

# American Journal of Science

DECEMBER 1958

## STRATIGRAPHY AND RADIOCARBON DATES AT SEARLES LAKE, CALIFORNIA

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**ABSTRACT.** Upper units of the strata beneath Searles dry lake, in a desert basin in southeastern California, record two deep lakes each followed by precipitation of evaporites and at least near-desiccation. Each lake is thought to imply a pluvial climate; the times of near-desiccation represent the warmer, drier, nonpluvial climate of today.  $C^{14}$  dates of samples from these strata show that the later of the two pluvial climates lasted from before 23,000 to  $\sim$ 10,000 yr. B.P.; it was therefore contemporary with the classical Wisconsin glaciation of central United States. The earlier pluvial had been well established by  $\sim$ 46,000 B.P. and had begun to wane before  $\sim$ 32,000 B.P. The later history of the lake in the Searles basin is in agreement with the published data on the later history of Lakes Bonneville and Lahontan. Still earlier lake fluctuation can be discerned in underlying strata, but these are not controlled by dates.

### LOCATION AND BRIEF DESCRIPTION

Searles Lake occupies one of the many structural basins in the Mojave Desert region of southeastern California; it lies 170 miles northeast of Los Angeles (fig. 1). It is notable for the great volume and purity of the salt beds occurring beneath its floor.

Like many other "lakes" in the Basin-and-Range province, Searles is essentially a dry lake (plate 1). It has an area of about 60 square miles, four-fifths of which is salt-incrusted sand, silt and clay. The central part, about 12 square miles in area, has a firm salt surface from which common salt can be harvested. The salt body, the surface of which is exposed in its central part, is thick and grades radially outward, beneath peripheral accumulations of mud, into saliferous clay, silt and sand, and altogether underlies an area of about 40 square miles (fig. 2). This enormous mass of salines is porous; its voids, estimated at 40 percent of its volume, are filled to the surface with a saturated bittern. Although the bittern varies in composition, its chief constituents are sodium and potassium chlorides, sulfates, carbonates, and borates. Following infrequent floods, pools on the surface of the salt are colored red owing to the abundant presence of red bacteria and algae.

The bittern is worked on a large scale by two companies, the American Potash & Chemical Corporation at Trona on the northwestern margin of the lake, and the West End Chemical Company at Westend on the southwestern side. The former plant produces potash salts, borax, boric acid, soda ash, salt cake, bromine, lithium carbonate, and phosphoric acid, while the latter firm produces mainly soda ash, borax, and salt cake from the bittern.

The purpose of the present paper is to describe in general terms the stratigraphy of the sediments beneath Searles Lake, to present  $C^{14}$  dates obtained from core samples, and to comment on the significance of both stratigraphy and dates for the Pleistocene history of the Searles basin.

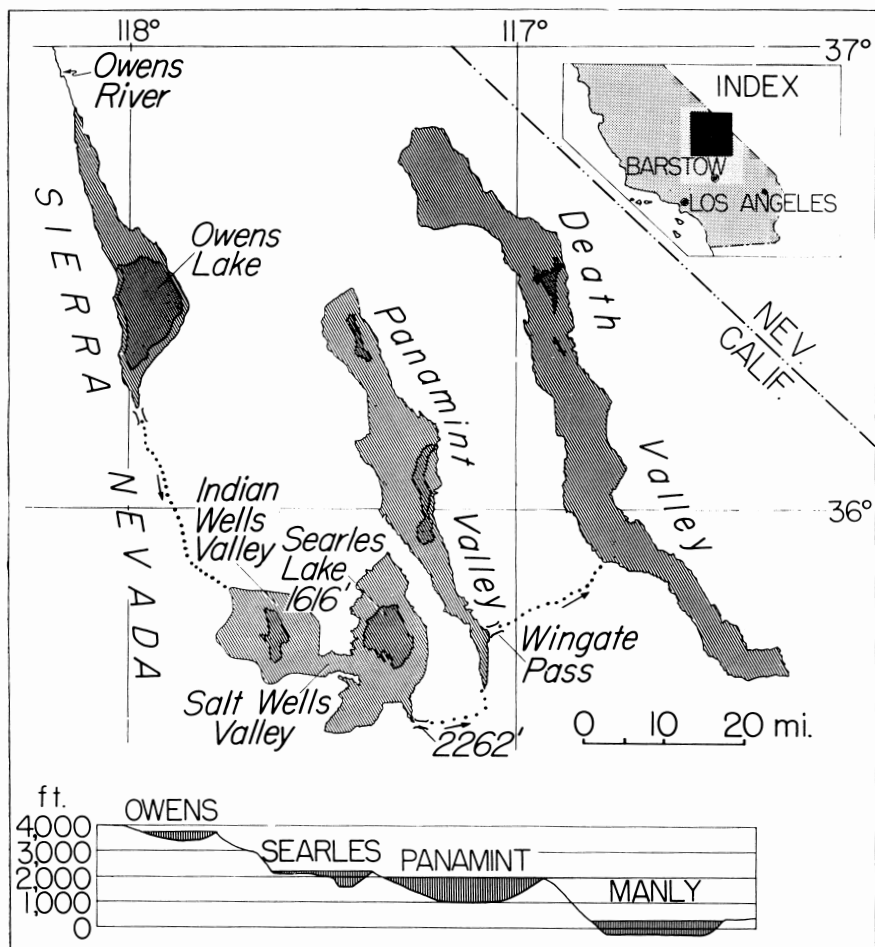


Fig. 1. Map and cross-section showing Searles Lake and chain of pluvial lakes (shaded) of which Ancient Searles lake was a part. Dotted lines show routes of former connecting streams. Sources: H. S. Gale 1915; Blackwelder 1933; U. S. Geol. Survey topographic maps.

#### THE CHAIN OF BASINS AND ANCIENT LAKES

The former existence of a large lake in the Searles basin is established by strandlines, subsurface stratigraphy, fossil fish and mollusks, and deposits of tufa. The former lake was recognized by H. S. Gale (1914a; 1915) as one of a chain of four lakes—the ancient Owens, Searles, Panamint, and Manly lakes (fig. 1), on which other published references are Blackwelder (1933; 1941). and Antevs (1938). The chain was fed principally at its northwestern end, by streams draining a 130-mile segment of the east slope of the Sierra Nevada. The ancient lakes have been generally regarded as dating from episodes of glaciation, when lowered temperatures reduced evaporation, and increased discharges resulted from increased precipitation and secondarily from the

presence of numerous glaciers on the east side of the High Sierra. As a result the lakes filled their basins and overflowed from one basin to the next.

The outflow from Ancient Searles lake discharged into the Panamint Valley, where another lake, having an area of 272 square miles and a maximum depth of more than 900 feet (Thompson, 1929, p. 186), discharged eastward through Wingate Pass into Lake Manly in Death Valley, the terminus of the lake system. Lake Manly, described by Blackwelder (1933), had a maximum depth of about 600 feet, but was relatively short lived. As it had no outlet, it fluctuated at all times with varying inflow and evaporation. Probably it was nearly fresh during its expansion and became increasingly saline during its shrinkage. Because of the state of preservation of strandline forms and de-

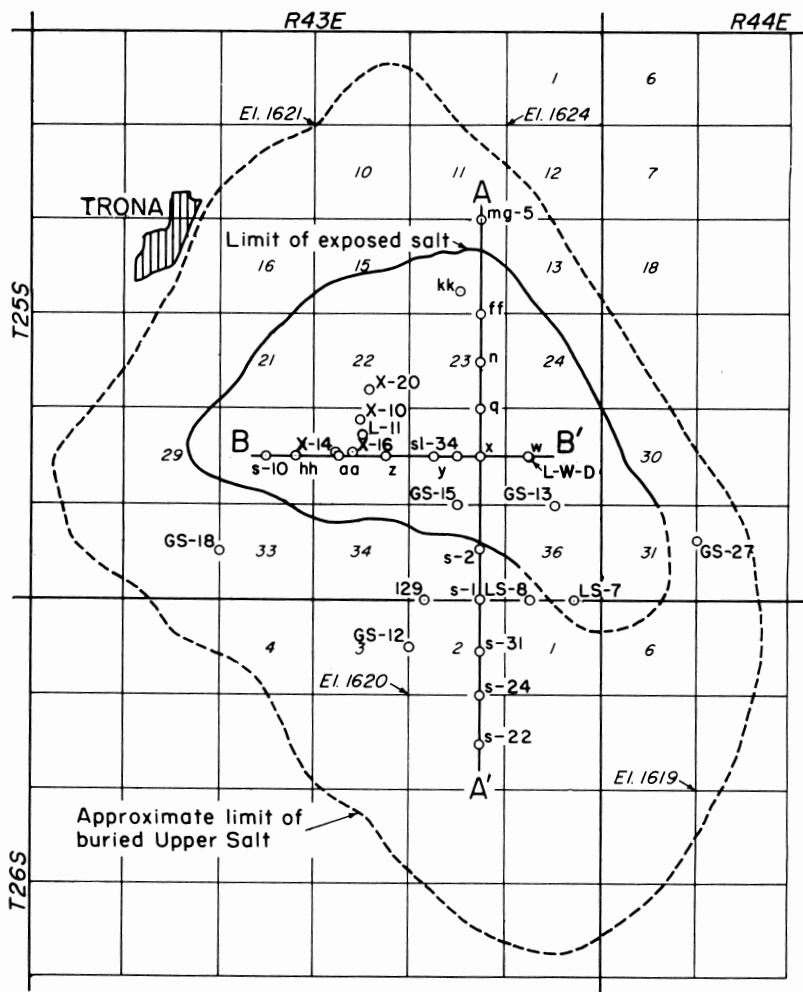


Fig. 2. Map of Searles Lake showing section lines, approximate areas of exposed and buried salt, and locations of 30 boreholes (from among several hundred), mentioned in the text or shown in figures 3 and 4.

