



The Geology and Economic Development of Searles Lake

by
Gail Moulton¹ and Ken Santini²

ABSTRACT

Searles Valley is located approximately 125 miles northeast of Los Angeles in the Basin and Range Province. Occupying the lowest part of the valley is Searles Dry Lake Playa, which is about 9 miles long and 7 miles wide. Three major subsurface evaporite horizons have been identified and are termed from bottom to top, the Mixed Layer, Lower Salt and Upper Salt. The evaporite beds were formed by desiccation of runoff from the eastern Sierra Nevada during Quaternary time. The saline beds are generally brine saturated with the important ions being sodium, potassium, carbonate, bicarbonate, sulfate, chloride and borate. These ions are present in the brines in various concentrations and have combined to form the minerals halite, hanksite, trona, nahcolite, burkeite, borax, thenardite, sulfahalite, glaserite and others. North American Chemical Company selectively pumps the interstitial brines to feed their chemical plants located on the western edge of Searles Lake. Minerals have been mined since 1873, beginning with borax and trona scraped from the surface. Brine processing began in 1914 with potassium chloride and borax recovery. Expansions have added sodium sulfate and soda ash to the product mix. Currently, dredging of trona ore is also taking place.

INTRODUCTION

Searles Valley, approximately 125 miles northeast of Los Angeles, is near the southwest corner of the Basin and Range Province and just north of the Mojave Desert. Occupying the lowest part of the valley is Searles Dry Lake Playa, which is approximately 9 miles long (north to south) and 7 miles wide (east to west). See Figure 1. The playa covers about 40 square miles at an elevation ranging from 1614 to 1624 feet above sea level. Mud forms much of the surface, although nearly pure halite crops out over an area of approximately 12 square miles in the center. See Figure 2.

To the west and northwest of Searles Valley is the southern half of the Argus Range. The highest elevation in the Searles Valley area is Argus Peak with a summit of about 6562 feet above sea level. On the southwest are the Spangler Hills, the El Paso Mountains and the Lava Mountains. Also located on the southwest part of Searles Valley is the Pinnacles National Scenic Area. The Pinnacles are a unique geologic feature composed of vertical tufa spires up to 140 feet in height. They occur in what was an arm-like bay on the southwest side of the former lake, and were formed by tufa precipitating around the

orifices of springs. To the southeast are the Granite Mountains. Well developed, coalescing alluvial fans extend into the valley from the Slate Range to the east. The fans in the Argus Range are not as well developed.

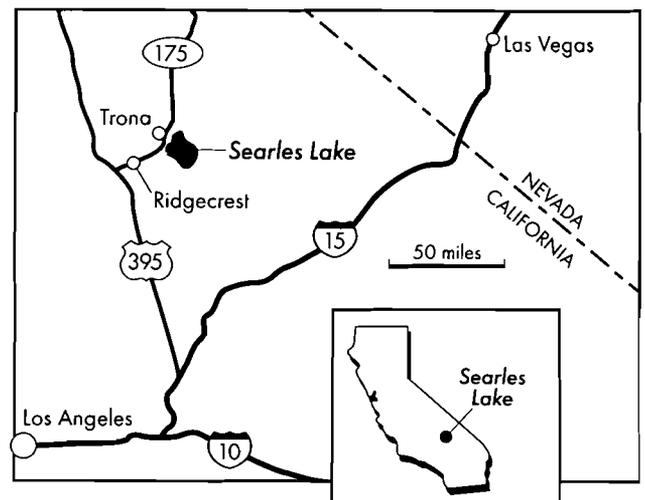


Figure 1. Location of Searles Lake, CA.

¹North American Chemical Company, P.O. Box 367, Trona, CA 93562

²Santini and Associates, 1396 S. Ward Way, Lakewood, CO 80228

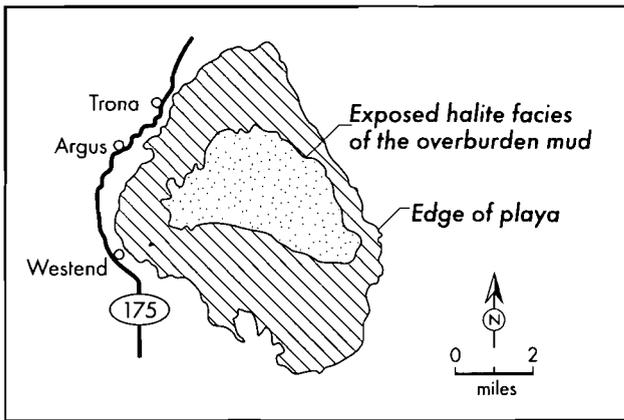


Figure 2. Searles Dry Lake Playa.

