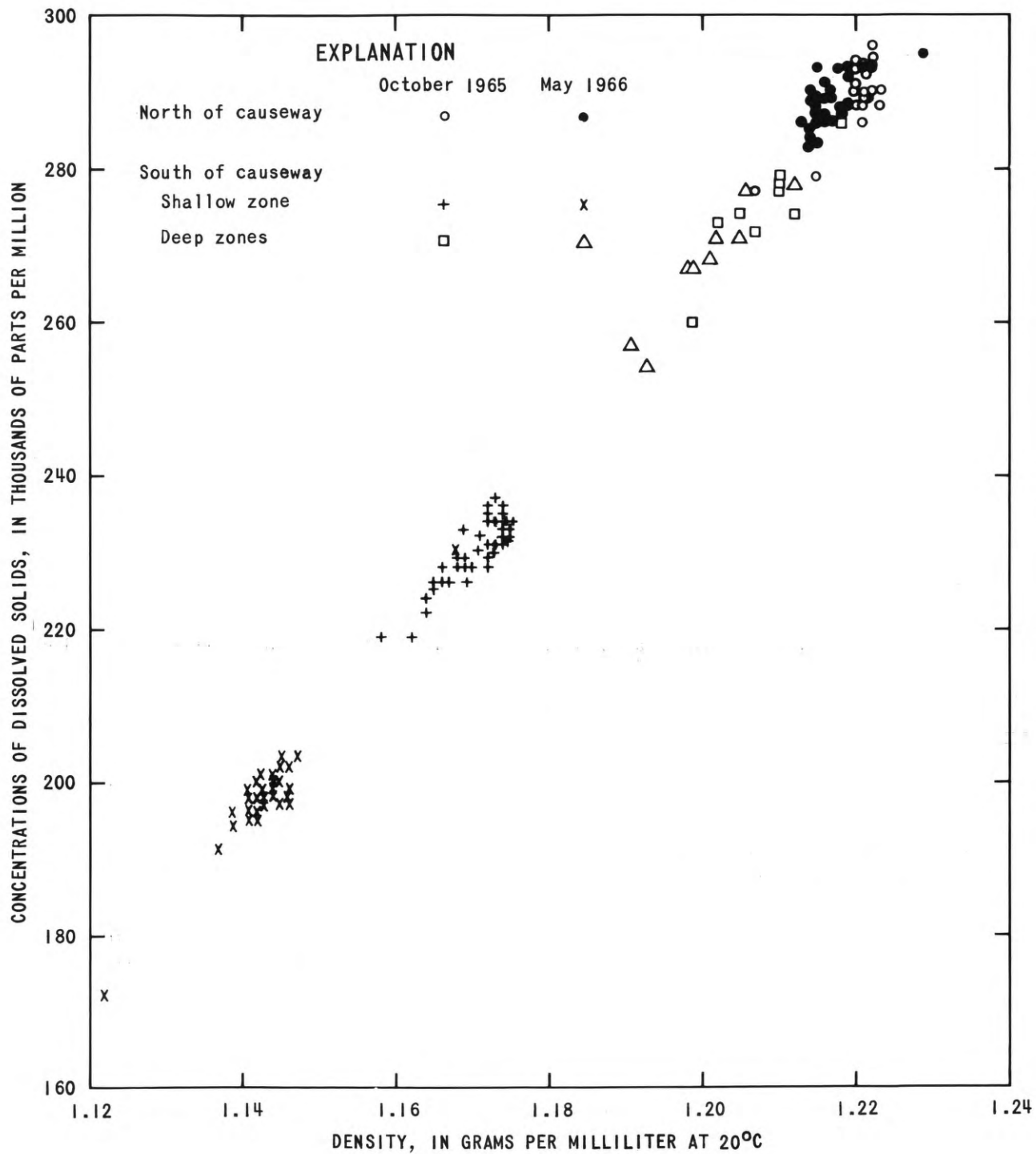


Figure 9. — Seasonal variations of the relation of concentration of dissolved solids to density of the brines of Great Salt Lake.

Table 2. — Analysis of samples obtained on selected dates from site 7 at depth of 5 feet. (Dissolved constituents and dissolved solids in parts per million.)

Item	December 1963 ^{1/}	July 1964	October 1965	May 1966
Temperature (°F)	35	81	62	66
Calcium (Ca)	256	198	213	148
Magnesium (Mg)	12,800	11,700	12,400	11,800
Sodium (Na)	79,900	76,800	80,100	79,900
Potassium (K)	7,570	7,000	7,640	7,040
Lithium (Li)	-	42	62	52
Bicarbonate (HCO ₃)	497	464	513	484
Sulfate (SO ₄)	20,000	22,700	24,400	23,100
Chloride (Cl)	154,000	150,000	148,000	147,000
Boron (B)	29	41	49	37
Dissolved solids	288,000	284,000	288,000	289,000
Density, grams/ml	1.220	1.214	1.221	1.215

^{1/} Sample collected at 1-foot depth.

Analyses for samples from sites 5, 6, and 11 and to a lesser extent from sites 1, 2, and 4 (table 7) show a dilution at the surface from snowmelt in January 1965. A slight dilution at site 10 in May 1966 probably was caused by flow from the southern part of the lake through the causeway and culverts. Sites 9, 10, and 11, near the north side of the causeway, otherwise show little effect of dilution by brine from south of the causeway.

Despite relative uniformity of the concentration of dissolved solids, small differences in space and time occur in the concentrations of individual ions. The differences are indicated in table 2 by the data from a depth of 5 feet at site 7, which site and sampling depth were selected as being representative of the northern part of the lake. The December 1963 sample was collected after a hot, dry period about a month after the lowest lake stage of record (October 1963). These data may be contrasted with the analysis for a sample that was collected in October 1965 after a wet, cool period, but also shortly after the low lake stage during 1965. The July 1964 and May 1966 samples were collected near the peak lake stage for each year. The peak for May 1966 was approximately 1.5 feet higher than the peak for July 1964.

As shown in table 2, magnesium, potassium, dissolved solids, and density values were about the same for all conditions observed. Sodium concentrations remained approximately the same, probably because sodium is involved in the deposition and solution of sodium chloride during one season and Glauber's salt during another season. Chloride concentrations decreased only slightly throughout the period. Sulfate concentrations varied throughout the year because of the annual cycle of precipitation and re-solution of Glauber's salt due mainly to temperature changes. In December 1963, after a period of deposition, the con-

centration was 20,000 ppm; whereas in October 1965, before deposition began, the concentration was 25,400 ppm. The calcium and bicarbonate concentrations also tended to vary. These variations might be explained by the uptake of calcium by algae that live in the lake (Kevern, 1964, p. 1445-1446); and as a result of precipitation of calcium carbonate by algae at times of rapid photosynthesis (Quinn, 1966, p. 31). The variations in the concentrations of lithium and boron and other trace elements are not understood. However, the variations are probably due to combination of a variety of causes such as the biologic environment, the presence of trace ions as colloids, and possible sulfate entrapment due to ion association or sorption. The erratic nature of ionic concentrations can be observed in the analyses of samples from both parts of the lake.

Solid salt (sodium chloride) forms an appreciable part of the minerals in the northern part of Great Salt Lake. During the main evaporation season (June through October) small clusters of salt crystals accumulate on the lake surface and a layer of salt is precipitated on the lake bottom. Near Rozel Point (fig. 1) the precipitated salt is 99.6 percent sodium chloride. (See table 3.)

Table 3. — Analysis of the salt crust sampled near Rozel Point, 1964.

Constituent	Composition (percentage by weight)
Calcium (Ca)	0.0
Magnesium (Mg)	.0
Sodium (Na)	39.9
Potassium (K)	.1
Sulfate (SO ₄)	.3
Chloride (Cl)	59.7
	100.0

Observations that began in 1963 indicate that a permanent salt crust of undetermined thickness probably covers most of the northern lake bottom. A residual crust was found on the part of the lakeshore that annually is inundated. Near Rozel Point, the crust on the shore was about 1 mile wide and gradually thickened lakeward to about 8 inches at the brine's edge.

Rain in the spring of 1964 dissolved almost half of the crust on the shore and left well-defined drainage patterns in the remaining crust. (See F in fig. 3.) During the summer of 1965 only a few hundred feet of crust bordered the lake, except at the northernmost extremity which had no residual salt crust at all.

Three salt-accumulation gages were installed near Rozel Point during July 1964. The gages were constructed over the salt crust at the following locations:

(1) At the beach formed by the lowest recorded lake stage, (2) just lakeward from the high-water mark of 1964, and (3) landward from the high-water mark of 1964. Table 4 indicates the salt accumulation or loss at these gages. The method of construction of the salt gages is described in the appendix.

Table 4. — Salt accumulation or loss near Rozel Point, 1964-66.

Time period	Accumulation (+) or loss (-) (inches)		
	Gage 1	Gage 2	Gage 3
July 17, 1964 - Oct. 15, 1964	+3.5	+0.5	-0.8
Oct. 15, 1964 - July 1965	-4.5	+ .5	- .2
July 1965 - Oct. 6, 1965	+1.3	+ .8	-1.0
Oct. 6, 1965 - May 25, 1966	(1/)	-7.3	-2.2

1/ Gage destroyed by storm.

At gage 1, salt was deposited during the July to October periods and redissolved during the October to July period. Most of the salt crust probably was deposited as a result of evaporation and removed as a result of the inflow of slightly fresher brine from the southern part of the lake. At gage 2, salt accumulated uniformly from July 1964 to October 1965 but was redissolved rapidly from October 1965 to May 1966. This gage was under water each spring and early summer, and each successive period of evaporation during the summer and early fall lowered the lake stage below the gage and left a new layer of salt at the gage. During the winter and spring of 1965-66, however, rapid inflow of brine inundated the gage and dissolved the salt crust. At gage 3, salt dissolved at varying rates for the entire period from July 1964 to May 1966. This gage was above the water until May 1966. The solution of salt crust at this gage probably was dependent only on the amount of rainfall in the area until the gage was inundated during the spring of 1966.

Chemical Characteristics South of the Causeway

The brine south of the causeway is not well mixed except during the short periods immediately following severe regional storms. During most of the year the brine is stratified, and the near-surface zone is the least uniform from one season to the next. (See fig. 9.) The main cause of variation in the concentration of dissolved solids in the brine is dilution by seasonal surface inflow.

To contrast the nonuniformity of the brine in the southern part of the lake with the uniformity of that in the northern part, the mean and the standard deviations

Table 5. — Mean and standard deviation in the concentrations of dissolved solids in different parts of the lake. (Based on data collected during October 1965 and May 1966.)