posits. and of the streamway at Wingate Pass, Blackwelder inferred that Lake Manly and Ancient Panamint lake were contemporaneous with the highest shore features in the Searles basin, but not with lower ones. In other words, that with cessation of outflow of Ancient Searles lake the chain consisted only of the Owens-Searles system, although of course small independent fluctuating lakes might have existed then in Panamint and Death Valleys. The chain of lakes, as described and interpreted in the literature, affords a reasonable explanation of the stratigraphic section, discussed hereafter, beneath the floor of Searles Lake.

All four basins contain successions of strandlines, but those in the Searles basin<sup>1</sup> are probably more numerous and more distinct than those in the other basins. They include narrow wave-cut benches and pebble beaches, so discontinuous that no single one continues around the basin without a break. The highest and strongest of the conspicuous strandlines is at an altitude of about 2,260 feet. On the southeast side of the basin it leads into a pass that evidently was the lake outlet while the water surface stood at that altitude.

Blackwelder (1941; 1954, p. 35-36) reported from reconnaissance the possible presence of two groups of strandlines: a weathered and dissected group that he thought might correlate with the Tahoe glaciation in the Sierra Nevada, and a lower, fresher group that might correlate with the Tioga glaciation.

When at its maximum recorded height the Ancient Searles lake had an area of about 385 square miles and probably was at least 750 feet deep. It was common to three basins, from west to east: Indian Wells Valley, Salt Wells Valley, and Searles basin proper (fig. 1). Indian Wells Valley is much shallower than Searles basin and contains a large volume of sand and silt, interpreted by H. S. Gale (1915, p. 269) as a deltaic deposit built by the inflowing stream. The present writers agree with Gale, and believe that he did not sufficiently emphasize the occurrence of lacustrine silt in the southwestern part of Searles basin. The large body of sandy sediment in Salt Wells Valley continues eastward with decreasing grainsize and altitude, partly fills the broad depression connecting Salt Wells Valley with Searles basin, and underlies dissected benches throughout an area aggregating many square miles in southwestern Searles basin. In that area it consists predominantly of dusky yellow green silt and fine sand resembling the coarsest fraction of the Parting Mud, described hereafter, beneath the central part of the basin. Although it seems likely that the silt passes eastward beneath the floor of the basin and is continuous with the Parting Mud, we do not know that this is the case.

The silt contains mollusk shells. Small collections of the shells from surface exposures in Owens basin, Indian Wells and Salt Wells Valleys, and Searles basin were examined by Dwight W. Taylor (written communication). He found that the nearest occurrence alive of some of the 13 species represented is in the Sacramento Valley in northern California, and on this basis inferred that when the fossil fauna was living the Searles Lake region had considerably cooler summers than it has today. The difference in mean July temperature between the two districts today is about 4.5°C.

<sup>1</sup> Possibly first described by E. E. Free, in unpublished notes quoted verbatim by Huntington (1914, p. 559-560).

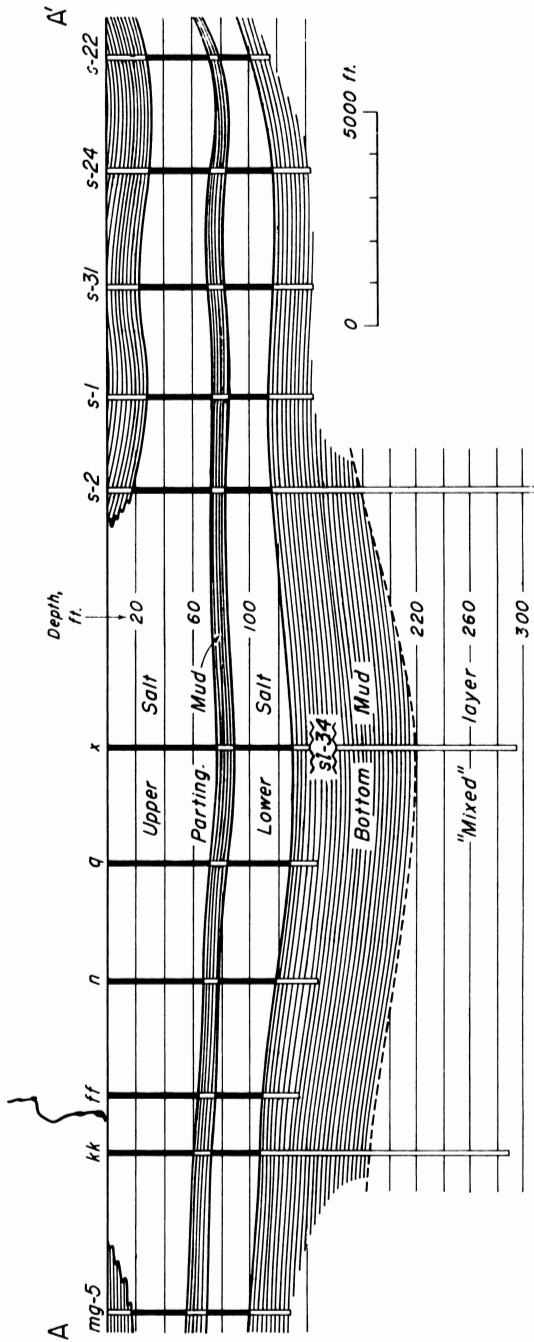


Fig. 3. North-south section AA' (fig. 2), constructed from core-drill logs to show stratigraphic units described in text.

## STRATIGRAPHY

Searles Lake is underlain by a remarkable sequence of sediments, from which much has been learned about the Pleistocene history of the basin and from which further information will surely be derived. Even from the few borings available to him, H. S. Gale (1914a, p. 404) recognized that the sediments are of lake origin. Since the time of his study many core borings have been made by the American Potash & Chemical Corporation and its predecessors, by the U. S. Geological Survey, and by others. Numerous borings have been made to depths of 70-90 feet, many to about 150 feet, several have penetrated to approximately 300 feet, and one boring extends to 875 feet. The locations of 30 boreholes are shown for example in figure 2; two sections constructed from the logs of eighteen of these borings are shown as figures 3 and 4.

Study of the resulting cores has confirmed H. S. Gale's opinion and has made it clear that the Searles Lake stratigraphy represents lakes that succeeded each other in time and that fluctuated in response to changes of climate. It is our purpose not to detail the stratigraphy but to describe major units. Those which are of chief present interest, because they are young enough to be datable by  $C^{14}$ , occur within the uppermost 200 feet of the section, and are shown by a graphic log, figure 5. The names used in this paper are those used informally by the American Potash & Chemical Corporation. These are, from the top downward, Upper Salt, Parting Mud, Lower Salt, Bottom Mud, and "Mixed" layer. The descriptions and thicknesses given below pertain to the central part of the basin. The units change facies toward the margins, but we are not concerned here with their marginal relations. As the stratigraphic units are believed to include two natural pairs, a Parting Mud-Upper Salt pair and a Bottom Mud-Lower Salt pair, they are so described in the following paragraphs.

