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SALT IN CALIFORNIA

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ABSTRACT

Common salt (NaCl) is a basic material for human existence as well as for the chemical industry. California's output in 1953 of more than a million tons valued at over $6 million was about 6 percent of the United States production.

Halite, natural sodium chloride, occurs dissolved in sea water, in the brines of some undrained desert basins, and in some springs and wells. Rock salt, formed by the evaporation of brine, occurs as crystal bodies in desert playas of Pleistocene age and as beds in older rocks. California is one of the few places in the United States where the recovery of salt from sea water by solar evaporation is economically feasible. The salt industry is centered in the south end of San Francisco Bay where the Leslie Salt Co. operates one of the world's largest solar evaporation plants. Smaller plants are operated on San Diego Bay, Newport Bay, and near Moss Landing. The solar evaporation process is essentially fractional crystallization. Sea water is first brought to saturation in a series of concentrating ponds where calcium carbonate and gypsum precipitate. The saturated brine or pickle is run into crystallizing ponds where salt forms, and the magnesium-rich mother liquor or bittern is sold to chemical companies for further processing. Once a year the salt is harvested with mechanized equipment and washed with strong brine. The product, crude undried salt, contains 99.4 percent NaCl. Two general types of refined salt are produced, kiln dried, 99.8 percent pure, and vacuum refined, more than 99.95 percent pure.

A minor proportion of the California salt production comes from the desert regions. Solar evaporation is applicable to many terrestrial brines, although differences in brine composition and concentration require modification of the sea water process. The Long Beach Salt Company recovers salt from the surface brine of Koehn Lake by solar evaporation, and this method has been practiced at Salton Sea. At Bristol Lake the California Salt Company quarries salt from a buried crystal body, and the Pacific Salt and Chemical Corporation scrapes salt from the exposed crystal body of Searles Lake. Large reserves of salt exist in the brine-permeated crystal bodies of Cadiz Lake, Danby Lake, and Dale Lake, in the surface crusts of Death Valley and Saline Valley, and in folded and faulted Tertiary deposits in the Avawatz Mountains.

Crude salt sold in bulk to chlorine-caustic manufacturers accounts for nearly half the California production. Water treatment, refrigeration, and livestock consume smaller amounts. Minor uses include food preparation, the processing of hides and leather, and the manufacture of soap. Table and household uses account for an estimated 2.7 percent of the total.

One of the first salt plants on San Francisco Bay was built in 1862. Well into the 20th century the industry consisted of a host of small, inefficient plants, few of which had annual capacities of more than 10,000 tons. The series of events that lead to the consolidation of nearly all the Bay area's salt-producing capacity in the hands of one organization began about 1900, and the process was completed in 1941.

The desert salt deposits were known at an early date. In the Salton Sea region salt was produced from 1884 until the flood of 1905 and 1906. Salt operations began at Danby Lake in 1890, at Bristol Lake in 1909, and at Koehn Lake in 1914. The production of salt from Saline Valley followed the completion of an aerial tramway across the Inyo Range in 1913.

tailed discussion of the solar salt industry is to be found in another section of this bulletin.

Natural conditions are so favorable for making salt on the Alameda County shore of San Francisco Bay that the first white settlers found natural salt deposits in the tide pools among the marshes. These deposits, which were as much as eight inches thick, were very impure and contained appreciable amounts of magnesium salts and the other dissolved solids in addition to sodium chloride that are present in sea water.

Salt Ponds. Preston (1890) has described an interesting salt pond that in the 1890's existed just north of Redondo Beach, and within 300 yards of the ocean. Lake Salinas, as the pond was called, has long ago been filled in. The pond was filled with a concentrated chloride brine having a much higher proportion of magnesium than sea water. Apparently no direct connection with the sea existed, for the bottom of the pond was composed of fresh-water-bearing clay, and the pond level was about 5 feet above the high tide mark. The pond appeared to have received only the drainage of the immediate area, and perhaps its saline content was derived from salt spray.

In 1901 and 1902, a company attempted to develop salt brine near Oceanside and Carlsbad, San Diego County. According to G. E. Bailey (1902, p. 133), brine was obtained from wells sunk in old, nearly dry lagoons. It would be interesting to know if this brine was merely sea water that seeped in from the ocean, or was, like the brine of Lake Salinas, of unusual composition.

Salt Deposits of Isolated Basins

Salton Sea Region

The Salton Sea region, which is approximately the equivalent of the Colorado Desert, has been considered to be an example of an arm of the sea that has been cut off and desiccated (Grabau, 1920, pp. 146-151). The Colorado Desert, a northwest-trending structural trough, bounded by active branches of the San Andreas fault, is a continuation of the trough occupied by the Gulf of California and is separated from the Gulf by the delta of the Colorado River. The lowest part of the basin is a little more than 270 feet below sea level. Prior to 1905 a playa existed near Salton Station and substantial quantities of salt were recovered from the saline crust. With the flooding of the basin with fresh water from the Colorado River and the formation of Salton Sea in 1905 and 1906, this industry was destroyed; but by 1935 evaporation had concentrated the fresh water to the point where recovery of salt by solar evaporation was feasible. Solar evaporation is favored by an average summer temperature of close to 100° and an average rainfall of only one to five inches a year.

The trough occupied by the Gulf of California and Salton Sea is thought to have been formed by faulting in early Pleistocene time. During the very late Pleistocene epoch, the Salton Sea region was occupied by a body of water called Lake Cahuilla or Blake Sea that left beach lines around the basin at about the 40 foot contour. The presence of fresh or at least brackish water fossils and reefs of calcareous tufa leave little doubt that Lake Cahuilla contained fresh water. The final disappearance by evaporation of the Quaternary lake is thought to have taken place comparatively recently, perhaps within 400 years (MacDougal, 1917, p. 457). MacDougal has shown that Lake Cahuilla was but the last of a number of fresh water lakes that occupied the Salton Basin. Without doubt the water came from the Colorado River which in 1900 was flowing along the crest of the delta and may well have discharged into the basin in the geologically recent past. Much evidence (Sykes, 1937) has been accumulated to show that at the time of the flood the Colorado was tending to seek new channels toward the Salton Basin and would in all probability have flooded the basin without assistance from man. Indeed, it was with considerable difficulty that the river has been forced back to the southeast side of the delta.

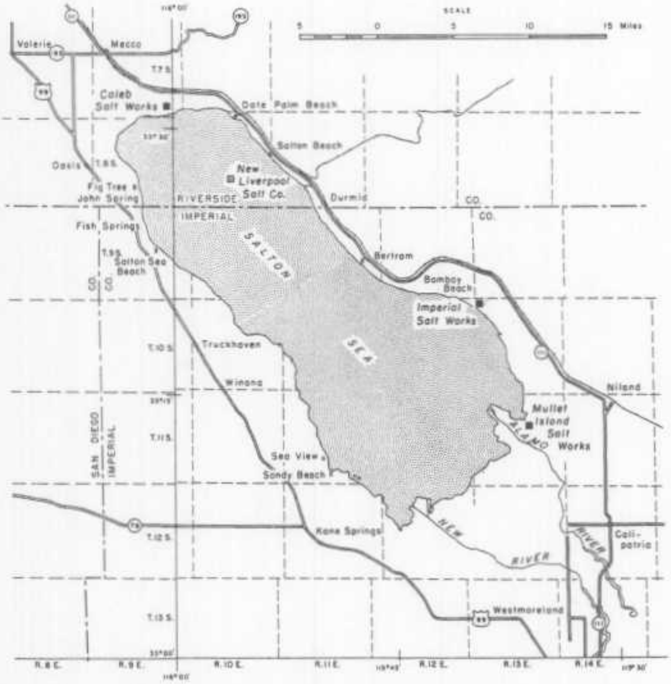

FIGURE 1. Map of Salton Sea region showing locations of salt plants and sampling stations.

W. P. Blake and many others believed that when the Salton Basin was formed the sea flooded it and that the Gulf of California extended to the vicinity of Indio. Gradually as the Colorado River built its delta into the Gulf the upper end was cut off from the open sea. At one or more times the Colorado River emptied into the part of the Gulf north of the delta barrier, displaced the sea water, and formed the fresh water lakes whose beaches and deposits remain. E. E. Free (1914, pp. 25-27) has questioned that the Salton Basin ever was filled with sea water. He postulated that the basin floor originally was above sea level and that the building of the delta dam accompanied a subsidence of the floor.

The evidence furnished by the salines is inconclusive because the saline deposits of the Salton Basin are of terrestrial rather than marine character. Any evaporites that may have originated from sea water that might once have filled the basin have been either dissolved and swept out or modified before the desiccation of Lake Cahuilla by influxes of fresh water from the Colorado River. Buried saline deposits of the marine type may exist, but none have been discovered.

Before the flood, Salton Basin was a bare, alluvium-filled plain bordered by alluvial fans that flanked the adjacent mountains. The playa near Salton Station varied in appearance. At times, as in 1849 and 1891, it was covered by as much as 6 feet of water that came from the Colorado River in periods of high water; at other times it was dry and covered with a crust of comparatively pure salt.