	Northern part	Entire southern part	Southern part 0-16 ft.	Southern part below 16 ft.
Mean (\bar{x})	285,000	231,000	228,000	268,000
Standard deviation (s)	7,500	85,100	22,000	15,000
s as a percent- age variation from \bar{x}	2.6	36.8	9.7	5.6

in concentrations of dissolved solids in the two parts of the lake are calculated. (See table 5.) If the concentrations of dissolved solids in the southern part of the lake as a whole are used, the standard deviation indicates a nonuniform mass with deviations of almost 37 percent from the mean. If the same data are divided into groups representing shallow (brine from the surface to a depth of 16 feet) and deep (brine below 16 feet) zones, the deviation is reduced to less than 10 percent. The random effects indicated by the 9.7 percent deviation in data from the shallow zone results mainly from the fluctuation of concentration caused by seasonal inflow. The deviation of 5.6 percent in data from the deep zone is more nearly comparable to the 2.6 percent deviation in data from north of the causeway, but the greater deviation suggests that even the deep zone south of the causeway is diluted by surface inflow.

The Shallow Zone

The chemical characteristics of brine in the shallow zone (from the surface to a depth of 16 feet) appear to be uniform even though the concentration of dissolved solids varies slightly with depth and somewhat more from season to season. The variation with depth is due to the lag in the mixing of surface inflow with brine. Fresher water tends to override the brine rather than mixing with it. The variation with time is due to the difference in volume of inflow from year to year, to the relative sequence of periods of cyclic inflow and evaporation, and to the precipitation of Glauber's salt during the winter.

The concentrations of dissolved solids in samples collected at site 15 (fig. 1) at a depth of 5 feet approximate the average concentration of dissolved solids found in the shallow zone. (See fig. 10.) Consequently, as a means of convenience, data from site 15 at a depth of 5 feet are used as the basis for the following discussion of the chemical characteristics of the shallow zone.

Data collected at site 15 during the period December 1963-May 1966 are shown in table 6. The December 1963 data represent the effect on the brine of a series of dry years, whereas the October 1965 data represent

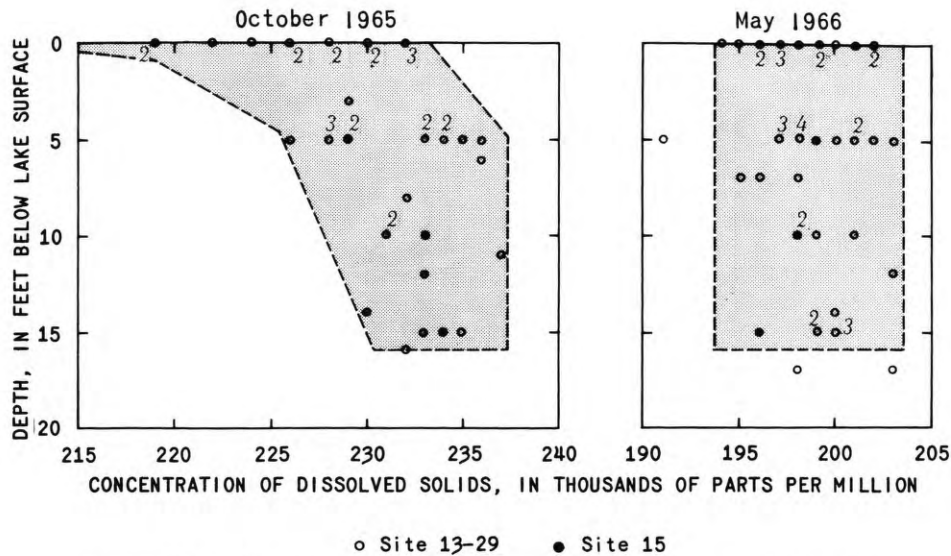


Figure 10. — Concentrations of dissolved solids in brine in the shallow zone in the southern part of Great Salt Lake. Number data point indicates the number of analyses represented.

the effect of 2 years of increased inflow. The concentration of each ion except calcium and bicarbonate during December 1963 is significantly greater than the concentration of that ion during October 1965. The July 1964, July 1965, and May 1966 data represent peak lake stages for the respective years. The amount of inflow to the lake in 1964 and 1965 was about the same and resulted in ionic concentrations of about equal magnitude. The May 1966 data show the effect of greatly increased inflow on concentration; the ionic concentrations, except bicarbonate and fluoride, are significantly less than those during July of the previous 2 years. The variation in ionic concentrations, as shown in table 6, demonstrates the effect of inflow on the concentrations and indicates that the lake south of the causeway is not at saturation with respect to sodium chloride and has rarely approached saturation since 1957. The concentrations of calcium, bicarbonate, lithium, boron, and the trace ions probably are affected by the biologic environment and other factors such as they are north of the causeway.

The Deep Zone

Brine in the deep zone (below 16 feet) has a higher concentration of dissolved solids than the brine in the shallow zone throughout the southern part of the lake. Two distinct brines coexist within the deep zone in the southern part of the lake; one is near the causeway and one is in the southern part of the lake. These brines are derived from two sources, each of which yields a distinct brine with chemical characteristics different from each other. The two brines apparently merge in the center of the southern part near site 22 (fig. 1) where data from a depth of 23 feet indicate some mixing between the two deep layers.

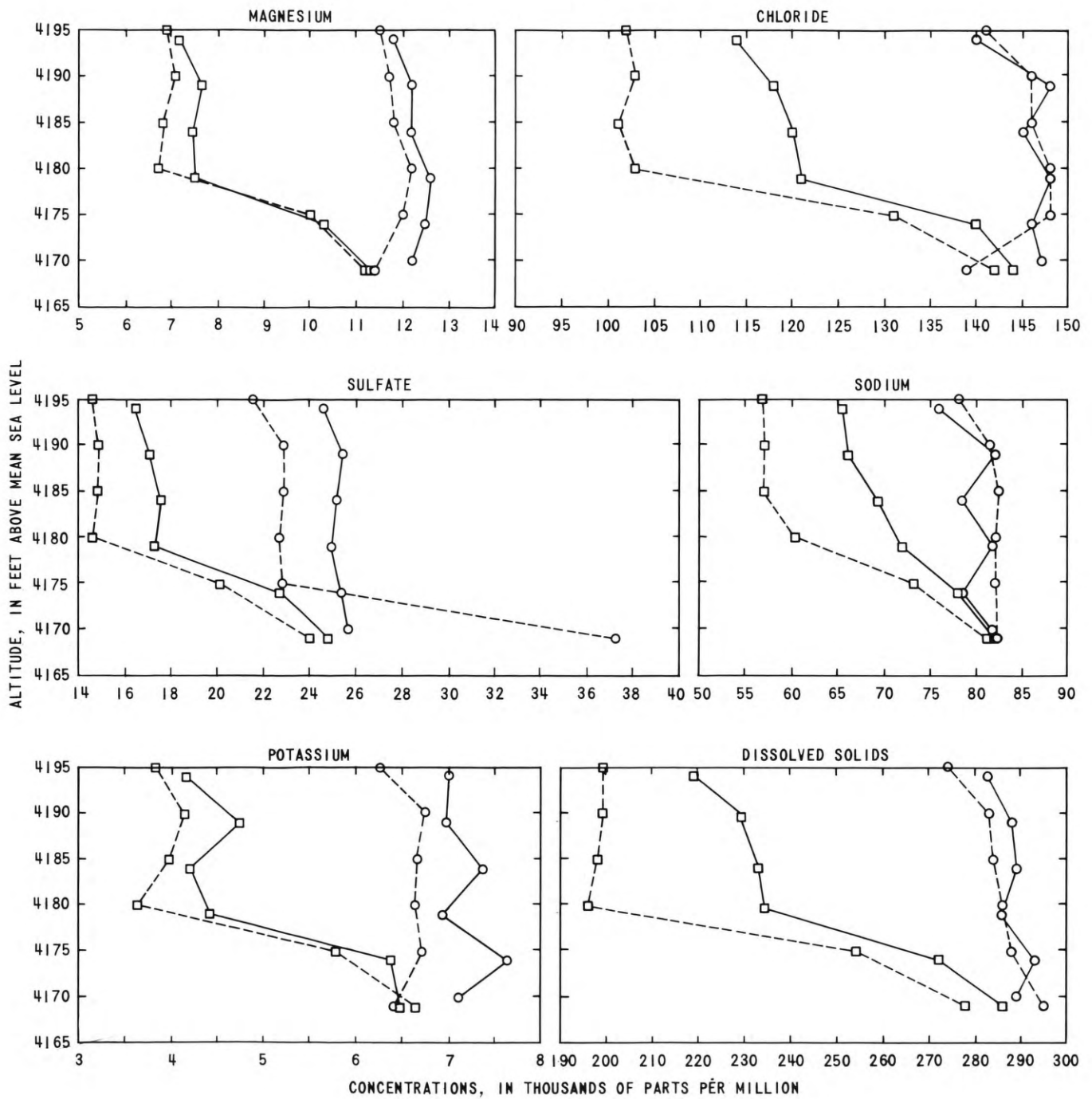
Near the causeway, the brine below 16 feet is derived from the northern part of the lake. Figure 11 compares

the variations of concentrations of dissolved solids and constituent ions with depth at maximum and minimum lake stages during the 1966 water year at sites north and south of the causeway. The figure shows that for all the chemical parameters, the brine in the deep zone at site 15, south of the causeway, is similar to the brine at site 10, north of the causeway. This relation, together with the known southward flow of brine through the causeway, demonstrates the source of the brine in the deep zone near the causeway. The zone of mixing between the brine in the shallow zone and the brine in the deep zone is represented in figure 11 by the sloping curve below a depth of 15 feet (4,180 feet above msl) at site 15.

Table 6. — Analyses of samples obtained on selected dates from site 15 at a depth of 5 feet. (Dissolved constituents and dissolved solids in parts per million.)

Constituent	December 1963 ^{1/}	July 1964	July 1965	October 1965	May 1966
Temperature (°F)	49	81	77	61	64
Calcium (Ca)	255	224	264	274	176
Magnesium (Mg)	8,960	7,340	7,340	7,740	7,080
Sodium (Na)	84,600	71,200	72,200	66,200	57,000
Potassium (K)	5,080	4,690	4,570	4,750	4,140
Lithium (Li)	-	37	35	36	33
Bicarbonate (HCO ₃)	395	369	384	392	389
Sulfate (SO ₄)	24,600	16,100	17,000	17,000	14,900
Chloride (Cl)	149,000	121,000	120,000	118,000	103,000
Boron (B)	39	22	23	24	16
Dissolved Solids	257,000	226,000	228,000	229,000	199,000
Density, grams/ml	1.196	1.165	1.168	1.169	1.141

^{1/} Depth not determined but in the vicinity of 5 feet.