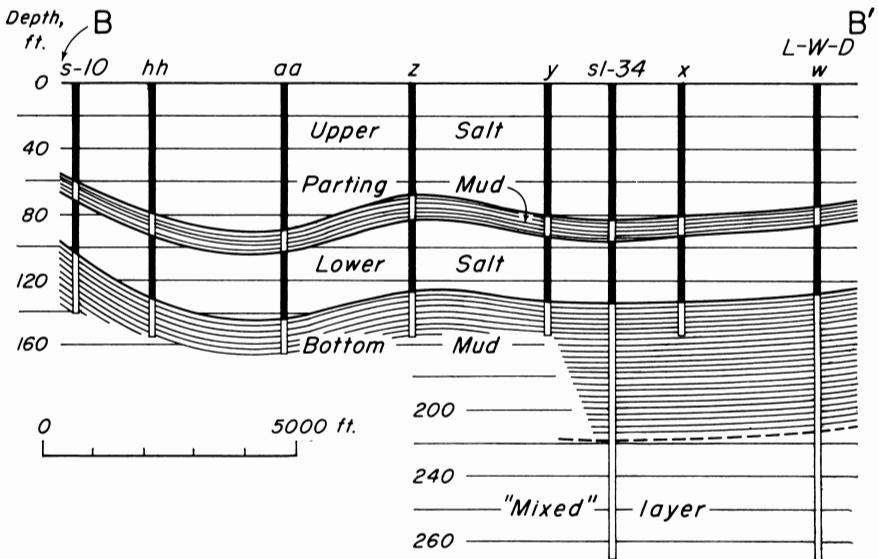


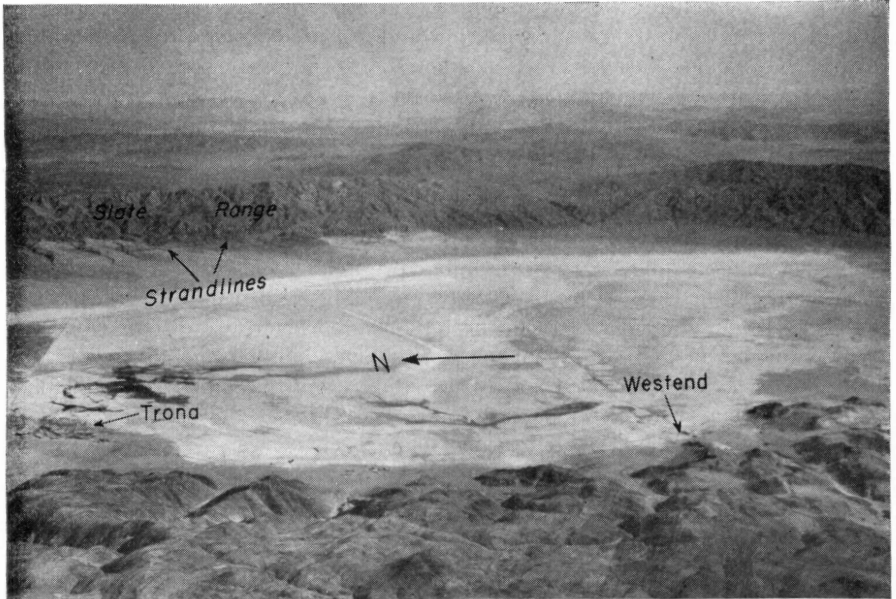
Fig. 4. West-east section BB' (fig. 2).

PARTING MUD AND UPPER SALT

The Parting Mud, 10 to 13 feet thick, consists of saliferous clay and fine silt, dusky yellow green when dry, with parallel, flat-lying laminae (pl. 2, fig.

PLATE 1

Searles Basin and Lake



*American Potash & Chemical Corporation*

Fig. 1. Searles basin seen looking southeast from directly over the Argus Range, the western rim of the basin. The distance between Trona and Westend is about 4 miles. Outlet of the ancient lake is out of view to the right.



*Ward C. Smith, U. S. Geological Survey*

Fig. 2. Shoreline of Ancient Searles lake along east side of basin.

1). Seen megascopically the laminae consist of alternating light-colored layers mostly less than 2 mm thick, and thicker dark layers up to 1 cm thick. Under 90x magnification the laminae show no evidence of possessing graded bedding; instead the darker laminae are seen to consist of distinct laminations of a smaller order of size, some of which are lenticular and can not be followed laterally through the length of a hand specimen. Examination, by Dr. J. E. Sanders, Yale University, of a single thin section under a petrographic microscope revealed that the small coarse fraction, fine sand to coarse silt in size, consists of quartz with small amounts of biotite, tourmaline, glass, and unidentified minerals. The finer fraction, a large proportion of the whole, includes abundant unidentified carbonates. The proportion of clay-size to coarser particles was not determined. The dark-colored layers include significant amounts of clastic material; the light-colored layers appear to be chemical precipitates. The samples from which two  $C^{14}$  dates were obtained (table 2, GRO-1460, 1464) contained only about 12 percent insoluble, presumably clastic material (Hl. de Vries, unpublished), most or all of which probably resided in the dark-colored layers. Whether the substances in the light-colored layers were sedimented in part from mechanical suspension or were all precipitated chemically on the floor of the lake was not determined. In either event they appear to have undergone some recrystallization.

Although the material, here called mud, itself consists predominantly of salts, its content of true evaporites is not known. To the extent that the substances in the light-colored layers are chemical precipitates on the lake floor, it can be inferred that the lake water was saturated with carbonates even during times when the mud was accumulating. There is little doubt that two substances, at least, in the Parting Mud are true evaporites: (1) disseminated crystals of the relatively insoluble minerals gaylussite and pirssonite, particularly near the upper and lower contacts, and (2) large crystals of borax (tincal) scattered sparsely through the uppermost few inches of the mud, immediately below the layer of trona that constitutes the basal part of the Upper Salt. Probably the borax was formed through seasonal chilling of the concentrating brine just before saturation with trona was reached.

Apart from the occurrence of these crystals, the top and base (plate 2, fig. 2) of the Parting Mud are in sharp contact with the overlying and underlying salt bodies.

The Parting Mud contains fossil fishes, pollen, and disseminated organic matter. It was examined<sup>2</sup> for diatoms, but with negative results, presumably because during diagenesis the strongly alkaline water dissolved any diatoms then present. The Mud will also be examined,<sup>3</sup> for limnic animals in the hope that data on salinity, temperature and depth can be derived from them.

A fossil fish 8 inches long was found at a depth of 68 feet in the Parting Mud in core ff (fig. 3). It was identified<sup>4</sup> as a member of the minnow family Cyprinidae, probably of the genus *Siphateles*. No significant ecologic inference has been drawn from this find.

Pollen from both the Parting Mud and the Upper Salt has been examined

<sup>2</sup> By Dr. Ruth Patrick, Academy of Natural Sciences, Philadelphia.

<sup>3</sup> By Dr. E. S. Deevey, Yale University.

<sup>4</sup> By Dr. Carl L. Hubbs, Scripps Institution of Oceanography.

PLATE 2  
Sediments of Ancient Searles Lake (photographs courtesy American Potash and Chemical Corporation)

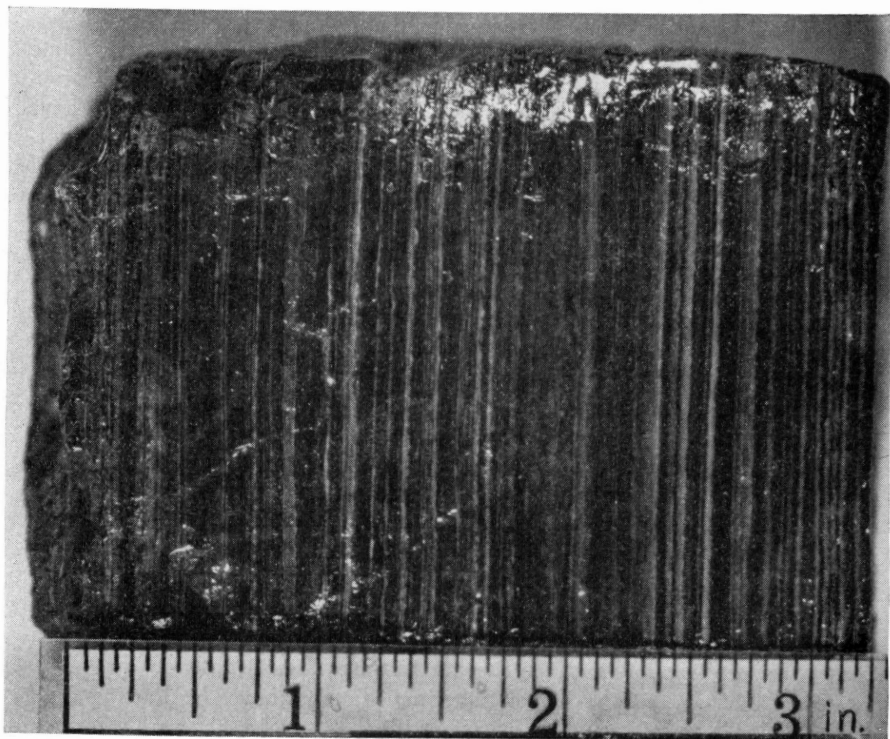


Fig. 1. Hand specimen of Parting Mud, showing lamination.

