Great Salt Lake, Utah, and its Environment

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ABSTRACT

The Great Salt Lake in northwestern Utah is a remnant of the Pleistocene Lake Bonneville. Since it has no outlet, its size is dependent upon precipitation and evaporation. Precipitation is variable, but the annual average that falls directly into the Lake ranges between 4 1/2 and 6 inches, whereas the eastern shore line watersheds receive from 14 to 18 inches annually. Evaporation from the Lake ranges from 3.14 to 3.80 feet per year. Most of the inflow to the Lake is via surface streams, springs, and ground water which are supplied by waters from the higher watersheds. Historically, its surface area has fluctuated more than a thousand square miles and its volume change from the high and low lake levels, a vertical range of 20 feet, has been approximately 21 million acre-feet. Great Salt Lake is very shallow; its greatest depth was approximately 29 feet in April, 1965; much of its present shore line slopes at grades near 1 to 500.

The density of Great Salt Lake brines has ranged from 1.104 to 1.221, while the dissolved solids have varied from 151,000 to 288,000 parts per million. The Lake brine contains approximately 8.6% sodium, 4.6% potassium, 8.0% magnesium, 14.7% chloride, 1.7% sulfate and minor amounts of miscellaneous ions.

Life in the Lake, not counting bacteria, is more or less limited to the tiny brine shrimp, Artemia gracilis, the fly Ephydra, and the blue-green algae Aphanothece packardii.

Sediments of the Lake bottom, in order of areal extent, are 'clays,' oolitic sands and algal reefs. Highly-calcareous clays are generally varied; they show approximately 12 pairs of laminae per inch. The calcareous oolites range from 0.14 to 1.0 mm in diameter. The algal reefs or bioherms are composed principally of layered secretions of calcium carbonate and comprise over 100 square miles of the Lake area.

Prior to 1959, there had been no historic record of subaqueous precipitation of sodium chloride onto the Lake bottom. In 1959, the Southern Pacific Railroad's rock fill across the Lake created a divided Lake. By 1963, approximately a foot of sodium chloride had been deposited on the bottom of the northern arm, where evaporation greatly exceeds precipitation. The salt deposited amounted to approximately 730 million tons, which was about 19% of the 3,830 million tons which should have been contained in the 1963 brine inventory. Data is presently being collected to support recommended remedial measures.

THE GREAT SALT LAKE AND ITS DESERT

Introduction

Great Salt Lake and a few intermountain playas are the surviving remnants of the Pleistocene Lake Bonneville. Lake Bonneville was the largest of the Great Basin lakes. It occupied the eastern portion of the basin, and its catchment area comprised approximately 54,000 square miles or about a fourth of the area of the Great Basin (Gilbert, 1890). The bulk of Lake Bonneville occupied all of northwestern Utah below the general elevation of 5,235 feet, its initial spillway level (Fig. 1). Parts of the lake extended 50 miles northward into southern Idaho to a place called Red Rock where Lake Bonneville found an outlet via the Snake River system to the sea. Here the draining Bonneville waters cut a gorge, since then modified, from the spillway elevation of 5,235 feet downward for 435 feet to an elevation of 4,800 feet, the Provo stage or level. The minerals concentrated in the remnants of Lake Bonneville represent those which were present in the lake when it reached its Provo level and those which have subsequently been supplied from its watershed.

The Great Salt Lake is the largest remnant of Lake Bonneville comprising approximately 1,000 square miles in early 1965. Second in size is the Sevier Lake (Sink) of 187 square miles; third is the fresh waters of Utah Lake with 134 square miles. The largest playa is the Great Salt Lake Desert comprising 4,572 square miles and containing subsidiary salt pans, the Wendover Salt Flats, and the Silver Island (Potter's) Salt Pan respectively of 150 and 20 square miles. Other smaller playas of the Lake Bonneville drainage are the playas of Pine, Wah Wah, White (Tule), Snake, Rush, Parowan, Cedar, and Cedar City Valleys.

The Bonneville Basin or catchment system comprises approximately 53,325 square miles of territory. Precipitation averages 14.44 inches annually over the area for a total of approximately 40 million acre-feet. Temperature and general arid conditions prevail, and probably less than one tenth of the water crop ever reaches the lakes or playas of the area.

The concentration of minerals and the chemical character of the brines and ground waters beneath the desert playas is relatively unknown. Recently, the range of analyses of the Great Salt Lake Desert brines indicates that much more work remains to be done before a reliable inventory of the metals contained can be established.

SALIENT PHYSICAL FEATURES

GREAT SALT LAKE

Great Salt Lake and its desert occupy 6,172 square miles in northwestern Utah. The surface of the lake responding more or less to broad climatic cycles is in critical balance with precipitation and evaporation, and has fluctuated as much as 20.05 feet in historic times (since measurements have been recorded) (Fig. 2). The highest level was attained in June, 1873, when the lake stood at 4,211.65 feet above sea level, the lowest level on November 8, 1961, when the lake's surface was at an elevation of 4,191.60 feet. The lake comprised 2,185 square miles at its highest level and 915 square miles at its lowest level, a change of 1,270 square miles.

Great Salt Lake is extremely shallow. The lowest point of its bottom is near 4,164.8 feet above sea level; the deepest part of the lake has ranged between 26.6 and 46.65 feet. The slope of the bed and shores is commonly near 1 to 500 and large areas have slopes near 1 to 5,000.

Based on very limited bathymetric data, the volume of the lake has fluctuated between 30,000,000 and 8,733,000 acre-feet, a volume change of 21,267,000 acre-feet. Table 1 shows the approximate range in area and volume for different lake stages.