□ Site 15 ○ Site 10 ——— October 1965 - - - - May 1966

Figure 11. — Variations with depth of concentrations of dissolved solids and constituent ions at high and low lake stages during the 1966 water year at sites 10 and 15.

A different deep brine was identified in the south end of Great Salt Lake. The brine below 16 feet at site 28 is representative of the deep brine there; and figure 12 compares concentrations of dissolved solids and constituent ions for sites 15, 25, and 28. Data from site 25 are used to supplement those at site 28, because the characteristic brine of the deep zone did not exist at site 28 during both sampling periods. The data in figure 12 indicate that although the concentration of dissolved solids and constituent ions at sites 15 and 28 vary in a generally similar manner according to depth and season, significant differences of concentrations exist between the two sites.

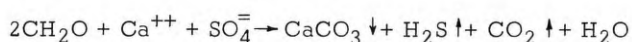
The two deep brines also may be differentiated by plotting ionic concentrations against density (Handy, 1967). Figures 13 and 14A show that the relation of sodium, chloride, lithium, and magnesium to density in the brine in the deep zone in the southern part of the lake is different from those relations for brine in the rest of Great Salt Lake. Only data for October 1965 were used in figures 13 and 14A. Figure 14B shows the lithium-density relation using data for all sampling dates during the investigation. Relations shift, owing to the effect of dilution, and the resulting scatter of points obscures any otherwise obvious differences. Thus, types of brine are best distinguished with this method by using data collected during a short period of time.

The source of the brine in the deep zone in the south end of the lake is not known. However, only three sources of constituent ions apparently are available for the generation of this brine--one is the shallow zone in the lake, another is the sediments that form the lakebed, and the third is ground water that discharges upward through the bed of the lake.

The brine in the shallow zone alone cannot be the source of the brine in the deep zone. Brine from the shallow zone, after concentration by evaporation would be similar in chemical character to the brine in the deep zone south of the causeway at site 15. It would not be enriched in sodium ions and depleted in sulfate ions as is the brine in the deep zone in the southern part of the lake.

The other two possible sources--the lake sediment and ground water--may interact to form the brine in the deep zone. The mechanism for the occurrence of this deep brine is not understood, but probably is related to the following factors: (1) The Oquirrh Mountains, which adjoin the south end of Great Salt Lake, in part receive more than 40 inches of precipitation annually, but relatively little water runs off in surface streams (W. V. Iorns, oral commun., 1965). The rocks in the Oquirrh Mountains are intensely faulted and fractured, thus providing ample opportunity for subsurface drainage. Wells tapping gravel deposits at the north end of the mountains have yields exceeding 3,000 gpm (gallons per minute), and some of the wells have specific capacities exceeding 100 gpm per foot of drawdown (Marine and Price, 1963, p. 14). It is suggested, therefore, that appreciable quantities of

ground water move from the rocks of the Oquirrh Mountains toward the lake through unconsolidated aquifers at the north end of the mountains. (2) Much of the water pumped from wells at the north end of the Oquirrh Mountains contains several thousand parts per million of sodium and chloride ions in solution but less than 250 ppm of sulfate ions (Marine and Price, 1963, p. 27). (3) Beds of Glauber's salt ($\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$) have been found beneath lake deposits along the south shore of the lake (Cohenour, 1966, p. 155). If beds of Glauber's salt also underlie the lake, the ground water moving through these beds would gain large quantities of sodium and sulfate ions. (4) Fetid lake sediments beneath the lake bottom provide a highly reducing, saline environment that favors decay reactions such as:



The authors believe that the origin and mechanism of formation of the deep south-end brine is an important area of study. The many chemical reactions that could take place, the possibility that a large volume of ground water may be involved, and the possibility that interstitial brine may be recirculating provide the necessary interest to initiate studies of the mechanisms which seem to be important to the hydrology of the land and to the utilization of the resources contained therein.

Physical Characteristics

Temperature

Observations of the temperature of the brine in Great Salt Lake can be summarized as follows: The temperature of brine 5 feet below the surface of the lake is 1-14 degrees (F) greater than the monthly average air temperature at Brigham City for the month preceding that in which samples were collected (U. S. Weather Bur., 1964, 1965a, and 1966). During the period 1951-60, the highest monthly average maximum temperature at Brigham City was 96.4° F during July 1960, and the lowest monthly average maximum temperature was 29.0° F during January 1955 (U. S. Weather Bur., 1965b). The recorded temperatures of brine at the bottom of the lake were as much as 20 degrees cooler than the temperatures at 5 feet during July 1964 and July 1965. As winter approached, the brine near the surface cooled more rapidly than the brine near the bottom. During October 1965, the temperatures of the brine near the bottom at some sites were as much as 10 degrees warmer than the temperatures of the brine near the lake surface. During winter, however, storms and temperature inversion appeared to mix the brine sufficiently to produce relatively uniform vertical temperatures.

As the brine cools in the winter, Glauber's salt (sodium sulfate) precipitates on the lake bottom and along the shore. Precipitation is more pronounced as the concentration of dissolved solids of the brine increases. The solubility of Glauber's salt decreases about tenfold with a temperature change from 90° to

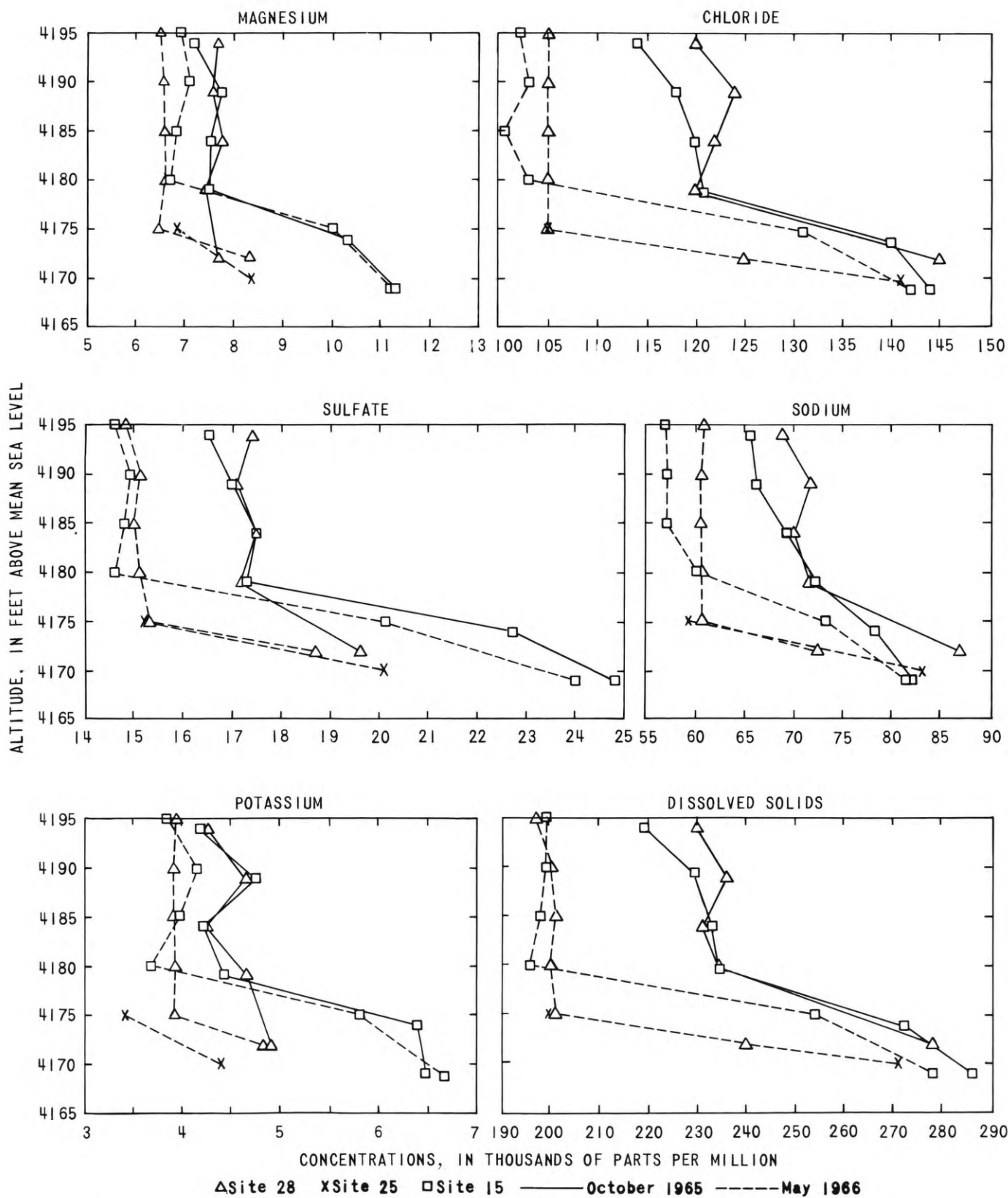


Figure 12. — Variations with depth in concentrations of dissolved solids and constituent ions at high and low lake stages during the 1966 water year at sites 15, 25, and 28.