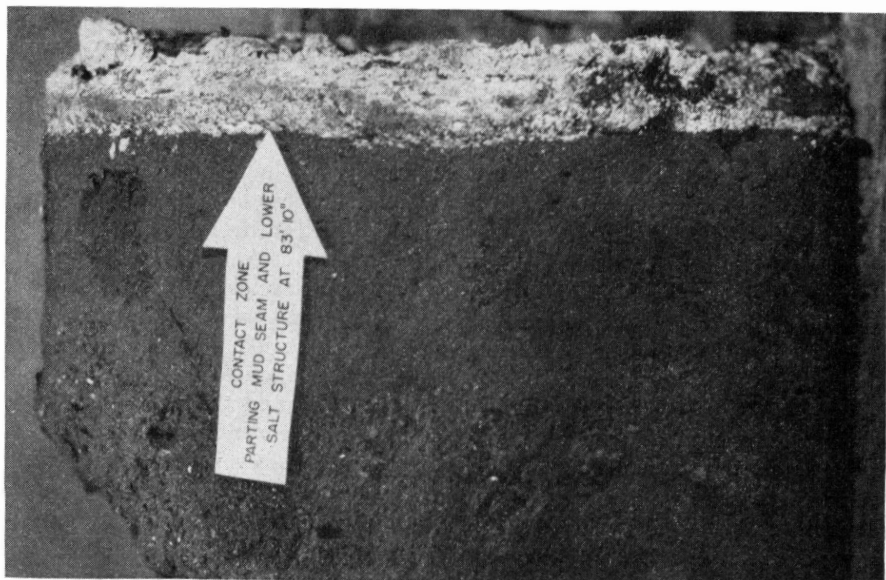


Fig. 2. Segment of 9-inch drill core showing sharp contact of Parting Mud (dark) on Lower Salt (light). The up-

in detail (Roosma, 1958). The results show, through the stratigraphic distribution and relative abundance of juniper compared with *artemisia* and chenopods, that the local climate was cooler and wetter during deposition of the Parting Mud than during precipitation of the overlying Upper Salt.

Chemists of the Research Laboratory of the American Potash & Chemical Corporation, under the direction of W. A. Gale, found that the Parting Mud contains disseminated organic matter varying in amount from less than 0.1 percent to as much as 1.5 percent of the weight of the sediment. Samples were concentrated for study in this way: sections of drill core from selected depths were broken up, dried at 140°F, and crushed to a coarse powder. Organic material was extracted in a large Soxhlet-type extractor by dissolving in methanol. The clear, filtered methanol solution was evaporated down to a syrup, and distilled water added drop-wise over a period of several days to precipitate the organic matter in particles coarse enough to be separated by filtration. The residue was washed with dilute HCl and then with distilled water. The precipitate was dried and dissolved in acetone, and the small inorganic residue was filtered off. The acetone filtrate was evaporated down to a thick slurry on a water bath and further evaporated to dryness in a vacuum desiccator. From the final product, weighing 50 to 70 gm, a small sample was analyzed for ash content by decomposing with sulfuric acid, igniting at 800°C, and weighing the residue. In each sample the residue contained molybdenum, iron, and phosphate, but no alkali metal salts such as would have been present if soluble inorganic carbonates remained in the organic extract.

The organic matter in dry form is almost black in color, but in dilute solvent solution it is an orange dye. It possesses pronounced fungicidal properties. Because of its color and its molybdenum content it is believed to have originated, in part at least, in some of the various forms of chromogenic organisms such as the red and green bacteria now living on the surface of Searles Lake. These red bacteria have been found to contain comparable amounts of molybdenum. Such acetone-soluble organic matter constitutes, on an average, about 0.2 percent (by weight) of the Parting Mud, with some thin layers containing more than 1 percent dry basis.

The organic matter is a complex mixture of substances. An investigation (Vallentyne, 1957) using chromatographic methods has shown the presence of a number of carotene compounds, xanthophylls and possibly echinenone, together with several other unidentified substances. The Parting Mud was also found to contain green chlorophyll-like pigments, extractable with methanol but not with acetone. Hence the organic content of the sediment seems to be a composite residue of algae, bacteria, and other micro-organisms that infested the waters of Searles Lake during deposition of the Parting Mud.

The Upper Salt, 60 to 90 feet thick, consists of layers of salts, mostly alkali chlorides, carbonates and sulfates. Most of the salt layers are rather pure, but some are separated from others by partings of mud. Evidently the Upper Salt consists of the evaporites precipitated during progressive desiccation of the deep lake in which the Parting Mud had been deposited.

The basal part of the Upper Salt, immediately above the Parting Mud, consists of a layer of trona about 5 feet thick. As trona, the stable form of

sodium carbonate in equilibrium with atmospheric  $\text{CO}_2$ , has a rather low solubility in sodium chloride solutions, it would have been one of the first sodium salts (other than the calcium-sodium carbonate double salts such as gaylussite) to precipitate from these brines. The other evaporites are difficult to explain in physical-chemical terms, owing to the complexity of the sequence. Chatard (1890, p. 59; see also H. S. Gale, 1915, p. 286) experimented with the evaporation of water from Owens Lake under natural open-air conditions. Chatard's analysis of the resulting evaporites, at various stages of the process, showed that (1) sodium bicarbonate was precipitated early; (2) carbonates as a group were precipitated almost continuously throughout much of the process; (3) sulfate precipitation tended to concentrate during an intermediate phase; (4) sodium chloride precipitation increased progressively with time; (5) carbonate could be precipitated by chilling. The sequence of minerals in the Upper Salt is generally compatible with Chatard's results, if it is assumed that initial compositions were comparable. Variations in the sequence admit the possibility that variations in climate occurred during the process, but are not known to demand them.

As a pair the Parting Mud and Upper Salt are the record of two phases of evaporation of a deep lake. The rather sharp contact of the Parting Mud on the underlying Lower Salt (mostly halite and trona near its top) suggests that the deep lake formed rather suddenly, and rapidly became deep enough to permit the sedimentation of clay on the floor, in parallel, nearly undisturbed laminae. The cores examined afford no good evidence that the surface of the underlying salt was dissolved appreciably by the lake water overlying it. If no solution did in fact occur, this might be explained by the supposition that the basal laminae of the Parting Mud were deposited rapidly enough to form a quick seal over the salt. Even in this early phase evaporation must have occurred to an extent sufficient at times to saturate the water with relatively insoluble pirssonite and gaylussite. The greater rarity of these minerals in the stratigraphic middle portion of the Parting Mud suggests that net evaporation reached a minimum around a midpoint in the history of the "freshwater" lake.

Little information on salinity is obtained from the presence of *Siphateles* (?) in the upper middle portion of the Parting Mud, because the members of this genus live under a wide variety of physical and chemical conditions in the region today (Miller, 1949, p. 451).

It is not known whether the lake, during its Parting Mud phase, overflowed its basin or not, because there is no physical connection between bottom sediments and strandlines. The stratigraphy can be reasonably explained on either assumption.

That net evaporation increased towards the end of Parting Mud time is suggested by the increase in scattered pirssonite and gaylussite crystals in the top part of the mud. The sharp contact of Upper Salt on Parting Mud records the cessation of deposition of mechanically transported sediment, followed by increase in salinity of the water to the saturation point for trona. As the principal if not the sole source of sediment in the center of the Searles basin

was the Owens River-Owens Lake system, it is reasonable to suppose that the Parting Mud had been derived from that system, and that the clay fraction at least had remained in suspension while passing through Owens Lake. A drill core from the dry floor of that lake (Smith and Pratt, 1957, p. 5) showing more than 900 feet of clay and other mechanical sediments with virtually no evaporites, is compatible with this supposition, which, however, can be verified only through detailed study of the sediments beneath both basins. Very likely, then, the top of the Parting Mud records the cessation of overflow of Owens Lake, cutting off the chief source of both water and suspended sediment for the Searles basin. Cessation could have resulted most reasonably from warming and drying of the regional climate, a trend indicated by pollen study, whereby the change from juniper, prominent throughout Parting-Mud time, to desert plants, prominent throughout Upper Salt time, is shown to have been rather rapid (Roosma, 1958). The indicated climatic difference is compatible also with the cooler, wetter climate implied by the fauna of the silt exposed in the southwestern part of the Searles basin, on the assumption that that silt is contemporaneous with the Parting Mud.

The cessation of clay sedimentation and the inception of predominant precipitation of trona were two separate events, although both are logically attributable to a single cause, cessation of inflow. With consequent marked increase in net evaporation, saturation with trona occurred in Ancient Searles lake, but the physical evidence affords no information on the time lag between the two events. Nor are the depths of water at the times of these events known, because the strandlines have not been correlated with the floor stratigraphy.

The subsequent history of the lake is one of continued evaporation, and precipitation of evaporites, with changes and interruptions as suggested, although not clearly defined, by the sequence of substances in the Upper Salt. The thin layers of mud occurring within the Upper Salt are continuous enough through the central part of the basin to suggest the possibility of temporarily renewed inflows of sediment-laden water. Whether the mud in these layers originated upstream from Owens Lake and arrived via that lake, or whether, like the surface mud that overlies the periphery of the Upper Salt, it was washed in from the sides of the Searles basin itself, could be learned only from detailed examination of the mud. The possibility of renewed overflow of Owens Lake is discussed in a later section, in the light of  $C^{14}$  dates.

