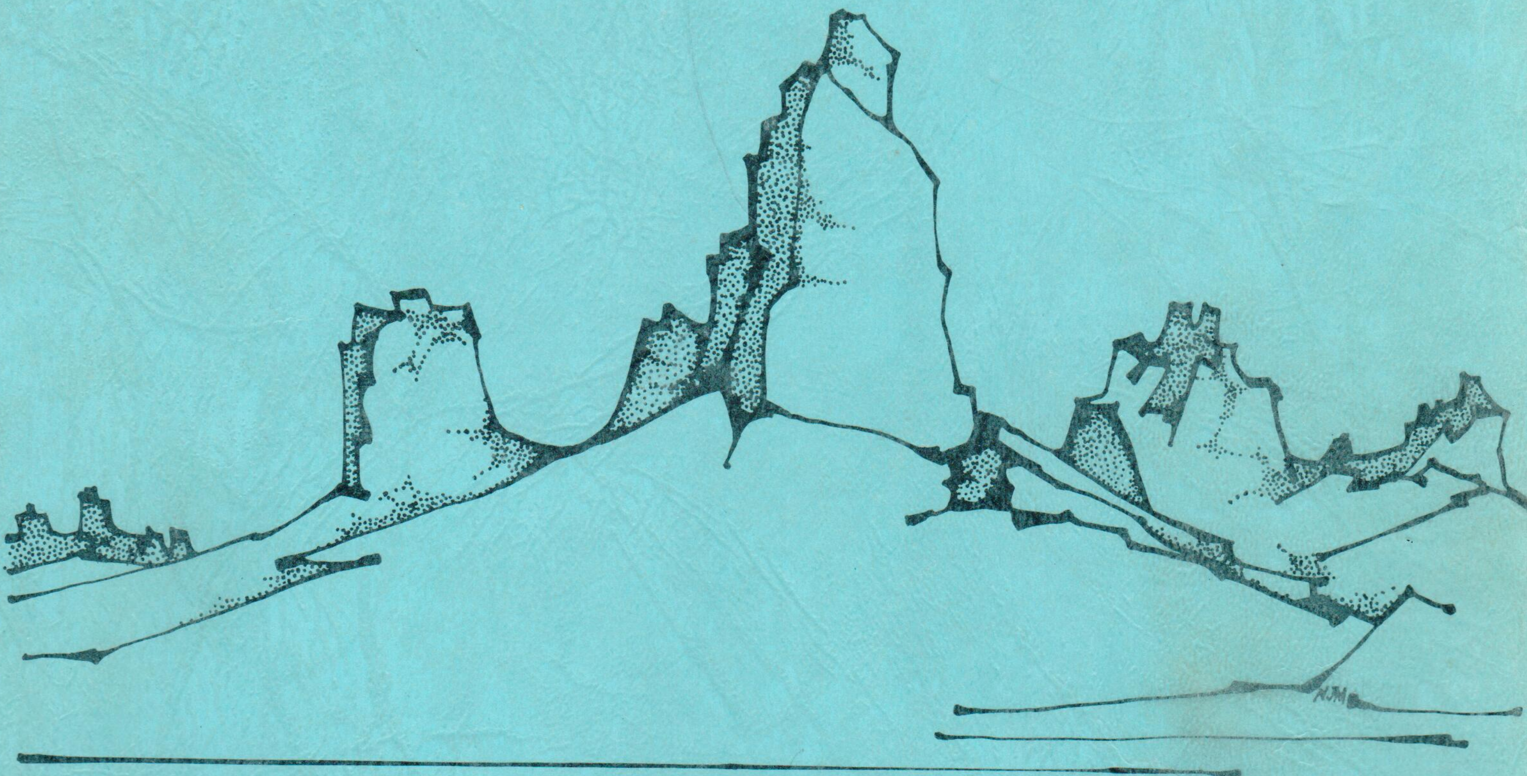


PLEISTOCENE GEOLOGY AND PALYNOLOGY

SEARLES VALLEY, CALIFORNIA

GUIDEBOOK FOR
FRIENDS OF THE PLEISTOCENE
PACIFIC COAST SECTION
SEPTEMBER 23-24, 1967

R. J. McLaughlin

PLEISTOCENE GEOLOGY AND PALYNOLOGY
SEARLES VALLEY, CALIFORNIA

FIELD GUIDE TO EXAMPLES OF LATE QUATERNARY GEOLOGY
SEARLES VALLEY, CALIFORNIA

By G. I. Smith
U. S. Geological Survey
Menlo Park, California

SUMMARY OF PALYNOLOGICAL DATA FROM SEARLES LAKE

By E. B. Leopold
U. S. Geological Survey
Denver, Colorado

ARCHAEOLOGY OF THE MOJAVE DESERT AND ITS PLAYAS: SELECTED REFERENCES

By E. L. Davis
San Diego Museum of Man
San Diego, California

GUIDEBOOK FOR
FRIENDS OF THE PLEISTOCENE
PACIFIC COAST SECTION
SEPTEMBER 23-24, 1967

FIELD GUIDE TO EXAMPLES OF LATE QUATERNARY GEOLOGY

SEARLES VALLEY, CALIFORNIA

By

George I. Smith
U. S. Geological Survey, Menlo Park, California

CONTENTS

FIELD GUIDE TO EXAMPLES OF LATE QUATERNARY GEOLOGY, SEARLES VALLEY, CALIFORNIA

By George I. Smith

INTRODUCTION

Searles Valley lies near the southwest corner of the Basin Range province and about midway between the south ends of the Sierra Nevada and Death Valley (fig. 1). Both Searles Valley and the lake within it, Searles Lake, are commonly mentioned in geologic studies of the late Quaternary, and this is a guide to some of the more easily reached and informative examples of its geology.

During the Pleistocene, as noted by Gale (1914), Searles Valley was the site of a large lake, about 25 miles long and 10 miles or more wide (fig. 2). It was part of a chain of lakes that was nourished chiefly by waters flowing from the east side of the Sierra Nevada (fig. 3). The lakes along the high Sierras that were part of this chain included Lake Russell (now Mono Lake), Adobe Lake, Round Valley Lake, and Owens Lake (see fig. 1). Owens Lake overflowed southward to Indian Wells Valley to form China Lake; it overflowed eastward into Searles Valley to form Searles Lake. At the highest stages, Searles and China coalesced into one lake that drained southeast into a stream that led to Panamint Valley. Although the record is not clear, the lake in Panamint Valley apparently overflowed eastward into Death Valley during the most intense pluvial episodes and contributed, along with the Mojave and Amargosa Rivers, to the formation of Lake Manly.

The climate in Searles Valley today is hot and arid (fig. 4). In the summer, temperatures range daily from 70° to 80°F to well over 100°F, and precipitation is sporadic and small. In the winter, temperatures range daily from near or below freezing to 50° to 70°F, and precipitation comes mostly from regional storms that bring steady rains. The floral assemblages characteristic of the valley are noted in the section by Estella Leopold.

Human activity today in Searles Valley revolves chiefly around the two chemical companies that pump brines from beneath the surface of Searles Lake and extract industrial chemicals from them. The American Potash & Chemical Corp., at Trona, produces sodium carbonate, sodium sulfate, potash, borax, lithium, phosphate, and bromine. The West End Plant of the Stauffer Chemical Co., at Westend, produces sodium carbonate, sodium sulfate, and borax. This deposit has a total production value (essentially during the period 1926 to the present) of about three-quarters of a billion dollars, and it annually accounts for 5 to 10 percent of California's mineral production (exclusive of fuels).

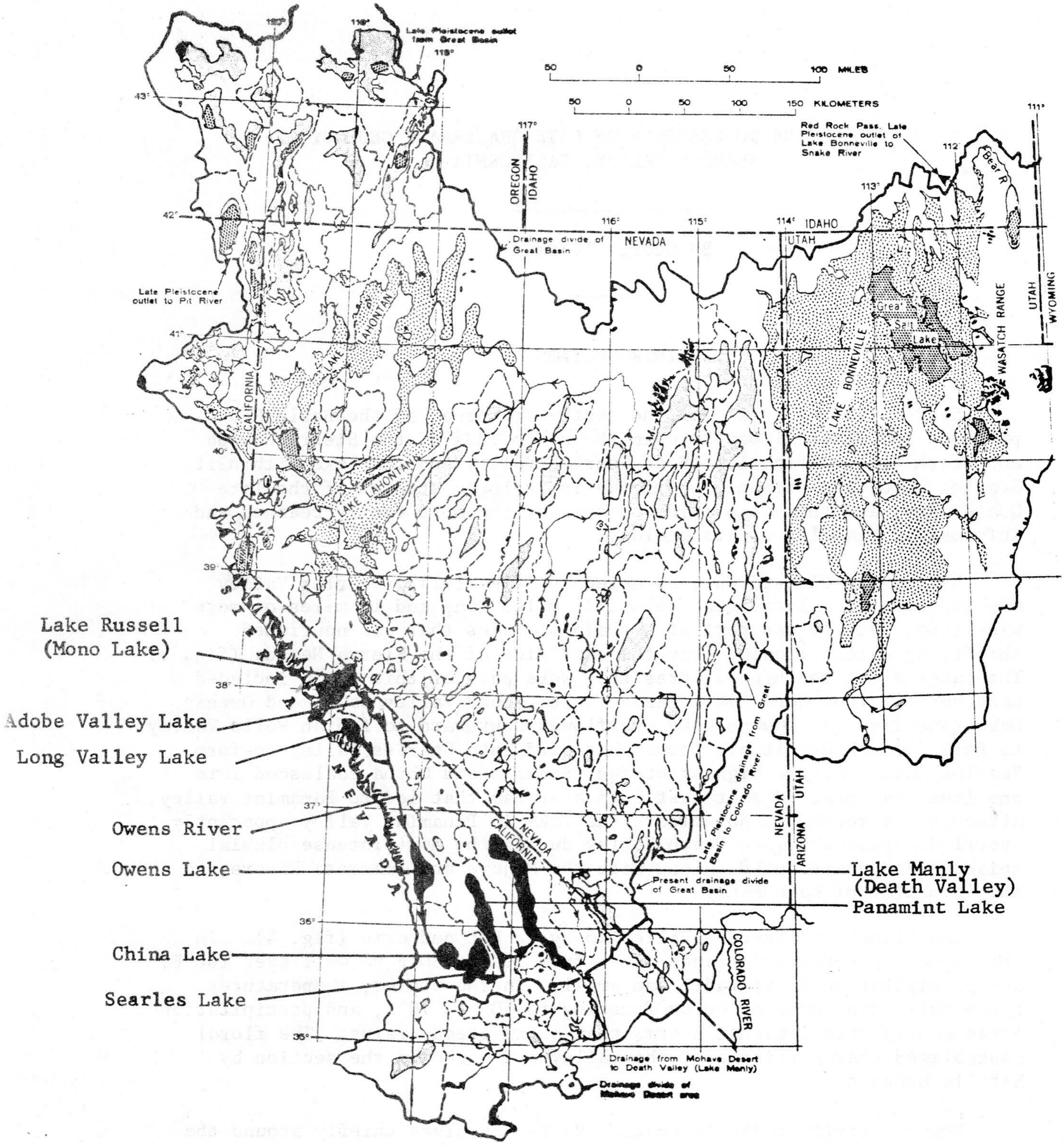


Figure 1. Index map showing relation between lakes of Wisconsin age in Owens River system (large black areas) and others in the Great Basin. Overflow connections between basins shown by solid lines and arrows; basin boundaries shown by dashed lines. Small black areas along Sierra Nevada and other high mountain ranges represent glaciers. Map adapted from Morrison (1965).

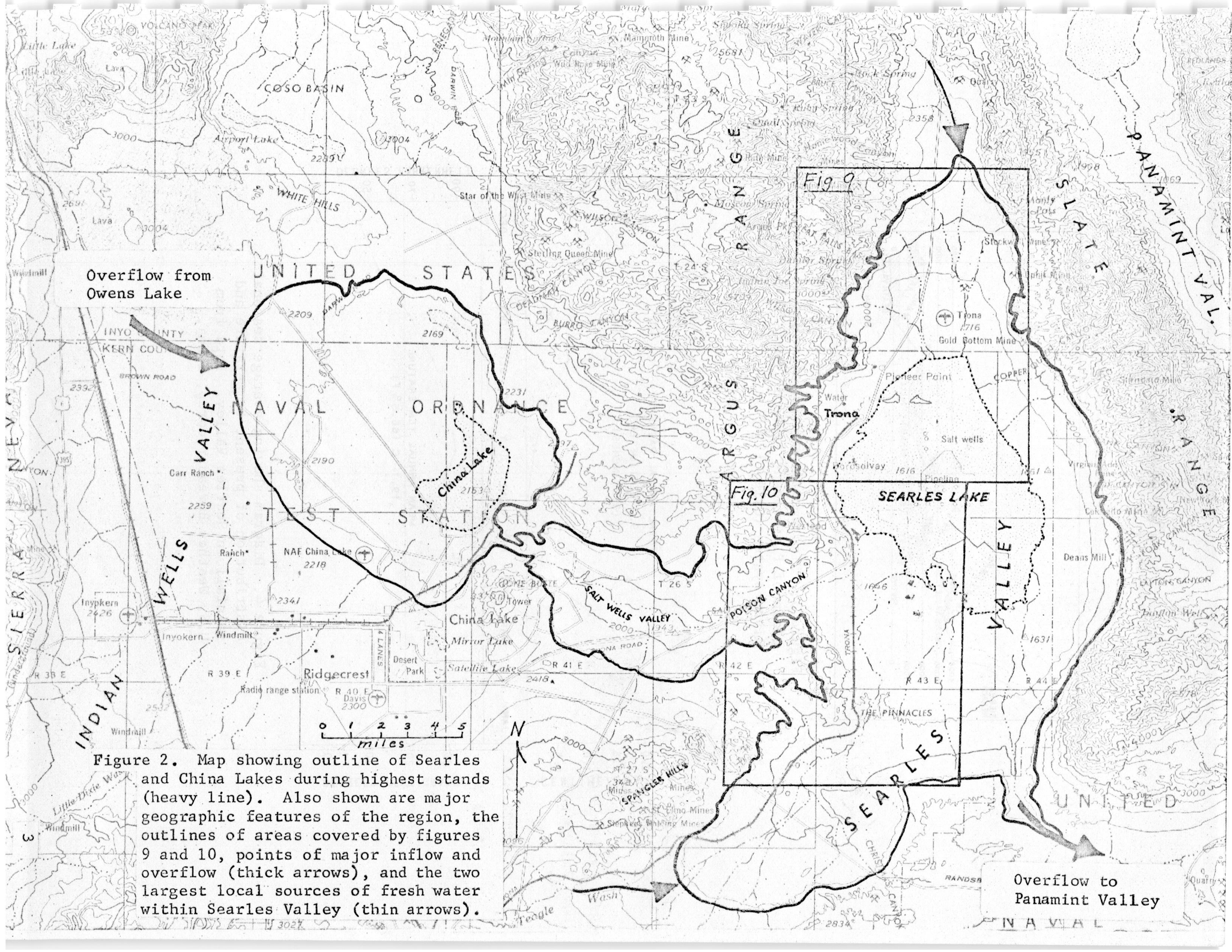


Figure 2. Map showing outline of Searles and China Lakes during highest stands (heavy line). Also shown are major geographic features of the region, the outlines of areas covered by figures 9 and 10, points of major inflow and overflow (thick arrows), and the two largest local sources of fresh water within Searles Valley (thin arrows).