GEOLOGY

Searles Valley is a closed structural basin filled with alluvium and non-marine evaporites. The thickness of the fill ranges from zero at the periphery to over 3,000 feet in the deepest portions of the basin. A core hole (KM-3), drilled in 1968, intersected basement rock at a depth of 3,003 feet. The bedrock found is quartz monzonite, which is also the major rock type of the Argus and northern Slate Ranges. In Searles Lake, brine-bearing evaporite horizons alternate with mud beds. See Figure 3. Evaporite horizons were formed during periods of high evaporation and low rainfall. The resulting beds are generally thicker in the lake center, and thin toward and eventually pinch out at the edges of the lake. Mud beds were formed during full lake conditions, and in most cases, become thicker toward the edges, grading into coarse, clastic sediments at the base of the mountains.

The saline beds are generally brine saturated, white to pink in color, hard and very porous. The important ions are Na⁺ (sodium), K⁺ (potassium), CO₃²⁻ (carbon-

Table 1. Minerals associated with the saline horizons.

Borax	Na ₂ B ₄ O ₇ • 10H ₂ O
Burkeite	2Na ₂ SO ₄ • Na ₂ CO ₃
Glaserite	K ₃ Na(SO ₄) ₂
Halite	NaCl
Hanksite	9Na ₂ SO ₄ • 2Na ₂ CO ₃ • KCl
Nahcalite	NaHCO ₃
Northupite	Na ₂ CO ₃ • MgCO ₃ • NaCl
Sulfohalite	2Na ₂ SO ₄ • NaCl • NaF
Teepleite	Na ₂ B ₂ O ₄ • 2NaCl • 4H ₂ O
Thenardite	Na ₂ SO ₄
Tincalconite	Na ₂ B ₄ O ₇ • 5H ₂ O
Trona	Na ₂ CO ₃ • NaHCO ₃ • 2H ₂ O

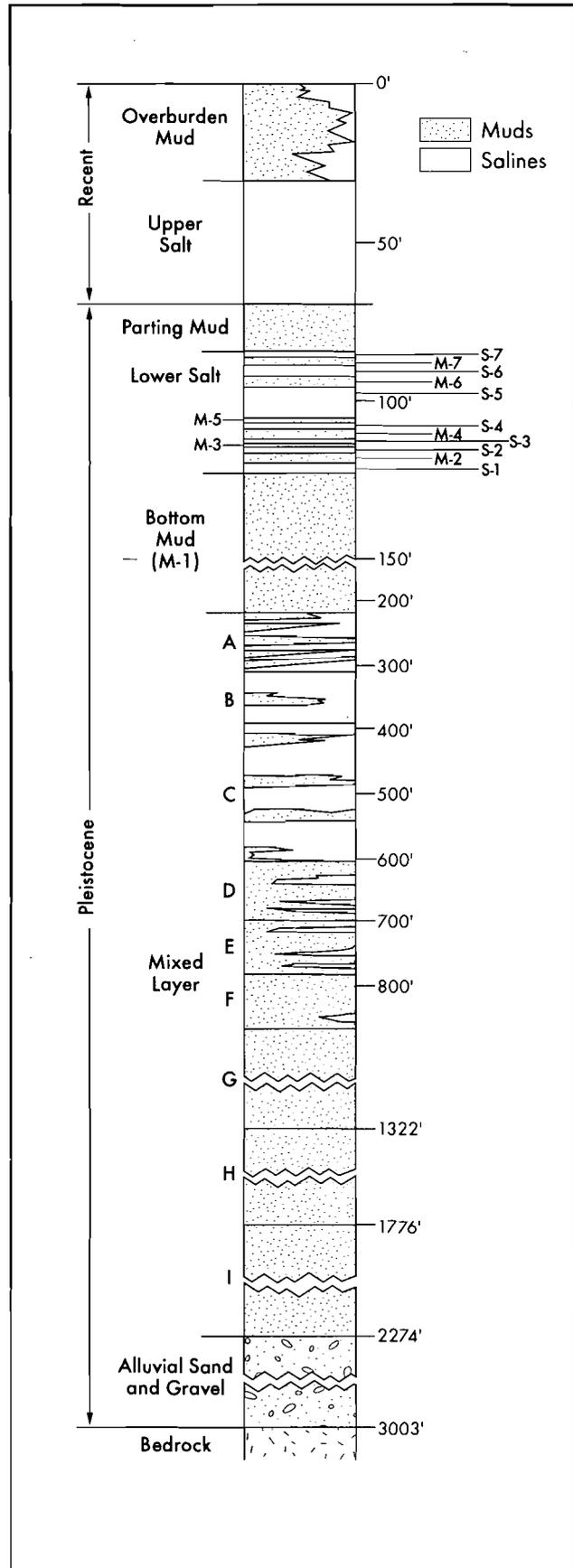


Figure 3. Stratigraphic column.