In connection with inflow to Searles basin, calculation suggests that an influent stream with only modest discharge would suffice to balance evaporation from the surface of a lake in the Searles basin. According to Blaney (1957) about 79 inches of water can be expected to evaporate annually, under the existing climate, from the basin of Silver dry lake, 75 miles southeast of the Searles basin. The climates over the two basins do not differ greatly. A lake occupying the entire floor of the Searles basin would have an area of about 60 square miles. Assuming this area and the stated rate of evaporation, such a lake would lose about 11 billion cubic feet of water annually. To balance this loss a continuous influent discharge of only about 325 cu.ft./sec. would be required. Under a cooler, moister climate evaporation would be less and the inflow needed to balance it would be reduced correspondingly.

## BOTTOM MUD AND LOWER SALT

The Bottom Mud and the Lower Salt constitute a related pair similar in many respects to the Parting Mud-Upper Salt pair. Together they represent an older, relatively deep lake that subsequently evaporated to a shallow, very saline lake or perhaps to complete dryness.

The Lower Salt, 25 to 35 feet thick, consists of layers of mixed salts with intervening partings of mud. Except that it is thinner and includes more mud partings, it generally resembles the Upper Salt, with trona and other carbonates predominating in its lower part and with halite occurring in its upper part. Its lower and upper surfaces of contact are sharply defined. The sharp lower surface is believed to represent the cessation of deposition of fine suspended sediment and hence probably a time when Owens Lake ceased to overflow. The distinct upper surface resembles that of Searles dry lake today, and may therefore represent complete desiccation; on the other hand it may represent only the floor of a very shallow saline lake.

The Bottom Mud, like the Parting Mud, is overlain abruptly by the trona in the base of the succeeding salt body. Its base, however, differs from the clearly defined base of the Parting Mud in that the mud grades downward, through alternations of mud and evaporites, into the underlying "Mixed" layer. For the purpose of this discussion the base of the Bottom Mud is fixed arbitrarily at depth 219 feet in core L-W-D, following the usage of G. I. Smith (unpublished), the depth at which evaporites become more abundant than mud in the downward direction. As thus defined the Bottom Mud is about 100 feet thick in the central part of the basin.

From inspection of core logs this layer is judged to be essentially similar to the Parting Mud, although it is somewhat more variable in composition. A noteworthy difference is a layer of mirabilite ( $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ ), 5 to 11 inches thick, at about the stratigraphic middle of the Bottom Mud. The mirabilite implies marked chilling of the lake water, and is compatible with the concept that the deep lake resulted from climatic cooling that reached its greatest intensity near the middle of Bottom-Mud time. Whether such cooling did in fact occur depends partly on evidence that may be found in other areas.

## "MIXED" LAYER

The "Mixed" layer, gradationally underlying the Lower Salt, extends down below the bottom of the deepest hole drilled (borehole L-W-D; Smith and Pratt, 1957, p. 25-51); it is therefore at least 700 feet thick. In the uppermost 150 feet (depth 177.4 to 310-315 in core L-W-D) it consists mainly of relatively insoluble minerals such as nahcolite, trona, and gaylussite, with a little clay and no halite. Apparently this sequence represents a time during which the lake was saline but did not reach the crystallization point for  $\text{NaCl}$ . This condition could be explained by the assumption that at the time the lake was overflowing continuously into Panamint Valley. Conceivably the halite encountered beneath the floor of Panamint Valley (Smith and Pratt, 1957, p. 58) at depths exceeding 80 feet represents solutes that entered from Searles Lake at this time.

The uppermost 150 feet of the "Mixed" layer are underlain by a sequence, more than 500 feet thick, in which trona and other carbonates are predominant, with much smaller amounts of halite and some layers of mud. Most of the zones are thin, but one 20-foot zone and one about 70 feet thick consist mainly of halite. The upper surfaces of these zones might represent surfaces of desiccation or near-desiccation that succeeded fairly long episodes in which saline lakes partly filled the basin. Thin layers of carbonates alternating with halite may represent shallow, short-lived lakes somewhat resembling playas. The "Mixed" layer as a whole implies warmer and drier conditions than those inferred from the Bottom Mud and Parting Mud. The climate represented seems to have ranged from one like that of today to a cooler, moister one, but with lower temperature not sustained as long as were the later conditions implied by the Bottom Mud and the Parting Mud.

The events and climates inferred from the foregoing description of the stratigraphic units are rationalized in table 1. In the table the term nonpluvial refers to a climate similar to that of the present day. The term pluvial refers to a climate appreciably cooler and moister than that of today. No other significance is attached to these terms.

TABLE 1

Rationalization of Stratigraphy and Shore Features of the Searles Basin with Climate. (Although the suggested correlation of stratigraphic units with strandlines seems probable, it is not established).

Stratigraphic units — Basin floor —	Strandlines	Implied events	Inferred climate
Upper Salt	Low strandlines	Cessation of inflow; at least near-desiccation; possibly with interruptions	Nonpluvial
Parting Mud	Higher strandlines; upper limit undetermined	Refilling of basin with fresh water to an undetermined altitude	Pluvial
Lower Salt	Not identified	Cessation of inflow; at least near-desiccation; possibly with interruptions	Nonpluvial
Bottom Mud	Higher strandlines, not separately identified. Possibly partly or wholly obscured by strandlines of the younger lake	Filling of basin with fresh water to an undetermined altitude	Pluvial
"Mixed" layer	Strandlines, probably now obscured by strandlines of later date	Basin at least partly filled with water much of the time, with occasional shrinkage to saturation point for Na carbonates, and possibly desiccation	Nonpluvial to intermediate

## RADIOCARBON DATES

*Dates from the Searles Lake sequence*

The discovery that the Parting Mud contains extractable organic matter opened the way for  $C^{14}$  dating of that layer, and made possible the identification and correlation, not only of the pluvial-lake phase represented by that layer, but also of the evaporite phases represented by the two salt bodies.<sup>5</sup> Samples of organic matter concentrated from drill cores were dated at the University of Chicago in 1953 and 1954, and later others were dated at the laboratories in Groningen and Yale Universities and in the U. S. Geological Survey, and at the Magnolia Petroleum Company Field Research Laboratory.<sup>6</sup> The samples dated are shown by number in table 2, which also shows the core from which each sample was taken and the substance used for dating. Figure 5 is a generalized column in which the dated samples are represented by black rectangles. The height of each rectangle shows the stratigraphic thickness for which the date is an average. The thicknesses vary with the concentration of  $C^{14}$  needed for processing in the various laboratories. From figures 3 and 4 it is seen that the thicknesses of the stratigraphic units vary slightly from one core to another within the central part of the Searles basin. Hence the column in figure 5, being generalized, includes a small distortion of the vertical dimension, as samples from 7 different cores are plotted on it. With one exception noted hereafter, the positions of the samples shown in the figure are plotted according to their distance from the top or base of the stratigraphic unit in which they occur, whichever is the smaller.

The rocks underlying the drainage basin that contributed to Ancient Searles lake include very few carbonate rocks. Hence it is likely that recycled ancient carbonates were not present in sufficient concentration to affect the  $C^{14}$  dates by more than a slight amount.

The most clearly established results of dating pertain to the Parting Mud, the unit on which dating efforts were concentrated first. The dates are consistent internally within statistics, and the results from the three laboratories represented are consistent also. As discussed in a foregoing section, the base of the Parting Mud shows that a dry or nearly dry saline flat in the Searles basin gave way to a lake in which mud was actively deposited. This implies that Owens Lake was then full to overflowing and was discharging actively into the Searles basin (fig. 1). Such an event demands a cooler and moister climate than that which preceded or followed the lake episode, as do also the pollen data for the Parting Mud, and some of the mollusks in the exposed silt on the assumption that silt and Parting Mud are correlative.

According to the dates inflow of water began before 23,000 yr. B.P. (the average of the six finite dates from near the base of the Parting Mud), and ceased about 10,000 B.P. if cessation of mud deposition was caused by cessation of overflow of Owens Lake. That inflow ceased because of climatic warm-

<sup>5</sup> The dating possibilities were the subject of correspondence among W. A. Gale, Eliot Blackwelder, R. F. Heizer, Ernst Antevs, R. F. Flint, and W. F. Libby.

<sup>6</sup> The samples marked C in table 2, column 1 were obtained from organic carbon extracted from pulverized core by means of organic solvents as described on a foregoing page. All the other organic-carbon samples listed were obtained from carbon recovered by burning pulverized core from which carbonates had been removed previously.