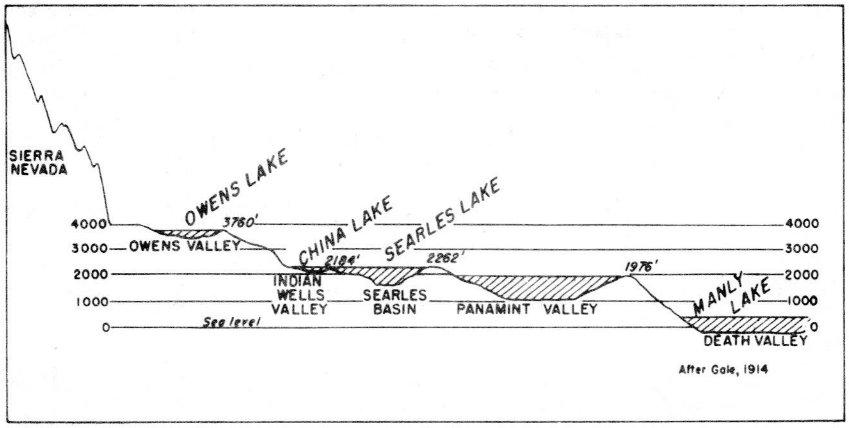


Figure 3. Diagrammatic section showing chain of Pleistocene lakes in Owens River system (Gale, 1914).

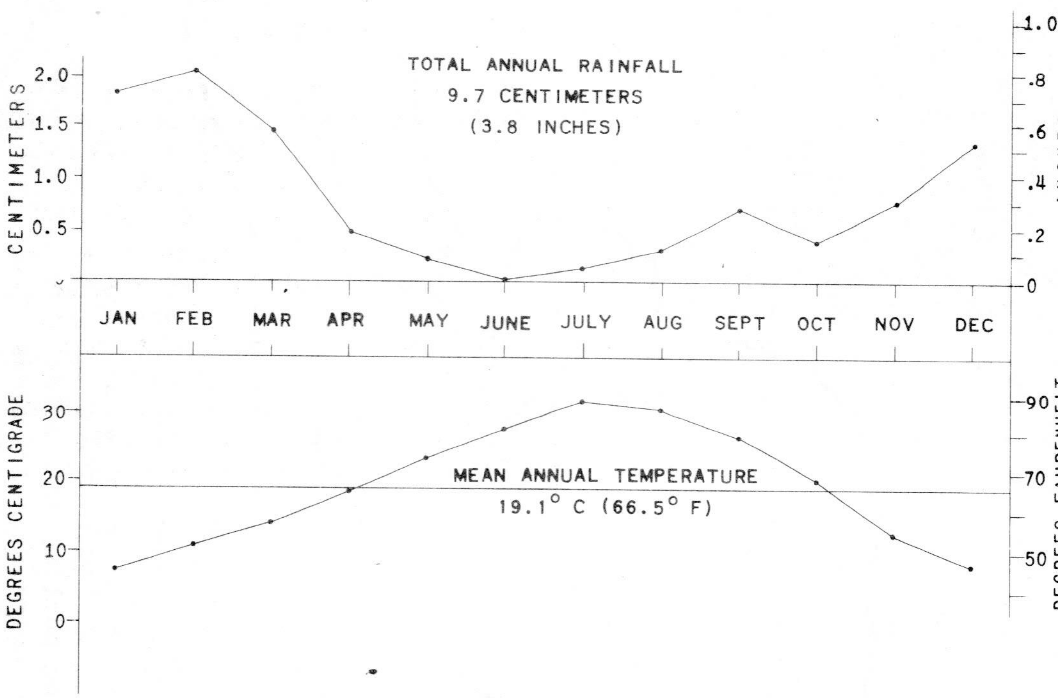


Figure 4. Diagram showing average seasonal distribution of present temperature and rainfall in Searles Valley. Data from U.S. Weather Bureau records, Trona.

This guide has been prepared for the fall 1967 Field Conference of the Friends of the Pleistocene, Pacific Coast Section. It does not constitute a formal publication, and the contributors would like to ask that all users of it refrain from citing the data in it or the guidebook itself in formal publications. This is partly because many of the ideas are introduced solely for the sake of discussion, and partly because the report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards or stratigraphic nomenclature.

SUMMARY OF LATE QUATERNARY HISTORY OF SEARLES VALLEY

The geologic history of Searles Lake during the last 150,000 years, as inferred from cores of subsurface deposits and exposed sediments, is shown in figure 5. A diagram showing that history in more detail for the last 40,000 years is shown in figure 6. These figures are reproduced from a preliminary report prepared in 1965 (Smith, 1965, 1967?), and subsequent findings--some of which are evident at the stops listed in this guide--will force minor revisions prior to final publication. Systematic study of the cores was started in 1953; mapping of the exposed geology began in 1960 and is now nearly completed. Preliminary interpretations of these data have been published (Smith, 1962, 1965, 1967?; Smith and Haines, 1964), and what follows is a summary of those papers.

Several dozen cores, representative of the upper 150 feet of sediments beneath the present surface of the valley floor, have been studied extensively (Flint and Gale, 1958; Haines, 1959; Smith, 1962; Smith and Haines, 1964; Stuiver, 1964), and one core extending to a depth of 875 feet has been described (Smith and Pratt, 1957). These show that the subsurface deposits down to at least 875 feet consist of an alternating series of mud layers that indicate large permanent lakes, and saline layers that indicate small saline or dry lakes (fig. 11). The geologic ages assigned to them were proposed earlier (Smith, 1962). Absolute ages less than 45,000 years are based on 73 published C-14 dates shown in figure 12; 39 of them are on disseminated organic carbon, 32 on carbonate minerals, and 2 on wood (Flint and Gale, 1958; Smith, 1962; Stuiver, 1964). Ages of more than 45,000 years are estimated from rates of mud sedimentation determined within the C-14 dated section.

Most of the lacustrine sediments exposed on the sides of the valley surrounding Searles Lake have been mapped geologically and related to the subsurface deposits. This mapping has provided data on the upper limits reached by the large permanent lakes and has revealed details of their fluctuations. The exposed evidence of these lakes and their fluctuations is of several types. Shorelines, beaches, and bars are well preserved on the upper levels of the valley. These generally cannot be related to each other, though, and they have not been used extensively to reconstruct the sequence of events in the lake history. The most informative record is provided by the lithology, distribution, and stratigraphic sequence of the lacustrine and nonlacustrine sediments, and by the unconformities and fossil soils that indicate gaps in their deposition. In the exposed

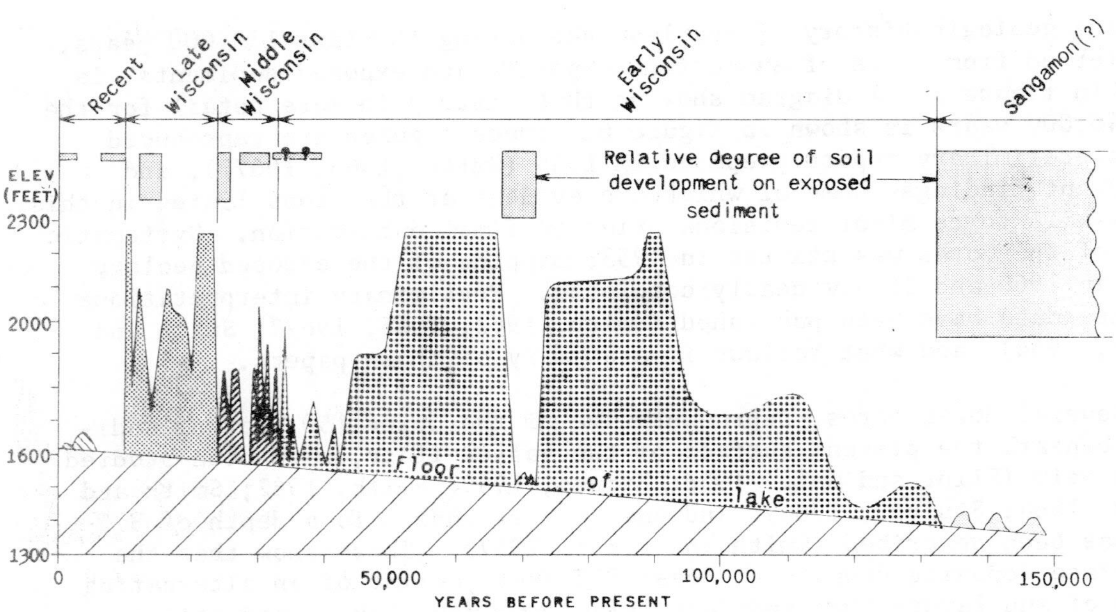


Figure 5. Diagram showing inferred history of Searles Lake during interval between present and 150,000 years ago (Smith, 1967?).

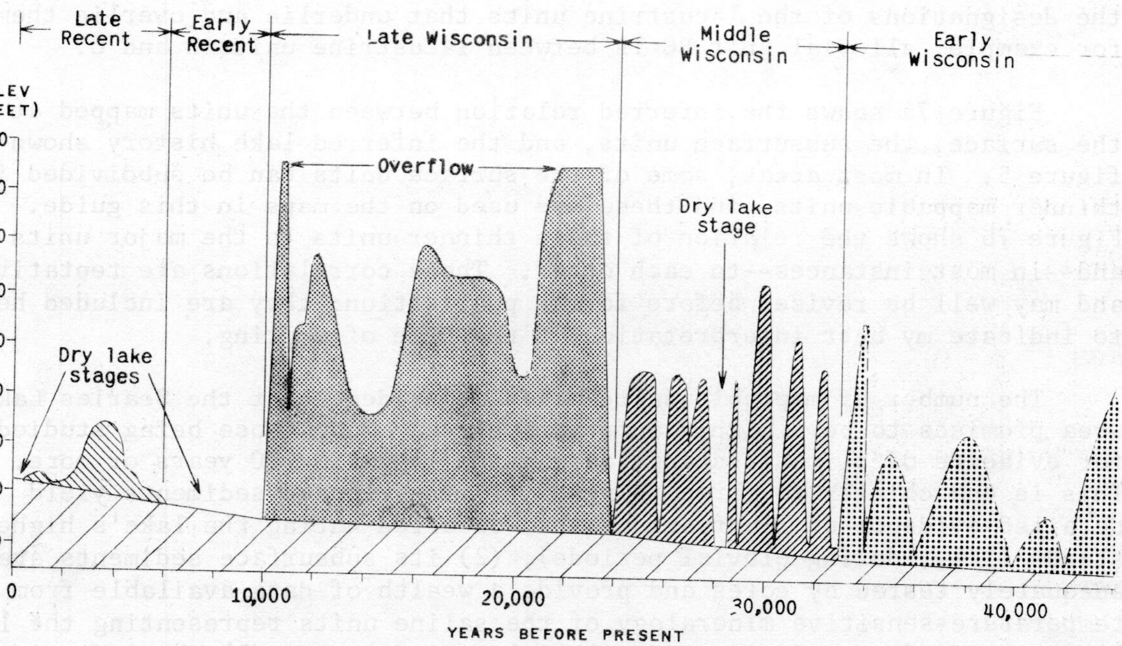


Figure 6. Diagram showing inferred history of Searles Lake during interval between present and 40,000 years ago (Smith, 1967?).

deposits, the record of events correlated with the period extending from middle Wisconsin to Recent times is best preserved. The best explored part of the subsurface section--the Overburden Mud, Upper Salt, Parting Mud, and Lower Salt--is also considered correlative with this period.

In this guide the exposed deposits have been assigned informal names to facilitate description. Four main lacustrine units are recognized and assigned the letters A (for the oldest) to D. The units between them are largely nonlacustrine, although in some areas--especially at lower elevations--they include major proportions of lacustrine deposits. The nonlacustrine deposits have been assigned double letters according to the designations of the lacustrine units that underlie and overlie them; for example, alluvial unit BC is between lacustrine units B and C.

Figure 7a shows the inferred relation between the units mapped at the surface, the subsurface units, and the inferred lake history shown in figure 5. In most areas, some of the surface units can be subdivided into thinner mappable units, and these are used on the maps in this guide. Figure 7b shows the relation of these thinner units to the major units and--in most instances--to each other. These correlations are tentative and may well be revised before formal publication; they are included here to indicate my best interpretation at the time of writing.

The number of mappable units makes it evident that the Searles Lake area promises to be a highly informative area among those being studied for evidence of climatic change during the last 150,000 years or more. This is due chiefly to three things: (1) its exposed sediments yield detailed evidence of fluctuations that occurred during the lake's higher stands (i.e., during pluvial periods); (2) its subsurface sediments are adequately tested by cores and provide a wealth of data available from the temperature-sensitive mineralogy of the saline units representing the lake's lower stands (i.e., during interpluvial periods); and (3) the inflow to the basin was abnormally sensitive to climatic change. This sensitivity is due to the fact that when Searles Lake was the terminus of the chain, small changes in regional precipitation--acting on the combined drainage areas of the connected lakes--drastically changed the quantity of water flowing into Searles Lake. When the lake was cut off from this upstream supply of water, the inflow was greatly reduced and evaporation quickly converted Searles to a small saline lake or a salt pan. Conversely, when precipitation increased enough to restore the overflow from upstream, the amount of water flowing into Searles basin increased disproportionately. The lakes in Searles Valley thus had histories of extremes, and for this reason their record provides an uncommonly sensitive indicator of climatic change.

The history of fluctuations of Searles Lake can be correlated with the histories of nearby areas. Figure 8 suggests possible correlations with pluvial events in Lake Lahontan and glacial events in the Sierra Nevada. The sources of data for those areas did not assign absolute ages, so in constructing figure 8, the ages of the events in the Sierra Nevada and Lake Lahontan have been adjusted to fit the ages assigned to the correlated events in Searles Lake.

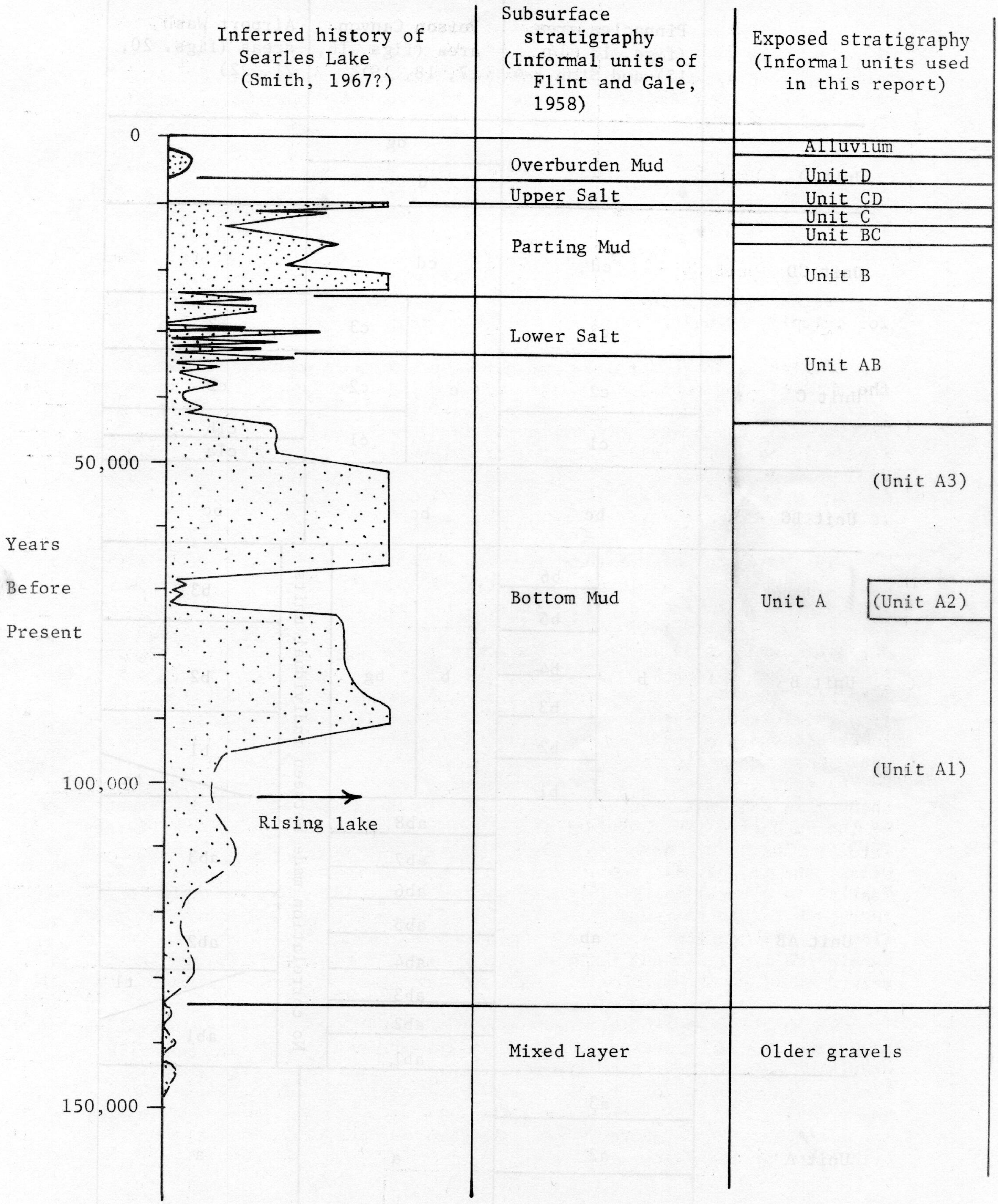


Figure 7a. Tentative correlations between inferred history of Searles Lake and the major units of its subsurface and exposed stratigraphy.