But a fragmentary description of the playa has come down to us, and the subsurface seems to have been explored by a single borehole that was about 15,000 feet west of Salton, a railroad station approximately 6 miles north of the boundary between Riverside and Imperial Counties. In 1891 according to Preston (1893) 6 inches of black mud covered a crust 7 inches thick that was composed of sodium and magnesium chlorides. Beneath the crust was 22 feet of black ooze with a water content of over 50 percent and consisting "largely of chlorides and carbonates of sodium and magnesium, the soda salts predominating, besides fine sand, iron oxide, and a small amount of organic matter." Below the ooze hard clay extended to the bottom of the hole, which was 300 feet deep.

The brine had a specific gravity of 27° Be, but no other quantitative data are available. Salt produced from the brine by evaporation, however, had the following analysis (Preston, 1893, p. 388):

NaCl	94.68%
$CaSO_4$	0.77%
$MgSO_4$	3.12%
Na_2SO_4	0.68%
H_2O	0.75%
	100.00%

An analysis of the crust made by E. T. Allen of the United States Geological Survey is as follows (Clarke, 1903):

NaCl	94.54%
KCl	0.31%
Na_2SO_4	3.53%
$CaSO_4 \cdot 2H_2O$	0.79%
Moisture	0.14%
Insoluble residue	0.50%
	99.81%

Salton Sea was formed during 1905 and 1906 by water from the Colorado River that broke into irrigation canals (Sykes, 1937, pp. 111-120). When the flow was controlled in February 1907, Salton Basin was flooded to the minus 195 foot contour. The fresh water immediately began to dissolve the exposed playa salts, and by the middle of 1907 the salinity of Salton Sea reached the nearly uniform value of 3648 parts per million, showing that the solution of the playa salts was complete (Ross, 1914).

As the analysis included in table 1 shows, the water in 1907 was a dilute sodium chloride-sulfate brine with an appreciable content of the slightly soluble carbonates and sulfates of calcium and magnesium. On the assumption that all of the dissolved solids originated from either the playa salts or the fresh water of the flood, Ross calculated the average composition of the playa salts. He concluded that over 90 percent of the sodium and chloride and 70 percent or more of the magnesium and sulfate in Salton Sea came from the playa salts and that the river was the predominating source of only calcium and carbonate. On the further assumption that the playa salts originated from the desiccation of a hypothetical original Salton Sea, the water of the original Salton Sea can be compared with other chloride waters. The hypothetical sea is lower in magnesium, potash, and bromine and higher in calcium and sulfate than sea water; and it resembles much more closely the chloride-sulfate waters found in desert basins such as Death Valley, Saline Valley, and Dale Lake.

Following the flood, evaporation began to lower the level of the water at the rate of four to five feet a year; and if it were not replenished by the drainage from the irrigation systems of the Imperial and Coachella Valleys, Salton Sea would have returned to the playa state between 1925 and 1930.

As the accompanying graph shows, the level fell at a substantially uniform rate until the latter part of 1919. Since that time evaporation has been approximately balanced by inflow. The seasonal variations in the amount of fresh water used for irrigation are reflected in a rise in the level of Salton Sea in the spring

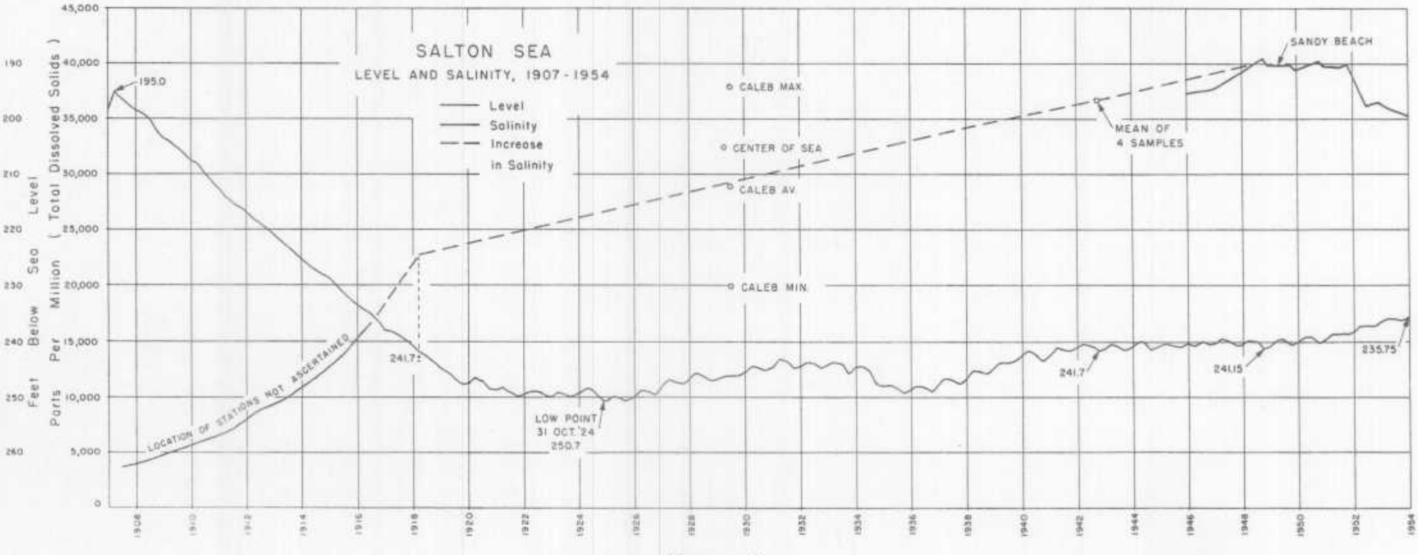

FIGURE 2.

and a drop in the fall. Superimposed on these annual level changes are long term changes. The level reached its lowest point, 250.7 feet below sea level, in November 1924. During the next 11 years it rose to 243 feet and declined nearly to the 1925 level. It averaged 240 feet or a little lower throughout the 1940's, and in 1951 it began to rise again. On March 31, 1954, the level of Salton Sea was 234.75 feet below sea level.

Complete analyses of the water of Salton Sea are available for 1907 to 1916 inclusive (MacDougal, 1917, p. 466) and from 1946 to the present. For the intervening years there are two analyses for 1929 and the mean of four analyses from different parts of the sea in 1942. In the years prior to 1920 when inflow was small the total dissolved solids present in Salton Sea remained substantially unchanged, but as evaporation reduced the volume of water the salinity rose at a uniform rate from 3648 parts per million in 1907 to 16,472 parts per million in 1916. Some samples taken in 1911 (Ross, 1914, p. 43) show that the salinity in all parts of the sea was essentially uniform. Some salts must be added by mineral springs such as the mud pots at the southwest end of Salton Sea. The brine from wells on nearby Mullet Island is rich in chlorides (table 2, analysis 11). As will be shown, however, an increase in the relative proportion of chloride in Salton Sea has not occurred, and therefore additions of salts from mineral springs have not been significant.

After inflow became significant the salinity was much less uniform. The Imperial Irrigation District has established five sampling stations where samples have been taken one to three times a year and at the same day beginning late in 1945. At one station, near the mouths of Alamo and New Rivers, the salinity is substantially lower than the average, but at the other four stations the salinity differs by as much as 10 percent. This range of salinity, however, is of the same order of magnitude as that in different parts of the southern end of San Francisco Bay. Since 1945 the salinity has varied inversely as the volume of the sea. It reached a maximum of about 40,000 parts per million in the fall of 1948 when the surface was about 241 feet below sea level. At the end of 1953 when the level stood a little higher than 236 feet the salinity was 35,000 to 35,500 parts per million.

Prior to 1953 the level had been below 236 feet since the latter part of 1916. The salinity in 1916 and 1953 when the volume of the sea was equal would have been the same if the total quantity of dissolved solids present had remained unchanged, but, in fact, the salinity in 1953 was more than double that in 1916. Probably the additional dissolved solids have originated from the essentially fresh irrigation water that has been flowing into Salton Sea since 1920.

The total quantity of dissolved solids can be compared at all times when the level was the same. The increase in the total dissolved solids present is shown on the graph by a dashed line connecting the points for October 1942 and September 1948 when the level was between 241 and 242 feet. Projected backward to 1918 when the level was about the same, this line passes close to the extension of the salinity curve plotted from the 1907-1916 analyses; and it is in agreement with the 1929 analyses of 32,200 and 36,500 parts per million when the level was considerably lower.

Over the years the relative proportions of the dissolved solids have changed. Between 1907 and 1916 marked decreases in calcium and carbonate and smaller decreases in potassium and magnesium were noted. Although the water was not saturated with respect to calcium carbonate, lime was withdrawn by organisms to form calcareous deposits (MacDougal, 1917, pp. 467-469). The decrease in potassium has not been explained. During this period the proportion of chloride was noted to increase slightly, while that of sulfate decreased.