PHYSICAL CHARACTERISTICS AND CLIMATIC FACTORS

Great Salt Lake is closely related to climatic variations; its water budget laggingly responds to the annual variations of precipitation and evaporation. High annual lake levels occur in May and June in response to spring rains and meltwater from snow packs in the Unita and Wasatch Mountains. Evaporation is dominant from July through November, and annual low lake levels occur in November and early December. The average annual variation in lake levels is approximately 1 to 1 1/2 feet. Since lake levels were recorded in 1850 the lake has experienced three major periods of high water and three of low water (Fig. 3). Presently the lake is in a low water stage. It is interesting to note that each high stage is from 4 to 7 feet lower than the previous high level, and that each low stage is 2 feet lower than the previous low. It is not clear whether this gradual stage reduction is the result of cultural development, or of a broad climatic trend, or a combination of both.

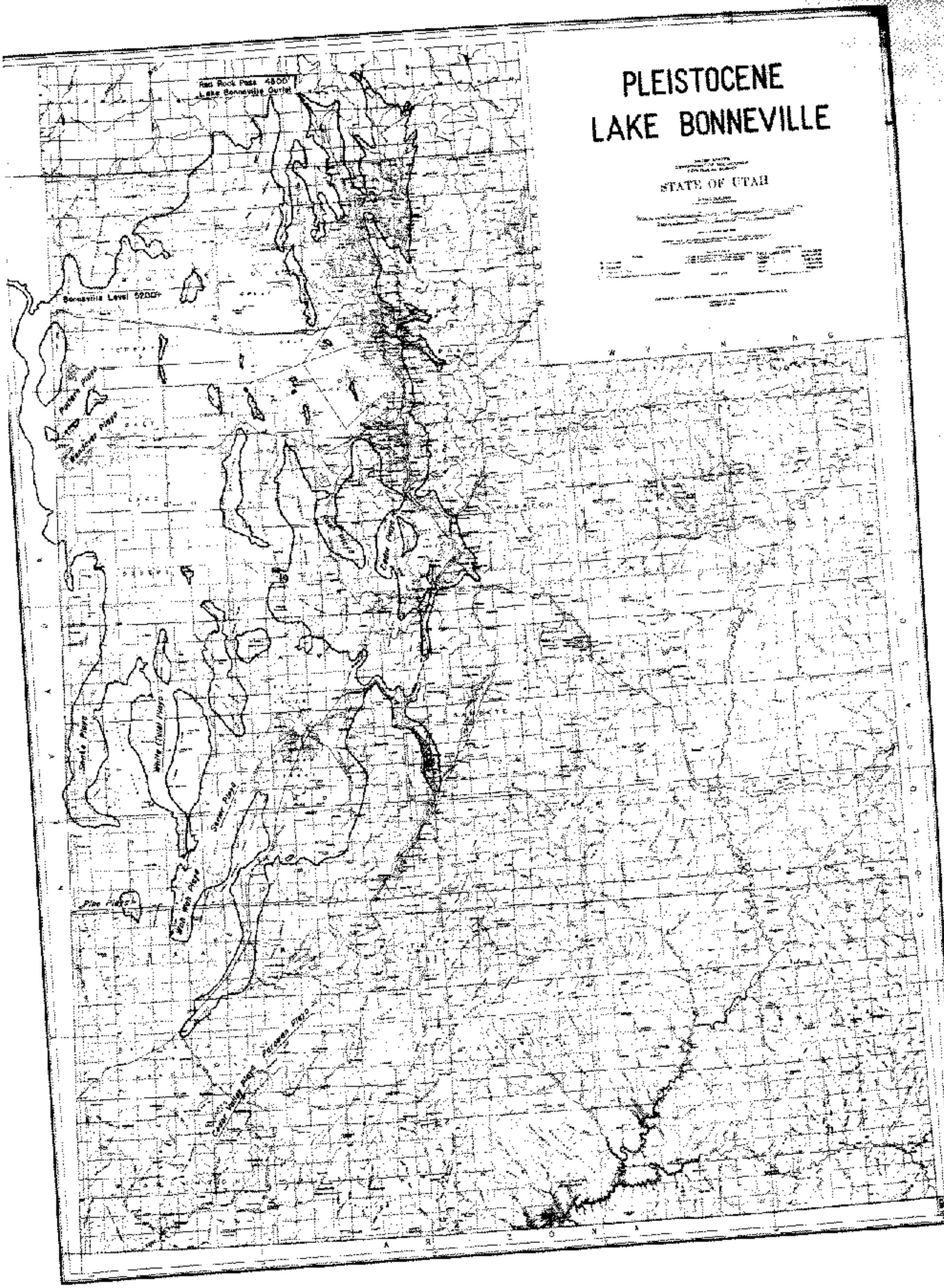
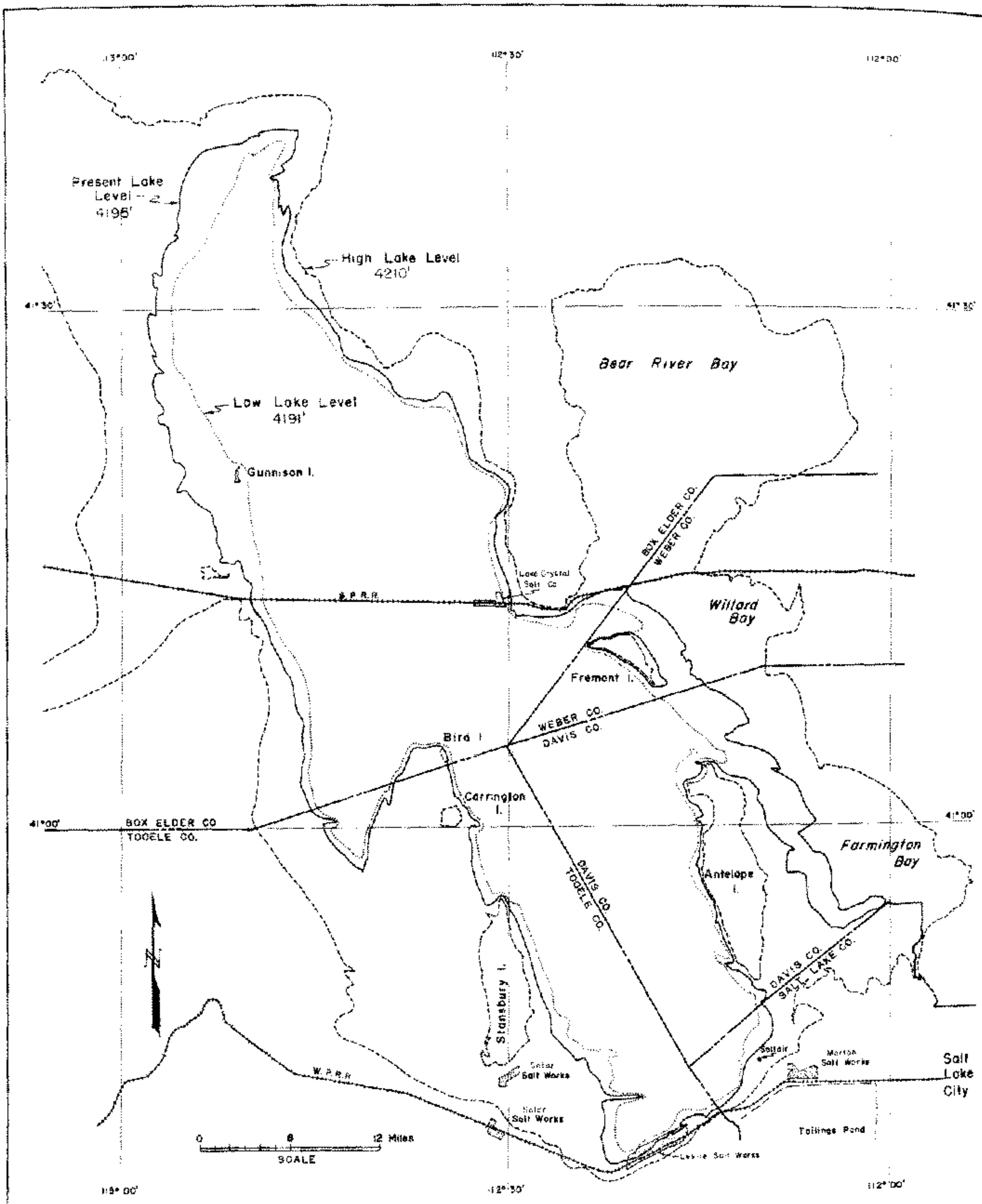