	Pinnacles area (figs. 13, 14, 15) and Stop 1-4	Poison Canyon area (figs. 16, 17, 18, 19)		Airport Wash areas (figs. 20, 21, 22)
Unit D	d	dg d		
Unit CD	cd	cd		
Unit C	c3 c2 c1	c3 c2 c1 (c)		c3 c2 c1b c1a
Unit BC	bc	bc		bc
Unit B	b: b6 b5 b4 b3 b2 b1	b, bg	No correlation made between individual units	b3 b2 b1 tn
Unit AB	ab	ab8 ab7 ab6 ab5 ab4 ab3 ab2 ab1	No correlation made between individual units	ab3 ab2 tl ab1
Unit A	a3 a2 a1	a		a

Figure 7b. Tentative correlation of subdivided units used on detailed maps and sketches of this report.

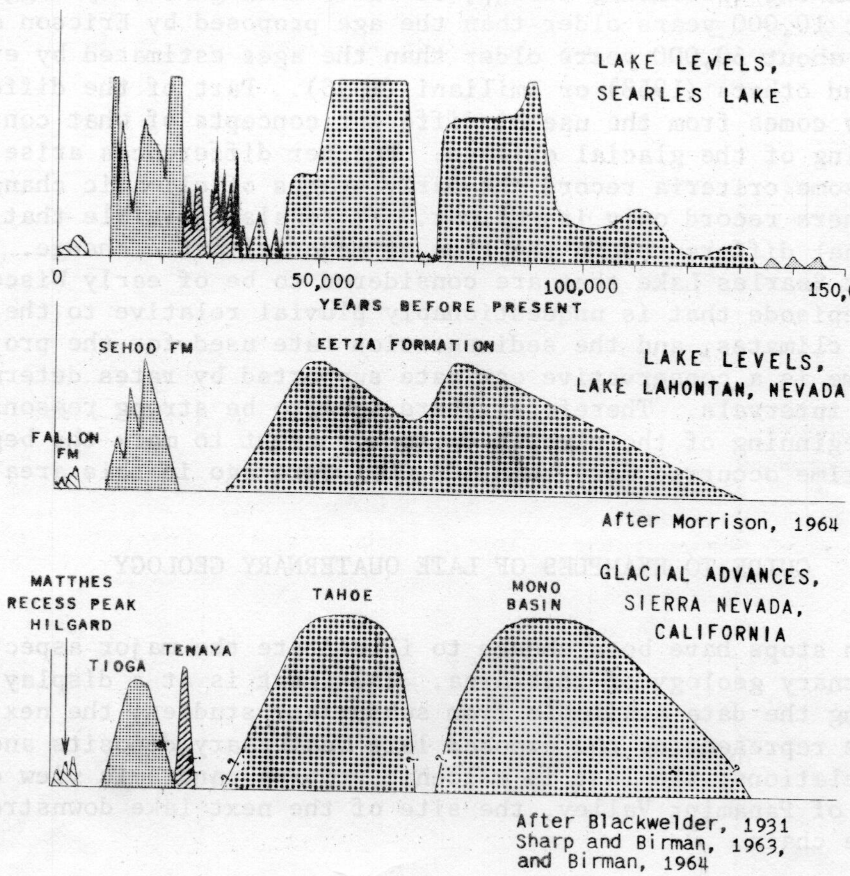


Figure 8. Correlation chart showing inferred relation between geologic histories of Searles Lake, Lake Lahontan, and Sierra Nevada glaciers (Smith, 1967?).

The absolute ages and the correlations with the mid-continent stages shown on figures 5 and 6 are as proposed previously (Smith, 1962). The absolute ages of the events within the range of the C-14 dating method seems to correlate satisfactorily with dated glacial and interglacial events of other areas. The estimated date of about 130,000 years for the beginning of the Wisconsin, though, is older than generally suggested. It is about 10,000 years older than the age proposed by Ericson and others (1964) and about 60,000 years older than the ages estimated by either Broecker and others (1958) or Emiliani (1955). Part of the difference undoubtedly comes from the use of different concepts of what constitutes the beginning of the glacial episode. Further differences arise from the fact that some criteria record the early stages of climatic change, whereas others record only its climax. It is also possible that there were regional differences in the time of major climatic change. However, the muds at Searles Lake that are considered to be of early Wisconsin age record an episode that is unquestionably pluvial relative to the preceding or present climates, and the sedimentation rate used for the projection back in time is a conservative estimate supported by rates determined from many dated intervals. Therefore, there seem to be strong reasons to infer that the beginning of the pluvial episode thought to mark the beginning of Wisconsin time occurred more than 100,000 years ago in this area.

GUIDE TO EXAMPLES OF LATE QUATERNARY GEOLOGY

Eleven stops have been chosen to illustrate the major aspects of the late Quaternary geology of this area. The first is at a display of cores representing the data available from subsurface studies; the next nine are at outcrops representing the exposed late Quaternary deposits and their geologic relations; the last is a scenic stop--a panoramic view of the north half of Panamint Valley, the site of the next lake downstream in the Pleistocene chain.

The trip starts at the parking lot opposite the Trona school. This point, the trip route, and the locations of the several stops are shown on figures 9 and 10. Stops planned for the first day are numbered in sequence 1-1, 1-2, etc.; stops planned for the second day are numbered 2-1, 2-2, etc.

Each stop is described briefly in the accompanying text. The main features of interest to be seen at each stop are described and possible interpretations are suggested; much of the value of the trip, however, is expected to come from on-the-spot comparison of the accompanying maps and diagrams with observed field relations, and from discussion. Locations of the five preliminary geologic maps included in this guide are shown on figures 9 and 10. The geology visible en route between stops is briefly described at the end of the section concerning the previous stop; geology en route to the first stop of each day is described in a separate paragraph.

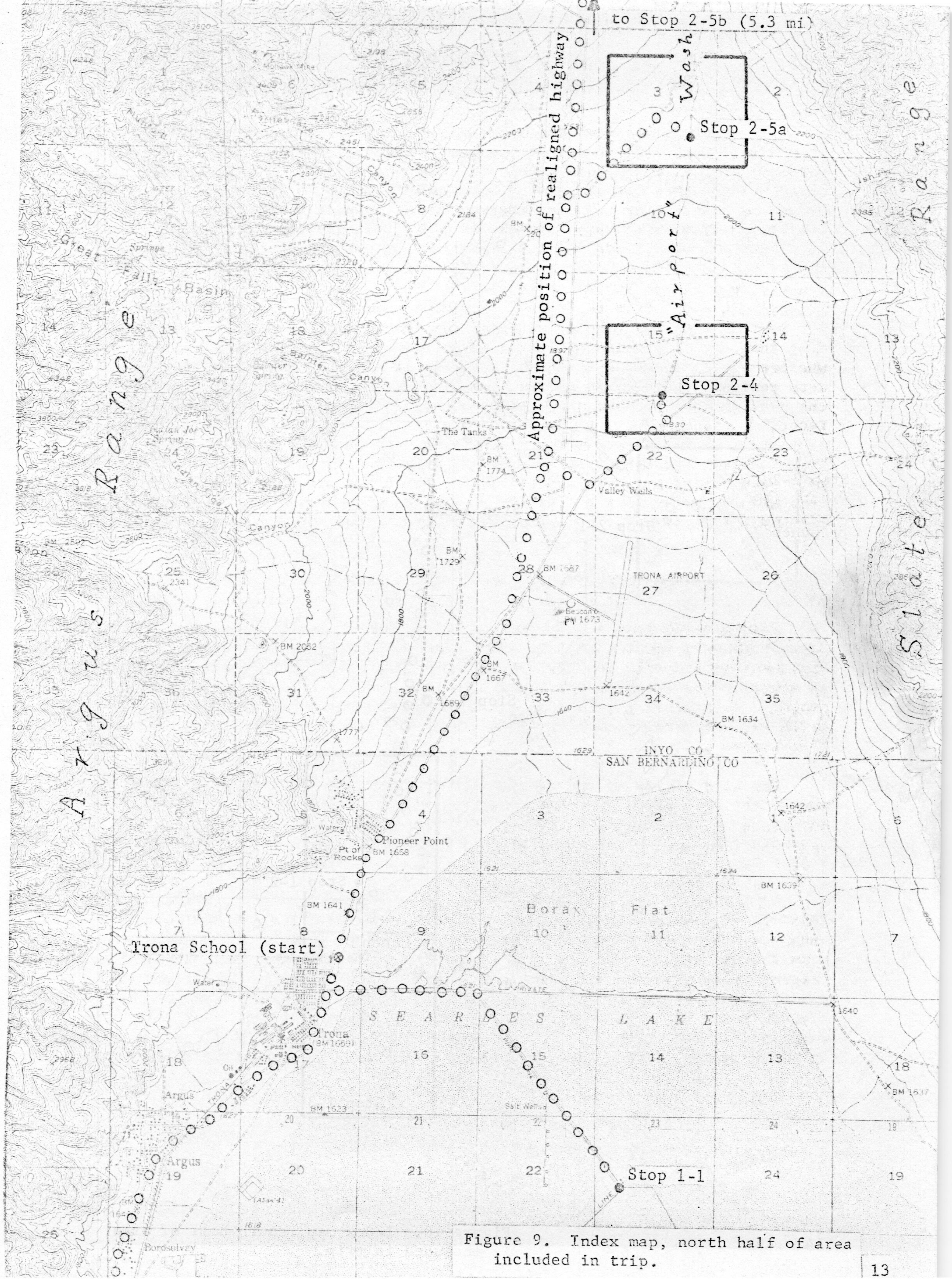


Figure 9. Index map, north half of area included in trip.

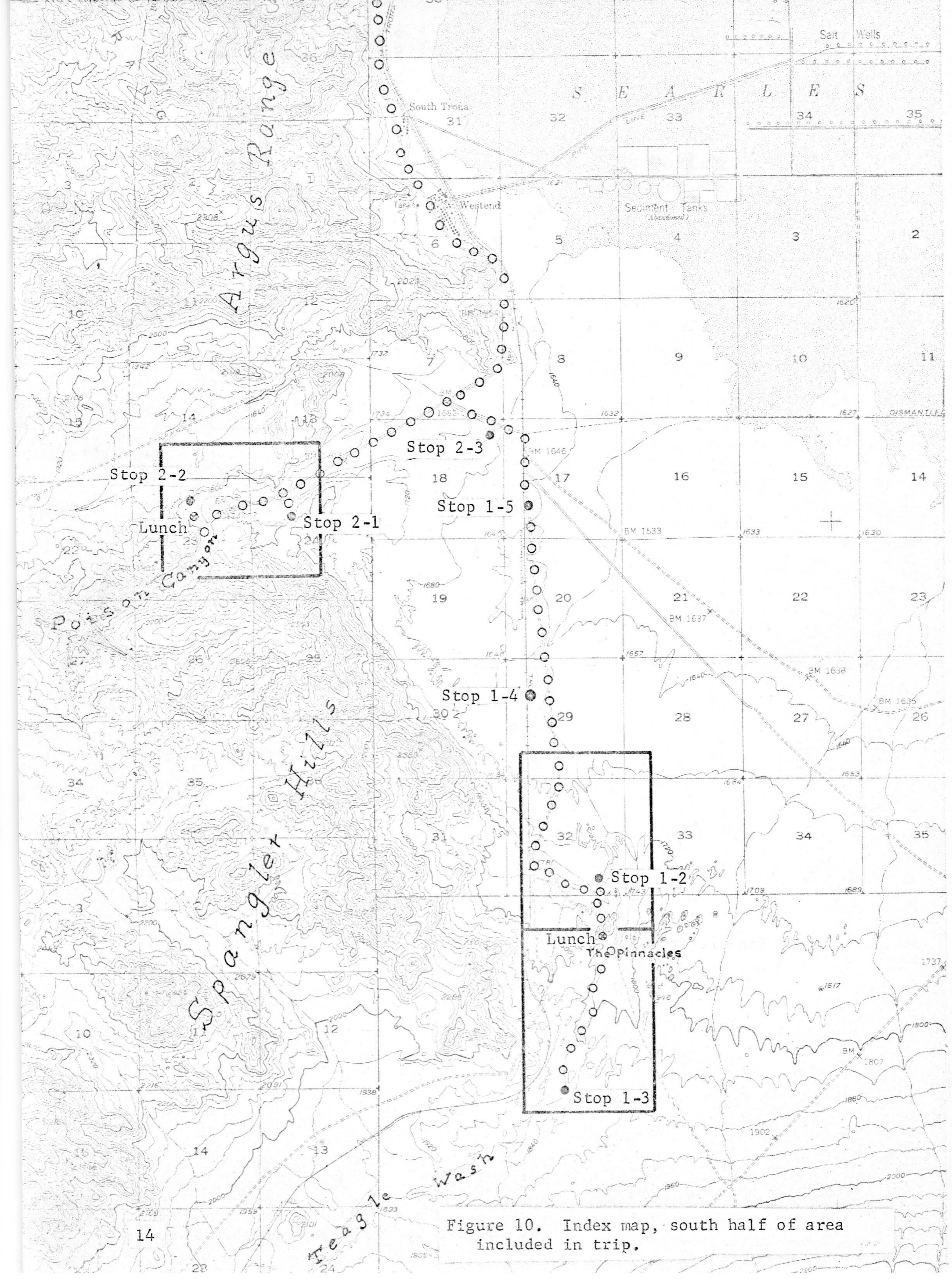


Figure 10. Index map, south half of area included in trip.

First Day

Travel from the starting point--the parking lot across the highway from the Trona school--to the first stop is about 3.5 miles. The group heads south on the highway 0.2 mile, then turns east on the road that leads to the dry lake. At the bend, 1.3 miles from this turnoff, turn southeast to stay on the blacktop road to its end.