ate), HCO_3^- (bicarbonate), SO_4^{2-} (sulfate), Cl^- (chloride) and $\text{B}_2\text{O}_7^{2-}$ (borate). These ions are present in the brines in various concentrations, and have combined to form the major evaporite minerals of halite, hanksite, trona, nahcolite, burkeite, borax, thenardite, sulfohalite and glaserite. See Table 1.

The mud beds, in general, are dark green to brown, soft, porous, and may have a distinct mercaptan (rotten eggs) odor. The important ions in the muds are Ca^{2+} (calcium), Na^+ (sodium), Mg^{2+} (magnesium) and CO_3^{2-} (carbonate). These have precipitated as fine-grained aragonite and dolomite, in addition to fine and coarse-grained gaylussite and pirssonite. The surface mud bed (Overburden Mud) also contains halite, borax, hanksite, trona and thenardite locally.

Mixed Layer

The Mixed Layer is a sequence of mud and evaporite beds overlying arkosic sand and gravel. See Figure 3. The lowermost muds were estimated to be 3.2 million years old (Smith, 1979). Although the lateral and vertical extent of the Mixed Layer beds have not been fully explored, they are known to cover less area than younger, near surface evaporites. See Figure 4. The Mixed Layer also has a complicated structure, including tight folds and faults, which are not found in the younger Bottom Mud above.

The upper Mixed Layer is divided into several units based on differences in electrical conductivity and mineral composition, while the lower Mixed Layer is divided on the basis of mineral composition alone. There are a total of nine units present (A to I). Since the upper Mixed Layer evaporite horizons are predominantly trona and nahcolite, the resulting interstitial brines are high in sodium

carbonate and low in sodium chloride. Thus, these horizons are of value as a soda ash source. In contrast, the lower Mixed Layer evaporite horizons consist mostly of halite and thenardite, which makes them unsuitable as a soda ash source. When these latter two minerals dissolve, they prevent carbonate minerals from dissolving, resulting in a low sodium carbonate grade.

Bottom Mud

The Bottom Mud is underlain by the Mixed Layer and overlain by the Lower Salt. This mud horizon covers a much larger areal extent than the saline beds above. It is about 100 feet or greater in thickness and forms a bowl-shaped structure with the thickest part near the lake center. The unit is composed of mud beds with abundant gaylussite and minor dolomite, calcite, halite, thenardite, mirabilite, trona and borax.

Lower Salt

The Lower Salt is underlain by the Bottom Mud and overlain by the Parting Mud. Thickness ranges from approximately 40 feet in the lake center to zero at the edges. It is composed of seven evaporite beds separated by six mud beds. The evaporite beds are predominantly trona and halite, although borax, burkeite, nahcolite and northupite are also found.

The mud beds are composed of dark, clay-sized saline and clastic minerals, in addition to megascopic crystals of gaylussite, pirssonite, halite and borax.

Lateral changes from the lake center to the edges include (1) an increase in the carbonate content of the brine; (2) a decrease in halite content and (3) a thickening of the mud beds.