The 1945-1953 analyses are not identical, but no changes in the relative proportions of the dissolved solids are apparent in this short interval. Compared with the 1907-1916 analyses, however, they show that significant changes have occurred. The most pronounced change has been in the ratio of chloride to sulfate which in 1907-1916 was about 3.7 to one and increasing slowly. In 1929 it was nearly five to one, but in 1945-1953 it was only 2.2 to one. Quite possibly it reached a maximum at the end of 1919 when inflow of sulfate-rich irrigation water from the Colorado River water became significant and has been decreasing subsequently. It seems likely that if this trend continues, the proportion of sulfate will become so great within a relatively few years that the water of Salton Sea will deposit sodium sulfate rather than sodium chloride upon evaporation.

Regarding the other ions present in Salton Sea water, the relative proportion of sodium is about the same as it was in 1907-1916, and both calcium and carbonate seem to have become stabilized also. The relative proportions of potassium and magnesium have increased.

The accompanying table illustrates the changes of salinity and level of Salton Sea.

Changes in salinity and level, Salton Sea.

Date	Elevation of surface (feet below sea level)	Salinity (PPM)
June 3, 1907 (location not known)	195.9	3,648
May 25, 1908 "	199.9	4,372
June 8, 1909 "	204.7	5,194
May 22, 1910 "	208.8	6,038
June 3, 1911 "	213.8	7,180
June 10, 1912 "	217.8	8,465.5
June 18, 1913 "	220.0	10,025.6
June 12, 1914 "	226.0	11,796
June 8, 1915 "	230.1	13,774
June 10, 1916 "	234.3	16,472
March 21, 1929 (Fish Springs)	246.0	36,500
March 21, 1929 (center of sea)	246.0	32,200
October 1942 (mean of 4 samples)	241.7	36,713
December 12, 1945 (Salton Sea Beach)	240.6	37,073
December 20, 1946 "	240.5	37,191
December 17, 1947 "	240.6	38,536
September 20, 1948 "	241.0	41,637
December 15, 1948 "	240.8	39,234
September 19, 1949 "	240.6	40,461
December 15, 1949 "	240.3	38,521
September 20, 1950 "	240.1	39,520
December 22, 1950 "	239.7	38,308
September 25, 1951 "	238.9	39,558
November 19, 1952 "	237.2	36,228
November 23, 1953 "	236.0	35,545

log illustrates the typical sequence (Teeple, 1929, pp. 15, 16):

0-15 feet	Halite
15-20 feet	Halite, hanksite, and trona
20-25 feet	Mostly hanksite
25-40 feet	Hanksite, halite, trona, and borax
40-55 feet	Hanksite, halite, trona, borax, and glaserite
55-65 feet	Mostly glaserite and halite
65-70 feet	Trona, halite, and hanksite
70-75 feet	Trona, halite, hanksite, and borax

In other holes the surface layer of nearly pure halite is commonly found. Below the surface layer the same salts are encountered as in the example above but in different proportions.

Neither the brines nor the crystal bodies contain calcium or magnesium salts, although they are present among the crystals disseminated in the impervious mud.

Owens Lake

Owens Lake is a source of sodium carbonate and borax. Salt has never been recovered from it.

Mono Lake

Mono Lake, because of its distance from transportation and comparatively low salinity of its water, has never been an important source of salines. A few hundred pounds a year of high-priced medicinal salt have been prepared by evaporating the water in kettles heated by wood fires.

Deep Springs Valley[*]

Deep Springs Valley, a desert basin in T. 8 S., R. 36 E., MDM, 24 miles east of Bigpine, Inyo County, has been considered as a source of sodium and potassium salts. The valley is an alluvium-filled sunken fault block, whose floor is 13 miles long, 4½ miles wide, and from 1,000 to 3,000 feet below the mountains that inclose it. In the southeastern part is Deep Springs Lake, a shallow body of concentrated brine about a mile in diameter, that is fed by nearby springs of warm water and by occasional cloudbursts. Fossiliferous lake beds high on the mountains show that in relatively late Quaternary time the valley was a fresh water lake 400 to 500 feet deep, whose outlet was eastward through Soldier Pass to Eureka Valley.

About 1920 the Inyo Chemical Company prospected Deep Springs Lake for potassium and sodium salts, but the results did not encourage further work. The lake water was found to contain 8.42 percent dissolved solids, while three shallow holes sunk on the northeast shore encountered brine containing about 20 percent dissolved solids. The brine is of the sodium chloride-sulfate type with considerable carbonate and potassium. Sodium chloride, however, amounts to less than half of the dissolved solids.

Borax Lake

Borax Lake, Lake County, contains water of the same type as those described above, except that the borate content is unusually high. Very similar was the brine of neighboring Lake Hachinhama from which borax was recovered by fractional crystallization in California's pioneer borate operation (Ayers, 1883).

Black Lake

Black Lake (Loew, 1876) is a body of carbonate-sulfate water, near Benton, Mono County, in T. 1 S., R. 31 E., MDM. Chloride is present, but in a subordinate amount. The lake is a narrow body a mile long, up to 500 feet wide, and up to 70 feet deep, which is fed, at least in part, by nearby hot alkaline springs. No salines have been recovered from it. The dark color of the water, for which the lake is named, is caused by the presence of organic matter in solution.

Saline Springs and Wells

Saline springs and wells occur in California, but there has been production from only three. Salt was produced from springs near Sites, Colusa County from 1895 to 1908, from the waste water of a Solano County gas well from 1907 to 1918, and from hot, artesian wells on Mullet Island, Imperial County. In all these cases, solar evaporation was practiced.

At Sites (Goodyear, 1890; Watts, 1892) a number of salt springs occur on the margin of a small lake. They are reported to lie along an anticlinal axis, and the water rises through unaltered sandstone. Probably the connate water of these sediments is the source of the salines. No complete analysis of the brine is available, but of a total dissolved solids content of 3159 grains per gallon (about 5 percent) sodium chloride amounts to nearly half. Calcium chloride comprises most of the remainder of the dissolved solids; a small amount of iodine is present also. The brine is associated with a small quantity of natural gas. Salt produced from the brine contained 96.84 percent sodium chloride.

The Solano County gas well (Bradley, 1916) which was in sec. 24, T. 5 N., R. 1 W. MDM., was drilled by the Rochester Oil Company in 1901. The hole bottomed at 1820 feet in the Upper Cretaceous Chico formation, but both the gas and brine came from a zone 1520 feet below the surface. No analysis of the brine is available.

On Mullet Island, Imperial County, at the southeast end of Salton Sea some salt was produced in 1919 from salt springs. During 1927, 1928, and 1929 Captain Charles Davis sunk two wells 900 and 1,400 feet deep that encountered hot brine high in sodium and calcium chloride (Coleman, 1929, p. 221). An analysis is included in table 2. Salt was produced from this brine by solar evaporation in 1934; and the Mullet Island Salt works, productive from 1940 to 1942, obtained a portion of its brine requirements from the wells.

In addition salt was produced from a well near Yreka, Siskiyou County, about 1884 (Williams, 1885, p. 847). The well, which was 675 feet deep, yielded brine at the rate of 10,000 gallons per hour.

The first report of the State Mineralogist (Calif. Min. Bur., 1880) contains a description of a salt spring in sec. 30, T. 13 N., R. 8 E., MDM, in Placer County. The water, which on evaporation produced salt, had a salinity of 1143.6 parts per million.

G. A. Waring (1915) has described a number of other springs that contain appreciable quantities of salt. Most of them are small and comparatively dilute, and it is believed that sodium chloride has not been produced

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[*] See Miller, W. J., 1928; Tucker and Sampson, 1938.

Continued evaporation of the bittern produces varying results. Depending on the temperature and the composition of precipitated salts remaining in the bittern, different hydrated salts and complex salts may form. The last traces of sodium chloride are not precipitated until nearly complete desiccation.

Some natural chloride brines that contain high proportions of magnesium and bromine resemble bitterns artificially produced from sea water. They are called natural bitterns and are believed to have formed by the natural evaporation of sea water. No important natural bitterns are known in California.

The Evaporation of Terrestrial Waters

The precipitation of salts from terrestrial waters, while analogous, differs in detail from the precipitation of sea salts. Every brine must be considered as an individual case, although some generalizations can be made. First to be precipitated are the slightly soluble carbonates of calcium and magnesium, followed by gypsum. Many chloride waters yield salt and then sodium sulfate; but if the proportion of sulfate is high, sodium sulfate may precipitate before salt. Because the solubility of sodium sulfate depends to a marked degree on temperature, some chloride-sulfate brines precipitate sodium sulfate before salt in cold weather and salt before sodium sulfate in hot weather. A few chloride brines such as those of Bristol and Cadiz Lakes that are unusually low in sulfate and carbonate, precipitate salt from a calcium chloride mother liquor. From volcanic type brines, which contain abundant carbonate, trona ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$) is in many cases the first of the more soluble salts to precipitate, and trona is followed by salt or sodium sulfate. The study of systems of several salts is laborious, and but a comparatively few have been completely investigated.