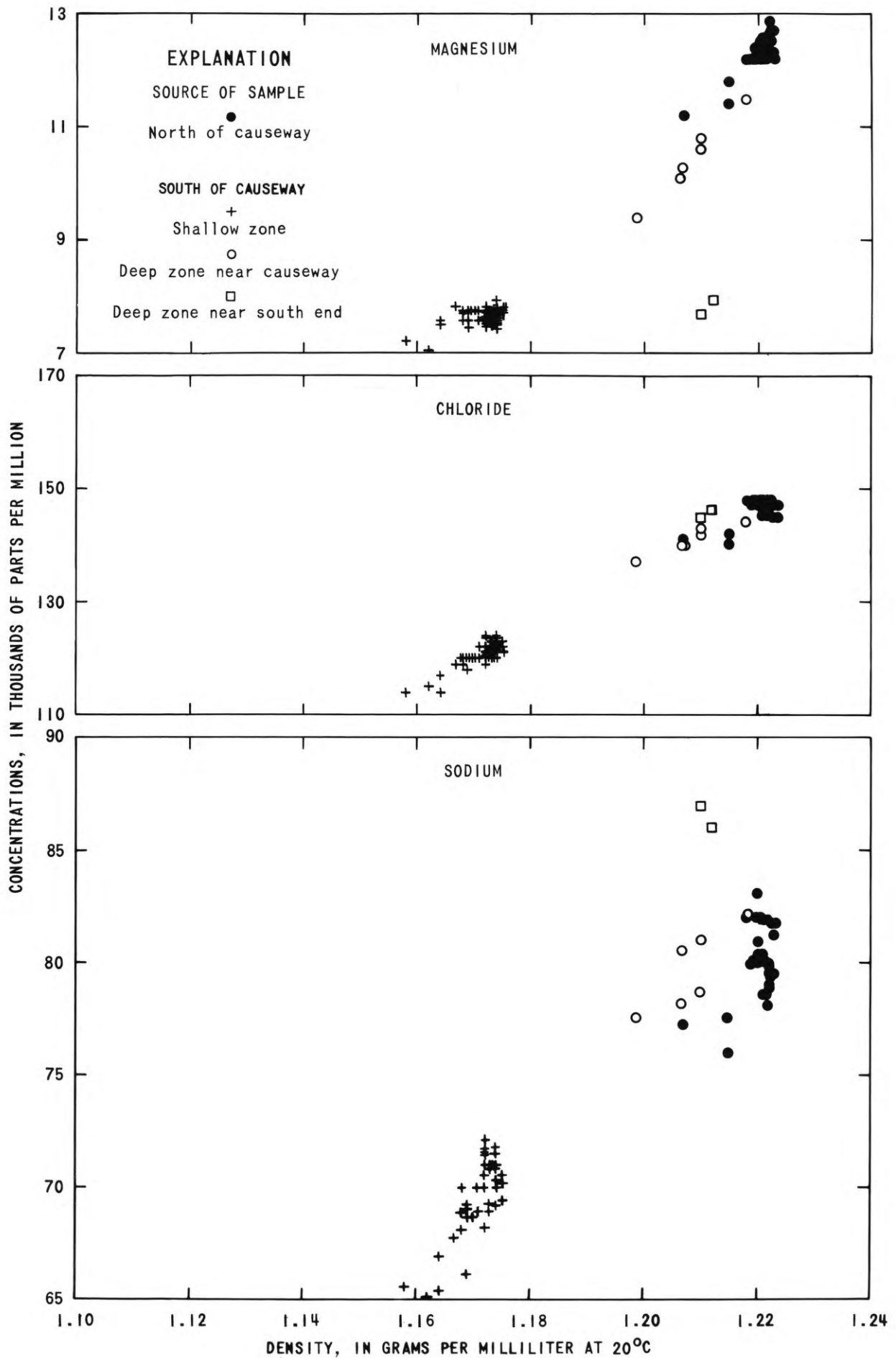


Figure 13. — Relation of concentrations of magnesium, chloride, and sodium to density of the brine, October 1965.

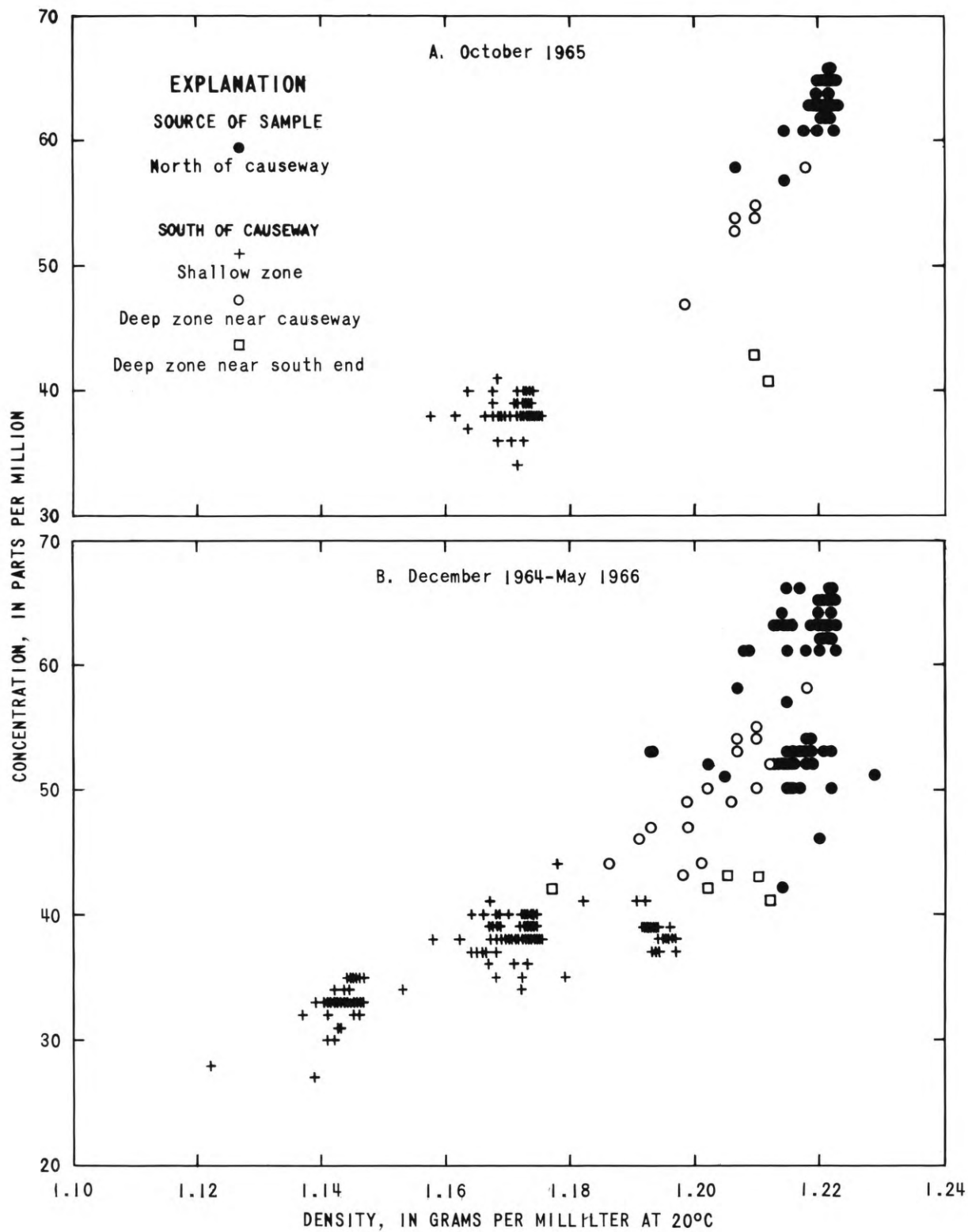


Figure 14. — Relation of lithium concentration to density of the brine, October 1965 and December 1964-May 1966.

20° F. The resulting crystals of Glauber's salt that form along the shores are rolled into rectangular and cylindrical pellets by wave action and are deposited in a white reef a few yards offshore. During January 1964, the reef was from 30 to 50 feet wide and about 3 feet thick and almost encircled the northern arm of the lake. The precipitation of Glauber's salt resulted in the decreased concentrations of sulfate and sodium ions noted in the analyses of samples obtained in January 1965. The reef is redissolved in the spring as the lake warms and rains fall.

Visual Characteristics

Brine in the northern part of Great Salt Lake is red-dish-brown. The color is apparently due to algae (Quinn, 1966, p. 30), which abound in the saturated brine. These algae seem so numerous that visibility through the brine is limited to about 2 feet. The red-dish-brown color also appears during late summer in the shallow areas of the southern part of the lake when the concentration approaches saturation.

Brine in the southern part of the lake is green. However, the intensity of the green does not affect visibility through the brine. Brine shrimp and detrital material or weather conditions may reduce visibility to as little as 5 feet locally; but bottom features that are 10-15 feet below the surface generally are clearly discernible.

Figure 3 illustrates the difference in clarity between the two parts of the lake. The algal reefs and sand on the bottom are clearly visible through 4 feet of brine at E, south of the causeway, while the salt crust cannot be seen through 3 feet of brine at G, north of the causeway.

During the winter, visibility through the brine on both sides of the causeway is poor, due in part to minute particles of precipitated sodium sulfate.

CONCLUSIONS

Great Salt Lake is not a homogeneous body of brine. In the undivided lake, prior to 1957, the entire lake was directly diluted by inflow during the spring and subsequently concentrated by evaporation during the summer and fall. Based on the data from this investigation, it is inferred that parts of the undivided lake contained brines of different densities. During the main evaporation period, salt was precipitated in most of the shallow bays around the edges of the lake. Density currents would have moved saturated brine from the bays toward deeper parts of the lake. The mixing effects of other currents and winds would have maintained a shallow well-mixed zone in the open lake.

The construction of a railroad causeway across Great Salt Lake in 1957 radically changed the hydrology and the chemical environment of the lake. Although the causeway does not prevent interchange of brine between the northern and southern parts of the lake that

it created, the causeway does retard interchange to the extent that brine in the northern part remained saturated during 1963-66. The southern part of the lake was more dilute than at comparable lake stages prior to causeway construction.

The interchange of brine through the causeway only slightly affects the brine in the northern part of the lake by local seasonal dilution. The northward inflow of dilute brine and the southward outflow of concentrated brine, however, controls the thickness of the salt crust in the northern part. If the causeway were not permeable, the crust would continually accumulate, and the northern part of the lake would continually diminish as an effective brine storage area. The relations among inflow, outflow, and crust thickness in the northern part of the lake are important factors in the chemical hydrology of the lake as a whole and need additional study. Such study would provide valuable information for future lake management.

The interchange of brine through the causeway directly affects the chemical character of the southern part of the lake. Concentrated brine from the northern part is the source of one of the three types of brine identified in the southern part. A concentrated brine in the deep zone in the southern end of the lake may result from ground water discharging upward through the bottom of the lake. The character of the brine in the deep zone in the southern part of the lake and the mode of generation require further, more precise study, because future manipulation of Great Salt Lake as a source of minerals and for recreation will be affected by the area in which the brine is generated.

The studies during 1963-66 incidentally demonstrated the intricate interrelation and effects of wind, inflow, and lake currents on both mixing and distribution of the brines in the southern part of Great Salt Lake. Studies specifically designed to describe the mutual relations are needed.