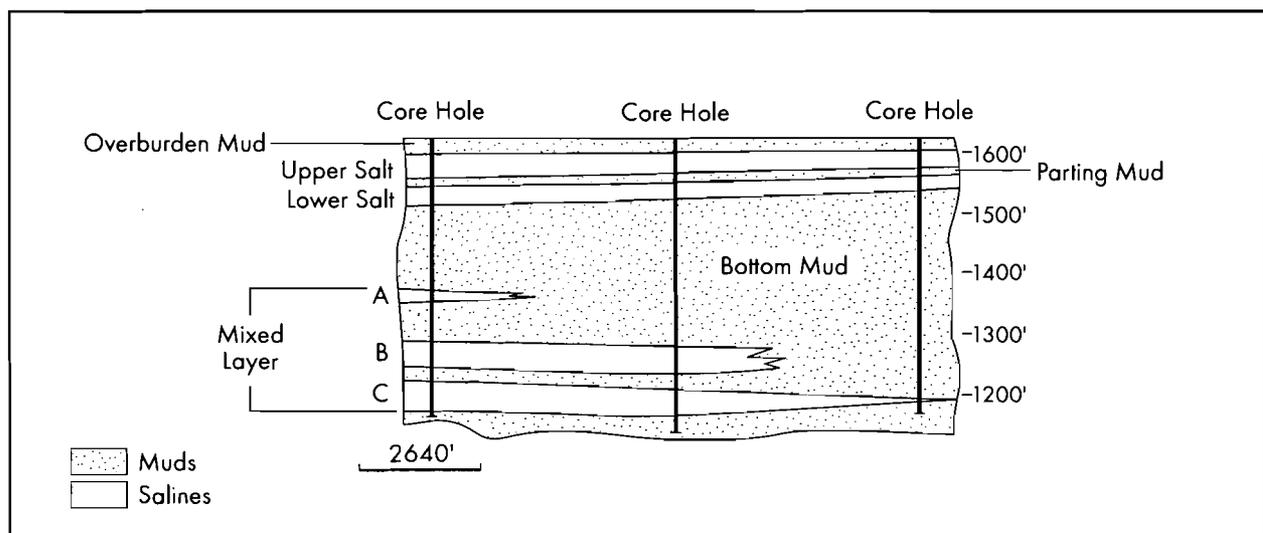


Figure 4. Geologic Cross section (looking north).

Parting Mud

The Parting Mud is underlain by the Lower Salt and overlain by the Upper Salt in the central part of the lake. It is in contact with the Bottom Mud and Overburden Mud around the edges of the lake. The horizon is approximately 10 feet thick in the lake center and thickens to 26 feet or more toward the edges. On the periphery of the lake, this mud unit is difficult to distinguish from the Bottom and Overburden Muds.

The Parting Mud is composed of saline and clay-sized clastic minerals, as well as abundant megascopic pirssonite and gaylussite with minor amounts of borax, northupite, trona and hanksite. The content of soluble minerals may exceed 50 percent in some areas.

Upper Salt

The Upper Salt is underlain by the Parting Mud and overlain by the Overburden Mud. It ranges in thickness from about 75 feet at the lake center to zero along the edges.

The unit can be divided into two members. The lower member extends to the outer edges of the lake and is composed mostly of beds of trona and halite. Thin beds of hanksite and borax, and minor amounts of burkeite and thenardite are also found. Similar to the Lower Salt, the halite content decreases toward the lake edges. The lower member of the Upper Salt is generally thin in the lake center and thickens toward the edges, before it pinches out. However, this is not true on the east side of the lake, where the bed thins abruptly. The upper member of the Upper Salt is thickest at the lake center, and thins toward the edges. It is composed of halite and hanksite with some trona beds, and minor amounts of borax and sulfohalite.

Overburden Mud

The Overburden Mud is underlain by the Upper Salt. It is characterized by two facies. The central facies is approximately 23 feet thick and is composed of alternating saline and mud beds. Most of the salines are halite, however, locally beds of hanksite, trona, borax and thenardite are found. Pirssonite also occurs in this facies. Toward the edges of the lake, the halite facies grades into a dark brown to black pirssonite-bearing mud, which is up to 33 feet thick. This mud unit, in turn, grades into silt, sand and gravel.

GEOLOGIC ENVIRONMENT AND HISTORY

Searles Valley contained a series of lakes for much of the last 3.2 million years. During pluvial periods of the Pleistocene, Searles Lake was the third in a chain of five lakes, which received water from Owens River. See Figures 5 and 6. Owens River received most of its water from the eastern slopes of the Sierra Nevada and transported it

to Owens Lake. Although, during some periods, Mono Lake and tributaries to that basin, also added their waters to those of Owens River. When Owens Lake filled to a level about 200 feet above its present surface, it overflowed southward into China Lake. China Lake, in turn, overflowed eastward into Searles Valley to form Searles Lake. During its highest stages, Searles Lake stood at a level 640 feet above the present valley floor, and coalesced with China Lake to form one body of water. This large lake overflowed around the south end of the Slate Range into Panamint Valley, where a lake 60 miles long and 930 feet deep was formed. Panamint Lake, in turn, spilled over Wingate Pass into Death Valley. However, Searles Lake was usually the last in the chain and, as a result, underwent extreme fluctuations in lake level. With the large combined drainage area of the connected lakes, small changes in regional precipitation drastically altered the quantity of water flowing into Searles Lake. When the lake was cut-off from upstream water, inflow was greatly reduced and evaporation quickly converted Searles into a small saline lake or salt playa. The periods when precipitation increased enough to restore inflow from upstream, the basin would fill, occasionally reaching overflow at approximately 460 feet above the present surface.