The Formation of Salt Deposits

From the above considerations, it would be expected that an evaporating body of saline water would deposit layers of saline minerals with the least soluble at the base and the most soluble at the top. The final deposit should be a mixture of complex and highly soluble salts. In nature the complete series of saline minerals is rare, although it occurs at Stassfurt, Germany, and near Carlsbad, New Mexico. More commonly salt and gypsum occur together, but the minerals more soluble than salt are not present. Other deposits, including those in Bristol Lake, Danby Lake, and Death Valley, California, consist of salt only. Probably the origin of most saline deposits is complex because the simple desiccation of a body of saline water is likely to result in a deposit of mixed salts. The tide pool deposits found on the San Francisco Bay marshes consisted of sodium chloride heavily contaminated with the calcium and magnesium salts also present in sea water.

Deposits in Desert Basins

Although the undrained basins of the California deserts are ideal localities for the concentration of saline water, only a few contain crystal bodies. Most playas contain salines only in the form of thin, efflorescent crusts or of crystals disseminated in the mud. Foshag (1926) has pointed out that saline matter reaches the typical playa by underground circulation, and much of it is brought to the surface by capillary action where it forms efflorescent deposits. In addition, the high temperature and concentration of brine close to the surface cause a portion of the brine to diffuse downward to cooler layers where euhedral crystals form.

Crystal bodies seem to have formed only in basins that contained saline lakes and that received the clarified drainage from a large area for a long time. Salton Sea

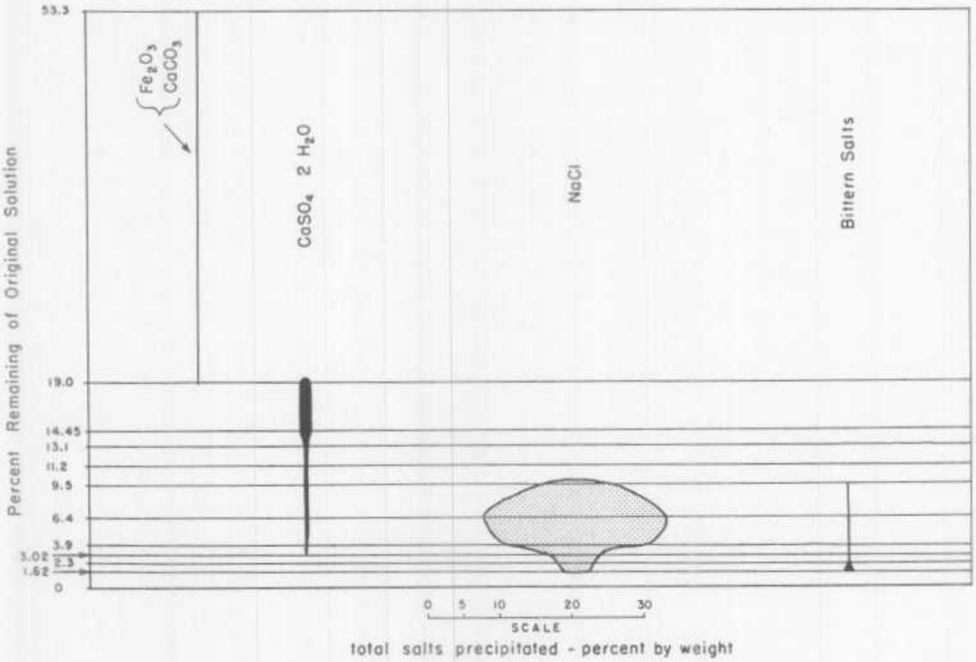

FIGURE 12.

is a saline lake in which fresh water containing but a few hundred parts per million of dissolved solids is being concentrated by evaporation. As described elsewhere in this report, evaporation from the surface of Salton Sea, amounting to 5 or 6 feet per year, is roughly balanced by inflows of fresh water from the irrigation systems of the Imperial and Coachella Valleys. Dissolved solids brought in with the irrigation water have accumulated in Salton Sea, and the salinity of its water more than doubled between 1916 and 1953. If existing conditions remain unchanged, the salinity will increase until the water is saturated with one or more salts.

Pleistocene Lake Deposits. In Pleistocene time some of the rivers that rise in the Sierras flowed far out into the desert, and many of the desert basins contained lakes. From old shore lines and channels cut in bedrock the stream pattern during the later glacial stages can be reconstructed, but erosion has largely obliterated the evidence left by lakes and streams in the earlier glacial stages.

The best known of the Pleistocene saline lake deposits are those of Searles Lake and Owens Lake. Gale (1913) and Blackwelder (1954) have described the Pleistocene Owens Valley drainage which flowed through Owens Lake, Haiwee Meadows, China Lake, and Indian Wells Valley to Searles Lake. At times Searles Lake had an outlet through Panamint Valley to Death Valley. Almost all the salines existing in Owens Lake and Searles Lakes were derived from Owens River.

Any lake in this chain that had an outlet must have contained fresh water. In 1912, when Owens Lake contained a saline body of water, Gale (1913) reasoned that the salts in it must have accumulated since the surface dropped below the level of the outlet. From the tonnage of salts in the lake and the annual contribution from the river, he calculated that the outlet ceased to flow about 4000 years ago. Following the completion of the Los Angeles aqueduct and the diversion of Owens River in 1913, Owens Lake has nearly evaporated. Today it contains a porous crystal body of mixed salts in equilibrium with saturated brine.

During two arid intervals Searles Lake was the sink of Owens River and received the entire flow, clarified in the basins upstream. The lower crystal body formed in the first interval and the upper crystal body in the second. Between the intervals of salt deposition the river flow was augmented, and Searles Lake contained fresh water or unsaturated brine. A layer of mud that was deposited protected the lower crystal body from solution. The age of this mud layer has been calculated by the carbon 14 method to be a little more than 16,000 years, and the upper crystal body is believed to have been deposited following the close of the Tioga glacial stage (Mumford, 1954). The lower crystal body may have formed following the Tahoe stage (Blackwelder, 1954).

At various times during the Pleistocene epoch Death Valley received the waters of the Owens, Mojave, and Amargosa Rivers, and it probably contained saline lakes during all the glacial stages (Blackwelder, 1954). No physiographic evidence for an outlet has been found, although the present distribution of fish suggests a Pleistocene connection between Death Valley and the Colorado River, possibly by way of the Bristol Basin and Danby Lake (Miller, 1946). The salt on the surface of the Death Valley floor was deposited from a comparatively small lake that occupied the valley in Tioga time; some of the buried salt beds may have been deposited from the larger Lake Manly of Tahoe age (Blackwelder, 1954).

In contrast with the complex saline deposits of Owens Lake and Searles Lake, the salines of the other Pleistocene lakes of California are comparatively simple. The crystal bodies of Death Valley, Bristol Lake, and Danby Lake consist of salt only; that of Dale Lake consists of salt and thenardite; and that of Cadiz Lake consists of salt and gypsum. One explanation is that because of particular local circumstances the lake brines contained little but the salts now present in the crystal bodies and mother liquors. A second explanation is that the concentration of the brine was maintained by some means in the precipitating ranges of gypsum, salt, and thenardite; and the brine never became saturated with the more soluble salts.

Pre-Pleistocene Deposits

Several deposits of saline minerals in California occur in Tertiary lake deposits not greatly different from the Pleistocene lake deposits. They have been more or less folded and faulted, and the mother liquor from which the salines crystallized has been drained away. Although many of the gypsum and borate deposits of California formed in Tertiary lakes, the Avawatz Mountains salt deposits are the only known Tertiary salt deposit in the state. The structure of the Avawatz Mountains deposits is so complex that the geologic history is obscure, but probably one or more saline lakes formed on a relatively flat surface. The precipitation of salines seems to have occurred at two distinct times separated by an interval when only clastic sediments were laid down. In the first, salt-precipitating conditions prevailed; and in the second, gypsum was formed.