PLEISTOCENE
LAKE BONNEVILLE
STATE OF UTAH
Red Rock Pass 4800'
Lake Bonneville Outlet
Bonneville Level 5200'+
Wendover Playa
Snake Playa
White (Tule) Playa
Sevier Playa
Wah Wah Playa
Pine Playa
Cedar Valley Playa
Parowan Playa
W Y O M I N G
A R I Z O N A

Figure 1.



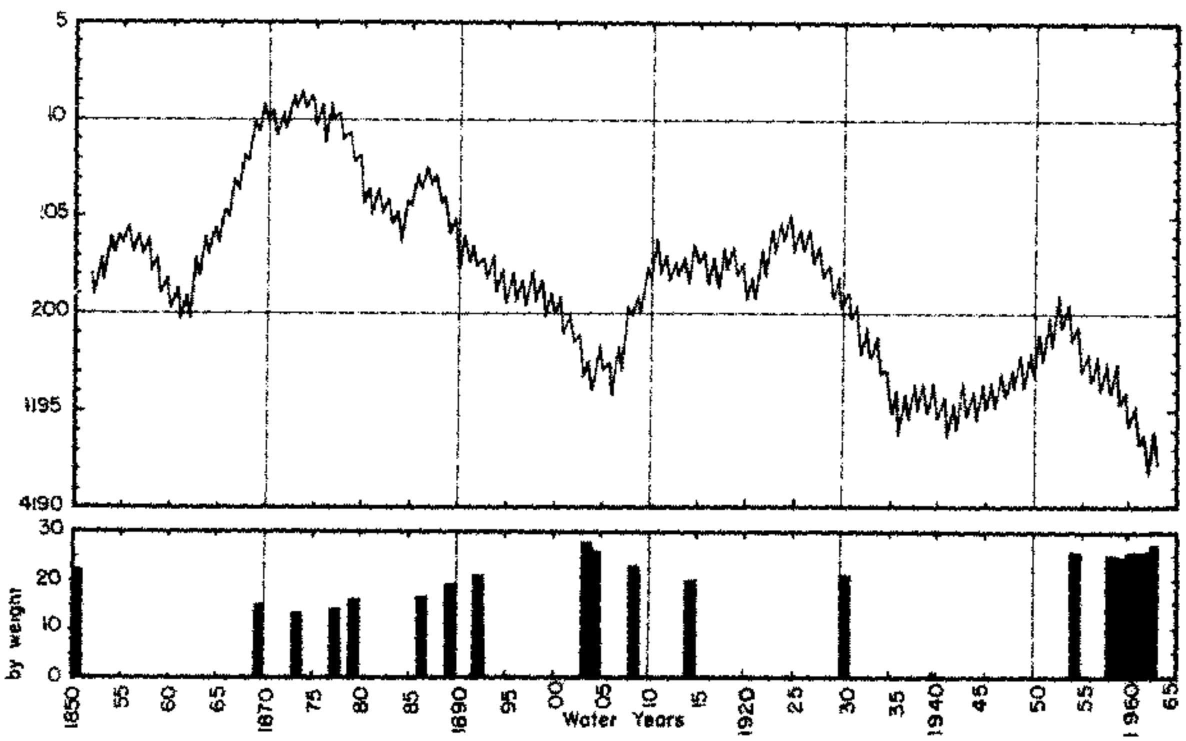
GREAT SALT LAKE

Figure 2.

.E 1. GREAT SALT LAKE STAGE-AREA-VOLUME RELATIONSHIPS*

:l :	Area (Sq. Miles)	Area (Acres)	Volume (Acre-Ft.)	Volume Change (Acre-Ft.)
	0	0	0	0
	180	115, 300	288, 320	288, 320
	423	270, 550	1, 253, 000	964, 680
	626	400, 970	2, 931, 810	1, 678, 810
	770	492, 700	5, 166, 050	2, 234, 240
	884	565, 600	7, 811, 890	2, 645, 840
	1, 096	701, 300	10, 979, 190	3, 167, 300
	1, 680	1, 075, 380	15, 420, 920	4, 441, 730
	2, 016	1, 290, 100	21, 334, 620	5, 913, 700
)	2, 122	1, 358, 200	27, 955, 400	6, 620, 780

dmate -- based on incomplete data.



'igure 3. Hydrograph of Great Salt Lake showing yearly maximum and minimum elevations of lake surface, 1851-1962, and the dissolved-solids content of the brine.

The average annual evaporation from Great Salt Lake ranges from 3.14 feet at low lake stages to 3.80 feet from the high stages. Precipitation into the lake is variable with an annual range from 4 1/2 to 6 inches on the western shores and 14 to 18 inches on the eastern edge. The annual runoff and river discharge range from .8 to 1.3 million acre-feet during low water stages to 1.9 to 3.5 million acre-feet during the high stages. Comparisons (Peck, 1954) of hydrometeorological data of the watersheds of the lake with the lake data indicates that the ground-water contribution to the lake is greater than one-third of the total inflow. Other estimates of the ground-water contribution range upward to one-half of the total inflow. Using the scant data, the Utah Geological Survey calculates that the annual ground water increment probably represents about 22% of the total water added regardless of the stage of the lake (Fig. 4).

The density of the lake brines has ranged from 1.104 to 1.221 from 1850 to the present. Since 1959 when the Southern Pacific Railroad completed a cross-lake embankment effectively severing the northern third of the lake from the southern two-thirds there have been marked changes in the physical and chemical characteristics of the divided waters. The northern arm does not receive inflow proportionate with the southern arm; thus evaporation is more pronounced resulting in a northward hydraulic gradient. Preliminary data indicates that there also exists a density gradient which is allowing heavier northern brines enriched in bitterns to flow southerly as an underflow through the two culvert openings in the embankment. The net result is that the southern arm is becoming more dilute in sodium chloride and slightly enriched (over average) in the bittern salts. Also, the lessening of the total salt content in the southern segment results in increased evaporation. Current studies are being conducted to determine the effects and rates of changes in the distribution of the ions contained in the two lake segments, and to recommend the necessary remedial steps necessary to maintain a healthy extractive industry.

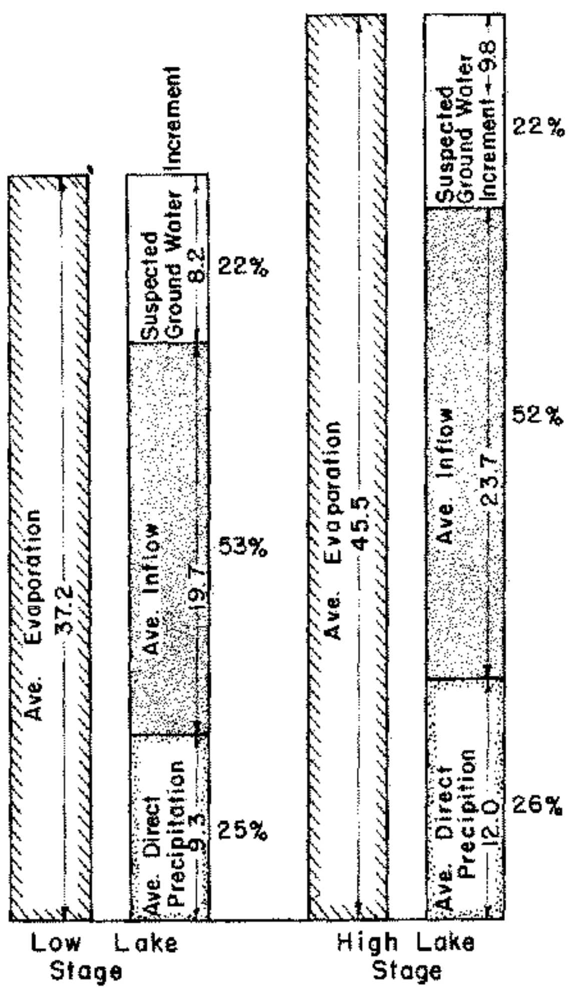


Figure 4.