TABLE 2  
Radiocarbon Dates, Listed by Sample Number

Sample no. <sup>1</sup>	Core no. (fig.2)	Stratigraphic position (fig.5)	Sub- stance <sup>2</sup>	Age (C <sup>14</sup> yr B.P.) and dating method <sup>3</sup>	Reference
C-615	LS-7 or LS-8	Lowest 2.0 ft of Parting Mud.	OC	>16,000	G Libby 1951, p. 294.
C-616	LS-7 or LS-8	Uppermost 2.0 ft of mud in the Bottom. Mud immediately below Lower Salt.	OC	>19,000	S Libby 1954, p. 138.
C-894	129	Uppermost 1.0 ft of Parting Mud.	OC	10,494 ± 560	S Libby 1954b, p. 739.
C-895	129	1.0 ft of Parting Mud 3.0 to 4.0 ft below top of Parting Mud.	OC	15,089 ± 1000	S idem
C-896	129	1.0 ft of Parting Mud, 6.5 to 7.5 ft below top of Parting Mud.	OC	18,000 ± 730	S idem
C-897	129	Lowest 1.0 ft of Parting Mud, ~11.5 ft to 12.5 ft below top of Parting Mud.	OC	23,923 ± 1800	S idem
GRO-1460	X-20	1.0 ft of mud from Lower Salt, 3.3 ft to 4.3 ft above base of Lower Salt.	OC	32,300 ± 400 <sup>4</sup>	G Unpublished letter
GRO-1464	X-20	0.8 ft of mud from Bottom Mud, 9.5 ft to 10.3 ft below top of Bottom Mud.	OC	46,350 ± 1500 <sup>4</sup>	G idem
GRO-1802	X-20	Trona from Lower Salt, 2.3 to 2.6 ft above base of Lower Salt.	CO <sub>3</sub>	31,100 ± 400 <sup>4</sup>	G idem
GRO-1805	X-20	Trona from Lower Salt, 5.5 to 5.8 ft above base of Lower Salt.	CO <sub>3</sub>	31,750 ± 600	G idem
GRO-1808	X-20	Trona from Lower Salt, 0.7 to 0.8 ft below top of Lower Salt.	CO <sub>3</sub>	22,620 ± 200 <sup>4</sup>	G idem
GRO-1814	X-20	Trona from Lower Salt, 7.9 to 8.2 ft below top of Lower Salt.	CO <sub>3</sub>	25,600 ± 230 <sup>4</sup>	G idem
RC-18	GS-18	Lowest 0.2 ft of Parting Mud, 11.6 ft to 11.8 ft below top of Parting Mud.	OC	22,400 ± 1000 <sup>5</sup>	G idem
RC-33	X-16	Lowest 0.5 ft of Parting Mud, 13.5 ft to 14.0 ft below top of Parting Mud.	OC	22,800 ± 1400	G idem
RC-34	X-16	Uppermost 0.5 ft of mud in the Bottom Mud immediately below Lower Salt.	OC	>30,000	G idem
RC-35	X-16	0.4 ft of Parting Mud, 9.2 ft to 9.5 ft below top of Parting Mud.	OC	22,600 ± 1400	G idem

RC-36	X-16	Mud from 26.3 ft to 26.5 ft below top of Upper Salt.	OC	10,270 ± 450	G	idem
RC-50	X-16	Mud seam 33.0 to 33.3 ft below top of Upper Salt. (organic-carbon content)	OC	11,400 ± 600	G	idem
RC-50C	X-16	idem: carbonate content.	CO <sub>2</sub>	9,900 ± 500	G	idem
W-248	GS-12	Trona from 3.0 ft above base of Upper Salt.	CO <sub>2</sub>	8,550 ± 250	G	Rubin & Suess, 1956, p. 444.
W-340	GS-27	Twig from Lower Salt, approximately 3.0 ft above base of Lower Salt.	wood	26,700 ± 2000	G	Rubin & Alexander, 1958, p. 1484.
W-341	GS-27	Gaylussite from Lower Salt, approximately 3.0 ft above base of Lower Salt.	CO <sub>2</sub>	23,000 ± 1400	G	idem
W-343	GS-27	0.1 ft of mud from Lower Salt, approximately 3.0 ft above base of Lower Salt.	OC	29,500 ± 2000	G	idem
Y-267	129	Lowest 1.0 ft of Parting Mud, ~11.5 ft to 12.5 ft below top of Parting Mud. (=C-897)	OC	21,200 ± 2170	G	Preston, Person, & Deevey, 1955, p. 958.
Y-281	LS-7 or LS-8	Uppermost 2.0 ft of Bottom Mud immediately below Lower Salt. (=C-616)	OC	>29,630	G	idem
Y-574a	X-20	Uppermost 0.7 ft of Parting Mud.	CO <sub>2</sub>	11,810 ± 140	G	Unpublished data
Y-574b	X-20	idem	OC	10,700 ± 130	G	idem
Y-575a	X-20	0.6 ft of Parting Mud, 2.9 ft to 3.5 ft below top of Parting Mud.	CO <sub>2</sub>	12,420 ± 160	G	idem
Y-575b	X-20	idem	OC	12,730 ± 210	G	idem
Y-576a	X-20	0.8 ft of Parting Mud, 6.5 ft to 7.3 ft below top of Parting Mud.	CO <sub>2</sub>	16,890 ± 210	G	idem
Y-576b	X-20	idem	OC	16,620 ± 320	G	idem
Y-577a	X-20	Lowest 0.7 ft of Parting Mud, 11.1 ft to 11.8 ft below top of Parting Mud.	CO <sub>2</sub>	23,610 ± 1750	G	idem
Y-577b	X-20	idem	OC	24,690 ± 1070	G	idem

<sup>1</sup> C = University of Chicago; GRO = Groningen University; RC = Magnolia Petroleum Company Field Research Laboratory; W = U. S. Geological Survey; Y = Yale Geochronometric Laboratory.

<sup>2</sup> OC = organic carbon concentrated from sediment; CO<sub>2</sub> = inorganic carbonate from evaporite.

<sup>3</sup> S = solid carbon; G = gas (CO<sub>2</sub>, C<sub>2</sub>H<sub>2</sub>, or CH<sub>4</sub>).

<sup>4</sup> Average of two measurements, the two agreeing within statistics.

<sup>5</sup> Average of 4 samples, each run in duplicate.

ing and drying is supported by the pollen statistics already mentioned. The Parting Mud therefore represents a pluvial episode at least 13,000 years long but not greatly in excess of that length.

The rate of sedimentation can be approximated only crudely because each date is only the average date of a particular stratigraphic thickness of sediment. On the basis of the four finite Chicago dates (on organic carbon) the 5-foot thickness of mud measured from the center of sample C-897 to the center of C-896 was deposited in about 5,000 years, the next 3.5 feet, between C-896 and C-895, in about 4,500 years, and the next 3 feet, between C-895 and C-894, in about 4,500 years. According to these rough values sedimentation rates were about 1 ft./1,000 yr. early in the period, decreasing to about 1 ft./1,300 yr. in the middle, and to 1 ft./1,500 yr. toward the end, averaging 1 ft./1,175 yr. for the whole period.

On the other hand, the four Yale dates (Y-574b to Y-577b) on organic carbon<sup>7</sup> give sedimentation rates of about 1 ft./500 yr. early in the period, about 1 ft./1,000 yr. in the middle, and almost 1 ft./3,000 yr. toward the end, averaging 1 ft./1,260 yr. for the whole period. It is not known which sequence of dates affords the more reliable basis of measurement; more detailed examination of the sedimentary laminae might furnish a clue.

From the dates of the Parting Mud it can be inferred that crystallization of the Upper Salt occurred during some part of the last 10,000 years. It was hoped that dates from the salt body itself would make possible greater precision, but the three values obtained have not accomplished this. Samples W-248 and RC-50c consisted of inorganic carbonate from trona. Their use was based on the principle that CO<sub>2</sub> dissolved in the lake, in approximate equilibrium with atmospheric CO<sub>2</sub>, was the source for inorganic carbonates precipitated on the lake floor as well as for organic carbon. However, as figure 5 shows, not only are W-248 and RC-50c not consistent, but there is a small discrepancy, within statistics, between RC-50c and RC-50, organic carbon from the same 0.3 feet of sediment. Whether the latter discrepancy is real can be learned only from more dates, which are not available at present. A similar discrepancy appears in the group W-340, 341, and 343 from the Lower Salt, as noted hereafter, although the group GRO-1460, 1802, and 1805 agree within statistics. The discrepancies therefore may be related to contamination of the carbonates while in the ground or to laboratory procedures. Whatever their cause, for the present the two organic-carbon dates are preferred to the two carbonate-carbon dates from the Upper Salt.

The strata beneath the Parting Mud are less well dated. The dates presently available indicate that the lake that earlier occupied Searles basin had already existed for a long period at the time represented by the organic-carbon sample GRO-1464, about 46,000 yr. B.P. Mechanical sedimentation in the lake had ceased and precipitation of trona had begun prior to about 32,000 yr. B.P., the approximate date of samples GRO-1805, 1460, and 1802 from the basal part of the Lower Salt. If we apply the mean rate of sedimentation indicated for the Parting Mud, about 1 ft./1,200 yr., to the 10-foot thickness of sediment be-

<sup>7</sup> These are considered more reliable than carbonate-carbon values, owing to the probably greater freedom of organic carbon from alteration by exchange after deposition.