For the great interbedded salt deposits of the world, a playa origin seems unlikely because of their size. They are commonly considered to have formed from the evaporation of large volumes of sea water in basins cut off from the open sea by tectonic movements, although a continental origin (Rutten, 1954) has been proposed for the Zechstein of Germany. The bar theory of Ochsenius (Grabau, 1920, pp. 128-130) supposes a basin having a constricted connection with the open sea in a region of high evaporation. The loss of water from the basin by evaporation would establish an inflow of sea water, and the salts thus brought into the basin would accumulate in it. Under stable conditions enough sea water might enter and evaporate to form a thick deposit of salts. Recently it has been shown (King, 1947; Scruton, 1953) that in an estuary with a restricted inlet where evaporation exceeds the inflow of fresh water, equilibrium is established between evaporation, supplies of fresh and sea water, and the return flow of concentrated brine to the open ocean. Under conditions of high evaporation the return flow is hindered by dynamic restrictions such as friction between currents as well as physical barriers such as a bar. A strong salinity gradient is set up with the salinity increasing away from

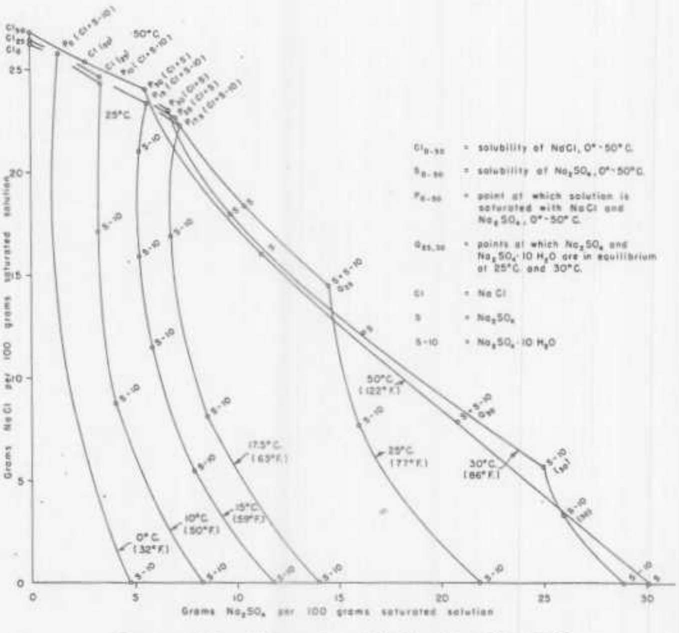

FIGURE 46. The system $NaCl - Na_2SO_4 - H_2O$

fate. At point P_1 the solution is saturated with both sodium chloride and sodium sulfate.

At higher temperatures the solubility curve is shifted to the right and at lower temperatures to the left. $Cl_2P_2S_2$ is the solubility curve at a lower temperature T_2.

An example will illustrate the practical significance of the solubility relations of sodium chloride and sodium sulfate. Let Q_2 be the composition of an unsaturated solution of temperature T_1. If the solution be evaporated the concentration will increase, but the proportions of chloride to sulfate remain the same. The composition will therefore reach point Q_2 on the solubility curve. Further evaporation will cause the precipitation of sodium chloride, and the composition will follow the solution curve toward P_1.

If, when the solution has reached the composition Q_3 the temperature falls to T_2, the solubility curve will be shifted to $Cl_2P_2S_2$. Point Q_3 will therefore fall in field III, and the solution will contain an excess of sodium sulfate. The line Q_3-Q_4 represents the precipitation of sodium sulfate resulting from the cooling of the solution from a temperature of T_1 to T_2.

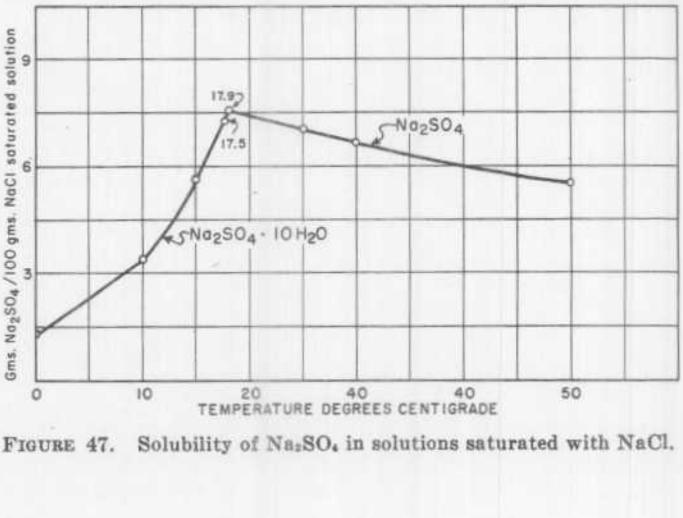

FIGURE 47. Solubility of Na_2SO_4 in solutions saturated with NaCl.

The third diagram represents the system $NaCl - Na_2SO_4 - H_2O$ at several temperatures drawn to scale. It will be noted that in the temperature range 0° C. to 50° C. the portion of the solubility curve ClP, in which sodium chloride is the solid phase, is shifted but slightly. At temperatures above 17.5° C. a third solid phase, anhydrous sodium sulfate, appears; and at above 32.75° C. hydrous sodium sulfate disappears entirely. As may be deduced from the first diagram, the solubility curve reaches its farthest point to the right at 32.75° C. At higher temperatures it shifts progressively to the left.

In the fourth diagram the P points are plotted against temperature. The curve shows the maximum sodium sulfate content of sodium chloride-sulfate solutions that yield sodium chloride upon evaporation.

California Practice

Salton Sea

Natural Conditions. The water of Salton Sea is a sodium chloride brine with an appreciable proportion of sodium sulfate. As mentioned in an earlier section of this report the proportion of sulfate seems to be increasing. The dissolved solids content, approximately that of sea water, was about 3.5 percent in November 1952. Rainfall in the area is about 2 inches per year, and the average evaporation rate determined by pan tests is 108 inches per year. From measurements of the sea level and estimates of the inflow made about 1910, the actual evaporation from the surface of Salton Sea itself has been computed to be 65 to 70 inches per year.

FIGURE 48. Imperial Salt Works, Salton Sea. Ruins of the washer. Between 1946 when the plant was last operated and 1954 Salton Sea rose about 5 feet and flooded the plant site.

At present overflow and drainage from the Imperial Valley irrigation system is more than enough to compensate for the loss of water from Salton Sea by evaporation. In recent years the level has been rising, and large areas along the flat southern and southeastern shores have been flooded.

The Imperial Salt Works. The Imperial salt works was the largest on Salton Sea and the last of a number of solar evaporation plants built by Seth and Chester Hartley. Salt was produced by them from 1935 through 1942. The operation was then sold to the Western Salt

Company, and Chester Hartley was retained as superintendent. Production was last reported in 1946. The washing plant and crystallizing ponds were under water in 1953.

The plant was 2 miles south and west of Frink Station on the shore of Salton Sea on land leased from the Imperial Irrigation District.

When in operation the plant had a capacity of 16,000 tons of salt a year obtained from 160 acres of concentrating ponds and 14½ to 15 acres of crystallizing ponds. Water was taken in through a canal roughly a quarter of a mile long driven approximately normal to the shore line and concentrated in two series of nine ponds, one on each side of the canal. The ponds were confined between end levees parallel to the canal and were separated by additional levees normal to the gentle slope of the land towards Salton Sea. A pump or pumps of 2700 gallons per minute capacity lifted water from the head of the canal to the first pond in each series. After the initial pump lift, the water flowed by gravity through the ponds, controlled by gates set in the dividing levees. In order to minimize stagnant areas, the intake point of each pond was at the corner diagonally opposite the outlet.

Evaporation in the concentrating ponds brought the brine to saturation with respect to sodium chloride. The first several ponds served also as settling basins in which insoluble matter, dead birds, and other rubbish were removed. In ponds seven and eight pink algae developed. The final pond, number nine or the gypsum pond, was filled with brine having a specific gravity of 22° Be, and pickle ready for the crystallizing ponds was withdrawn at 28.95° Be. At this concentration all traces of gypsum had precipitated.

The formation of gypsum in pond nine was so copious that within the life of the plant pond nine became entirely filled, and it was necessary to use pond eight as the gypsum pond.

The plant had two crystallizing ponds, each supplied from a series of concentrating ponds. Eight inches of pickle were kept on the salt formed, because this condition caused the maximum growth of half-ground-size crystals, the grade that was most readily marketed. Bittern was withdrawn at 31.85° Be and discarded.

The temperature was a critical factor because the bittern was rich in sodium sulfate. At less than about 38° F. sodium sulfate would precipitate in the crystallizing ponds on the salt already formed. In order to prevent this "freezing out" of sodium sulfate, the harvest was started early in October.

The salt was harvested once a year. The crystallizing ponds were drained and harvested at once before the exposed salt hardened. A dragline scraper lifted the salt and loaded it into side dump cars that were hauled to the washer by a gasoline locomotive. Two portable runways 4 feet wide built of planks were laid on the salt to support the treads of the dragline. At the washer cars were dumped into a pit large enough to accommodate five cars at a time. The salt received three washes with pickle, and the dirty wash brine was clarified in a settling pond before being used again.

Mullet Island Salt Works. The Mullet Island salt works of the Reeder Salt Company was near Mullet Island in section 9, T. 11 S., R. 13 E., S.B. on land leased from the Imperial Irrigation District. Production was reported from 1940 to 1942 inclusive and a small production was reported from the same locality in 1919 and 1934.

Salt was produced by the solar evaporation of the water of Salton Sea supplemented with brine from an artesian well on Mullet Island. Some bittern, recorded in the statistics files of the Division of Mines as calcium chloride, was sold for laying dust on roads. In the early operations well brine only was evaporated. An analysis of the well brine is included in table 2.