The geology visible between the parking lot and the turnoff consists of alluvium and older alluvium which underlies the road, lake deposits to the west along the base of the Argus Range (mostly gray lacustrine gravels and pinkish-brown nodose tufa), and lake deposits (correlated with Unit D) to the east, which form the surface of the playa itself.

After the turnoff to the lake, the road is on muds of Unit D that are equivalent to the Overburden Mud of the subsurface stratigraphy. The muds cover an area of about 28 square miles and grade into a central area of about 12 square miles in which halite forms the surface. The gradational contact between muds and halite is about a mile from the end of the road. About 5-7 miles east of this road, the Slate Range can be seen. Well-developed shorelines may be visible along its lower gravel slopes. The most prominent of these is the highest shoreline of Searles Lake at an elevation of about 2,280 feet, 660 feet above the level of the playa surface.

Stop 1-1

Location: Pumphouse in center of Searles Lake (indefinite)

Time: 1½ hours

Objectives: To examine cores representative of subsurface deposits, discuss subsurface stratigraphy, mineralogy, C-14 dates, fossil pollen, and paleoclimatic implications

Cores from the subsurface deposits of Searles Lake are to be on display, courtesy of the American Potash & Chemical Corp. Published descriptions of these deposits are given by Smith and Pratt (1957), Haines (1959), and Smith and Haines (1964), and their stratigraphy is outlined by Flint and Gale (1958) and Smith (1962). The material that follows comes from these sources.

A diagrammatic summary of the stratigraphic units and their compositions is shown in figure 11. A list of the common evaporite minerals found in these cores follows; those generally found in saline layers are marked with an asterisk; those found in mud layers are not.

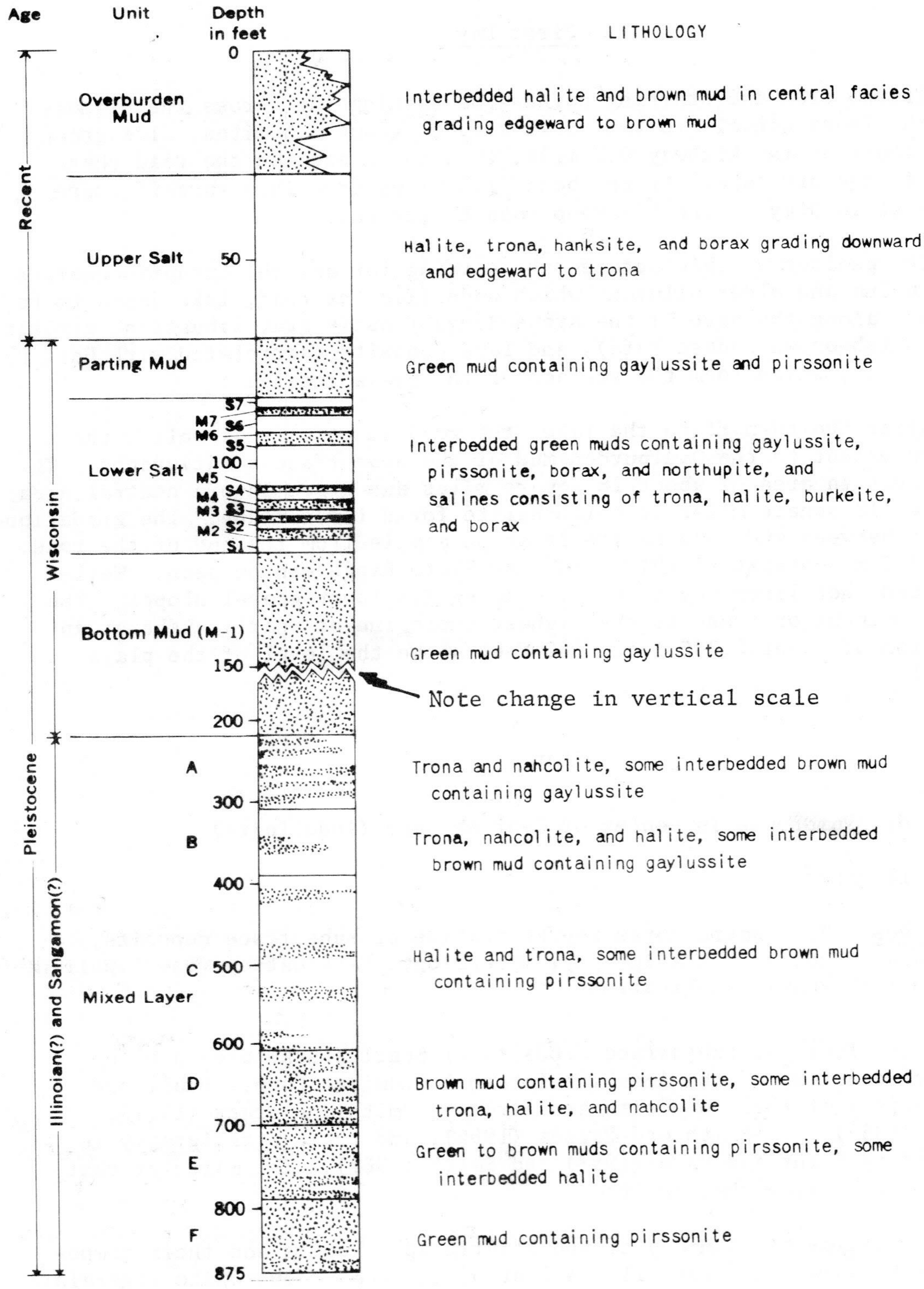


Figure 11. Summary of subsurface stratigraphy (Eugster and Smith, 1965).

Common Evaporite Minerals in Searles Lake Cores

(Idealized chemical compositions shown in parentheses)

*Aphthitalite ($K_3Na(SO_4)_2$)

Aragonite ($CaCO_3$)

*Borax ($Na_2B_4O_7 \cdot 10H_2O$)

*Burkeite ($2Na_2SO_4 \cdot Na_2CO_3$)

Dolomite ($CaMg(CO_3)_2$)

Gaylussite ($CaCO_3 \cdot Na_2CO_3 \cdot 5H_2O$)

*Halite ($NaCl$)

*Hanksite ($9Na_2SO_4 \cdot 2Na_2CO_3 \cdot KCl$)

*Mirabilite ($Na_2SO_4 \cdot 10H_2O$)

*Nahcolite ($NaHCO_3$)

Northupite ($Na_2CO_3 \cdot MgCO_3 \cdot NaCl$)

Pirssonite ($CaCO_3 \cdot Na_2CO_3 \cdot 2H_2O$)

*Sulfohalite ($2Na_2SO_4 \cdot NaCl \cdot NaF$)

*Thenardite (Na_2SO_4)

*Trona ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$)

Tychite ($2Na_2CO_3 \cdot 2MgCO_3 \cdot Na_2SO_4$)

In general, the muds are dark colored, soft, and impervious. Some are massive; others have thin white laminae of aragonite and other minerals. Megascopic crystals of secondary minerals (chiefly gaylussite and pirssonite) commonly cut across bedding. The finely crystalline material consists of a mixture of Na, Ca, and Mg carbonates, and subordinate amounts of other salines, authigenic silicates, clastic silicates, and partly decomposed organic material.

The salines consist of porous aggregates of light-colored crystals that commonly are large, nearly euhedral, and mostly formed by recrystallization after the original saline layer was deposited. Some, however, are fine grained and are probably original deposits. The minerals in the saline layers are compounds made up of Na or K combined with carbonate, bicarbonate, sulfate, chloride, and borate.

Most of the stratigraphic names shown on figure 11 are informal terms that have been used for years by those working on the deposit (Flint and Gale, 1958). The subdivisions of the Lower Salt and the Mixed Layer were proposed by Smith (1962).

Comparison of figure 11 with figure 7 makes it evident that most of the geologic time recorded in these sediments is represented by the mud layers. The saline layers account for only brief periods. However, these were the extreme periods of aridity, and some of the saline layers are composed of temperature-sensitive mineral assemblages that provide additional data on the actual climates that existed during these episodes.

In reconstructing the history of Searles Lake, saline layers in the subsurface section are considered to be products of very low or dry lakes. Mud layers are interpreted as evidence of perennial lakes, but the levels of those lakes within the basin are deduced from outcrops. For this reason, the saline layers in the cores inspected at Stop 1-1 can be closely related to the lake's low-level fluctuations shown in figures 5 and 6, but the high-level fluctuations shown in these figures are based upon geologic mapping.

Carbon-14 dates from subsurface material are numerous. Figure 12 lists the published dates, and a sizable number of new dates will be made available in the future. Most materials dated are either disseminated organic carbon or inorganic carbon in carbonate. Two are on fragments of wood. Some of the inorganic carbonate dates are in line with the organic carbon dates above and below them, but some are not; in general, the inorganic carbonate dates are considered less reliable because subject to contamination during recrystallization, so in figure 12 they are enclosed by parentheses.

There is a problem in relating the dates on disseminated carbon--derived chiefly from organisms composed of matter that incorporated CO_2 dissolved in the lake--to the dates on contemporaneous material that incorporated CO_2 from the atmosphere. One check is provided by two dates on Unit M-3, 26,700 $\pm$ 2,000 years on wood, and 29,500 $\pm$ 2,000 years on disseminated organic carbon; the difference suggests that the disseminated carbon gives a "date" nearly 3,000 years too old because of the reservoir of old carbon dissolved in the lake water (see Broecker and Orr, 1958; Broecker and Kaufman, 1965). However, the CO_2 regimen must be variable in a fluctuating lake, so a single correction factor cannot be used throughout the section.

Fossil pollen are well preserved in the organic-rich muds, and a large number of samples have been studied. These are discussed in the section by Estella Leopold.

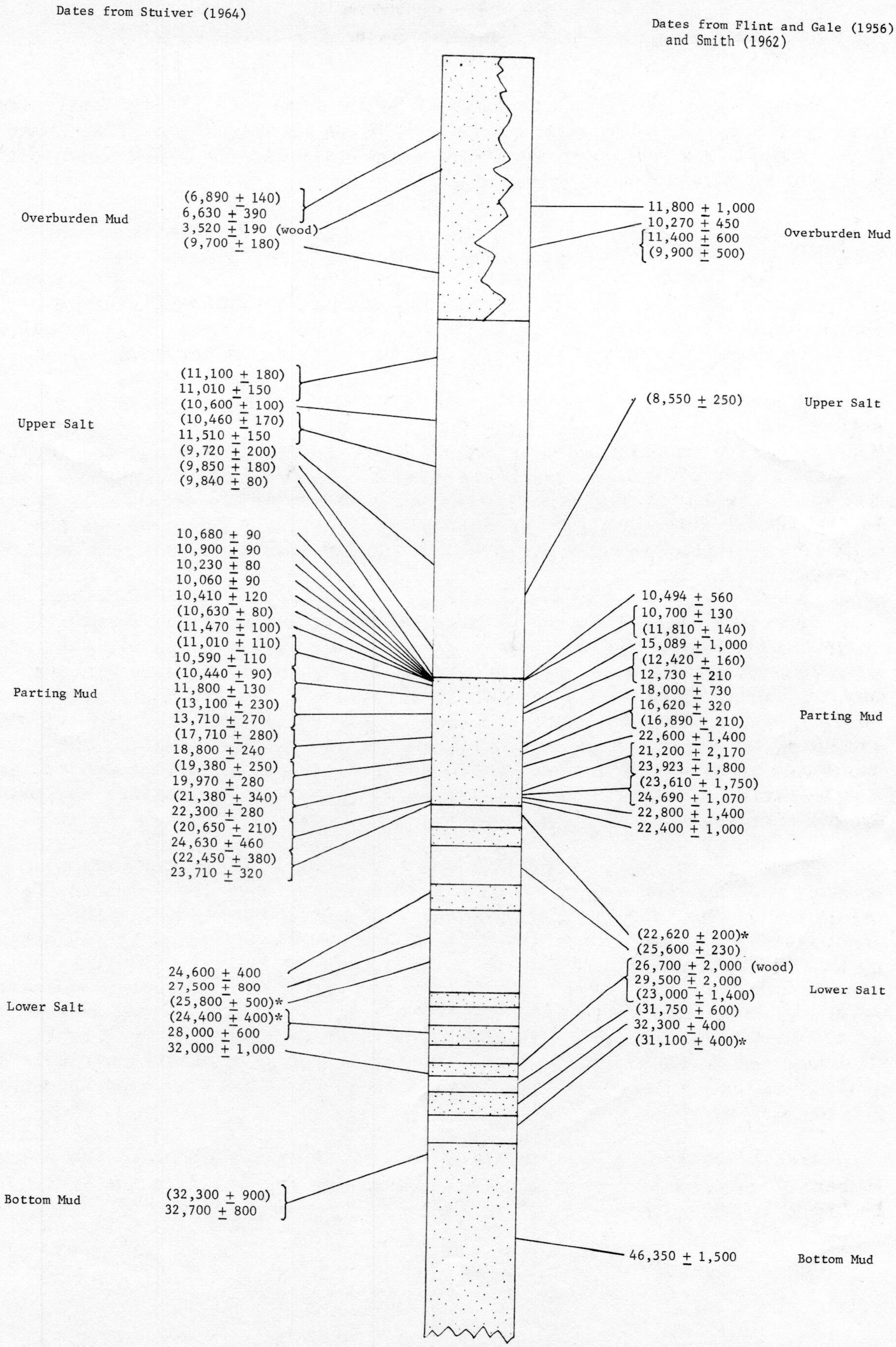


Figure 12. Summary of published C-14 dates on subsurface samples from Searles Lake. Dates in parentheses are on carbon in inorganic carbonates and are considered relatively unreliable; dates followed by asterisk (*) were suspected by Stuiver (1964) of being contaminated; remaining dates are on organic carbon disseminated in lake mud except for two on wood.

Geology along route to next stop: The trip to the next stop (about 16 miles) travels back to the edge of Searles Lake and then along the edge of the lake for almost 8 miles. In this segment, the highway travels near the contact between lake deposits of Unit D (and in some areas, C) on the east, and alluvium or older alluvium on the west. Along the foot of the hills, still farther to the west, gravels of Unit BC form most of the faintly grassy boulder slopes that have shorelines carved on them; they commonly display a weak calcareous soil developed at the close of BC time. Lighter gray lake gravels of Unit B are visible along the edges of some of the canyons. Pinkish-brown nodose tufa forms a thin coating over large areas between elevations of about 1,800 feet and 2,000 feet; lithoid tufa forms benches at the level of the high shoreline (2,280 ft) along the sides of most canyons.

About half a mile after the highway turns away from the lake and heads southwest, the trip route turns left onto the dirt road leading to The Pinnacles. After crossing the railroad tracks of the Trona Railway, the road heads south. Along this route--both to the east and west of it--large areas of slightly dissected light-colored lake silts and fine sands are visible; these are mostly deposits correlated with Units B, BC, C, and D. Units B and C here are light-colored clays and silts with sand partings. Unit BC consists of orange-tan well-sorted coarse sand. Stops 1-4 and 1-5 will include further discussion of Units B and BC. Deposits of Unit D are mostly pinkish-tan silt and fine sand that weather to soft puffy surfaces covered by scattered angular fragments of dark rocks.

About 3½ miles south of the railroad crossing, the road travels up the north slope of a gravel bar (see fig. 13); lake sands correlated with Units B and C form the surface on the lower north slope, but erosion exposes the dark-gray gravels of the bar itself near the crest. The trip route descends down the steep south slope of this bar, turns east, and stops near the east end for Stop 1-2.