LAKE SEDIMENTS

There are three principal types of bottom sediments, 'clay,' oolitic sands, and algal reefs; and in recent years sodium chloride is being subaqueously precipitated.

The 'clays' of Great Salt Lake are of three general lithologic types (Schreiber, 1958); they total approximately 1,450 square miles of the lake bottom below the 4,200-foot contour. Type I consists chiefly of very calcareous silts and clays with oolites and abundant faecal pellets (from the brine shrimp Artemia gracilis; it averages 50% sand, 34% silt, and 16% clay. Type II consists primarily of a calcareous, clayey silt; it averages 5% sand, 70% silt, and 25% clay. Type III lithology is a calcareous, very silty sand; it averages 53% sand, 35% silt, and 12% clay. Most of the 'clay' sediments are dark gray to black when first recovered, but they oxidize to lighter shades of gray and olive. Organic matter ranges from 0.45 to 4.50 weight per cent. One of the outstanding characteristics of the lake sediments is their high carbonate content. The carbonate of the 'clays' ranges from 10 to 75%. Laminations are commonly present that closely resemble glacial varves. Though generally indistinct, the laminae range from 1 to 3 mm in thickness (composite of one light and one dark bank) and average 12 per inch of sediment.

The oolitic sands comprise the next most abundant bottom and near shore sediment. Except n areas where algal bioherms are developed, oolitic sands are dominant on and along shore lines which abutt the main body of the lake. They aggregate approximately 125 square miles of the lake oottom and relicted lands. There is little or no development of oolites in the back bay area, the area between Antelope-Fremont Islands trend and the east shore. Oolite sands are largest and best developed along windward shores where waves from the open lake impinge on headlands. Here the oolites average 0.8 to 1.0 mm in diameter; elsewhere oolites are between 0.14 and 0.63 mm in diameter (Eardley, 1938). The nuclei of the oolites are mineral granuals and the rodlike bodies or fragments of faecal pellets of the brine shrimp, Artemia gracilis. Quartz grains are the most common of the mineral particles with orthoclase and calcite in significant amounts; some heavy minerals are also present. Microscopically the cross section most of the oolites display has well-developed concentric bands, and many of these have strongly-developed secondary radial structure. The banding is most noteable in oolites where an abundance of clay particles occur at the interfaces of the concentric layers. Aragonite comprises the dominant mineral of the oolites with the balance of 3 to 7.5% being dolomite. The origin and growth of the oolites is closely related to the chemistry of the lake brine and the physical conditions of the near-shore areas. Oolite growth seems to be related to the late summer period of greatest evaporation. The winnowing and tumbling of the oolites allow for concentric growth. It is also suggested that the relatively insignificant maximum size of the oolites is directly related to the density of the lake brines. Allowing that exceptional shore line conditions of vigorous wave action can produce large oolites, for the most part the size ranges of the oolites are related to the sink-float cutoff properties of the brine. In other words larger oolites would form on the shore lines of a receding lake whereas smaller maximums in oolites would prevail when the lake rises and becomes less dense.

The algal reefs or bioherms similar to the oolite development are confined to the more shallow saline portion of the lake. Bioherms range from a few inches to as much as 15 feet in thickness. Areally the reefs comprise an excess of 100 square miles of the lake and relicted area below the 4,200 foot contour. Biohermal structures are the result of secretions of calcium and magnesium carbonate in a ratio of 11 to 1 by the algae Aphanothece packardii. The bioherms develop in the shallow water as rounded pillowlike masses which gradually coalesce into broad 'trough and mound' areas (Fig. 5). The mounds may range up to 30 feet in diameter with irregular secondary mounds which average 18 inches in relief. The surface texture of the reefs is rough and hackly; internally the individual 'heads' or mounds show crude banding.

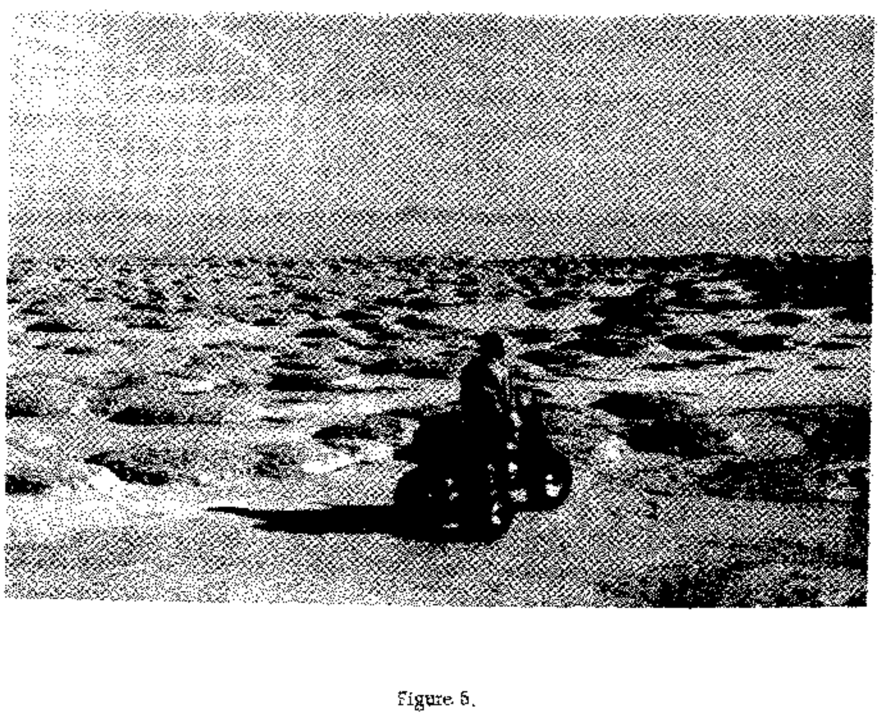


Figure 5.