The Reeder plant contained a series of three concentrating ponds. In the first the concentration was raised to 30 percent of saturation, to 50 percent in the second, and to 70 percent in the third. The concentrated brine was pumped to crystallizing ponds where salt formed. A portion of the bittern was pumped out of the crystallizing ponds while crystallization was in progress, but most of the bittern was discarded just before the harvest. Much of the salt produced was used locally for the icing of refrigerator cars.

The Salton Works. The Salton works, the first solar evaporation plant built on Salton Sea by Seth Hartley, was on the north shore 6 miles southeast of Mecca. It was active from 1927 to about 1930. Four concentrating ponds totaling 250 acres in area supplied pickle to 12 acres of crystallizing ponds. A crop of about 1500 tons was harvested in 1929, but little if any of it was marketed.

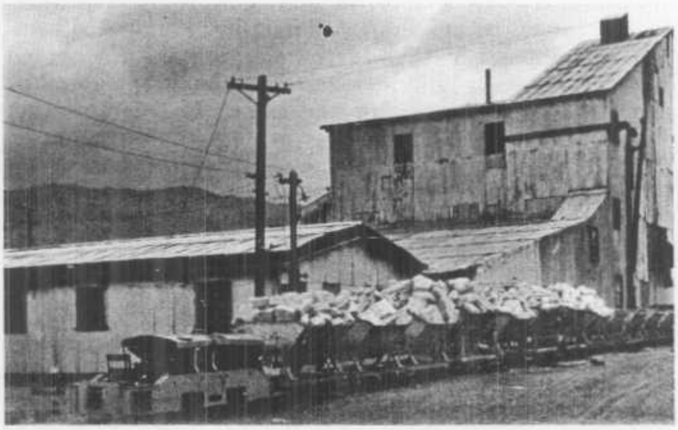

FIGURE 49. Long Beach Salt Company, Saltdale plant. The mill and train of salt blocks from the crystallizing ponds.

Saltdale Works, Long Beach Salt Company *

The Saltdale works of the Long Beach Salt Company is in section 3, T. 30 S., R. 38 E., M.D. (projected) at Saltdale on the north margin of Koehn Dry Lake. Salt has been produced intermittently since 1914. The Long Beach Salt Company acquired the operation in 1928, and the Western Salt Company has owned the Long Beach Salt Company since 1950.

Salt is produced by the solar evaporation of the surface brine of Koehn Lake. The operation is dependent upon the run off of storm water from the surrounding mountains which collects in the lake and dissolves a thin

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* Plant visits April 1953, February 1955.

the rate of 50,000 pounds a year. The product was used by the Hercules Powder Company as an absorbent in the manufacture of dynamite. The bittern after the removal of sulfate with calcium hydroxide, was treated with carbon dioxide gas obtained by burning coke; and the magnesium carbonate precipitate was filtered and dried (Hanks, 1882, p. 223).

The manufacture of magnesium oxychloride cement created a market for magnesium chloride, and this salt was produced at San Diego Bay prior to the failure of the Otay Dam in 1916 (Mason, 1919, p. 530). Salt works bittern was evaporated to precipitate the remaining sodium chloride and sulfates, yielding an impure magnesium chloride liquor. Following the flood the salt plant was rebuilt, but bittern salts were not recovered for a number of years.

The shortage of chemicals during World War I created a new interest in bittern. Several plants were built in which, by further evaporation of the bittern in vacuum pans followed by cooling, sodium chloride, magnesium sulfate, and carnallite ($KCl \cdot MgCl_2 \cdot 6H_2O$) were precipitated, leaving a magnesium chloride mother liquor. Magnesium chloride was produced in both liquid and solid form, and some plants recovered magnesium sulfate and potassium chloride also (Tressler, 1923, pp. 66-69). Production by the Oliver Salt Company at Mount Eden and the Marine Chemical Company at Long Beach began in 1916. The Whitney Chemical Company, a subsidiary of the Leslie Salt Refining Company, followed in 1917; and in 1919 the California Chemical Company began production at Chula Vista.

The National Kellestone Company, a large manufacturer of oxychloride cement, decided to enter the magnesium chloride field and organized a subsidiary, the California Chemical Corporation. In 1923 the plant of the California Chemical Company at Chula Vista was purchased, and a much larger plant was built that is still in operation. The management of the California Chemical Company then built another plant at Newark and operated it under the name of Industrial Chemical Corporation until 1927.

When chemicals became plentiful again, the California magnesium chloride producers operated at a disadvantage; and by 1928 all but the California Chemical Corporation had ceased production. Then the California Chemical Corporation arranged long-term contracts for bittern with the salt companies on San Francisco Bay and purchased the small plant of the Industrial Chemical Corporation at Newark.

Because the market for magnesium chloride was limited, the California Chemical Corporation developed ways to recover additional commodities from bittern. Bromine was produced for the first time in California in 1926. The plant, at Chula Vista, contained a Kubierschky tower in which chlorine displaced bromine from the bittern; and it operated until 1946. A second tower was operated at San Mateo until late 1929 or early 1930; and a larger plant with three towers was built at Newark in 1931. Research was also initiated on the precipitation of magnesium hydroxide from bittern with lime. The calcination of San Francisco Bay shells to form the lime required was studied in a small plant at Newark that began commercial production in the fall of 1930. A pilot plant was then built at Newark in which magnesium hydroxide precipitated from bittern with lime could be carbonated to make basic magnesium carbonate or calcined to make magnesia. In February 1937, soon after the operation was acquired by Westvaco Chlorine Products Corporation, construction began on a magnesia plant at Newark. Today Westvaco Chemical Division of Plant Food Machinery & Chemical Corporation, successor to the California Chemical Corporation and Westvaco Chlorine Products Company, produces magnesia, bromine, and gypsum products at Newark and magnesium chloride at Chula Vista.

The Plant Rubber and Asbestos Company at Redwood City also produced magnesia from bittern between 1933 and 1941. In this operation magnesium hydroxide was precipitated with crude soda ash made by calcining trona ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$). The magnesium hydroxide was converted to basic magnesium carbonate and used for thermal insulation.

SALT IN THE DESERT

Although the large scale production of salt from sources other than sea water did not begin until World War II, most of the desert salt operations date back to the World War I period. Some operations originated in the late 19th century.

Salton Sea

The salt deposits of the Salton Sea region were known and described as early as 1848 and were worked on a small scale. The first organized production, however, came in 1884 (Bailey, 1902, p. 124) when the New Liverpool Salt Company commenced operations. The plant, at the north end of Salton Sink, was connected with the railroad at Salton by a mile long spur. Several methods of operation have been described, but most of the salt was scraped from the playa crust with plows.

The New Liverpool Salt Company's works were destroyed by the flood of 1905 and 1906 which left the property 60 feet beneath the surface of Salton Sea. No more salt was produced from Salton Sea until, in 1927, Seth Hartley began experimenting with solar evaporation near Caleb at the north end of the sea. A crop of 1500 tons was harvested in 1929 (Tucker and Sampson, 1929, p. 526), but no further activity has been recorded. Seth Hartley and his son Chester, however, built two more solar salt plants. The last and largest was the Imperial Salt Works near Frink which was brought into production in 1935. In 1943 the Western Salt Company bought the plant; and in 1947, after the precipitation of sodium sulfate caused the loss of a year's crop, the operation was abandoned.

The only other production of salt by solar evaporation in this area has been near Mullet Island. In 1919 the Mullet Island Paint Company produced some salt from salt springs and in 1934 the Mullet Island Development Company obtained salt from well brine. The Reeder Salt Company's Mullet Island Salt Works, productive from 1940 through 1942, evaporated Salton Sea water supplemented with well brine.

Bristol Lake

The California Salt Company may be traced back to the Crystal Salt Company of California. The claims were located for calcium chloride, and the production

Table 1. California brines (lakes and playas).