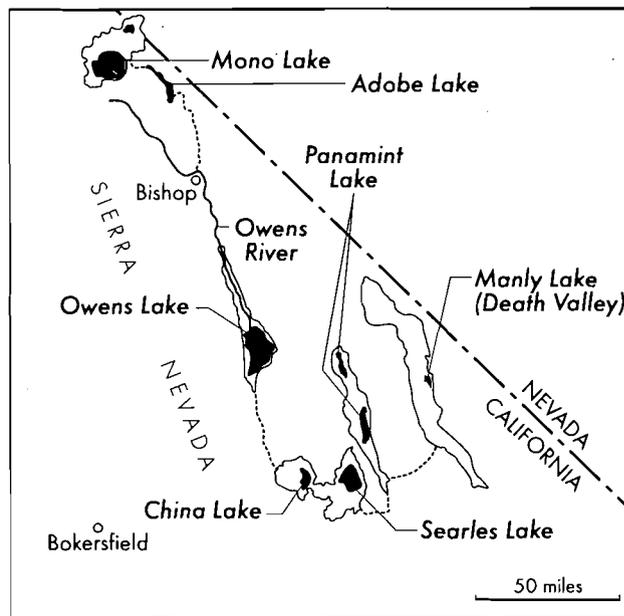


Figure 5. Pleistocene lakes of the Owens river system.

The large volume of components in the evaporite horizons of Searles Lake was introduced into the valley by water. Many of the components are found in almost all waters draining from bedrock terrane, among them, calcium, sodium, potassium and magnesium. All natural

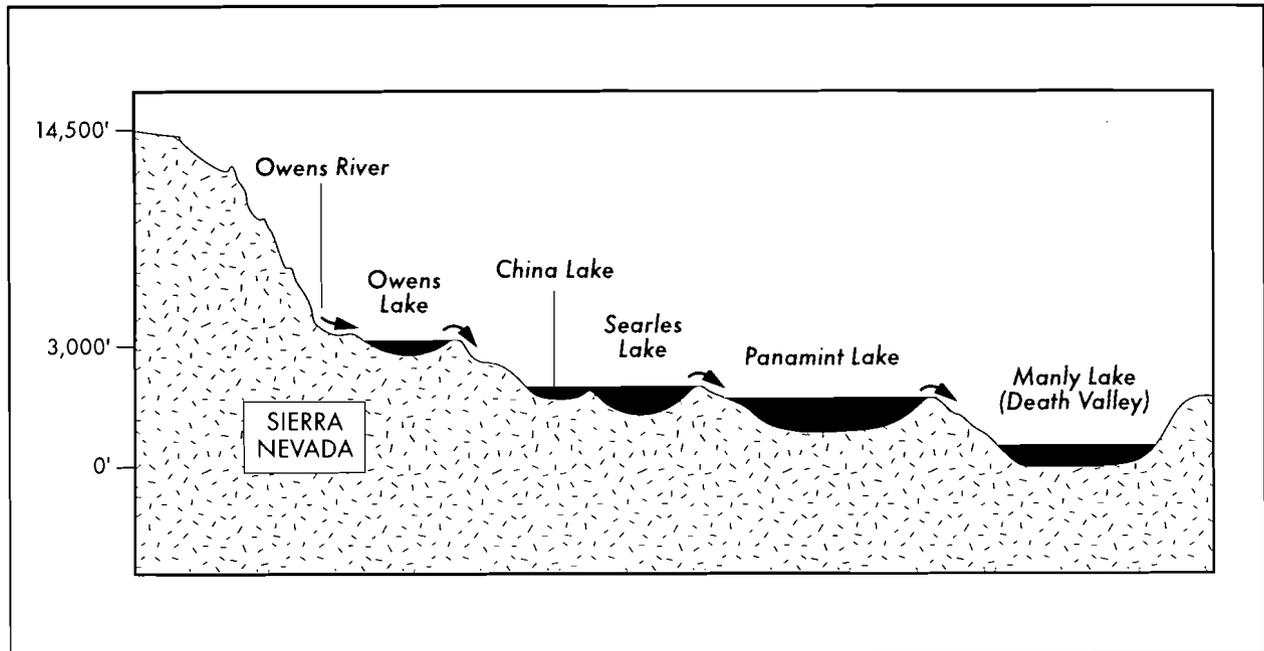


Figure 6. Chain of Pleistocene lakes, Owens river system.

waters also contain carbonate and bicarbonate contributed by the atmosphere. Smith (1976), estimated that about two-thirds of the sodium, chlorine and bromine were derived from atmospherically transported sea salts, and the solution of Cenozoic halite deposits in the drainage area. Approximately one-third of the sodium, chlorine and bromine came from thermal springs in the Long Valley area (south of Mono Lake). Most of the boron was also derived from these thermal springs. In addition, some boron was contributed by the Coso thermal springs located southeast of Owens Lake. The erosion of Cenozoic lake beds and gypsiferous sediments in the drainage area provided sulfate to Searles Lake.