EVAPORITES FROM GREAT SALT LAKE BRINES

Evaporites deposited in Great Salt Lake consist of sodium chloride and hydrous sodium sulfate. Until 1959 there was practically no subaqueous precipitation of sodium chloride to the lake bottom. Sodium chloride that was precipitated was the direct result of wind which produced sieches (wind tides) thus filling shallow depressions of relicted bottom areas with lake brines. Insignificant amounts of salt form on rocks, beaches, and pilings that front areas of deep water where wave action is severe. These crustations of salt are temporary, and they are dissolved and returned to the lake by action of rain and snow meltwater.

In 1959 the new embankment of the Southern Pacific Railroad Company's Lucin Cutoff route was completed. The new structure is a rock fill, designed to be slightly permeable and is vented by two 15-foot boat access culverts situated in the midlake area. The previous crossing (cutoff) consisted of rock fill and a 12.6 mile wooden trestle which allowed free exchange of water between the northern arm and the main body of the lake. The inflow into the northern cutoff arm of the lake is principally by direct precipitation and from the waters of Locomotive Springs at the extreme northern end of the arm. Since 1959 (Adams, 1964), through the summer of 1963, approximately one foot of salt was deposited on the bottom of the northern arm, an area estimated to be near 400 square miles. This represents approximately 730 million tons of sodium chloride which is approximately 19% of the estimated 3,830 million tons of sodium chloride which should have been in the 1963 brine inventory. Analysis by the U.S. Geological Survey of seven samples collected north of the fill and five from the main body of the lake in December, 1963, showed that the dissolved solids contained in the northern arm averaged 288,000 ppm whereas the main lake contained 259,000 ppm, a difference of 26,000 ppm or 10%. Since saturation relative to sodium chloride is near 275,000 ppm, the 13,000 ppm difference of dissolved solids in the northern arm indicates that saturation density has been exceeded by 4.7%. The Utah Geological Survey in cooperation with the U.S. Geological Survey is currently studying this problem of salt transfer by a systematic and periodic sampling program, but as yet data density is not sufficient to support or suggest effective remedial measures. Adams (1964) estimates that by 1975 the main body, the southern portion, of the lake will have freshened and will reach one half of the saturation concentration (140,000 ppm).

Mirabilite, the hydrous sodium sulfate being less soluble in cold water than in warm accumulates as temporary crystal mesh deposits in the deeper bottom areas during winter months. These deposits are local in extent and are redissolved as the lake warms. Also, during the winter months mirabilite crystals coat objects along the shore and seed crystals grow in the lake brines where they remain semi-suspended and subsequently are swept ashore to form rather extensive snow-white bars several feet deep, often scores of feet in width (Fig. 6). These bars form almost continuously along the shores subjected to the most violent and prevalent wave action. Under favorable conditions oolite sands are washed over the mirabilite and may be preserved as shallow shore line deposits of recrystallized mirabilite cementing a mixture of oolites and clay. Beds of sodium sulfate are responsible for much of the foundation support of the rock fill which replaces the trestle of the Lucin Cutoff of the Southern Pacific Railroad. The salt extends from the eastern shore area to beyond midlake, a distance of 9.5 miles. It lies between 15 and 30 feet below the lake bottom and ranges from a featheredge of crystal mush at the midlake locale to as much as 70 feet in thickness near the eastern shore. There is some question as to the origin of this salt layer. However, Eardley (1962) postulates that it was precipitated because of thermal variations of the lake brine, and that the precipitates were rapidly buried by protective coverings of clay (the thin clay interbeds). Not to be ruled invalid is the possibility of vertical and lateral migration

Figure 6.

dense brines enriched in sodium sulfate ions into a thermal environment conducive to sodium ılfate precipitation, the dense brine being derived from redissolving of mirabilite deposited in :eper portions of the lake. Also, the role of bacteria operating in conjunction with thermal gra- .ents might be a factor in the distribution of these mirabilite deposits.

LIFE IN AND ON THE LAKE

Great Salt Lake, though akin to a dead sea, is not lifeless. A few specialized types of plants ıd animals live and reproduce in great abundance in the lake (Eardley, 1938). Two animals and ıe plant comprise the visible forms: (1) the brine shrimp, Artemia gracilis, (2) the adult and ıpa of the fly Ephydra, and (3) the blue-green colonial algae, Aphanothece packardii. The brine ırimp and the algae are responsible for a significant amount of the carbonate deposition in the ıke as nucleii for oolites and as bioherms. The brine shrimp, less than a quarter of an inch in :ngth, is rusty to colorless and is seldom recognized, although it exists by the billions in the rine. Recently the shrimp and shrimp eggs have been sieved and packaged for tropical fish food. ıpae of the flies may be seen floating on the lake waters; but their presence is more readily ap- arent as fly-festooned smelly windrows of pupae and casts on and in scums on shallow pools. hey frequent the beaches in warm weather. Colonial blue-green algae are actually reddish-brown ı color and, when growing in the lake, form bioherms of stoney secretions which coalesce to ırm rough prickly reefs that are a hazard to boats and bathers.