	Percent of the dissolved solids																					
	Sea water, mean of 77 analyses (1)	Sea water bittern (2)	Salton Sea June 3, 1907 (3)	Colorado River at Yuma (4)	Hypothetical original Salton Sea (5)	Salton Sea June 10, 1916 (6)	Salton Sea March 21, 1929 (7)	Salton Sea Nov. 23, 1953 (8)	Dale Lake (9)	Danby Lake (10)	Cadiz Lake (11)	Bristol Lake (12)	Soda Lake (13)	Mojave River at Victorville (14)	Saline Valley (15)	Death Valley (16)	Mono Lake (17)	Deep Springs Lake, Inyo County (18)	Black Lake, Mono County (19)	Borax Lake, Lake County (20)	Searles Lake (21)	Owens River at Charlies Butte (22)
Cl	55.292	51.0	47.83	19.92	52.62	49.2	50.9	43.8	44.7	44.17	60.82	61.95	40.84	5.29	48.6	46.81	23.34	32.97	7.68	32.27	38.51	9.5
Br	0.188	0.5	Tr	---	Tr	---	---	---	---	---	---	---	---	---	---	---	---	---	Tr	0.04	0.25	---
SO_4	7.692	16.6	13.41	28.61	11.0	13.0	11.0	20.0	15.8	4.94	0.38	0.08	17.05	6.98	12.1	14.81	12.86	22.32	13.24	0.13	13.21	15.5
B_4O_7	---	---	---	---	---	---	---	---	Tr	---	---	0.01	0.68	---	Tr	0.44	0.32	0.42	Tr	5.05	3.66	---
CO_3	0.207	---	1.85	13.02	---	0.7	0.8	0.6	---	---	---	---	3.95	36.08	---	---	23.42	5.47	37.73	22.47	7.90	29.9
HCO_3	---	---	---	---	---	---			---	Tr	---	---	---	---	0.2	---	---	---	---	---	---	---
Na	30.593	16.8	31.29	19.75	33.14	33.0	31.2	30.0	36.7	50.73	30.71	20.55	37.43	13.21	36.4	36.5	37.93	33.18	39.05	38.10	28.72	19.8
K	1.106	3.3	0.65	2.17	0.30	0.4			0.02	---	1.41	1.18	Tr		1.2	1.35	1.85	5.64	2.03	1.52	7.73	
Ca	1.197	---	2.80	10.35	1.37	1.9	1.6	2.7	---	0.12	6.12	15.51	---	13.23	0.05	---	0.04	---	---	0.03	---	8.9
Mg	3.725	11.8	1.81	3.14	1.81	1.7	4.5	2.7	---	0.04	0.56	0.38	---	2.51	<0.01	0.05	0.10	---	---	0.35	---	3.4
Fe_2O_3	---	---	0.002	---	---	Tr	---	---	---	---	---	---	---	0.27	---	---	Tr	---	---	0.01	---	0.1
Al_2O_3	---	---	0.016	---	---	---	---	---	---	---	---	---	---	---	---	---	Tr	---	---		---	---
SiO_2	---	---	0.26	3.04	---	0.1	---	---	---	---	---	---	---	22.05	---	---	0.14	---	0.20	0.01	---	12.4
Misc. and organic	---	---	0.08	---	---	---	---	---	2.7	---	---	0.34 (Sr)	---	0.38 (NO_3)	1.4	---	---	---	Tr (Li, PO_4)	0.01 (PO_4)	0.02 (Li)	0.5 (NO_3)
Dissolved solids, ppm	35,000±	293,800	3,648	702	---	16,472	31,050	35,545	*298,000	271,200	73,600	279,149	305,137	113.4	*355,100	299,500	51,170	203,800	18,500	76,560	344,431	339
NaCl, % of dissolved solids	77.76	42.6	---	---	---	---	---	---	73.8	92.5	78.04	66.9	67.19	---	---	---	37.1	45.98	9.73	51.0	46.5	---

* Grams per liter.

(1) Sea water, mean of 77 analyses: Clarke, F. W., 1924a, The data of geochemistry: U. S. Geol. Survey Bull. 770, p. 127, analysis A.

(2) Sea water bittern: Recalculated from Seaton, M. Y., 1931, Bromine and magnesium compounds drawn from western bays and hills: Chem. and Met. Eng. vol. 38, no. 11, Nov.

(3) Salton Sea, June 3, 1907: Ross, W. H., 1914, Chemical composition of the water of Salton Sea and its annual variation in concentration, 1906-11, in MacDougal, D. T., and others, The Salton Sea: Carnegie Inst. Washington Pub. 193, p. 41, table 9.

(4) Colorado River at Yuma: Clarke, F. W., 1924b, The composition of river and lake waters of the United States: U. S. Geol. Survey Prof. Paper 135, p. 132, analysis 3.

(5) Hypothetical original Salton Sea: Ross, W. H., 1914, p. 45, table 15, analysis B.

(6) Salton Sea, June 10, 1916: Recalculated from MacDougal, D. T., 1917, A decade of the Salton Sea: Geog. Rev. vol. 3, no. 6, p. 468.

(7) Salton Sea, March 21, 1929, Sample from the center of the sea: Recalculated from Coleman, G. A., 1929, A biological survey of Salton Sea: California Div. Fish and Game, California, Fish and Game, vol. 15, pp. 221, 222.

(8) Salton Sea, Nov. 23, 1953, Salton Sea beach: Recalculated from analysis furnished by Imperial Irrigation District.

(9) Dale Lake: Recalculated from King, C. R., 1948, Soda ash and salt cake in California: California Jour. Mines and Geology, vol. 44, p. 190, table 1.

(10) Danby Lake, test well in sec. 22, T. 2N., R. 17E., SB: Recalculated from analysis furnished by Metropolitan Water District of Southern California.

(11) Cadiz Lake: Gale, H. S., and Hicks, W. B., 1920, Potash: U. S. Geol. Survey Min. Res. U. S., 1917, vol. 2, p. 418.

(12) Bristol Lake, sample from "canal" of National Chloride Co. of America: Recalculated from Durrell, Cordell, 1953, Celestite deposits at Bristol Dry Lake, San Bernardino County, California: California Div. Mines Special Rept. 32, p. 13, analysis II.

(13) Soda Lake: Clarke, F. W., 1914, Water analyses from the laboratory of the United States Geological Survey: U. S. Geol. Survey Water-Supply Paper 364, p. 33, analysis Q.

(14) Mohave River at Victorville: Clarke, F. W., 1924b, p. 132, analysis 3.

(15) Saline Valley: Recalculated from King, C. R., 1948, p. 190, table 1.

(16) Death Valley, well no. 200 at 38 feet: Gale, H. S., 1914, Prospecting for potash in Death Valley, California: U. S. Geol. Survey Bull. 540, p. 411.

(17) Mono Lake: Clarke, F. W., 1924a, p. 162, analysis A.

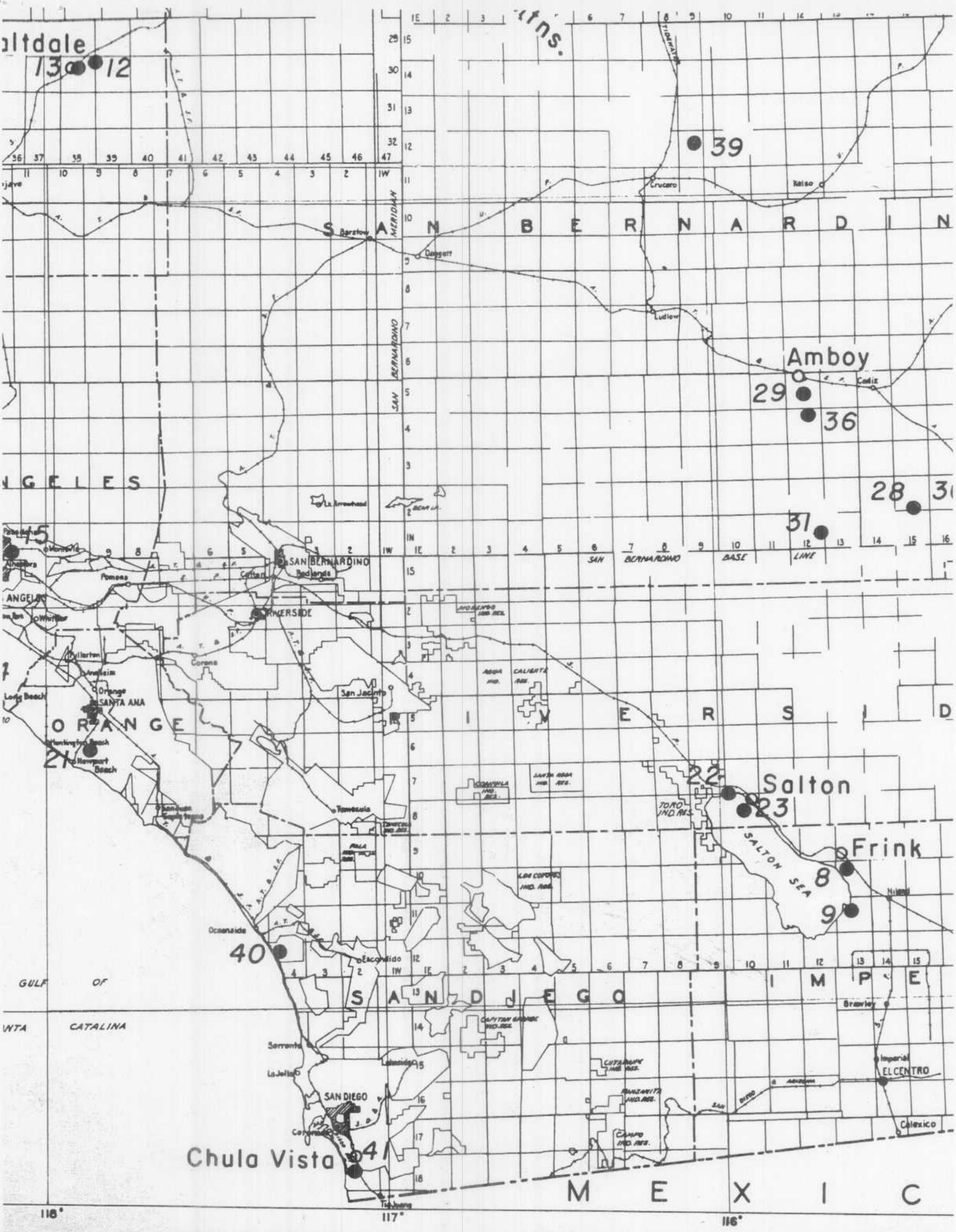
(18) Deep Springs Lake, Inyo County: Recalculated from Tucker, W. B., and Sampson, R. J., 1938, Mineral resources of Inyo County: California Div. Mines Rept. 34, p. 497.