The conclusions reached in this report are based on data collected during a period when the lake fluctuated through a range of about 4½ feet. Monitoring of variations in lake chemistry are needed during different lake stages to verify the conclusions drawn.

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APPENDIX

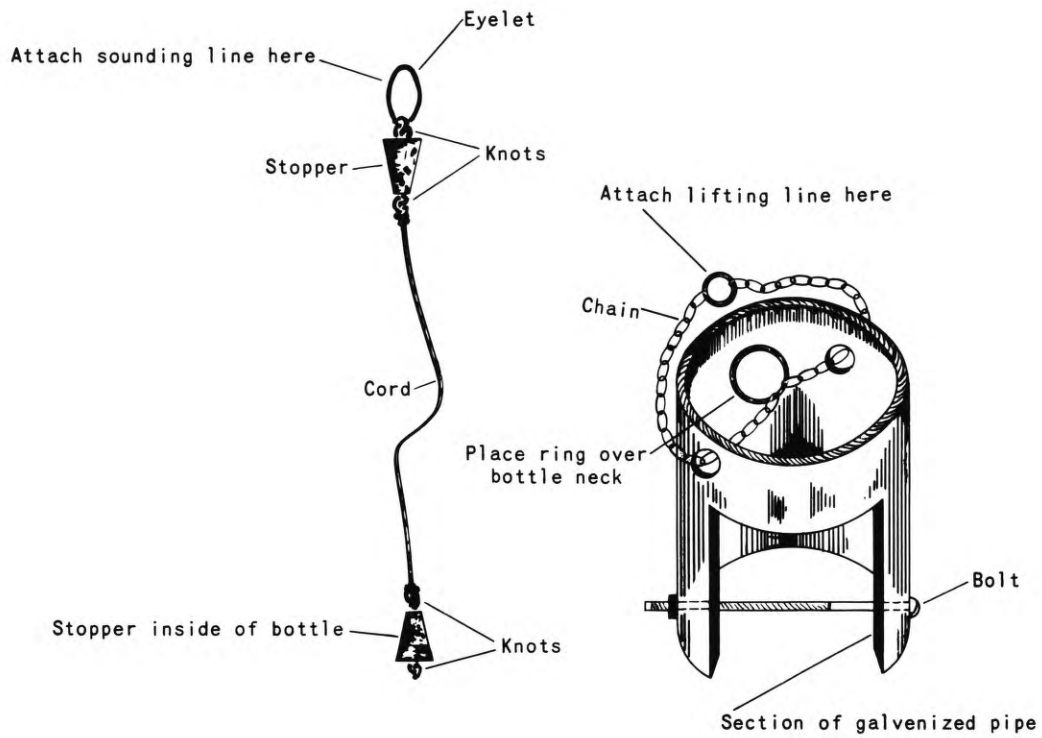


Figure 15. — Sampler.

APPENDIX

SAMPLING EQUIPMENT

The sampler consisted of a 2-liter polyethylene bottle fitted with two stoppers that were placed so that the bottoms of the stoppers were facing. The stoppers were attached with a cord as shown in figure 15. An eyelet was made from the cord at one stopper. The stopper with the eyelet was selected to fit the bottle securely; the other stopper was one size smaller. The smaller stopper was forced into the bottle. A sounding line attached to the eyelet indicated the depth of the bottle mouth and served as the bottle opener and closer. Thus, the bottle could be lowered and raised and a sample taken at the desired depth. The bottle was placed inside a close-fitting, short section of pipe closed at the bottom with a thin bolt. Two holes were drilled in the top of the pipe and fitted with a chain in which were placed two metal rings. One ring kept the bottle in place, the other ring was used for attaching the hoisting line.

ORTHOMETRIC ADJUSTMENT

At any latitude north or south of the equator, the surface of a free body of water at any altitude above sea

level does not lie parallel to mean sea level in a north-south direction, but rather is distorted and conforms to the resultant of gravitational and centrifugal forces. Water surfaces above sea level converge toward sea level as they approach the poles. Therefore, to project orthometrically a lake-surface altitude from the south end of Great Salt Lake north to the causeway, the altitude must be reduced by 0.19 foot. The correction is taken from a nomogram in topographic instructions issued by the U.S. Geological Survey (written commun., 1956).

SALT GAGE

Measurement of the position of the surface of the salt crust was made from a reference constructed as shown in figure 16. Before each measurement was made, the wire was leveled to determine if the post had heaved. No heaving was observed. The plumb bob was then lowered from one of the sinkers on the line to determine the distance from the line to the surface of the salt crust.

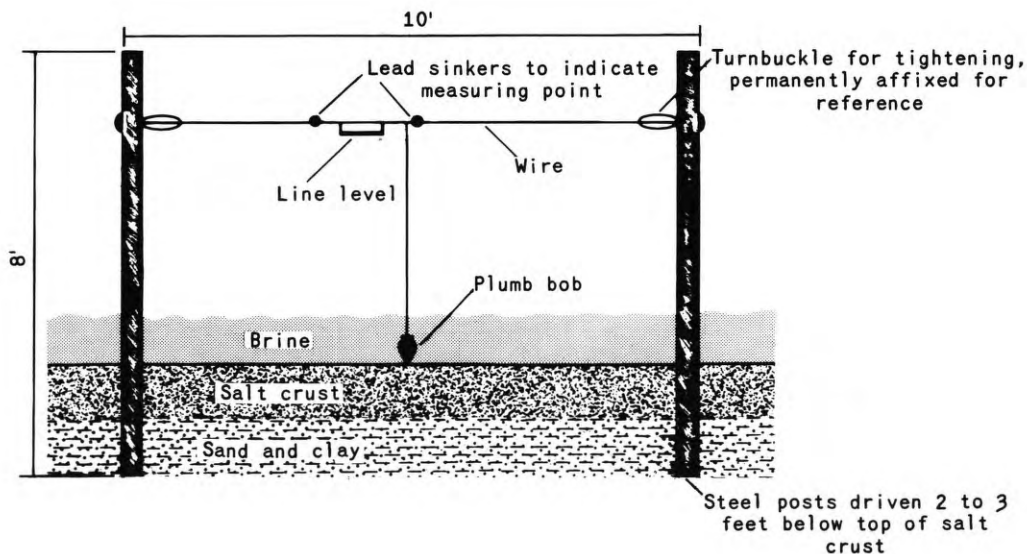


Figure 16. — Construction of salt gage.

Table 7. — Chemical analyses of brine from Great Salt Lake.

Altitude of water surface: Left blank if data not available to compute an accurate altitude.
 Depth: N, depth not obtained; S, sample taken less than 6 inches below the surface; T, samples were depth integrated over total depth. All other depths indicated are ±0.5 foot.