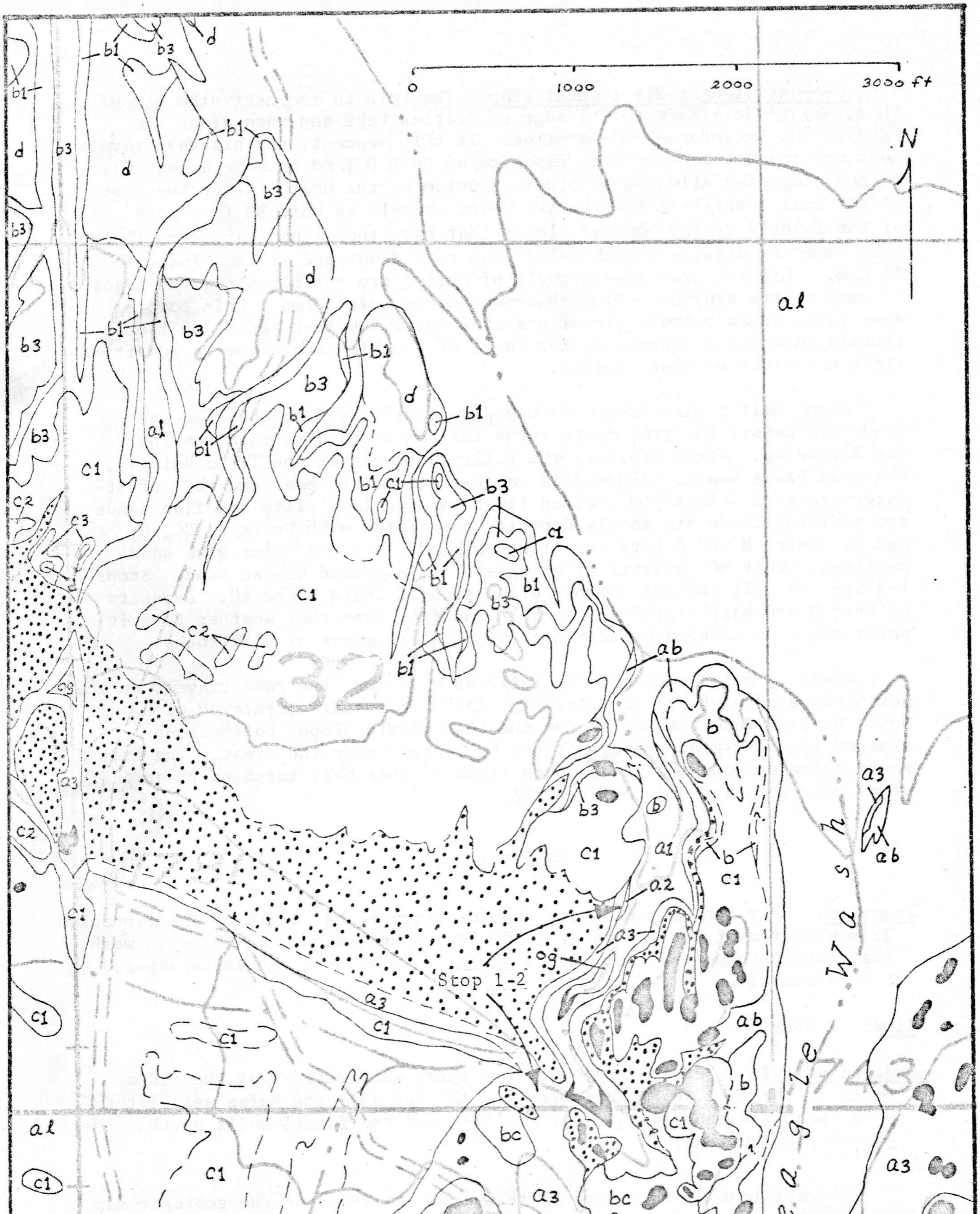
Stop 1-2

Location: Near the east end of a prominent gravel bar north of The Pinnacles. Trip will travel on foot about 1,500 feet downstream along the main wash that cuts through the east end of this bar, observing the units exposed on both sides of it

Time: 1 hour

Objectives: To observe examples of the three subdivisions of the oldest units in the lake sequence (Units A1, A2, and A3), the tufas associated with them, the underlying older gravels, and the fossil soils on the older gravels and Unit A2.

The relations of the units in this area are shown on the geologic map in figure 13.


0
1000
2000
3000 ft
N
Stop 1-2
Teagle Wash
al
d
b1
b3
c1
c2
c3
a1
a2
a3
ab
b
bc
og

EXPLANATION

Unit D	al	Alluvial gravel
	d	Lake silt, sand, and fine gravel, massive, tan to tan-orange; weathers to puffy surfaces with thin lag gravel
Unit C	c3	Lake silt and clay, mostly laminated, very light green to tan
	c2	Lake sand or pebble gravel, tan to dark-brown
	c1	Lake silt and clay, thinly bedded to laminated, very light green to tan
Unit BC	bc	Alluvial gravel, cobble to boulder, high percentage of nodose tufa fragments, forms pavements around large tufa masses
Unit B	b3, b1, b	b3, lake silt and sand, light-green to tan* b1, lake silt and sand, light-green to tan* b, lake silt, sand, and fine gravel, tan to light-green
Unit AB	ab	Alluvial sand and gravel, tan
Unit A		Lake gravel bar, forms prominent surfaces; fragments angular to subround, very dark gray
	a3	Lake silt, sand, and gravel, massive to well-bedded, medium-to light-gray
	a2	Alluvial gravel, small angular fragments, poorly sorted, grayish-orange, forms thin lenses; moderate to strong calcareous soil developed locally on unit
	a1	Lake gravel, some sand and silt, medium-to dark-gray, forms thin beds
	og	Old alluvial gravels, poorly sorted, contains prominent percentage of rounded boulders, tan to reddish-brown; strong calcareous soil developed locally on unit
		Undivided bedrock

Tufa, lithoid and nodose

*Unit B is divisible into six units to the northwest of this map area; the units represented on this map are the lowest (b1) and third (b3) of that sequence.

Figure 13. Geologic map and explanation, north half of the Pinnacles area.

Unit A2 — Orange color distinct — Thought by Smith to represent iron oxide from a desert varnish which was re distributed after burial in lake, later — correlated w/ salt units in lake represented by salt dep. in winter, sediment dep. in summer

A composite section of the deposits that are well exposed along the main wash at this locality is as follows:

Unit A3	Lake gravel, dark-gray, deposited as a bar, 0-5 ft Nodose tufa lenses, 0-5 ft Lake silt, sand, and gravel, medium- to light-gray, 0-30 ft Lithoid tufa
Unit A2	Alluvial gravel, orange, 0-2 ft
Unit A1	Lake silt, sand, and gravel, light-gray, 0-6 ft Lithoid tufa
Older alluvial gravels	Gray to greenish where part of soil profile, poorly sorted, large rounded boulders derived from areas 10-20 miles south, 0-6 ft. Strong calcareous soil represented by a Cca horizon

The lake deposits are distinguished from the alluvial deposits chiefly by criteria based on the size, sorting, and roundness of the clastic fragments, and the nature of the bedding, but no single criterion is diagnostic. This will be the first of several stops where the means used to distinguish lacustrine deposits from subaerial or fluvial deposits will be scrutinized.

The prominent gravel bar that extends 1½ miles west and about 1,000 feet east of this wash can be traced under deposits correlated with Unit AB. The entire lake sequence exposed in the canyon is thus considered to be part of Unit A. The surface of the gravel bar provides an excellent example of an exhumed physiographic feature; at one time, Units B and C rested on it, but erosion has removed them almost totally and the original feature stands exposed almost as if never buried.

Geology along route to next stop: The trip to the next stop (about 2 miles) will be interrupted by a lunch stop. This will be in the midst of The Pinnacles--towers of calcium carbonate tufa formed beneath the surface of the lake. As noted by Scholl (1960), at least two generations of tufa can be distinguished, an underlying lithoid tufa which makes up the bulk of the pinnacles (and is correlated here with the lakes responsible for deposits of Unit A), and a thin veneer of darker brown nodose tufa (which is mostly correlated here with deposits of Unit B). The flat areas between pinnacles are paved with tufa fragments that were transported during the interval responsible for Unit BC.

After lunch, the group will move to the next stop, probably in shifts via 4-wheel-drive vehicles. The trip is up Teagle Wash and the geology en route is shown on figures 13 and 14. Deposits representing most of the lake sequence are visible on this route. The older gravels crop out as boulder-strewn dark-brown slopes; Units A and AB are tan to slightly orange coarse sands and gravels that are exposed sporadically; Units B, C1, and C3 form light-green soft slopes, with the interbedded sand and gravel layers of units BC and C2 visible only as thin horizontal zones of coarser float.

Stop 1-3

Location: About 1¼ miles south of The Pinnacles, outcrop along east side of Teagle Wash

Time: 1¼ hours

Objectives: To study excellent exposures of older gravels, Units AB, B, BC, C1, C2, and C3, to observe erosional unconformity between Units AB and B, and to study fossil lag gravel along it.

The geologic setting of this outcrop is shown in figure 14. A diagrammatic sketch of the west-facing exposure is shown in figure 15.

This exposure can be regarded as a nearly complete scale-model of the deposits in Searles Valley; only Units A and D are missing. Unit A was removed by erosion, but fragments of ostracode-bearing clay derived from Unit A are found near the base of AB. Unit D is missing because it was not deposited this high in the basin.

The lithology of Unit AB is especially informative. The basal 4 feet consists of tan pebble alluvium that is distinct from the reddish gravels beneath it; this layer is typical of Unit AB in many parts of the basin, and is correlated with the deposits that overlie the bar-forming cobble gravels of Unit A seen at the previous stop. Above the basal 4 feet, Unit AB consists of lenticular silts, sands, and gravels that are most commonly orange; most are considered to be lacustrine, but a few could be fluvial or alluvial. They reflect deposition in environments that fluctuated rapidly between deep and shallow lacustrine (and alluvial?) conditions, and are correlated with Unit AB because of their lithology, stratigraphic position, and color (compare these deposits with those to be seen at Stop 2-1). They are correlated with subsurface deposits of the Lower Salt plus some of the underlying muds because that section also reflects a series of rapid fluctuations between deep water (mud) and shallow water or dry (saline) conditions.

The unconformity at the top of Unit AB is capped by a distinctive orange gravel. The unconformity itself is considered a product of sub-lacustrine erosion because its profile is so smooth and unaffected by the differences in erodability of different layers; this should be compared with the unconformity produced by subaerial erosion to be seen at Stop 2-2. The thin orange gravel that covers it appears to have been deposited after erosion took place, but is thought more likely to be a lag gravel formed during erosion, with the orange color caused by oxidation of a desert varnish formed on that lag gravel during its subsequent exposure to the atmosphere. Some reworking of the lag gravel by subaerial (alluvial or colluvial) processes also appears to have taken place during this exposure.

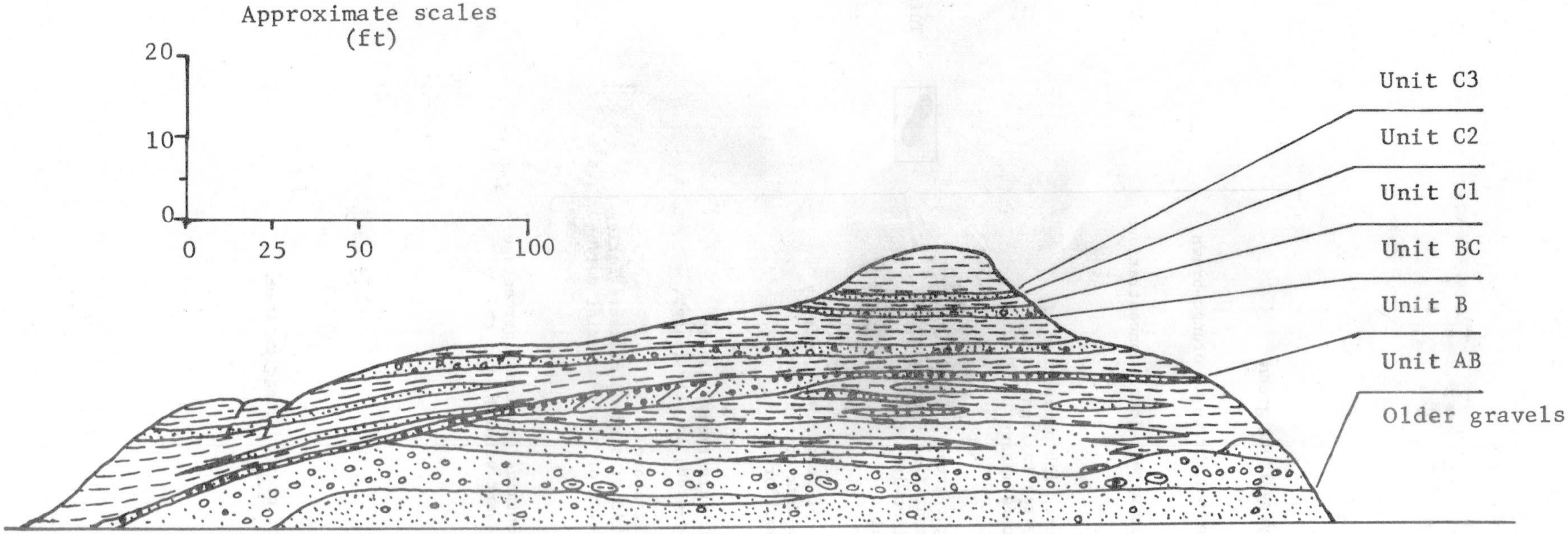
Lunch stop
Teagle Wash
Stop 1-3
N
0
1000
2000
3000 ft
al
ab
a1
a3
ag
b
b?
bc
c1
c2?
c3
cd?
og
og?

EXPLANATION

	al	Alluvial gravel
Unit CD	cd	Alluvial gravel, graded to top of Unit C
Unit C	c3	Lake silt and clay, mostly laminated, very light green
	c2	Lake (and alluvial?) gravels, weakly bedded, brown to orange-brown
	c1	Lake silt and clay, thinly bedded to laminated, local concentrations of gypsum crystals, very light green
Unit BC	bc	Alluvial gravel, cobble to small boulder, high percentage of nodose tufa fragments, poorly bedded, tan to light-orange-brown; forms pavements around large tufa masses
Unit B	b	Lake silt, sand, and gravel; mostly light green silt along Teagle Wash, grades east to well-sorted, fine, gray pebble gravel, and west to poorly sorted, light-gray to tan, calcareous coarse sand and fine gravel
Unit AB	ab	Alluvial sand and gravel; near and east of Teagle Wash, mostly tan pebble sand; west of wash, tan to dark orange-brown gravel composed of cobbles to large boulders
Unit A	a3, al, ag	a3, lake sand and gravel, poorly sorted, calcareous; mostly poorly bedded, light gray, well indurated, locally flaggy, light gray to brown al, lake sand and gravel, similar to unit above ag, boulder gravel with prominent shorelines; surface characteristics due to underwater erosion and winnowing of finer material during high stands of lakes
	og	Older alluvial gravel, poorly sorted, contains prominent percentage of rounded boulders coated by black desert varnish, tan to reddish-brown on fresh surfaces
		Undivided bedrock

Tufa

Figure 14. Geologic map and explanation, south half of the Pinnacles area.