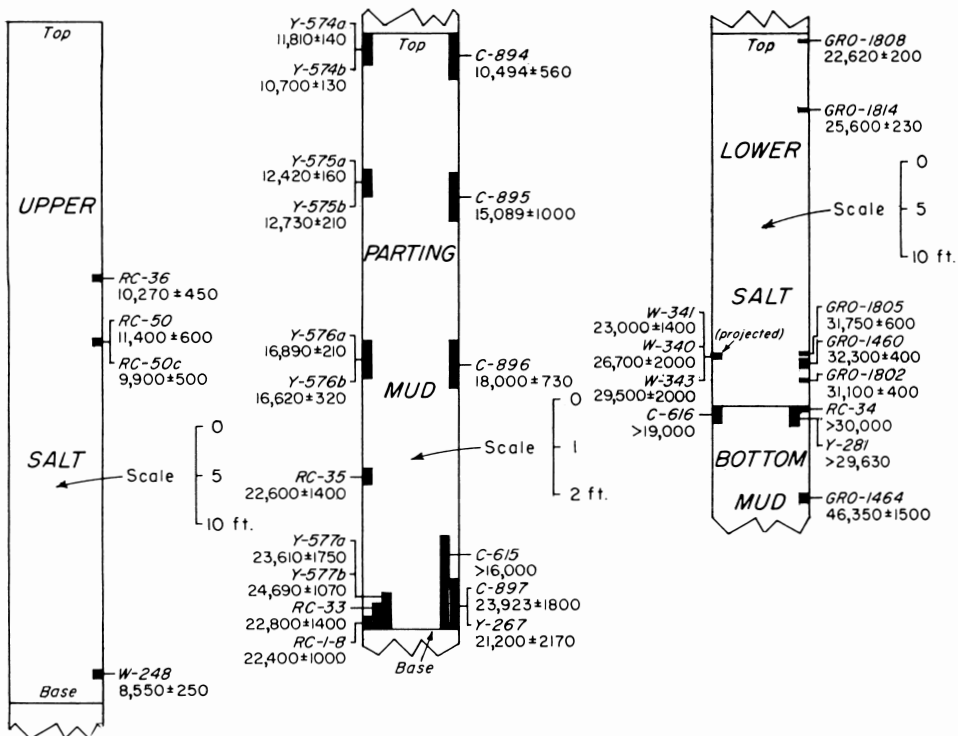


Fig. 5. Generalized columnar section of upper part of sequence developed from cores in central part of Searles basin, with positions and dates of C<sup>14</sup> samples. Laboratory numbers are keyed to table 1. Dates are quoted in years B.P. (before the present). Vertical scale in center column is not uniform with the two others.

tween GRO-1464 and the top of the Bottom Mud, we get a theoretical elapsed time of 12,000 years. Subtracted from 46,000 years, the approximate date of GRO-1464, this gives 34,000 years as a tentative date of the top of the Bottom Mud, a value in fair agreement with 32,000 years for GRO-1460. Application of the average Parting Mud sedimentation rate is, however, based only on assumption; the rates for the two mud bodies could have been different.

Although a date of about 32,000 B.P. is satisfactorily fixed for a zone near the base of the Lower Salt, samples from about the middle of that body give conflicting dates. Within a stratigraphic thickness of only 0.1 foot, organic carbon (W-343) gave ~29,500, inorganic carbon from carbonate (W-341) gave ~23,000, and wood from a fossil twig (W-340) gave ~26,700 years. The inorganic-carbon date is rejected as being inconsistent with the dates of GRO-1802, 1805, and 1460 and patently too young. The conflict between RC-50 and RC-50c, in the Upper Salt body, is analogous. The other two (W-340, W-343) agree within statistics and their average, ~28,100, is accepted tentatively as the best value available.

This value is not necessarily inconsistent with the adjacent GRO dates shown in figure 5, because two cores, 3.75 miles apart, are involved. In one of

them (GS-27), located near the margin of the basin, the Lower Salt is only about 23 feet thick, whereas in the other (X-20), near the center of the basin, the Lower Salt is 39 feet thick. Therefore, although W-343 and W-340 are at almost the same position measured from the base of the Lower Salt as is GRO-1802, they are probably younger than GRO-1802. On a basis of the thicknesses of the Lower Salt in the two cores, the position of the W samples has been projected into the generalized column for the central part of the basin as indicated in figure 5. Although determined mechanically this position is believed to be more realistic than one based on measurement from the base of the Lower Salt. Crystallization of the Lower Salt must have been embraced within the interval  $>32,000$  B.P. to somewhat more than  $23,000$  B.P., a period probably more than  $9,000$  yr. long, and desiccation or near-desiccation of the Searles basin at the end of Lower Salt time then occurred shortly before  $23,000$  yr. B.P. The duration of that condition seems to have been short.

We can attempt to estimate crystallization times for the Lower and Upper Salt bodies in another way. The thickness of the Lower Salt is a crude measure of the amount of dissolved substances brought into the earlier lake after it ceased to overflow, and is a still cruder measure of the time elapsed between cessation of overflow and near-desiccation, if we assume that the annual increment is known and was constant, and that the rate of evaporation also was constant. The  $C^{14}$  dates imply that about  $13,000$  years were required to bring enough dissolved substances into the Searles basin to precipitate, afterward, the (average) 80-foot layer (2.4 billion tons) of salts constituting the Upper Salt. This is at a rate of 1 foot (30,000,000 tons) of precipitated salts per 162 years of antecedent contribution. Assuming the areas of the Upper Salt and Lower Salt are equal and assuming a similar rate of contribution, the (average) 30-foot (0.9 billion tons) Lower Salt would have required 4,860 years of antecedent contribution after any overflow from the Searles basin had ceased.

Similarly, evaporation of Searles Lake to dryness during precipitation of the 80-foot Upper Salt (possibly with interruptions by freshening) required a maximum of  $10,000$  years. At an assumed similar rate of evaporation, and neglecting interruptions, precipitation of the 30-foot Lower Salt would have required a maximum of  $3,750$  years. Obviously these calculations are subject to large errors because of the assumptions made, and because they neglect loss of solutes through possible overflow from the Searles basin. In any case they refer only to the accumulation of the evaporites; they do not take account of the time interval between completion of precipitation of the Lower Salt and restoration of the lake represented by the Parting Mud. For what they are worth, the values are compatible with the  $C^{14}$  dates.

We have, then, a record, controlled by  $C^{14}$  dates, of two pluvial climates marked by deep-lake phases, each followed by a nonpluvial climate. The later, existing nonpluvial climate is marked by desiccation; the earlier one was marked by a similar condition or by something approaching it. The earlier pluvial began long prior to  $46,000$  B.P. and was on the wane before  $32,000$  B.P.; the later pluvial began at or before  $23,000$  B.P. and was on the wane before  $10,000$  B.P. The earlier time of maximum dryness immediately preceded

the onset of the later pluvial. The later desiccation is still in effect today; how long ago it started is not known.

*Date of last overflow of Owens Lake*

H. S. Gale (1915, p. 260-264) calculated the "age" of Owens Lake by dividing the amounts of chlorine and sodium in solution in the lake in 1912 by the respective annual inflow of these elements estimated from sampling of Owens River. By "age" he meant the time since Owens Lake ceased to overflow and began to accumulate these elements. He arrived at values of 4,200 years (Cl) and 3,500 years (Na).<sup>8</sup>

However, Antevs (1938, p. 191) showed that these values could be explained alternatively as representing the time since a rebirth of Owens Lake following evaporation to dryness, which should have occurred in the period (Hypsithermal and its equivalents) centered around 5,000 yr. B.P.

Whether H. S. Gale's values do in fact measure the cessation of Owens Lake overflow is not clearly evident from the stratigraphy of the Searles sediments. Those sediments tell us with certainty only that the approximate date 10,000 yr. B.P. sets a maximum limit to the time when the lake water became saturated with trona. It can be argued that that date also approximately measures the time when long-continued inflow to Ancient Searles lake, and hence outflow from Owens Lake, ceased. Other sources of inflow to Ancient Searles lake are negligible; water to maintain the lake would have had to come from a much greater segment of the eastern watershed of the Sierra Nevada than that which now furnishes water to Indian Wells Valley. However, the Upper Salt contains several mud partings. Conceivably these represent re-freshenings of Searles Lake, brought about by overflows of short duration from Owens Lake. Such overflows could have transferred accumulations of salts in solution from Owens Lake to Searles Lake. It is possible therefore that temporary overflows from Owens Lake to Searles Lake might have occurred less than 10,000 years ago. On the other hand if the mud partings represent sediment washed into the center of the basin from local sources, we know of no evidence that Owens Lake overflowed after the Parting Mud ceased to be deposited.