The fine clastics in lake muds were also transported into Searles Valley by inflow waters. These sediments were mixed with showering chemical precipitates formed when calcium and magnesium ions, in predominantly fresh runoff water, reacted with carbonate rich brackish water and brines trapped in Searles Valley.

COMMERCIAL DEVELOPMENT

Commercial development of Searles Lake extends back to the efforts of John Searles, who recognized that the crystals being recovered by Francis "Borax" Smith from Teels Marsh in Nevada, were similar to crystals he found on Searles Lake. The discovery prompted John and Dennis Searles to stake mining claims on the north end of Searles Lake and build a small experimental plant about 3 miles south of the present town of Trona. In 1876, the San Bernardino Borax Mining Company was formed with John Searles as president. The original land holdings had been expanded to 3 square miles. A plant was constructed with a reported capacity of 100 tons per month of borax.

Water supplies were developed from mountain springs south of Trona and a mule-drawn freight line was established to San Pedro to ship the product. This company operated until 1898.

The first plant designed specifically to recover potash was the Hornsey plant. The process initially carbonated brine to remove Na_2CO_3 . This was followed by evaporation to remove NaCl . The concentrated brine was cooled to recover a mixed crop of borax and KCl . The liquor was then evaporated further to remove Na_2SO_4 and NaCl , which were discarded. The mother liquor was again carbonated to remove the rest of the carbonate. Then it was mixed with the end brine, from the recrystallization of the mixed borax and KCl crop, to crystallize a marketable murate of potash. The Hornsey plant was dismantled in 1914.

During the Hornsey experiments and after reorganization of the company in 1913 as the American Trona Corporation, company president, Baron De Ropp, retained Charles P. Grimwood to develop a potash process. His experiments led to the one-step Grimwood process involving high temperature evaporation of brine, followed by cooling and crystallization of potash. Potash mother liquor was recycled to the evaporator. Construction of the plant began on October 21, 1916 in San Pedro, but it operated only intermittently. Grimwood's connection was severed in May 1918, but process development continued under John Teeple, a consulting chemical engineer, and the plant technical staff. Initially, the borax content of the potash product was too high for agricultural use. However, H. W. Morse discovered that potash crystallizes rapidly, while borax remains supersaturated.

in the mother liquor. This occurs long enough to efficiently separate the two products, thereby providing a satisfactory potash product. This improvement is still the basis for today's potash recovery process. In fact, the borax limit in potash product set by Morse and Teeple (0.5 percent) is the same limit in use today. As part of the quality improvement process for potash, a plant to recover purified borax was also installed. The first car of borax was shipped to the Corning Glass Works in May 1919.

The American Potash & Chemical Corporation was formed on June 4, 1926, to acquire the entire properties of the American Trona Company, which included the California Trona Company, the Trona Mercantile Company and the Trona Railroad Company. Remodeling and expansion of the plant, carried out under the new organization, were completed in 1927. During this remodeling, it remained in partial operation. The plant was further expanded in 1931 by addition of the soda products plant and No. 3 evaporator in 1937, followed by the carbonation plant in 1947. A further expansion was completed in 1962, with the addition of the No. 4 evaporator and the boric acid extraction plant, bringing the total plant capacity to 900,000 tons per year of primary production. American Potash & Chemical Corporation merged with Kerr-McGee Corporation on December 29, 1967. On December 1, 1990, North American Chemical Company acquired the entire Searles Valley Operation.

The second successful plant on Searles Lake, the Westend plant, was founded by "Borax" Smith. In 1918, he built a small plant, but it was plagued with operating problems and was subsequently closed. On February 26, 1920, Smith formed Westend Chemical Company and with the assistance of Henry Helmers, a young chemist, they worked out a process based on carbonating and refrigerating brine. The first borax was produced in 1926, and the first soda ash in 1927. The plant was later expanded in 1955 to produce sodium sulfate. In 1956, the Westend Chemical Company merged with Stauffer Chemical Company, from whom Kerr-McGee Corporation acquired the facility in October 1974.