Sampling site	Date of collection	Altitude of water surface (feet)	Depth (feet)	Temperature (°F)	Parts per million													Dissolved solids (Residue at 180°C)	Hardness as CaCO ₃	Density (gms/ml at 20°C)	pH
					Silica (SiO ₂)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Lithium (Li)	Bicarbonate (HCO ₃)	Sulfate (SO ₄)	Chloride (Cl)	Fluoride (F)	Boron (B)						
1	1-27-65		T	34	3.5	232	12,400	76,100	7,010	61	505	16,600	149,000	5.3	47	273,000	51,400	1.209	7.6		
	10-6-65		S	64	3.8	262	12,700	81,400	7,070	65	523	25,700	145,000	5.9	40	288,000	52,700	1.223	7.6		
	10-6-65		S	66	4.2	213	12,600	80,100	7,180	65	521	25,900	147,000	6.0	40	292,000	52,400	1.221	7.6		
	5-25-66	4,194.7	S	69	-	197	11,700	81,800	7,070	53	494	22,900	148,000	6.9	43	293,000	48,500	1.222	7.6		
	5-25-66	4,194.7	S	65	-	164	11,800	82,900	7,070	53	493	23,000	148,000	9.1	42	293,000	48,900	1.221	7.6		
2	1-27-65		T	34	2.7	199	12,500	73,900	7,210	61	505	17,700	151,000	5.7	46	276,000	52,000	1.208	7.7		
	10-6-65		S	64	-	279	12,500	78,100	7,450	64	506	25,400	145,000	-	45	290,000	52,000	1.222	7.6		
	10-6-65		S	62	-	230	12,400	80,000	7,630	64	516	25,200	148,000	-	48	293,000	51,600	1.220	7.6		
	5-25-66	4,194.7	S	69	-	197	12,000	82,000	6,900	53	489	22,500	150,000	11	40	292,000	49,600	1.219	7.6		
	5-25-66	4,194.7	S	65	-	197	12,000	78,900	6,970	53	486	22,700	148,000	10	40	293,000	49,700	1.218	7.6		
3	10-6-65		S	63	-	230	12,500	79,500	7,620	66	516	25,900	147,000	-	52	296,000	52,200	1.222	7.6		
	10-6-65		S	61	-	230	12,900	78,800	7,740	66	522	26,100	147,000	-	45	294,000	53,600	1.222	7.6		
4	1-27-65		T	36	3.4	214	13,300	78,700	7,210	66	506	20,400	155,000	5.4	46	276,000	55,100	1.217	7.5		
	10-6-65		S	62	4.0	263	12,200	83,200	6,880	65	505	25,100	148,000	5.2	41	291,000	50,700	1.220	7.6		
	10-6-65		S	61	3.8	214	12,200	82,000	6,970	65	505	25,100	148,000	5.7	37	290,000	50,700	1.220	7.6		
	10-6-65		S	61	3.7	312	12,200	82,000	7,210	61	503	25,100	148,000	5.0	41	291,000	50,800	1.220	7.6		
	5-25-66	4,194.7	S	65	-	197	12,000	81,100	6,970	52	486	23,100	148,000	8.4	39	287,000	49,700	1.218	7.6		
5	1-13-65		S	36	-	-	-	79,200	-	60	-	-	-	-	-	282,000	-	1.214	-		
	1-13-65		S	36	3.4	264	13,100	78,400	7,300	63	505	21,500	155,000	5.8	46	278,000	54,300	1.215	7.5		
	1-14-65		S	35	3.2	190	9,300	63,200	5,650	47	384	15,700	121,000	4.1	34	219,000	38,700	1.162	7.7		
	10-6-65		S	68	3.5	295	12,200	81,800	6,960	61	502	25,000	147,000	5.2	39	290,000	50,700	1.223	7.6		
	10-6-65		S	62	3.6	279	12,300	81,800	6,770	63	500	24,900	145,000	5.4	42	290,000	51,100	1.223	7.6		
6	5-24-66	4,194.7	S	69	-	165	11,800	79,700	6,860	52	483	22,700	146,000	8.9	42	289,000	48,800	1.214	7.6		
	5-24-66	4,194.7	S	64	-	182	11,900	80,200	6,860	52	486	22,800	147,000	7.8	39	290,000	49,400	1.214	7.6		
	12-16-63		S	37	-	-	-	74,000	6,390	53	451	18,200	142,000	-	-	284,000	-	1.222	-		
	1-14-65		S	36	3.6	218	10,900	74,000	6,390	53	451	18,200	142,000	4.9	40	252,000	45,300	1.193	7.6		
	10-6-65		S	66	-	266	11,200	77,300	6,830	58	477	23,500	141,000	-	37	277,000	46,800	1.207	7.7		
7	10-6-65		S	66	-	230	12,200	79,900	7,180	63	499	24,800	147,000	-	41	288,000	50,700	1.219	7.6		
	10-6-65		S	62	-	279	12,400	79,400	7,640	62	504	25,300	147,000	-	40	289,000	51,600	1.222	7.6		
	10-6-65		S	62	-	214	11,900	80,100	6,950	52	482	22,600	146,000	6.1	41	288,000	49,400	1.215	7.6		
	5-24-66	4,194.7	S	70	-	198	11,700	79,700	6,960	52	488	22,400	147,000	6.6	38	285,000	48,600	1.214	7.6		
	5-24-66	4,194.7	S	66	-	181	11,700	77,700	6,350	52	481	22,600	145,000	6.5	37	286,000	48,800	1.215	7.6		
8	12-16-63		S	35	3.9	256	12,800	79,900	7,570	-	497	20,000	154,000	-	29	288,000	53,400	1.220	7.4		
	12-16-63		S	38	1.6	-	-	76,800	7,000	42	464	22,700	150,000	-	41	284,000	48,600	1.214	7.5		
	7-13-64		S	81	1.1	198	11,700	76,800	6,780	46	479	27,400	148,000	-	42	289,000	50,400	1.220	7.4		
	7-13-64		S	22	2.4	164	12,200	79,300	6,780	46	479	27,400	148,000	-	42	289,000	50,400	1.220	7.4		
	10-6-65		S	66	-	246	12,200	79,800	7,640	62	508	25,400	147,000	-	47	292,000	50,800	1.221	7.6		
9	10-6-65		S	62	-	213	12,400	80,100	7,640	62	513	25,400	148,000	-	49	288,000	51,600	1.221	7.6		
	10-6-65		S	61	-	180	12,300	79,000	7,640	65	507	25,300	146,000	-	50	289,000	51,100	1.222	7.6		
	5-25-66	4,194.7	S	67	-	165	11,700	79,500	6,950	52	484	23,100	145,000	9.0	37	286,000	48,500	1.216	7.6		
	5-25-66	4,194.7	S	66	-	148	11,800	79,900	7,040	52	484	23,100	147,000	7.1	37	289,000	48,800	1.215	7.6		
	5-25-66	4,194.7	S	61	-	182	11,500	80,100	7,050	52	483	22,500	145,000	12	38	286,000	47,600	1.213	7.6		
10	1-27-65		S	36	-	-	-	82,600	-	63	505	20,400	148,000	-	-	279,000	50,800	1.213	7.5		
	1-27-65		S	36	3.4	198	13,300	80,600	7,210	63	507	20,500	153,000	5.0	46	280,000	55,100	1.216	7.5		
	1-27-65		S	36	-	-	-	80,100	-	64	507	20,300	144,000	-	-	281,000	50,600	1.214	7.5		
	1-27-65		S	36	3.0	215	13,300	73,800	7,270	63	512	21,000	147,000	4.8	45	284,000	55,200	1.214	7.5		
	1-27-65		S	36	-	-	-	83,300	-	66	514	20,700	151,000	-	-	281,000	53,800	1.215	7.6		
11	1-27-65		S	24	3.7	198	13,500	73,700	7,250	63	508	21,200	149,000	5.7	47	281,000	55,900	1.216	7.5		
	10-6-65		S	62	-	231	11,800	76,000	7,010	61	495	24,600	140,000	-	37	283,000	49,200	1.215	7.6		
	10-6-65		S	63	3.4	230	12,200	82,100	6,990	61	496	25,400	148,000	5.0	40	288,000	50,900	1.218	7.6		
	10-6-65		S	63	-	263	12,200	78,600	7,370	62	508	25,200	145,000	-	43	289,000	50,800	1.221	7.6		
	10-6-65		S	62	3.5	230	12,600	81,900	6,940	63	506	25,000	148,000	5.1	41	286,000	52,400	1.221	7.6		
12	10-6-65		S	20	6.0	-	295	12,500	78,600	7,640	514	25,400	146,000	-	41	293,000	52,000	1.221	7.6		
	10-6-65		S	24	6.0	3.6	230	12,200	81,900	7,110	63	513	25,700	147,000	5.3	39	289,000	50,800	1.221	7.6	
	5-24-66	4,194.7	S	69	4.0	196	11,500	78,300	6,270	51	471	21,700	141,000	8.1	37	274,000	47,700	1.205	7.6		
	5-24-66	4,194.7	S	62	3.4	185	11,700	81,500	6,770	53	473	22,900	146,000	12	40	283,000	48,600	1.214	7.6		
	5-24-66	4,194.7	S	61	3.6	172	11,800	82,400	6,670	53	476	22,900	146,000	10	40	284,000	48,800	1.214	7.6		