(19) Black Lake, Mono County: Clarke, F. W., 1924a, p. 162, analysis F.

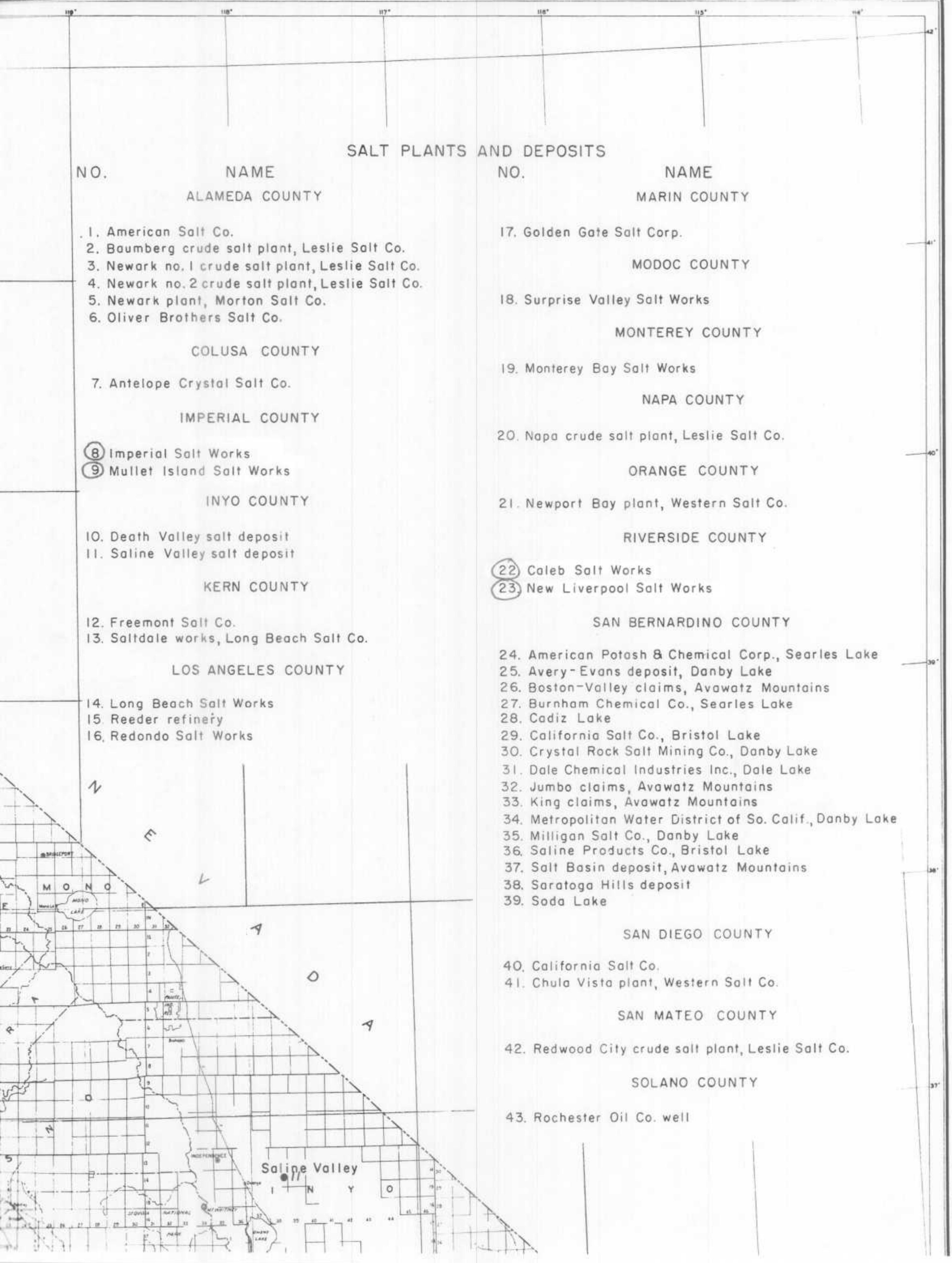
(20) Borax Lake, Lake County: Clarke, F. W., 1924a, p. 162, analysis H.

(21) Searles Lake, upper structure brine: Recalculated from Ryan, J. E., 1951, Am. Inst. Min. Met. Eng. Trans. vol. 190, p. 449, table 1.

(22) Owens River at Charlies Butte, mean of 36 10-day composite samples: Van Winkle, Walton, and Eaton, F. M., 1910, The quality of the surface waters of California: U. S. Geol. Survey Water-Supply Paper 237, p. 121.



altdale
13
12
39
Crucero
Kelso
Barstow
Daggett
Ludlow
Amboy
Cadiz
29
36
28
31
SAN BERNARDIN
SAN BERNARDINO MERIDIAN
SAN BERNARDINO BASE LINE
NGELES
Pasadena
Monrovia
Alhambra
15
Pomona
SAN BERNARDINO
Redlands
Colton
RIVERSIDE
Whittier
Fullerton
Anaheim
Orange
SANTA ANA
Corona
San Jacinto
Lk. Arrowhead
BEAR LK.
ORANGE
Huntington Beach
Newport Beach
21
San Juan Capistrano
Temecula
RIVERSID
Salton
22
23
SALTON SEA
Frink
8
9
Niland
Oceanside
40
Escondido
GULF OF SANTA CATALINA
SAN DIEGO
IMPE
Brawley
Imperial
EL CENTRO
Calexico
Sorrento
La Jolla
Lakeside
SAN DIEGO
Coronado
Chula Vista
41
Tia Juana
MEXIC
118°
117°
116°



SALT PLANTS AND DEPOSITS

NO. NAME

ALAMEDA COUNTY

1. American Salt Co.
2. Baumberg crude salt plant, Leslie Salt Co.
3. Newark no. 1 crude salt plant, Leslie Salt Co.
4. Newark no. 2 crude salt plant, Leslie Salt Co.
5. Newark plant, Morton Salt Co.
6. Oliver Brothers Salt Co.

COLUSA COUNTY

7. Antelope Crystal Salt Co.

IMPERIAL COUNTY

⑧ Imperial Salt Works
⑨ Mullet Island Salt Works

INYO COUNTY

10. Death Valley salt deposit
11. Saline Valley salt deposit

KERN COUNTY

12. Freemont Salt Co.
13. Saltdale works, Long Beach Salt Co.

LOS ANGELES COUNTY

14. Long Beach Salt Works
15. Reeder refinery
16. Redondo Salt Works

NO. NAME

MARIN COUNTY

17. Golden Gate Salt Corp.

MODOC COUNTY

18. Surprise Valley Salt Works

MONTEREY COUNTY

19. Monterey Bay Salt Works

NAPA COUNTY

20. Napa crude salt plant, Leslie Salt Co.

ORANGE COUNTY

21. Newport Bay plant, Western Salt Co.

RIVERSIDE COUNTY

㉒ Caleb Salt Works
㉓ New Liverpool Salt Works

SAN BERNARDINO COUNTY

24. American Potash & Chemical Corp., Searles Lake
25. Avery-Evans deposit, Danby Lake
26. Boston-Valley claims, Avawatz Mountains
27. Burnham Chemical Co., Searles Lake
28. Cadiz Lake
29. California Salt Co., Bristol Lake
30. Crystal Rock Salt Mining Co., Danby Lake
31. Dale Chemical Industries Inc., Dale Lake
32. Jumbo claims, Avawatz Mountains
33. King claims, Avawatz Mountains
34. Metropolitan Water District of So. Calif., Danby Lake
35. Milligan Salt Co., Danby Lake
36. Saline Products Co., Bristol Lake
37. Salt Basin deposit, Avawatz Mountains
38. Saratoga Hills deposit
39. Soda Lake

SAN DIEGO COUNTY

40. California Salt Co.
41. Chula Vista plant, Western Salt Co.

SAN MATEO COUNTY

42. Redwood City crude salt plant, Leslie Salt Co.

SOLANO COUNTY

43. Rochester Oil Co. well

Salt Institute

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