Several of the islands of Great Salt Lake are nesting areas for pelicans and seagulls (Fig. 7), ut the greatest waterfowl habitats are the relatively fresh water embayments between the ntelope-Fremont Islands trend and the east shore. Here extensive duck and goose refuges have een developed.

Figure 7.

CHEMISTRY AND MINERALS INVENTORY OF LAKE BRINES

Historically, the brines of Great Salt Lake have ranged in salinity from approximately 151,300 to 288,000 parts per million. These are general figures and represent either individual samples or composite samples of inadequate sample density. Present analytical work indicates significant chemical variations areally and with depth which are attributed to the immense size and shallowness of the lake which enhances the effect of currents and differential evaporation on the ionic distribution.

Table 2 (Hahl and Langford, 1963) shows the general range of the percentage composition (by weight) of the dissolved solids in the lake brine.

TABLE 2. PERCENTAGE COMPOSITION (BY WEIGHT) OF THE DISSOLVED SOLIDS IN GREAT SALT LAKE BRINE

Constituent	1850[1]	1869[2]	August 1892[1]	October 1913[2]	March 1930[3]	April 1960[3]	November 1961[3]
Silica, SiO_2	....	....	....	....	....	0.002	0.003
Iron, Fe	....	....	....	....	....	.00002	.00004
Calcium, Ca	....	0.17	1.05	0.16	0.17	.12	.10
Magnesium, Mg	0.27	2.52	1.23	2.76	2.75	2.91	3.49
Sodium, Na	38.29	33.15	33.22	33.17	32.90	32.70	31.53
Potassium, K	....	1.60	1.71	1.66	1.61	1.61	1.95
Bicarbonate as Carbonate, CO_3	....	....	....	.09	.05	.06	.07
Sulfate, SO_4	5.57	6.57	6.57	6.68	5.47	6.60	8.21
Chloride, Cl	55.87	55.99	56.22	55.48	57.05	55.86	54.59
Nitrate, NO_3	....	....	....	....	....	.03	.06
Boron, B	....	....	....	....	....	.01	....
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Dissolved solids, in per cent by weight of the brine	22.28	14.994	22.83	20.349	21.0	24.7	26.9

[1] Computed from data reported by Richardson (1906, p. 34).

[2] Reported by Clarke (1924).

[3] From Hahl and Mitchell (1963, p. 38) analyses for samples collected at Promontory Point south of RR fill (site 123 on Fig. 1).

3 (Hahl and Langford, 1963) shows the concentrations of dissolved constituents in the and of the surficial inflow.

ınual load of dissolved minerals which enters Great Salt Lake by surficial inflow in ; was approximately 2.0 million tons.

TABLE 3. CONCENTRATIONS OF DISSOLVED CONSTITUENTS IN GREAT SALT LAKE BRINE AND SURFICIAL INFLOW

(Concentrations in parts per million unless otherwise indicated)

.uent ɔerty	Great Salt Lake			Surficial inflow
	Maximum[1]	Minimum[1]	Average[2]	Discharge-weighted average[3]
, SiO_2.........	7.0	4.2	5.3	18
.num, Al......	2.6	2.5	....	....
Fe...........	.11	.02	.04	....
.um, Ca.......	463	265	319	94
ıesium, Mg....	9,440	6,920	8,050	49
ım, Na........	92,200	77,800	85,700	300
ssium, K......	5,570	3,810	4,550	20
ium, Li........	56	29	....	....
ırbonate, HCO_3 .	398	266	327	344
ate, SO_4.......	22,600	12,100	17,400	188
oride, Cl.......	158,000	133,000	147,000	475
.oride, F........	7.4	5.9	....	....
ide, I...........	.60	.26	.41	....
:rate, NO_3.......	154	61	82	4.1
ron, B...........	36	21	....	....
ssolved solids, calculated.......	285,000	240,000	263,000	1,320
ensity g/ml at 20°C	1.221	1.186	1.208	1.000

[1]Extremes observed from analyses of samples collected at sites 122, 123, 124, 131, 132 (see Fig. 1) during June 1959-November 1961.

[2]Average of analyses of samples collected at sites 123 (south of fill), 131, and 132 (see Fig. 1) in April, July, and October 1960 and January-February 1961.

[3]For water years 1960 and 1961, and from data in Tables 1 and 3.

A very approximate inventory of the salts which would have been precipitated from the total ke brine in April, 1963, is listed in Table 4.

TABLE 4. SALT INVENTORY OF GREAT SALT LAKE

April 15, 1963 --	Elevation -- 4,192.55 Density -- 1.216 Salinity -- 27.3% Area -- 601,951 Storage -- 9,300,145 acre-feet Lake water weighs 75.88 pounds / cubic foot and contains 20.72 pounds of salt.				
Assumed Chemical Combinations	% of Total Dissolved Solids (approx.)	Salt Content of Brine			
		Pounds per cubic foot	Pounds per acre foot	Tons per acre foot	Tons in Lake (thousands)
Sodium Chloride $NaCl$	77	15.95	694,782	347.4	3,231,000
Sodium Sulfate Na_2SO_4	9	1.86	81,021	40.5	377,000
Magnesium Chloride $MgCl_2$	5	1.04	45,302	22.7	211,000
Magnesium Sulfate $MgSO_4$	4	0.83	36,155	18.1	168,000
Potassium Chloride KCl	4	0.83	36,155	18.1	168,000
Others	1	0.21	9,148	4.6	43,000
TOTALS	100	20.72	902,563	451.4	4,198,000

OPERATIONAL PROBLEMS

Wave Action. Severe storms generally are either from the northwest or the south. Wind tides (sieches) in excess of three feet are common during sustained periods of high winds. The brine density (76 pounds per cubic foot) operating in conjunction with water level changes and the possibility of waves in excess of nine feet necessitates greater than normal structural requirements. Three-ton cap-stone for riprap facings are generally adequate for structures bearing the full brunt of storm waves.