Development of the mineral potential of Searles Lake would not have been possible without transportation. The twenty-mule teams of John Searles were the first such means to haul borax out of the desert (U.S. Borax, 1972). His Borax Flat to Mojave route was replaced by the Trona Railroad. In 1912, Robert Ashton, working under the direction of Austin, who was receiver for the California Trona Corporation, was given the job of establishing a rail route into Searles Valley. Ashton worked east and north along the west shore of the lake to the site of the California Trona Company camp at Searles Lake. The railroad was originally called the "Three Elephant Route" as many of

the officers in the company were English with a background from India. They noted the long trains of mules used to haul freight across the desert, and claimed three elephants could have done the job better. This idea is the origin of the still-used brand name "Three Elephant Borax" for Searles Valley boron products. The Trona Railroad carries much of today's production of over 1.8 million tons per year, and also carries 360,000 tons per year of coal used as fuel by valley chemical plants.

PRESENT OPERATIONS

Lake Brine and Water System

Feed for North American Chemical Company's Searles Lake Operations comes from brine-bearing evaporite horizons in Searles Lake. See Figure 7. These brines are produced from the evaporite horizons by a system of wells and pipelines for each plant. Each system is designed to produce the best brine available for the plant it supplies. In some cases, solar ponds concentrate brine to increase plant production. In other cases, effluent is injected into an evaporite horizon to manufacture brine by solution mining.

Brackish water for plant use is obtained from a system of wells and pipelines located on the north, west, and south sides of Searles Valley. The wells are completed in the alluvial sands and gravel beds that surround the saline body. Because there are no fresh water sources in Searles Valley, other than minor springs in the Argus Range, fresh water is piped in from Indian Wells Valley for industrial, as well as domestic use. The fresh water system consists of two pipelines and five wells.

Trona Main Plant Cycle

The main plant cycle consists of three major process plants. These are the evaporator, the potash plant and the borax plant. Brine from the lake first travels to the evaporator where water is removed by boiling. Sodium chloride and burkeite are then removed by crystallization. The potash plant quickly cools hot concentrated liquor from the evaporator, causing KCl to crystallize. Cooled liquor from the potash plant is fed to the borax plant, where it is held while borax crystallizes. The end liquor from the borax plant is mixed with the brine stream feeding the evaporators. Part of the KCl solids and high potash liquors are used to produce K_2SO_4 in a secondary plant.

Trona LLX-BAX Solvent Extraction Plant

Low quality lake brine is feed for the LLX-BAX process plant. Boron values are extracted from brine into an organic extractant, which complexes the boron values as sodium or potassium metaborate. Boron, sodium, and