*Possible dating of sediments in other basins*

Probably sediments of other lakes of the ancient chain likewise contain extractable organic matter. If so, and if suitable samples could be secured, the sequence of events inferred for Searles Lake could be checked in part by stratigraphic study and C<sup>14</sup> dating of such substances in Death, Panamint, and Owens Valleys. Borings made in Death Valley have established the presence, beneath its floor, of alternating layers of clay and evaporites (H. S. Gale, 1914b, p. 412-413). Dates on clay layers could be compared with the inference drawn by Blackwelder (1933, p. 470) from geomorphic features, that Lake Manly existed in Tahoe time but not in Tioga time. Borings made in Panamint Valley (Smith and Pratt, 1957, p. 51-62) show clay and silt with minor gypsum, carbonates, and halite. If dates are possible they should throw light on the time of last overflow of Ancient Searles lake.

<sup>8</sup> An early printing of H. S. Gale's report, still existing in some libraries, gives much larger values, which are corrected in a later printing.

## CORRELATION OF EVENTS IN THE SEARLES BASIN WITH EVENTS ELSEWHERE

*Glacial events*

Inclusive dates of the later pluvial period inferred at Searles Lake (>23,000 to ~10,000 B.P.) approximate the inclusive dates of the classical Wisconsin glaciation of central United States. In that glaciation the Laurentide Ice Sheet invaded the Great Lakes region about 25,000 B.P., reached a maximum at or later than 18,000 B.P., and after lesser readvances began its final retreat about 10,700 B.P. (See Flint and Rubin, 1955; Flint, 1955, 1956). The agreement of the two pairs of inclusive dates indicates a nearly 1-to-1 time relationship between the classical Wisconsin glaciation in the eastern part of the United States and the pluvial climate represented by the Parting Mud. This time coincidence agrees with stratigraphic evidence of coincidence of glacial with pluvial events elsewhere in the Basin-and-Range region (Gilbert, 1890, p. 305-311; Hunt, Varnes, and Thomas, 1953, p. 28; Putnam, 1950), and thereby indicates that the last glacial and the last pluvial, at least within the belt of westerly winds on the North American continent, are sensitively related to a climatic cause common to both.

The close time agreement between the Parting-Mud pluvial and the classical Wisconsin glaciation implies that the Bottom-Mud pluvial should find a correlative in the glacial sequence in North America. Evidence of glaciation in the range 40,000-50,000 yr. B.P. should be looked for in that sequence.

There exists no physical connection on the basis of which sediments in the Searles basin can be correlated with glacial features in the Sierra Nevada. However, the similarity of their climatic implications and stratigraphic positions suggest tentative correlation of the Bottom Mud with the Tahoe glacial unit and of the Parting Mud with the Tioga glacial unit. The two glacial units (Blackwelder, 1931) are not far apart in time and represent the two last major glacial climates in the Sierra Nevada. The correlation, which seems reasonable, could be tested best by C<sup>14</sup> dating.

*Lakes Bonneville and Lahontan<sup>9</sup>*

The dated sequence beneath Searles Lake can be considered profitably in connection with the record of Ancient lakes Bonneville and Lahontan. Since the classic work of Gilbert (1890) on Lake Bonneville, geologists have thought of the high-water phases of that lake as approximating glacial maxima, and of the low-water or desiccation phases as recording glacial minima; the Searles Lake data support that opinion, as do the minor recent fluctuations of Great Salt Lake, which are correlated with climatic variations. The Searles data likewise are compatible with the dates on core material from between 18 and 30 feet below the bottom of Great Salt Lake, and consisting of sediments of the last freshwater phase of the lake. The dates are 16,850±300 (W-321, organic carbon) and 16,680±300 (W-319, inorganic carbonate) (Rubin and Alexander, 1958, p. 1484).

The Searles Lake dates suggest further that net evaporation was in progress during a substantial later portion of the Parting Mud phase, because by the end of that phase, around 10,000 yr. B.P., the concentration of sodium

<sup>9</sup> A pertinent and informative paper (Broecker and Orr, 1958), not published until after the completion of the present paper, is recommended as a reference.

carbonate in the lake water had reached the precipitation point for trona. These dates are compatible with a group of  $C^{14}$  dates (discussed by Jennings, 1957) from Danger Cave, Utah, in the western part of the Bonneville basin only a little more than 100 feet above Great Salt Lake. The dates of 6 samples from 4 culture layers in the cave are internally consistent. The oldest, approximately 11,500 yr. B.P., directly overlies the beach gravel of a late phase of Lake Bonneville. The stratigraphy shows that the site was not submerged after the layer containing the sample was deposited. Hence Lake Bonneville was undergoing net evaporation, and uncovered the cave, at some time prior to 11,500 B.P., and after that date did not rise to the altitude of the cave. The compatibility of these Bonneville and Searles dates suggests that variations in the two lakes may have been broadly synchronous.

The relations at the Leonard Rockshelter, Nevada (Heizer, 1951) resemble those at Danger Cave. Situated in the downstream part of the Humboldt Valley, the rockshelter contains Lake Lahontan beach gravel at elevation 4,175 feet, more than 150 feet above the floor of Humboldt Dry Lake. Although not specified, it appears from the facts published that after the beach gravel was deposited the rockshelter was not later submerged. The date of bat guano immediately overlying the beach gravel is about 11,200 years, very close to that of the lowest culture layer at Danger Cave.

Compatible with those dates is the date of wood from the lowest culture layer in Fishbone Cave, facing Winnemucca dry lake, also in the Lake Lahontan basin and at an altitude less than 100 feet below that of the dated layer at Danger Cave. The site is reported to have been occupied by man shortly after the cave emerged; the date is approximately 11,200 years (Broecker, Kulp, and Tucek, 1958, p. 163).

According to the  $C^{14}$  dates the beach at Leonard Rockshelter and that at Danger Cave, formed during fluctuating subsidence of the Bonneville and Lahontan pluvial lakes, were built at some time prior to that of the Two Creeks peat in eastern Wisconsin. That peat was overwhelmed by glaciation, the Valdres readvance, believed to have reached its maximum around 10,700 B.P. (Flint, 1956). If the climatic change that caused that readvance was reflected in the regimens of Lakes Bonneville and Lahontan, any resulting rise of the lake surfaces was limited, for it failed to reach the altitudes of Leonard Rockshelter and Danger Cave. The change has not been discerned in the stratigraphy of Searles Lake. Apparently therefore it was not conspicuous in the southern part of the Basin-and-Range region.

If glacial readvances such as the Valdres were responses to local variations in a general continent-wide rise of atmospheric temperature, they are expectable where a large ice sheet is present in a state of metastability. But it is doubtful whether we should expect major response in the Basin-and-Range region, where glaciers were small and where, with the waning of Wisconsin glacial climate, the atmospheric circulation pattern may already have shifted enough to remove that region from the belt of "pluviality."

The fact that the sandals found at Fort Rock Cave, Oregon, and dated at 9,000 B.P. (ref. in Flint and Deevey, 1951, p. 278), were woven from sagebrush is compatible with the view that shortly after the time of the Valdres

maximum even the extreme northern part of the Basin-and-Range region was becoming arid.

Although the Searles Lake dates and inferred events can be reasonably correlated also with dated events recorded in parts of Europe and beneath the deep-sea floor, in the present paper no attempt is made to suggest such wider correlation.

#### SUMMARY

The Searles basin was one of a chain of four basins that held temporary Pleistocene lakes. It received influent drainage only when the Owens basin overflowed; this could have occurred only when the climate was cooler and moister than today's. Such a former climate is supported by fossil aquatic mollusks and by fossil pollen.

The presence of numerous strandlines around the basin establishes that a lake formerly existed, but it has not been possible to correlate the strandlines with the lake-floor sediments known from core borings.

At least two former lakes of different ages are indicated by two pairs of strata revealed in the cores. Each pair consists of clay and silt overlain by evaporites. The earlier lake lasted from before 46,000 to nearly 23,000 B.P., by which time it was dry or nearly so. The later lake formed about 23,000 B.P. and ceased to receive inflow about 10,000 B.P. The indicated fluctuations are believed to have been related directly to fluctuation of the regional climate.

Data from the Searles basin do not yet afford a decisive basis for judgment on the validity of H. S. Gale's calculation of the "age" of Owens Lake, nor on the times when Ancient Searles lake overflowed. The history and chronology of the later lake are compatible with published data on the history of Lakes Bonneville and Lahontan.

The inclusive dates of the later lake in the Searles basin approximate those of the classical Wisconsin glaciation. Hence they confirm the synchrony of the last glacial with the last pluvial climate within the belt of westerly winds over the North American continent.

#### ACKNOWLEDGMENTS

David V. Haines supplied samples recovered during the drilling of Geological Survey test holes at Searles Lake. Courtesies extended by G. I. Smith and Ward Smith of the U. S. Geological Survey and D. E. Garrett, Julien Phillips, and D. L. Sawyer of the American Potash & Chemical Corporation are acknowledged. C. I. Alexander of the Magnolia Field Research Laboratories, Hessel de Vries, and E. S. Deevey are thanked for cooperation in obtaining  $C^{14}$  dates and for permission to quote unpublished dates.

Helpful discussion of the manuscript by Hessel de Vries, G. I. Smith, W. S. Broecker, and Ward Smith is acknowledged.

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