Table 7. — Continued

Sampling site	Date of collection	Altitude of water surface (feet)	Depth (feet)	Temperature (°F)	Parts per million													Hardness as CaCO ₃	Density (gms/ml at 20°C)	pH
					Silica (SiO ₂)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Lithium (Li)	Bicarbonate (HCO ₃)	Sulfate (SO ₄)	Chloride (Cl)	Fluoride (F)	Boron (B)	Dissolved solids (Residue at 180°C)				
10	5-24-66	4,194.7	15	61	3.4	175	12,200	82,200	6,650	53	486	22,700	148,000	9.0	39	286,000	50,800	1.217	7.6	
	5-24-66	4,194.7	20	60	3.4	204	12,000	82,100	6,720	54	488	22,800	148,000	6.9	41	288,000	49,700	1.218	7.6	
	5-24-66	4,194.7	26	51	2.9	173	11,400	82,400	6,420	51	456	37,300	139,000	13	38	295,000	47,200	1.229	7.6	
11	12-4-63		N	43	-	-	-	-	-	-	-	-	-	-	290,000	-	1.219	-		
	1-14-65		S	36	3.5	185	11,100	73,000	6,390	53	444	17,800	141,000	4.2	38	250,000	46,100	1.193	7.6	
	10-6-65		S	60	-	264	11,400	77,600	6,910	57	495	23,600	142,000	-	35	279,000	47,700	1.215	7.7	
	10-6-65		S	64	-	214	12,200	80,000	7,410	63	498	25,200	147,000	-	37	288,000	50,600	1.220	7.6	
	10-6-65		S	61	-	214	12,400	80,300	7,550	63	508	25,700	148,000	-	37	290,000	51,600	1.220	7.6	
	5-24-66	4,194.7	S	74	-	200	11,200	78,500	6,200	50	471	21,400	141,000	10	36	273,000	46,600	1.202	7.6	
12	5-24-66	4,194.7	S	64	-	132	12,000	82,300	6,610	52	479	22,900	147,000	9.6	37	287,000	49,800	1.215	7.6	
	5-24-66	4,194.7	S	60	-	165	12,000	81,600	7,310	52	490	22,800	148,000	8.9	39	287,000	49,800	1.216	7.6	
	5-24-66	4,195.4	T	50	-	93	784	6,690	581	2.7	272	1,700	11,800	1.3	2.2	23,600	3,460	1.013	8.0	
13	12-3-63	4,191.7	N	43	-	-	-	-	-	-	-	-	-	-	271,000	-	1.208	-		
	10-4-65	4,193.8	S	65	11	62	805	7,330	616	0	1/330	1,400	12,900	4.6	0	25,200	3,460	1.011	8.3	
	10-4-65	4,193.8	S	63	4.4	257	7,830	71,700	4,860	34	392	17,600	124,000	4.6	23	235,000	32,800	1.172	7.8	
	10-4-65	4,193.8	S	64	4.3	239	7,730	71,000	4,730	36	390	17,400	121,000	3.9	19	237,000	32,400	1.173	7.8	
	5-24-66	4,195.4	S	67	-	221	7,330	57,800	4,000	32	386	14,400	103,000	6.1	15	195,000	30,700	1.141	7.9	
	5-24-66	4,195.4	S	64	-	210	6,990	57,400	3,910	34	385	14,400	103,000	5.3	16	198,000	29,300	1.144	7.9	
	5-24-66	4,195.4	S	64	-	210	6,990	57,400	3,910	34	385	14,400	103,000	5.3	16	198,000	29,300	1.144	7.9	
	5-24-66	4,195.4	S	63	-	193	7,000	58,800	3,990	35	388	15,200	105,000	4.9	17	200,000	29,300	1.144	7.9	
	12-4-66	4,191.7	N	48	-	-	-	-	-	-	-	-	-	-	265,000	-	1.200	-		
	12-17-63	4,191.8	N	35	3.8	-	-	-	-	44	-	19,300	149,000	8.0	-	275,000	40,500	1.206	-	
14	1-27-65	4,193.3	N	-	-	-	-	67,500	-	34	378	12,900	116,000	-	-	212,000	30,600	1.153	7.6	
	1-27-65	4,193.3	N	-	-	-	-	74,300	-	35	389	14,800	126,000	-	-	233,000	32,000	1.172	7.7	
	7-22-65	4,194.0	S	79	-	309	7,520	68,900	-	39	380	16,900	116,000	-	-	230,000	31,700	1.167	7.7	
	7-22-65	4,194.0	S	78	-	240	7,450	69,800	-	39	382	16,900	117,000	-	-	231,000	31,200	1.168	7.7	
	7-22-65	4,194.0	S	78	-	325	7,290	70,600	-	40	381	16,900	118,000	-	-	230,000	30,800	1.170	7.7	
	10-7-65	4,193.8	S	55	-	213	7,750	18,100	1,200	6.9	368	3,920	31,400	-	1.2	56,600	7,740	1.034	8.2	
	10-7-65	4,193.8	S	62	-	309	7,570	68,900	4,600	39	394	17,400	120,000	-	21	228,000	31,900	1.168	7.8	
	10-7-65	4,193.8	S	69	-	265	10,600	81,000	4,440	55	450	23,300	143,000	-	34	279,000	44,400	1.210	7.6	
	5-24-66	4,195.4	S	67	-	196	6,280	52,200	3,500	28	374	12,900	91,400	4.9	14	172,000	26,300	1.122	7.8	
	5-24-66	4,195.4	S	63	-	229	6,600	53,600	3,850	32	382	14,300	99,800	5.0	16	191,000	27,700	1.137	7.9	
15	5-24-66	4,195.4	S	62	-	210	6,890	55,500	3,990	34	386	14,900	103,000	5.6	17	199,000	28,800	1.144	7.9	
	5-24-66	4,195.4	S	62	-	210	6,890	55,500	3,990	34	386	14,900	103,000	5.6	17	199,000	28,800	1.144	7.9	
	5-24-66	4,195.4	S	56	-	191	10,500	72,200	5,550	49	449	21,400	137,000	6.6	34	267,000	43,600	1.199	7.5	
	12-3-63	4,191.7	N	49	2.9	255	8,960	84,600	5,080	-	395	24,600	149,000	-	39	257,000	37,500	1.196	7.5	
	7-13-64	4,194.0	S	81	4.3	224	7,340	71,200	4,690	37	369	16,100	121,000	-	22	226,000	30,700	1.165	7.6	
	7-13-64	4,194.0	S	58	3.1	198	10,400	79,300	6,150	42	433	24,800	145,000	-	37	280,000	43,200	1.214	7.4	
	7-22-65	4,194.0	S	78	-	309	7,270	71,400	-	40	389	17,100	119,000	-	-	228,000	30,700	1.166	7.8	
	7-22-65	4,194.0	S	77	4.9	264	7,340	72,200	4,570	35	384	17,000	120,000	4.1	23	228,000	30,800	1.168	7.7	
	7-22-65	4,194.0	S	60	3.1	258	10,800	79,600	6,110	54	443	23,900	142,000	5.3	32	276,000	45,000	1.210	7.4	
	10-4-65	4,193.8	S	63	-	260	7,190	65,600	4,170	38	396	16,500	114,000	-	31	219,000	30,200	1.158	7.8	
16	10-4-65	4,193.8	S	61	5.0	274	7,740	66,200	4,750	36	392	17,000	118,000	3.9	24	229,000	32,500	1.169	7.8	
	10-4-65	4,193.8	S	62	-	291	7,520	69,300	4,210	41	399	17,500	120,000	-	31	233,000	31,700	1.169	7.8	
	10-4-65	4,193.8	S	63	4.0	291	7,500	72,200	4,420	39	410	17,300	121,000	4.4	25	234,000	31,600	1.172	7.7	
	10-4-65	4,193.8	S	74	-	332	10,300	78,200	6,390	54	446	22,700	140,000	-	32	272,000	43,300	1.207	7.6	
	10-4-65	4,193.8	S	66	2.8	214	11,300	82,100	6,480	58	473	24,800	144,000	5.0	40	286,000	46,800	1.218	7.5	
	5-24-66	4,195.4	S	70	4.8	186	6,910	56,900	3,830	33	387	14,600	102,000	4.9	16	199,000	28,900	1.143	7.8	
	5-24-66	4,195.4	S	64	4.9	176	7,080	57,000	4,140	33	389	14,900	103,000	4.9	16	199,000	29,500	1.141	7.9	
	5-24-66	4,195.4	S	64	4.9	176	6,810	57,000	3,980	33	387	14,800	101,000	5.1	17	198,000	28,500	1.142	7.9	
	5-24-66	4,195.4	S	64	4.9	239	6,710	60,300	3,630	34	385	14,600	103,000	4.5	21	196,000	28,200	1.142	7.9	
	5-24-66	4,195.4	S	61	3.9	175	10,000	73,300	5,800	47	441	20,100	131,000	8.1	33	254,000	41,600	1.193	7.6	
17	5-24-66	4,195.4	S	53	2.7	172	11,200	81,300	6,660	52	460	24,000	142,000	7.6	37	278,000	46,600	1.212	7.5	
	1-27-65	4,193.3	T	39	-	-	-	78,000	-	41	406	14,900	134,000	-	-	246,000	35,300	1.182	7.6	
	10-4-65	4,193.8	S	65	-	293	7,100	65,100	4,190	38	389	16,400	113,000	-	46	219,000	29,900	1.162	7.8	
	10-4-65	4,193.8	S	67	-	275	7,750	68,100	4,170	40	394	17,200	119,000	-	22	229,000	32,500	1.168	7.8	
	5-24-66	4,195.4	S	63	-	204	6,820	61,200	3,570	33	388	14,600	103,000	8.9	23	196,000	28,500	1.139	7.9	
	5-24-66	4,195.4	S	63	-	176	6,750	61,100	3,560	33	377	14,600	103,000	7.1	22	195,000	28,200	1.142	7.9	
	10-1-65	4,193.8	S	59	-	276	7,510	65,300	4,180	40	393	17,100	114,000	-	22	222,000	31,600	1.164	7.8	
	10-1-65	4,193.8	S	61	-	308	7,650	68,300	4,390	40	389	17,400	119,000	-	23	228,000	32,200	1.172	7.8	
	10-1-65	4,193.8	S	70	-	232	10,800	78,700	6,700	54	435	23,200	142,000	-	33	277,000	45,000	1.210	7.5	
	5-24-66	4,195.4																		

Table 7. — Continued

Sampling site	Date of collection	Altitude of water surface (feet)	Depth (feet)	Temperature (°F)	Parts per million													Density (gms/ml. at 20°C)	pH
					Silica (SiO ₂)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Lithium (Li)	Bicarbonate (HCO ₃)	Sulfate (SO ₄)	Chloride (Cl)	Fluoride (F)	Boron (B)	Dissolved solids (Residue at 180°C)	Hardness as CaCO ₃		
19	10- 4-65	4,193.8	15	63	4.2	239	7,520	70,800	4,670	39	397	17,300	124,000	4.3	23	233,000	31,500	1.174	7.8
	10- 4-65	4,193.8	22	70	2.4	166	10,100	80,600	5,840	53	429	21,800	140,000	4.7	33	272,000	41,800	1.207	7.6
	5-24-66	4,195.4	5	65	-	140	6,960	59,000	3,700	33	388	14,900	104,000	9.3	19	197,000	29,000	1.143	7.9
	5-24-66	4,195.4	5	64	-	158	7,390	59,000	3,700	33	387	14,900	106,000	9.2	21	197,000	30,800	1.143	7.9
	5-24-66	4,195.4	10	63	-	175	6,890	56,400	3,900	33	385	14,700	103,000	6.8	18	198,000	28,800	1.143	7.9
	5-24-66	4,195.4	15	63	-	158	7,100	56,400	3,750	33	385	14,800	102,000	7.0	19	199,000	29,600	1.143	7.9
	5-24-66	4,195.4	20	61	-	137	8,140	69,500	4,720	39	406	18,100	118,000	9.1	23	230,000	33,800	1.168	7.7
	5-24-66	4,195.4	23	54	-	133	9,280	83,300	5,730	44	415	20,900	139,000	7.6	25	268,000	38,500	1.201	7.5
	7-22-65	4,194.0	5	80	5.1	241	7,290	72,100	4,500	37	385	16,700	120,000	4.2	25	225,000	30,600	1.165	7.7
	7-22-65	4,194.0	7	81	4.8	247	7,280	72,000	4,490	37	377	17,200	120,000	4.2	25	226,000	30,500	1.166	7.7
20	10- 4-65	4,193.8	5	64	4.2	275	7,750	69,400	4,580	38	394	16,600	120,000	3.8	23	228,000	32,500	1.168	7.8
	10- 4-65	4,193.8	6	64	4.1	239	7,730	71,500	4,740	39	402	17,400	122,000	4.0	25	236,000	32,400	1.174	7.8
	5-23-66	4,195.4	5	65	-	169	6,900	54,500	3,840	27	386	14,600	101,000	3.6	18	194,000	28,800	1.139	7.9
	5-23-66	4,195.4	7	62	-	158	6,870	54,400	3,840	30	387	14,900	101,000	6.0	19	198,000	28,700	1.141	7.9
	10- 4-65	4,193.8	5	62	-	290	7,490	70,000	4,330	38	394	17,600	121,000	-	29	232,000	31,500	1.174	7.8
21	10- 4-65	4,193.8	8	62	-	256	7,560	71,800	4,330	38	392	17,500	124,000	-	26	232,000	31,700	1.174	7.8
	5-23-66	4,195.4	5	64	-	158	7,060	54,400	4,040	30	384	15,000	101,000	4.0	18	200,000	29,400	1.142	7.9
	5-23-66	4,195.4	5	62	-	193	7,110	60,300	3,710	33	386	15,000	105,000	4.1	20	198,000	29,700	1.144	7.9
	5-23-66	4,195.4	10	63	-	165	7,040	60,300	3,710	33	383	15,100	105,000	7.6	21	199,000	29,400	1.144	7.8
	5-23-66	4,195.4	5	64	-	168	7,210	60,300	3,710	33	385	15,200	105,000	5.0	19	198,000	30,100	1.144	7.9
22	5-23-66	4,195.4	5	63	-	151	6,490	60,200	3,700	33	384	15,200	105,000	4.8	21	197,000	27,100	1.145	7.9
	5-23-66	4,195.4	15	62	-	182	6,520	60,300	3,710	33	392	15,200	103,000	3.6	21	200,000	27,300	1.144	7.9
	5-23-66	4,195.4	20	58	-	153	8,330	70,400	4,650	44	402	18,800	127,000	3.7	27	240,000	34,600	1.178	7.6
	5-23-66	4,195.4	23	53	-	200	8,580	82,700	4,640	42	384	20,000	144,000	4.9	27	271,000	35,800	1.202	7.4
	12-14-64	4,192.5	5	38	-	-	-	79,800	-	38	-	-	-	-	-	257,000	-	1.196	-
23	12-14-64	4,192.5	5	38	-	-	-	81,900	-	41	406	17,700	138,000	-	-	257,000	35,400	1.191	7.6
	12-14-64	4,192.5	10	38	-	-	-	79,300	-	38	-	-	-	-	258,000	-	1.194	-	
	12-14-64	4,192.5	15	39	-	-	-	83,400	-	39	399	18,100	140,000	-	-	260,000	35,400	1.193	7.6
	10- 4-65	4,193.8	5	61	-	274	7,320	69,400	4,350	38	399	17,100	120,000	-	24	226,000	30,800	1.169	7.8
	10- 4-65	4,193.8	5	63	-	308	7,490	70,500	4,340	38	399	17,300	122,000	-	22	229,000	31,600	1.172	7.8
24	10- 4-65	4,193.8	20	67	-	234	9,390	77,600	5,510	47	414	20,700	137,000	-	31	260,000	39,200	1.199	7.6
	5-23-66	4,195.4	5	64	-	182	6,700	58,400	3,520	31	388	15,100	103,000	4.5	22	201,000	28,000	1.143	7.9
	5-23-66	4,195.4	5	62	-	196	6,580	58,400	3,520	31	385	15,200	103,000	3.5	22	201,000	27,600	1.143	7.9
	5-23-66	4,195.4	21	55	-	134	8,650	80,500	4,580	43	401	20,300	136,000	5.0	27	267,000	35,900	1.198	7.4
	12-14-64	4,192.5	5	38	-	-	-	79,900	-	38	-	-	-	-	-	259,000	-	1.195	-
25	12-14-64	4,192.5	5	38	-	-	-	82,600	-	39	405	18,000	139,000	-	-	258,000	35,500	1.194	7.6
	12-14-64	4,192.5	15	38	-	-	-	81,700	-	39	409	16,800	139,000	-	-	259,000	36,200	1.192	7.6
	10- 7-65	4,193.8	5	62	-	326	7,830	67,800	4,260	38	394	17,000	119,000	-	29	226,000	33,000	1.167	7.8
	10- 7-65	4,193.8	5	62	-	326	7,710	68,700	4,250	38	397	17,000	120,000	-	30	226,000	32,500	1.169	7.8
	10- 7-65	4,193.8	14	64	-	273	7,510	69,300	4,240	38	399	17,300	120,000	-	24	230,000	31,500	1.173	7.8
26	5-23-66	4,195.4	5	63	-	182	6,680	59,300	3,420	33	384	14,800	105,000	3.2	20	197,000	27,900	1.146	7.9
	5-23-66	4,195.4	5	62	-	147	7,130	59,300	3,430	32	388	15,000	103,000	3.6	18	197,000	29,700	1.145	7.9
	5-23-66	4,195.4	17	62	-	168	6,820	59,300	3,420	32	382	14,900	105,000	3.5	18	198,000	28,400	1.146	7.8
	5-23-66	4,195.4	20	62	-	175	6,830	59,300	3,420	33	384	15,200	105,000	4.5	20	199,000	28,500	1.146	7.9
	5-23-66	4,195.4	25	52	-	183	8,370	83,000	4,410	43	392	20,100	141,000	4.8	26	271,000	34,900	1.205	7.4
27	12- 8-64	4,192.5	5	39	-	-	-	78,400	-	37	-	-	-	-	-	256,000	-	1.193	-
	12- 8-64	4,192.5	5	40	-	-	-	83,900	-	39	406	19,100	140,000	-	-	256,000	35,200	1.192	7.6
	12- 8-64	4,192.5	14	42	-	-	-	85,200	-	39	401	19,200	142,000	-	-	259,000	35,500	1.196	7.6
	10- 4-65	4,193.8	5	59	-	325	7,750	68,700	4,250	38	393	17,200	120,000	-	23	228,000	32,700	1.170	7.8
	10- 4-65	4,193.8	5	62	-	273	7,910	69,200	4,310	38	409	17,500	121,000	-	20	233,000	33,200	1.174	7.8
28	10- 4-65	4,193.8	18	67	-	380	7,950	86,100	4,760	41	371	19,900	146,000	-	34	274,000	33,600	1.212	7.4
	5-23-66	4,195.4	5	64	-	192	6,670	59,300	3,390	35	387	15,000	103,000	3.4	20	199,000	27,900	1.146	7.9
	5-23-66	4,195.4	5	63	-	164	6,690	59,300	3,390	35	384	15,000	105,000	5.3	20	202,000	27,900	1.146	7.9
	5-23-66	4,195.4	17	60	-	150	6,800	59,200	3,390	35	387	15,200	105,000	3.5	21	203,000	28,300	1.147	7.9
	12- 8-64	4,192.5	5	39	-	-	-	79,900	-	38	-	-	-	-	-	258,000	-	1.195	-
29	12- 8-64	4,192.5	5	44	-	-	-	84,000	-	39	399	19,400	140,000	-	-	259,000	35,400	1.192	7.6
	12- 8-64	4,192.5	14	44	-	-	-	84,400	-	37	399	19,100	141,000	-	-	260,000	35,500	1.194	7.6
	10- 4-65	4,193.8	5	61	-	324	7,770	69,400	4,230	38	391	17,500	121,000	-	31	232,000	32,800	1.175	7.8
	10- 4-65	4,193.8	5	61	-	324	7,770	70,700	4,230	38	393	17,500	123,000	-	29	233,000	32,800	1.175	7.8
	10- 4-65	4,193.8	16	62	-	307	7,730	70,200	4,370	38	398	17,600	122,000	-	30	232,000	32,600	1.175	7.8
30	5-23-66	4,195.4	5	64	-	175	6,730	59,300	3,400	35	386	15,200	103,000						