Currents. The effects of currents in the lake have never been adequately determined, however, the morphology of the headlands, spits and bars indicates a dominant counterclockwise circulation in the lake. Longshore currents are effective in distributing materials along the beach. The Salt Lake County boat harbor, a "T"-shaped structure, was completed in 1937 and was continually dredged until the early 1940's. Since then only limited dredging was done and it was terminated about 1956. Figure 8 of the boat harbor in early 1959 shows the effectiveness of the longshore drift in Great Salt Lake.

Wind Action. Sudden and violent winds often gusting in excess of 60 knots can be expected. Airborne dust, though infrequent, can be expected from the north, west, and south from the dry farm and desert areas during periods of sustained winds.

Corrosion. The high salinity of the lake waters, along with its correspondingly high conductivity, greatly increases the possibility of damage to hulls and immersed metals by electrolysis. Hulls may be protected by a cathodic protection system utilizing circuitry that ties in all hull units in one circuit and replaceable sacrificial anodes in another. The two circuits can be connected by an adjustable resistance for adequate protection without unduly wasting of the anodes.

Stationary structures above the water line or at shore sites will have greater, though relatively short, longevity by being kept well painted.

Wood Structures. Piling and wooden structures are more or less pickled in the brine. There are no organisms, except the possibility of extremely slow-acting bacteria, which assist

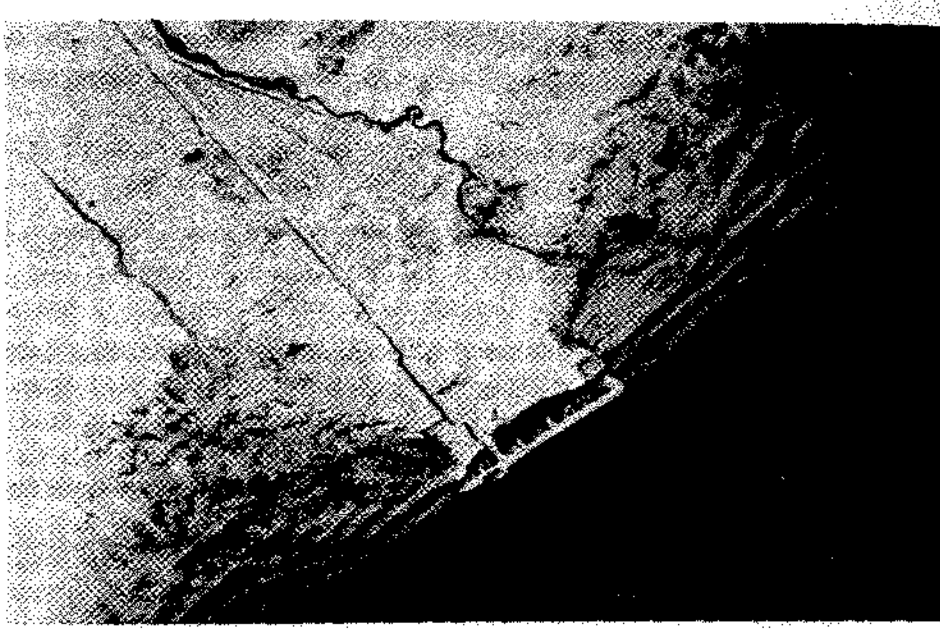


Figure 8.

in deterioration of woods. If wood is destroyed, it is principally through the process of crystal growth in the more porous woods. This process is assisted by and enhances capillary action which can gradually shred vertical wooden supports that are immersed in lake brines or in shore areas of heavy salt concentration. The crystal shredding, however, is an extremely slow process and structures are generally discarded before collapse occurs.

Salting of Equipment. The salinity being more than six times that of sea water causes problems in external salting. At certain times of the year, and always in the winter and/or in certain areas of the lake where the temperature of the brine is near the precipitation point of sodium sulfate, some extensive salting may occur. During construction and emplacement of materials for the railbed, there were times when hulls and propellors to towboats gathered enough salt in a span of several days to reduce their speed by one-fourth. Impellers of service pumps operating at 1,800 rpm can be stalled by salts accumulating on the vanes. Early in the construction of the fill excess salt accumulated on towboats and barges operating in the more remote western area of the lake could be removed by routing them in the eastern, fresher portions of the lake. As the project neared completion, it was necessary to dry-dock the towboats to remove the salt. Since marine operations were confined to the northern arm of the lake, the effects of evaporation in excess of inflow became more pronounced as the severance became more complete. This occurred within a span of 2 1/2 years (October, 1956 to May, 1959).

CONCLUSIONS

The Great Salt Lake, though enormous in size can be rather effectively controlled by diking as has been demonstrated by the effects which have been observed following the construction of the railroad fill.

The environment of Great Salt Lake will change, and it will be most dependent upon the demands, control, and uses of the surplus waters of the higher watersheds. The Utah Geological Survey is endeavoring to find the most effective means for controlling the lake within the limits of available water so that the brines will continue to be of a proper density for commercial solar salt operations.

Recent studies of piecemeal research indicate a pressing need for an expanded research program involving concurrent studies of all environmental factors which affect the lake.

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