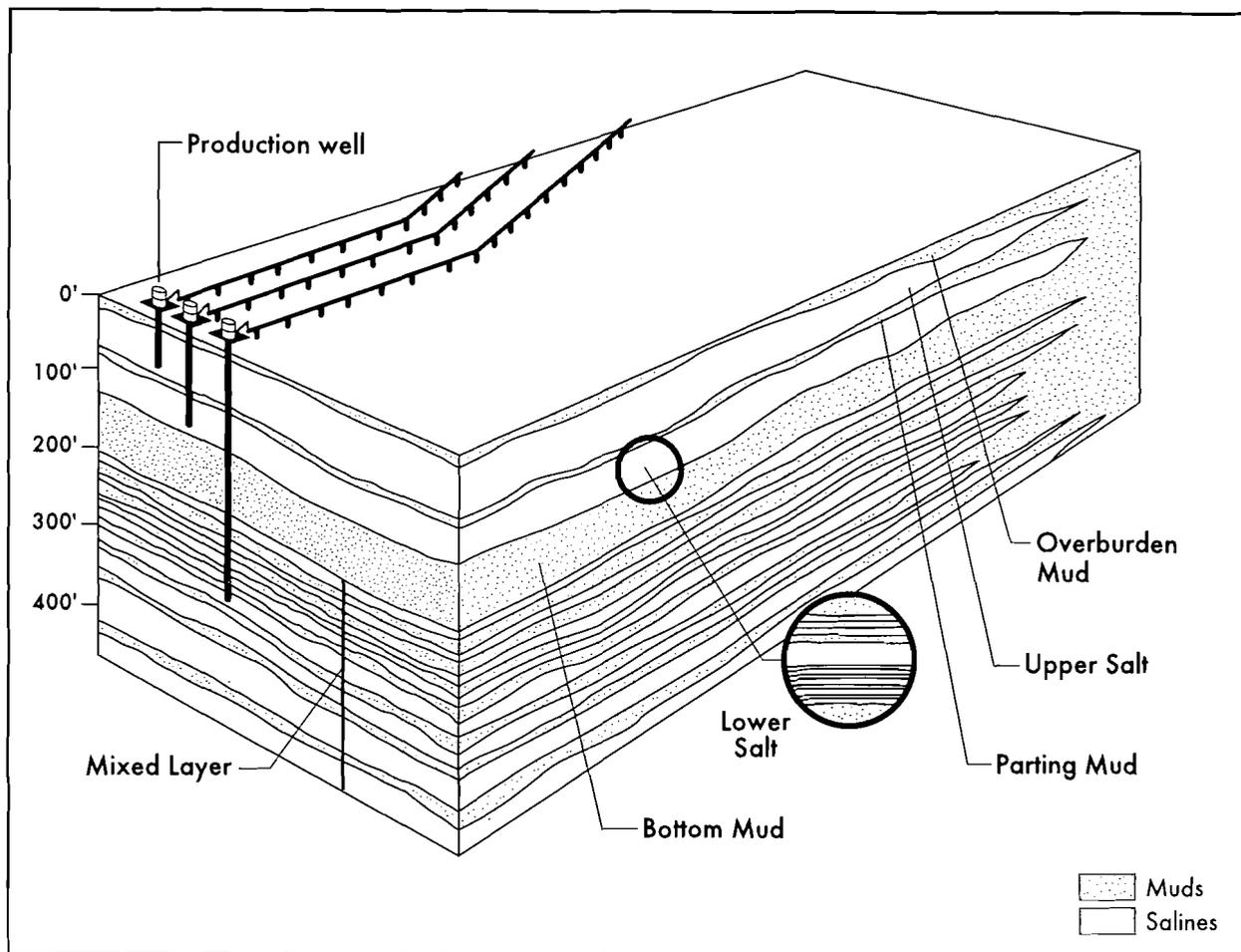


Figure 7. Solution Mining.

potassium values are then extracted into water by dilute sulfuric acid. This is evaporated and crystallized to produce boric acid, and mixed sodium and potassium sulfates. Mixed sulfates are a feed for the secondary K_2SO_4 plant.

Argus Plant

Argus plant feeds are Mixed Layer brine, burkeite solution from the main plant cycle evaporator and Lower Salt brine. All three feed materials are reacted with carbon dioxide gas to precipitate the less soluble sodium bicarbonate. This is removed by filtration. Filtrates from Mixed Layer brine and burkeite solutions are returned to the lake. The Lower Salt brine is processed separately, so that the bicarbonate filtrate can be processed at Westend for borax and sodium sulfate recovery. Sodium bicarbon-

ate filter cake is dried, decomposed, bleached, recrystallized and redried to yield dense soda ash.

Westend Plant

Carbonated Lower Salt brine from Argus is blended with a fraction of raw lake brine, refrigerated in seeded crystallizers, to recover crude borax, and refrigerated further to recover sodium sulfate decahydrate. Both intermediates are further refined to finished products.

Dredging

The near surface trona rich beds found along the western edge of the Upper Salt are mined with a bucket wheel dredge. The dredged material is stacked to drain off excess brine, and air dried, before being crushed and shipped to the customer by truck.

REFERENCES

- Friedman, I., Smith, G. I. and Matsuo, S. (1982): Economic Implications of the Deuterium Anomaly in the Brine and Salts in Searles Lake, California; *Economic Geology*; Volume 77, Number 3, pages 694 to 702.
- Moulton, G. F. (1980): *Compendium of Searles Lake Operations*; Society of Mining Engineers of AIME; Transactions Volume 27, pages 1918 to 1922.
- Santini, K. N. (1987): *Geologic Evaluation of the Southern Portion of Searles Lake, California*; Arizona Geological Survey Special Paper 4, page 134.
- Santini, K. N. (1983-1985): Unpublished Searles Lake geologic and exploration drilling field notes and reports; Anaconda Minerals Company.
- Smith, G. I., Barczak, V. J., Moulton, G. F. and Liddicoat, J. C. (1983): Core KM-3, a Surface-to-Bedrock Record of Late Cenozoic Sedimentation in Searles Valley, California; U. S. Geological Survey Professional Paper 1256.
- Smith, G. I. (1979): *Surface Stratigraphy and Geochemistry of Late Quaternary Evaporites, Searles Lake, California*; U. S. Geological Survey Professional Paper 1043.
- Smith, G. I. (1976): *Origin of Lithium and Other Components in the Searles Lake Evaporites, California*; U. S. Geological Survey Professional Paper 1005; pages 92 to 103.
- Sonia, J. A., Fairchild, J. L. and Moulton, G. F. (1978): *Exploration and Mining of the Mixed Layer Resources of Searles Lake, California*, unpublished report for Kerr-McGee Chemical Corporation, Trona, CA, September 1978.
- U.S. Borax (1972): 100 Years of U.S. Borax; U. S. Borax Centennial 1872-1972; *Pioneer Magazine*, September-October, pages 7 to 8.