Table 7. — Continued

Sampling site	Date of collection	Altitude of water surface (feet)	Depth (feet)	Temperature (°F)	Parts per million													Density (gms/ml at 20°C)	pH
					Silica (SiO ₂)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Lithium (Li)	Bicarbonate (HCO ₃)	Sulfate (SO ₄)	Chloride (Cl)	Fluoride (F)	Boron (B)	Dissolved solids (Residue at 180°C)	Hardness as CaCO ₃		
28	3/5-23-66	4,195.4	S	62	-	193	6,490	60,900	3,930	33	380	14,800	105,000	9.9	20	197,000	27,200	1.141	8.0
	5-23-66	4,195.4	S	63	-	175	6,580	60,700	3,910	33	386	15,100	105,000	8.2	20	200,000	27,500	1.145	7.9
	5-23-66	4,195.4	10	63	-	175	6,590	60,700	3,920	33	388	15,000	105,000	5.1	19	201,000	27,500	1.144	7.9
	5-23-66	4,195.4	15	62	-	175	6,590	60,700	3,920	33	390	15,100	105,000	4.4	18	200,000	27,500	1.144	7.9
	5-23-66	4,195.4	20	63	-	175	6,480	60,700	3,910	33	383	15,300	105,000	6.1	21	201,000	27,100	1.145	7.9
	5-23-66	4,195.4	23	60	-	119	8,300	72,400	4,820	42	394	18,700	125,000	7.1	24	240,000	34,400	1.177	7.6
29	12-14-64	4,192.5	S	34	-	-	-	78,900	-	37	-	-	-	-	-	254,000	-	1.194	-
	12-14-64	4,192.5	S	38	-	-	-	83,300	-	39	406	16,800	141,000	-	-	257,000	35,600	1.192	7.6
	12-14-64	4,192.5	12	39	-	-	-	80,800	-	41	403	11,400	141,000	-	-	256,000	35,400	1.192	7.6
	10- 1-65	4,193.8	S	58	-	325	7,590	69,000	4,240	36	391	17,300	120,000	-	28	230,000	32,000	1.171	7.8
	10- 1-65	4,193.8	S	60	-	324	7,780	70,100	4,200	40	390	17,600	122,000	-	30	234,000	32,800	1.174	7.8
	10- 1-65	4,193.8	12	60	-	324	7,570	70,400	4,200	40	395	17,400	122,000	-	29	233,000	31,900	1.174	7.8
	5-23-66	4,195.4	S	61	-	193	6,680	60,700	4,040	33	390	15,200	105,000	7.6	20	202,000	27,900	1.145	7.9
	5-23-66	4,195.4	S	62	-	158	6,600	60,700	4,040	33	386	15,200	105,000	5.6	20	203,000	27,500	1.145	7.9
	5-23-66	4,195.4	12	62	-	193	6,470	60,700	4,040	33	383	15,100	105,000	7.3	20	203,000	27,100	1.145	7.9

1/ Includes 14 ppm carbonate (CO₃).
 2/ Depth of 20-foot sample is uncertain.
 3/ Location of 5-23-66 samples is uncertain.

UTAH GEOLOGICAL AND MINERALOGICAL SURVEY

103 Utah Geological Survey Building
University of Utah
Salt Lake City, Utah 84112

THE UTAH GEOLOGICAL AND MINERALOGICAL SURVEY since 1949 has been affiliated with the College of Mines and Mineral Industries at the University of Utah. It operates under a director with the advice and counsel of an Advisory Board appointed by the Board of Regents of the University of Utah from organizations and categories specified by law.

The survey is enjoined to cooperate with all existing agencies to the end that the geological and mineralogical resources of the state may be most advantageously investigated and publicized for the good of the state. The *Utah Code, Annotated, 1953 Replacement Volume 5, Chapter 36, 53-36-2*, describes the Survey's functions.

Official maps, bulletins, and circulars about Utah's resources are published. (Write to the Utah Geological and Mineralogical Survey for the latest list of publications available).

THE LIBRARY OF SAMPLES FOR GEOLOGIC RESEARCH. A modern library for stratigraphic sections, drill cores, well cuttings, and miscellaneous samples of geologic significance has been established by the Survey at the University of Utah. It was initiated by the Utah Geological and Mineralogical Survey in cooperation with the Departments of Geology of the universities in the state, the Utah Geological Society, and the Intermountain Association of Petroleum Geologists. This library was made possible in 1951 by a grant from the University of Utah Research Fund and by the donation of collections from various oil companies operating in Utah.

The objective is to collect, catalog, and systematically file geologically significant specimens for library reference, comparison, and research, particularly cuttings from all important wells driven in Utah, and from strategic wells in adjacent states, the formations, faunas, and structures of which have a direct bearing on the possibility of finding oil, gas, salines or other economically or geologically significant deposits in this state. For catalogs, facilities, hours, and service fees, contact the office of the Utah Geological and Mineralogical Survey.

THE SURVEY'S BASIC PHILOSOPHY is that of the U. S. Geological Survey, i.e., our employees shall have no interest in Utah lands. For permanent employees this restriction is lifted after a 2-year absence; for consultants employed on special problems, there is a similar time period which can be modified only after publication of the data or after the data have been acted upon. For consultants, there are no restrictions beyond the field of the problem, except where they are working on a broad area of the state and, here, as for all employees, we rely on their inherent integrity.

DIRECTORS:

William P. Hewitt, 1961-

Arthur L. Crawford, 1949-1961