Unit C3: Silt, very light green, laminated

Unit C2: Sand, tan, very fine, cross-bedded

Unit C1: Silt, very light green, laminated, local concentrations of gypsum crystals

Unit BC: Sand and pebble gravel, tan to gray, larger fragments include prominent percentage of nodose tufa

Unit B: Silt and fine sand, 1-ft bed of gravel in middle. Silt and fine sand is thinly bedded, very light green; gravel is poorly sorted, gray, consists mostly of fragments of bedrock, very few of nodose tufa

Unit AB: Gravel, sand, and silt. Lower 4 ft is tan alluvial sand and gravel containing large fragments of ostracode-bearing clays. Middle 0-10 ft is interbedded lacustrine (and alluvial?) sands and silts, orange, mostly sand in lower half and silt in upper half. Upper ½ to 1 ft is prominent orange-stained gravel that caps eroded surface of underlying deposits, probably fluvial

Older gravels: Alluvial sand and gravel, reddish-brown to tan, mostly medium to coarse sand, locally contains prominent percentages of well-rounded boulders of volcanic rock derived from areas 10-15 miles south. Sharp upper contact

Figure 15. Sketch of exposure along Teagle Wash.

Unit B is of interest because of its lithology, which is essentially the same over large areas, and because of the coarse layer near its middle, which indicates a lowering of the lake level at the time. A carbon-14 date from a sample near the top of this unit shows it to be correlative with a point somewhat above the middle of the Parting Mud.

About 100 to 200 feet east of the exposure along the wash, Units AB and B wedge out against the upward-sloping contact of older gravels. Unit B changes facies rapidly and becomes a gray pea-sized pebble gravel that is also characteristic of this unit throughout much of the south half of Searles Valley. A weak calcic soil was developed on this gravel. It is characterized by pods of calcium carbonate about ¼ to ½ inch across scattered through a zone about a foot deep, and by a magenta or deep-pink coloration. The color is caused by numerous hairline color streaks on the surfaces of pebbles; the streaks appear to be stains caused by rootlets of unidentified plants that flourished on this soil cover during Pleistocene time. Another example of this fossil soil will be seen at Stop 1-5.

Unit BC is a pebble gravel characterized by a high percentage of nodose tufa fragments. This characteristic is especially notable in the deposits that form surfaces surrounding The Pinnacles at the lunch stop, but is found to be diagnostic of this unit for several miles southwest of Stop 1-3. Apparently an exceptionally large amount of nodose tufa was available, fragmented, and swept southwest along the bottom of the lake by strong winds during this one episode.

Units C1, C2, and C3 have lithologies that are typical of these units over large areas. Note especially the gypsum in Unit C1 and compare it with Unit C1 at Stop 2-1.

Geology along route to next stop: The route between Stop 1-3 and 1-4 retraces part of the trip to this point. See descriptions given at the end of Stops 1-1 and 1-2.

Stop 1-4

Location: About 1,000 feet west of road to The Pinnacles, along the tracks of the Trona Railway

Time: 1 hour

Objectives: (1) Study the detailed stratigraphy of Unit B in this area, where it can be separated into six units. (2) Observe alluvial fans (correlated with Unit CD) on slopes of Spangler Hills. (3) Discuss the techniques and results of the study of modern pollen fallout being conducted by Estella Leopold.

(1) In the area between the railroad tracks and the east edge of the Spangler Hills, a stratigraphic sequence that divides Unit B into six subdivisions has been mapped. As mapped, each of these (except the top subdivision, which is overlain by Unit BC) consists of 1-5 feet of lake clay, silt, or very fine sand, and an overlying layer that consists of ¼-3 feet of coarser lake sand. Contacts on the geologic map are placed at the tops of sand layers.

A composite--somewhat idealized--section of these subdivisions follows:

Unit B6	Silt, weathers greenish gray, thinly bedded, some fresh-water snails and clams
Unit B5	Sand, very coarse to medium, tan, locally orange, generally massive Silt to very fine sand, faintly laminated in upper half, prominently laminated in lower half
Unit B4	Sand, medium to fine, tan to gray Silt, greenish, massive, lenticular
Unit B3	Sand, medium to very fine, tan with streaks of orange, well-bedded Silt, white, very prominent laminae
Unit B2	Sand, medium to coarse, fairly well sorted, orange, especially in upper part, ripplemarks common Silt to very fine sand, greenish, laminated to massive; C-14 date on carbonate from base of this bed indicates an age equivalent to the lower part of the Parting Mud
Unit B1	Sand, medium, moderately well sorted, orange to orange-tan, local pods of ulexite, some clams and snails Silt, greenish, massive to faintly bedded

The significance of these sand layers is not fully understood. They are continuous beds that can be mapped over an area of several square miles and are considered to be indicative of something more than local variations in lithology. All are lacustrine deposits, so do not record a lowering of the lake below about 1,800 feet, yet seem to indicate episodes of increased wave action at low levels. This seems to be best explained by postulating five low-stand episodes within the time represented by Unit B. The problem is that deposits in other parts of the basin--even those at higher elevations--record fewer breaks. The history of the lake as shown in figures 5, 6, and 7, constructed before mapping in this area was completed, may have to be changed to accommodate the information provided by these deposits.

(2) About a mile west of the railroad tracks, on the lower slopes of the Spangler Hills, two fans can be seen. Shorelines visible on the slopes north and south of these fans are not visible on them; the shorelines were produced during the deposition of Units A, B, and C, so the fans are clearly younger. Most of the fan surface is graded to a level that coincides with the top of lake Unit C, and the toe of the fan is overlain by lake deposits correlated with Unit D. Most of the fan deposits are thus correlated with Unit CD. Present drainage on these fans is restricted to alluvial washes a few feet wide that are graded to levels 2-4 feet below the level of the older fan surface. The fragments on the older surface of the fan have a distinct orange stain developed on them by weathering, but desert varnish has not yet developed to any significant degree.

(3) Description of the studies of present-day pollen fallout is given in the section by Estella Leopold.

Geology along route to next stop: The route to the next stop retraces part of the route described in the section on Stop 1-1.

Stop 1-5 (optional)

Location: Near road to The Pinnacles, along low cut along railroad tracks

Time: 15 minutes

Objectives: Observe a fossil soil developed on Unit BC.

In a low cut along the railroad tracks, a fossil soil can be seen that is typical of that developed on Unit BC in many parts of the basin. Like the example seen at Stop 1-3, it is a calcareous soil composed of calcium carbonate pods, one-quarter to one-half inch across, dispersed through a zone a foot or two thick. As in most examples, the material between carbonate pods is partially altered to clays. The red rootlet marks like those seen in the soil developed on Unit B at Stop 1-3 are visible here, especially on the surfaces of the larger pebbles. The profile apparently represents only the Cca horizon, but its expression and thickness is remarkably constant throughout the south half of the basin.

At this locality the soil is developed on a pebbly orange-brown sand that is mapped as Unit BC. It is apparently lacustrine, but may be in part alluvial or fluvial. About 4 feet of this unit is exposed here (another 2 to 3 ft of soft sand from the railroad excavation is piled on the unit in some areas). Unit BC forms a large delta in this part of the basin, near the Pleistocene inlet. It is now extensively exposed because Unit C has been almost completely stripped off. This was probably due to wave action in the lake in which Unit D was deposited.

Geology along route to next stop: This is the last stop of the first day. The route back to Trona retraces the path described in the section on Stop 1-1.

Second Day

Travel from starting point--parking lot across highway from Trona school--to Stop 2-1 is about 10 miles. At turnoff to The Pinnacles, the route taken to Stop 1-2, the group stays on the main highway for another 1½ miles. Stop 2-1 is about three-quarters of a mile east of mouth of Poison Canyon and 1,000 feet south of the highway.

Geology en route is mostly as described in section on Stop 1-1. The essential aspects of the geologic setting of this area are that (1) it was part of the region into which both clastic and calcium carbonate deltas were rapidly built during each stand of the lake that rose above the 1,800-foot level (providing they did not inundate the divide into China Lake); (2) it is an area that was dissected rapidly during each low stand; and (3) snails, clams, and ostracodes that could not tolerate the salinity of other parts of the lake were encouraged to live in this region because of its abundant supply of inflowing fresher water.

Stop 2-1

Location: In amphitheater at east end of Poison Canyon, south of highway

Time: 1½ hours

Objectives: To review a nearly complete section of Unit AB, which is here separable into seven subdivisions, and to study the exposures of Units C1, C2, C3, and CD.

Unit AB, considered equivalent to the Lower Salt plus the upper few feet of the Bottom Mud (see fig. 7a), is represented in this exposure by about 50 feet of lake deposits that can be divided into seven units. An eighth unit, AB8, is exposed to the west and northwest (Stop 2-2). The geologic setting of these deposits is shown in figure 16; a description of the columnar section is given in figure 17.

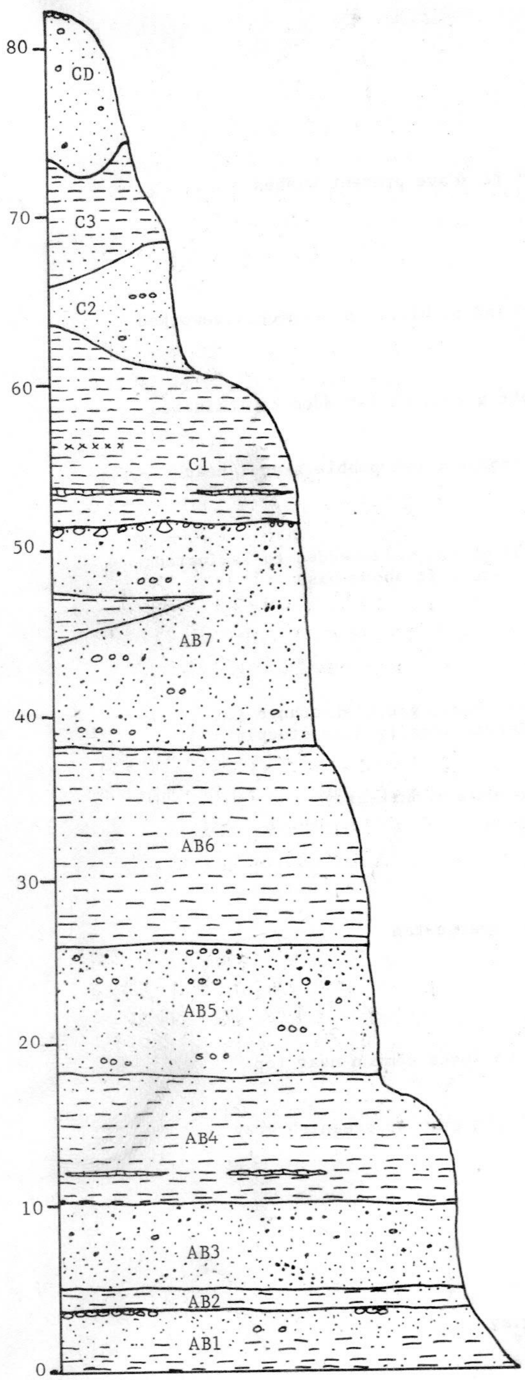
Correlation of individual units in this exposure with individual units in the Lower Salt may someday be possible, but additional data are needed. A reasonable lithologic correlation could be made, with the coarser units (AB1, AB3, AB5, and AB7) being correlated with four of the seven saline units, and the finer units (AB2, AB4, AB6, and AB8) being correlated with four of the six subsurface mud units. The lithologic correlation that appears to be most reasonable, however, does not agree with correlations indicated by C-14 dates. Several unpublished dates, by Rubin and by Stuiver, on materials collected from this exposure and others nearby indicate that the C-14 ages from Units AB1 to AB6 are more logically correlated with those from an interval ranging from the middle of the Lower Salt to a point several feet below its base. The dates from outcrops, however, are on diverse types of material and are not all consistent with each other, so correlations cannot be made on that basis alone.


Stop 2-1
Stop 2-2
Canyon

EXPLANATION

	al	Alluvium
	oal	Older alluvium, graded to levels 2 to 5 ft above present washes
Unit D	d	Lake sand and silt, tan-orange
Unit CD	cd	Alluvium and colluvium composed of sand and pebble sand; commonly reworked by wind, tan, graded to top of Unit C
Unit C	c3	Lake silt and clay, some sand, very light green, well-bedded to laminated
	c2	Sand and pebble sand, tan; composed of orange-brown pebble gravel near bedrock areas
	c1	Lake silt and clay, some sand, very light green, well-bedded to laminated; locally, a 1-inch layer of white tufa 2 to 3 ft above base
Unit BC	bc	Sand and pebble gravel, tan to orange
Unit B	b	b, lake silt, fine to very fine sand, micaceous, greenish-orange to greenish-gray, bedding faint to prominent, locally dips steeply
	bg	bg, lake gravels, pebble to cobble, dark- to very dark-gray
Unit AB	ab8	Lake silt, greenish-tan
	ab7	Sand and fine to coarse gravel, orange to orange-tan
	ab6	Lake silt and sand, tan
	ab5	Sand and fine gravel, tan to orange-tan, molluscs common near top
	ab4	Lake silt grading up to fine sand, very light gray to greenish gray
	ab3	Sand and fine gravel, tan to orange-tan
	ab2	Lake silt, light-green to greenish-gray
	ab1	Lake sand and silt, orange-tan to light-gray
Unit A	a	Lake silt, thin beds of sand, light-yellow to very light gray
		Undivided bedrock

Figure 16. Geologic map and explanation, Poison Canyon Wash.



Unit CD: Pebbly sand, tan, top surface covered by weak lag gravel; fair to poor sorting, beds locally well developed; basal contact sharp; probably alluvial or fluvial

Unit C3: Silt, 2 to 3 ft of very fine sand at base, unit similar to clay and silt of Unit C1; basal contact sharp

Unit C2: Sand, fine to coarse, tan or pinkish-tan; locally contains orange pebbles (reworked from Unit AB7?), fragments of nodose tufa, and clay fragments, plus a few molluscs; basal contact gradational

Unit C1: Clay and silt, locally laminated, weathers to buff-colored surfaces; 3 ft above base is a 1-inch-thick pinkish-tan layer of nodose tufa; about 7 ft above the base of this unit is a discontinuous thin layer of orange-weathering tuff(?); gypsum crystals locally common; basal contact sharp

Unit AB7: Sand, generally coarse to very coarse, mostly poorly sorted, especially in upper part, contains pebbles up to 1 inch in diameter, locally includes a 3-ft bed of calcareous silt near middle of unit; in this area, sand is tan to slightly orange, but in area just west and southwest, unit is conspicuously orange and its top surface is characterized by pronounced lag gravel; basal contact gradational

Unit AB6: Silty sand and sand, lower 1 to 3 ft finer and more calcareous and lighter colored; unit characterized by discontinuous beds several inches to a few feet thick; tan to very pale orange, weathers to puffy surfaces, and in this area has sink holes as much as 10 ft deep; a small number of snails and clams noted; contact with underlying unit locally sharp but generally gradational

Unit AB5: Sand, fine in lower part and coarse in upper part; pebbles up to 1 inch across locally common, include fragments of nodose tufa; bedding locally deltaic; molluscs scattered throughout; basal contact gradational in most places

Unit AB4: Silt and very fine sand, calcareous, basal 1 to 2 ft is white laminated silt and clay grading up into light-tan, less well bedded silt and very fine sand; about 3 ft up from base is a thin layer of white nodose tufa; gypsum crystals locally abundant; basal contact generally sharp

Unit AB3: Sand, medium to very coarse, local layers of pebbles up to 1 inch in diameter and clay fragments up to 3 inches in diameter; unit generally horizontally bedded, but locally cross bedded, especially in lower half; tan orange to orange; notable concentrations of molluscs in upper 1 ft; basal contact gradational

Unit AB2: Silt to very fine sand, some clay; faintly bedded; weathers to light-tan-green puffy surface, contains a few molluscs; basal contact sharp, locally characterized by a very thin white zone

Unit AB1: Silt and sand; lower half is silt and very fine sand, calcareous, faintly bedded, weathers to light-tan puffy surfaces; upper half is medium to very coarse sand containing 1-inch pebbles, cross bedded, with a 1-inch orange-stained zone at the top; in places, top of unit represented by a prominent lag gravel composed of dark angular fragments of hypabyssal rocks

Figure 17. Columnar section, south side Poison Canyon Wash.

The orange color of the sand layers in this section and the upward increase in color intensity are characteristic of Unit AB. The similarity between this color sequence and the sequence seen at Stop 1-3 is striking. When one adds the observation that Unit AB7 in this area is commonly a lag gravel, and that the gravel is stained to a distinctive orange color (which is interpreted to be due to formation of desert varnish that has since been partly oxidized and destroyed), a lithologic correlation between Unit AB7 and the gravel that capped the unconformity at Stop 1-3 seems justified.

Unit AB8 is missing from this exposure but will be seen at Stop 2-2. All of Units B and BC are also missing here but will be seen at the next stop.

Unit C1 is well exposed at the top of the hill. The thin layer of white tufa about 3 feet up from its base is an identifying characteristic of this unit over most of this amphitheater area. Note too the gypsum crystals in this unit that are reminiscent of those observed in the unit at Stop 1-3. Units C2 and C3 are also typical of the lithologies found over wide areas. The tan color of Unit C2 is a persistent characteristic that contrasts with most of the sand layers lower in the section which tend to be more orange.

The depositional environment of Unit CD is puzzling. It appears to be a near-shore lake deposit in many respects, but rests on a subaerially eroded surface and could be a very fine alluvium. Furthermore, its lithology appears to have been reworked by wind and colluvial action. Perhaps it is a product of several processes.

Geology along route to next stop: The geology along the route to the next stop is best shown by figure 16. In general, the lake deposits that form steep slopes belong to Unit AB, the softer greenish sandy deposits above them are part of Unit B, and the light-colored soft deposits on the highest ridges are part of Unit C. Unit D may form some of the deposits on the floor of the amphitheater, but their correlation is not clear.

Stop 2-2

Location: Near northwest corner of amphitheater at east end of Poison Canyon

Time: 1¼ hours

Objectives: To observe evidence of subaerial erosion between deposition of Units AB7 and AB8 and between Units AB8 and B, and to study the lithologies of these units not present at Stop 2-1.

At the previous stop, the stratigraphic sequence appeared to be relatively straightforward, but there was little evidence at that stop to indicate the existence of two missing units--AB8 and B. At this stop, the two units are present, and the erosion responsible for their absence elsewhere can be documented.

As can be inferred from the relations shown in figure 18, this stop is in an area that was on the north edge of a channel that was eroded after deposition of Units AB6 and AB7, but prior to deposition of Unit AB8 which rests in it. It is also near the south edge of a channel into which Unit B was deposited. Both unconformities are inferred to be products of subaerial erosion (as contrasted with the example of sub-lacustrine erosion observed at Stop 1-3 in Teagle Wash).

The chief point of this stop is to demonstrate how the lithologic units seen at the previous stop can be identified and how the new units can be placed in their proper stratigraphic position. It will also illustrate the types of facies changes that occur over very short distances (especially where there was some topographic relief on the underlying surface). Some may also find that the original dips in the deposits of Units AB8 and B are steeper than is normally expected, and that the angular discordance between bedding of undeformed sediments and the contacts above and below them is at odds with theoretical considerations.

Geology along route to next stop: The lunch stop is planned for the flat alluvial area just south of Stop 2-2. The geologic relations in this area are shown on figure 16.

After lunch, the trip will retrace the route back about 1½ miles to the turnoff to The Pinnacles and stop about half a mile from this turnoff (where the dirt road crosses the wash coming from Poison Canyon). The geology of the first half of this route is shown on figure 16. The geology along the wash from that point to Stop 2-3 is not well exposed. Along the north side of the highway, greenish silts and sands of Unit B are overlain to the east by the more orange deposits of Unit D, which are nearly concealed by loose colluvium and older alluvium. South of the highway, the orange-tan sands of Unit BC are overlain to the east by deposits of Units C and D like those to be observed at the next stop.

Stop 2-3

Location: Along wash from Poison Canyon near road to The Pinnacles

Time: 30 minutes

Objectives: To see examples of the deposits correlated with Unit D, deformation of them caused by postdepositional slumping, and their relation to Unit C.

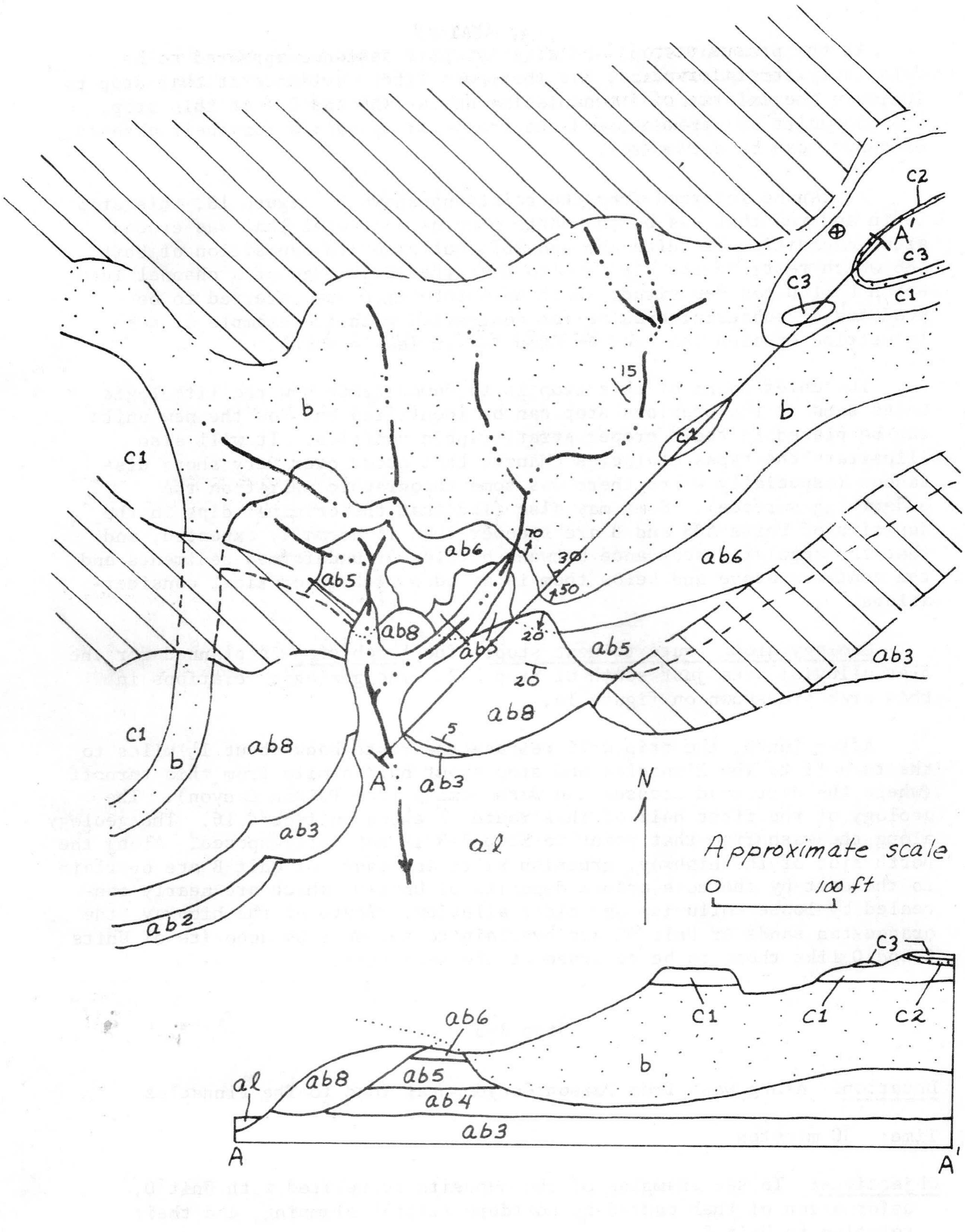


Figure 18. Geologic sketch map of an area along north side of Poison Canyon Wash.

EXPLANATION

Loose sand

al — Alluvium

Erosional unconformity

Unit C

c3 — Silt, calcareous, laminated, very light green

c2 — Sand, medium to coarse, well-sorted, tan

c1 — Silt, calcareous, laminated, very light green; gypsum crystals in upper part; layer of white nodose tufa 3 ft up from base

Unit B

b — Medium to very fine sand, well-sorted, high percentage of bleached biotite fragments, some silt beds; greenish-tan, locally slightly orange; beds locally dip steeply; lenses of brown nodose tufa near top

Erosional unconformity

Unit AB

ab8 — Silt, calcareous, white to light-green, grades laterally to tan medium sand where beds dip steeply; thins to west

Erosional unconformity

ab6 — Silt and fine sand, local lenses of medium sand, white to tan

ab5 — Sand, medium to coarse, possibly alluvial in part, orange; interbed of silt; molluscs near top

ab4 — Silt (not exposed in this area but shown in the cross section)

ab3 — Sand, medium to fine, locally coarse, orange; cross bedded

ab2 — Silt and sand, tan to light-greenish-tan

The main features to be seen at this stop are shown on the accompanying field sketch (fig. 19).

The laminated calcareous silts and clays of Unit C are restricted to a zone about 3 feet above the level of the wash. Evidence of erosion prior to deposition of the overlying unit is commonly present, and the overall relations as shown in figure 19 make it clear.

The deposits of Unit D are of three types, a light-green massive silt at the base, a well-sorted lacustrine sand, and an alluvial or fluvial pebble sand and gravel at the top. It is clear that a period of erosion occurred just before deposition of the alluvial or fluvial material; it is not clear whether or not erosion occurred between deposition of the lacustrine silt and the lacustrine sand. Much of the deformation in the silts appears to be due to postdepositional slumping, and it is possible that this alone created the relief found at the base of the lacustrine sand deposits.

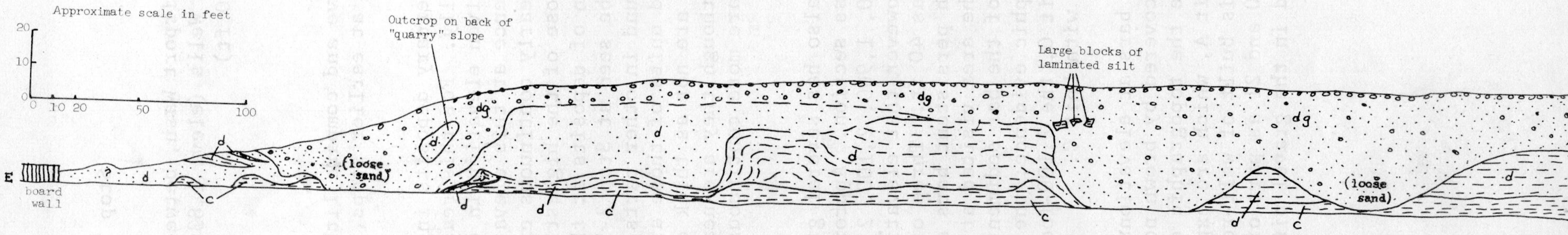
Steep original dips can be observed where the deposits shown as "dg" on figure 19 fill old channels; the most notable are on the left edge of the easternmost channel (marked "loose sand"), where beds have measured dips of 50°.

Geology along route to next stop: The trip retraces the route back to Trona, and descriptions of the geology are given in the discussion of Stop 1-1. Between Trona and Pioneer Point, the highway stays near the contact between lake silts of Unit D (on the east) and alluvium and older alluvium (on the west). Orange sands and gravels of Unit AB are visible along the lower slopes of the Argus Range. These are overlain by lighter colored deposits of Unit B plus large sheets of pinkish-tan nodose tufa. Older (Unit A) lithoid tufas are visible near the high shoreline (2,280 ft).

North of Pioneer Point, the highway is mostly on older alluvium that is smooth, slightly orange, nearly undissected, and graded to levels about 1 to 3 feet above the active washes.

From areas 1 to 2 miles north of Pioneer Point, very coarse boulders (e.g., up to 4 ft in diameter in the exposures nearest the highway) can be seen on the surface of the fan coming from Wilson Canyon. These are exhumed deposits and are equivalent in age to the pre-Wisconsin older gravels; lithoid tufa and deposits correlated with Units A1, A2, AB, and B overlie them. Fans with exceptionally large boulders are found elsewhere in Searles Valley and are also equivalent in age to the older gravels; this may signify more torrential precipitation in this area during that episode than at any time since.

About 3 miles north of Pioneer Point, the route turns east at the road to Valley Wells, stays south and later east of the fenced area, and heads northeast on the dirt road for about three-quarters of a mile. This segment of the trip is also over deposits of older alluvium. The trip stops just before the dirt road crosses "Airport Wash" (an informal name used in this guide for reference).



Unit D(?) — Sand and pebble gravel, fluvial or alluvial; tan, poorly sorted, subround to subangular fragments of rock, nodose tufa, and laminated silt; generally massive but locally well bedded, stands at dips up to 50°; partially developed lag gravel on top surface

Unit D — Sand and silt, lacustrine; sand is fine to very fine, tan to olive, well bedded to massive, well sorted; silt contains much clay in some layers, is massive, light green, calcareous, very plastic when wet, locally includes beds of very fine sand that are not shown on drawing

Unit C — Silt and clay, lacustrine; calcareous, characterized by thin white laminae

Figure 19. Sketch of exposure near east end of Poison Canyon Wash.

Stop 2-4

Location: Along Airport Wash, between intersection with road leading northeast from Valley Wells (elev. 1,830 ft) and gravel pit along east edge of wash (elev. 1,900 ft)

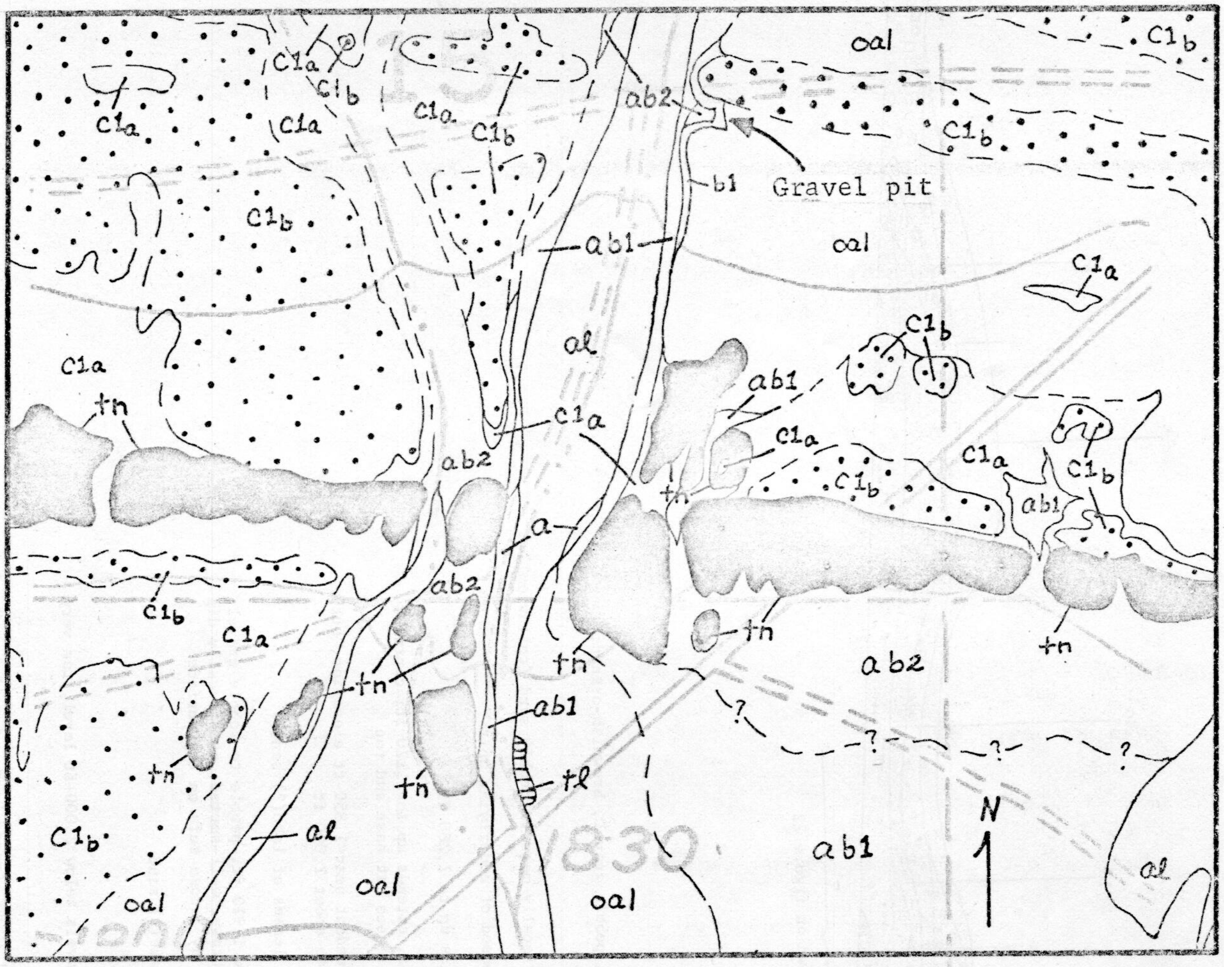
Time: 1¼ hours

Objectives: Observe and compare lithologies correlated with Units A, AB, B, and C as seen at earlier stops.

The late Quaternary deposits in Searles Valley have not been appreciably deformed tectonically. For this reason, the lake history inferred from exposures at any given elevation in one part of the valley must be compatible at least with evidence at this elevation in other parts of the valley. Airport Wash has nearly continuous exposures from elevations near 1,800 feet (fig. 20) up to those of the highest shorelines (see fig. 21). This stop permits observation of deposits at the lower elevations, and deposits at the higher levels can be seen at Stop 2-5a. All mapped units are correlated with the major units found in other parts of the valley; some are also correlated with the subdivided units of those areas and some are not. The deposits along Airport Wash are not as thick or as well exposed as those in the Poison Canyon area, even though they are near a major local source of inflow (see fig. 2), but they are more continuous than the deposits in the Teagle Wash area.

Airport Wash also has several gravel and sand bars visible on air photos and exposed in cross section. Approximate elevations of these are as follows: 1,850, 1,900, 1,920, 1,960, 2,100, 2,200, 2,210, 2,240, and 2,260 feet. It should be noted, however, that elevations on the crests of bars vary in this valley by as much as 40 ft. Three of these bars--at 1,960, 2,100, and 2,260--are correlated with persistent bars at the south end of Searles Valley (south and southwest of the area visited at Stop 1-3). Besides their similar elevations, the ages of the bar sediments are inferred to be the same on the basis of stratigraphic evidence; the 1,960-foot bar is built of deposits correlated with Unit C, the 2,100-foot bar is correlated with Unit AB, and the 2,260-foot bar with Unit C.

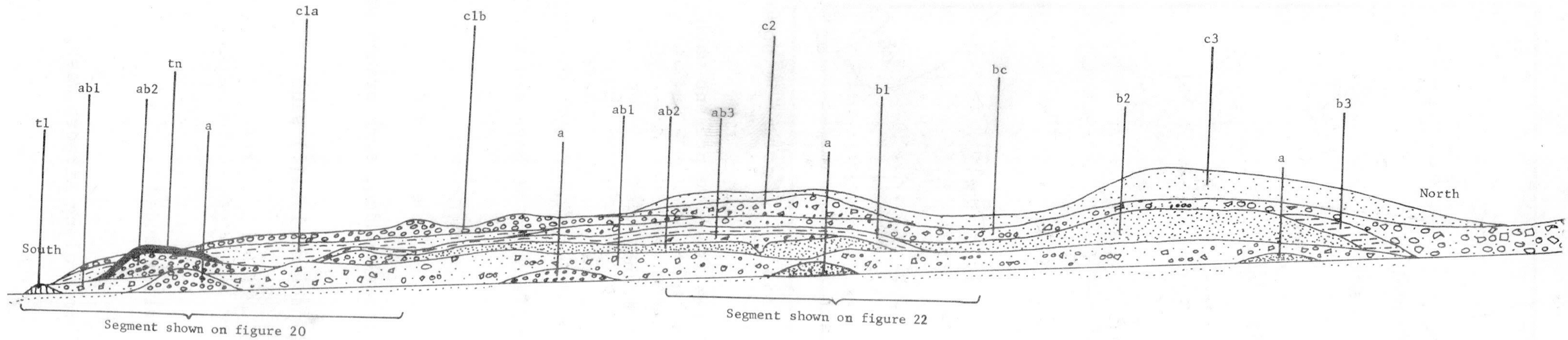
At this stop, bars at elevations 1,850 and 1,900 will be visited. The lower of these is covered by brown nodose tufa correlated with Unit B, but the bar seems to be the topographic expression of one formed by gravels correlated with Unit A, which are exposed along the level of the wash. The bar at 1,900 feet is built of well-rounded gray gravels and orange sands, shown on figures 20 and 21 as part of Unit AB2, that are now nearly buried though well exposed in the gravel pit in the area shown near the top of figure 20.



0 1000 2000 3000 ft

	al	Alluvium
	oal	Older alluvium, graded to levels 1-4 ft above present wash
Unit C	cl_b	cl_b, lake pebble gravel, brownish-orange
	cl_a	cl_a, lake sand and silt, tan
Unit B	b1	Lake silt, white to tan, white nodose tufa at base and top
	tn	Tufa, nodose, weathers dark brown
Unit AB	ab2	Lake gravel, gray, well-sorted, cross-bedded, some orange sand
	ab1	Alluvial sand and gravel, tan, lenses of lake(?) sand
Unit A	tl	Tufa, lithoid, weathers tan
	a	Lake gravel, gray, well-sorted, well-rounded

Figure 20. Geologic map and explanation of area along Airport Wash, elevation 1,850 feet.



Unit C	c3	Lake sand, tan, extends up to 2,280 ft
	c2	Alluvial gravel, gray-orange
	clb / cla	Lake deposits, extend up to 2,040 ft; <u>clb</u>, pebble gravel, brownish-orange; <u>cla</u>, sand and silt, tan
Unit BC	bc	Alluvial gravel, slightly orange stained, locally massive pebbly sand (colluvium?)
Unit B	b3	Lake silt, orange, trapped behind bar composed of underlying unit
	b2	Lake sand, very coarse, tan to gray, extends up to 2,260 ft
	bl	Lake silt, white to light-green, calcareous, extends up to 2,120 ft; contains ostracodes above 2,050 ft; nodose tufa lenses at base and top
	tn	Tufa, nodose, weathers dark brown, most abundant near 1,850-ft elevation, but found associated with overlying silt up to about 2,000 ft
Unit AB	ab3	Alluvial gravel and sand, orange, includes lenses of lake(?) sand
	ab2	Lake deposits, extend up to 2,100 ft; below 1,920 ft, pebble to cobble gravel, gray; above 1,920 ft, sand, tan to dark-brown, well-sorted, beds locally dip steeply; patches of lithoid tufa covered by nodose tufa on top surface
	abl	Alluvial sand and gravel, tan, lenses of lake(?) sand
Unit A	tl	Tufa, lithoid
	a	Lake deposits, gray well-rounded cobble gravels below 2,000-ft level, tan very coarse sand above 2,000 ft

Figure 21. Schematic diagram of stratigraphy exposed along Airport Wash. Actual length of segment shown, about 5 miles; most individual units have thicknesses between 1 and 5 feet. The segments included on figures 20 (Stop 2-4) and 22 (Stop 2-5a) also shown.

Unit AB1 at this stop consists of a tan pebble alluvium; it is lithologically similar to the lower part of Unit AB along Teagle Wash and occupies a comparable stratigraphic position. Unit B is represented only by a thin white calcareous silt plus nodose tufa (white where fresh, dark brown where weathered); red rootlet stains like those seen in examples of the soil developed on Unit BC are locally found on and in these deposits. Unit C is represented by a lower fine-grained unit and an upper pebble gravel that is stained a distinctive brownish-orange color.

Geology along route to next stop: The trip retraces its route past Valley Wells to the main highway, turns north for about 2.2 miles, then turns east along a poor dirt road for a distance of about a mile to a flat area suitable for parking. Much of the route along the highway lies on the west edge of the deposits seen in Airport Wash; the bar covered with nodose tufa is crossed about three-quarters of a mile north of the intersection with the Valley Wells road, and light-yellowish-tan sands and pebble gravels of Unit C are crossed at several points to the south and north. Alluvium and older alluvium make up the rest of the surface.

Along the base of the Slate Range, 2 to 3 miles east of the highway, most of the Quaternary deposits are sheets of windblown sand deposited by strong west winds, older alluvium, or older gravels (sloping surfaces now deeply dissected). Several thin beds of lake gravels are preserved in these older gravels. They underlie all the lacustrine units seen on this trip, and could be correlative with Illinoian deposits of the mid-continent area and with the Sherwin Glacial Stage in the Sierra Nevada.

Along the base of the Argus Range, 1 to 2 miles west of the highway, lake deposits related to Units AB (coarse orange gravels) and A (flaggy resistant tan sands) are seen. Near the mouth of the large canyon that drains Great Falls Basin (see fig. 9) lies a high ridge composed of tan-orange sand. This deposit and the upstream source from which it was derived (a coarse equigranular granite) supplied the well-sorted sand that makes up most of the lake deposits in the northwest part of Searles Valley. Wind-driven currents transported this sand north and east, subparallel to the lakeshore, to points about half a mile east of Airport Wash; this probably indicates that storm winds blew from the south or southwest during much of middle and late Wisconsin time.

Stop 2-5a

(Optional; depending on time, may have to be concurrent with Stop 2-5b)

Location: Airport Wash, near elevation 2,080 feet

Time: 1 hour

Objectives: Observe examples of Units A, AB, B, BC, and C; study structures in Unit AB2 that are indicative of near-shore depositional environment; observe examples of orange gravel thought to be equivalent to top of Unit AB in other areas.

The stratigraphy exposed at this stop is shown on figure 22 and is indicated diagrammatically on figure 21. As these figures show, Units AB and C are especially well represented in this area. Unit AB1, which consists mostly of tan alluvial gravel, forms the lowest bed along most of this part of the wash. Unit AB2 is brown, very coarse, very well sorted lacustrine sand with backset dips of 30° or more; this unit is correlated with the steeply dipping gravels exposed in the gravel pit at the previous stop. Lithoid tufa is found in and on this unit. It is also covered by a lens of distinctly orange alluvial gravel (AB3) that rests on an erosional unconformity; this gravel unit is considered to be the probable equivalent of the orange gravels found near the tops of Unit AB in the Teagle Wash and Poison Canyon Wash areas.

Unit BC is a thin layer of angular orange-stained gravel in most areas but in some is a brownish-orange pebble colluvium(?).

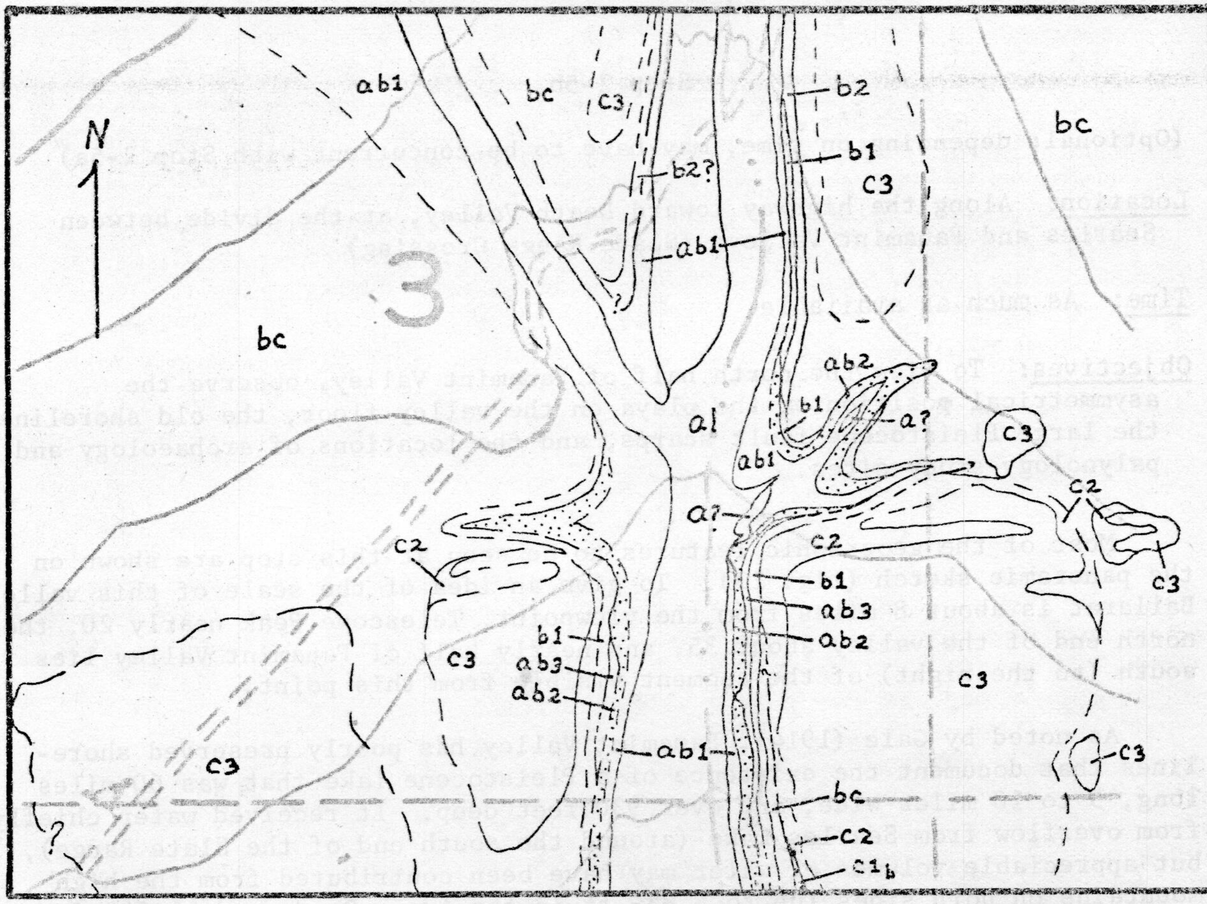
Unit C is represented here by the pebble gravel of the upper half of Unit C1, the angular alluvium of Unit C2, and the thin light-tan lacustrine sand that extends up to and forms faint bars at about 2,260 feet in this area. These subdivisions of Unit C are considered equivalent to the subdivisions made in the Teagle Wash and Poison Canyon areas.

Most of the sand in Units AB2, C1, and C3 was transported by lake currents from the Great Falls Basin drainage to the southwest.

Geology along route to next stop: If time permits, or alternative to this stop, the group will drive to the north edge of Searles Valley for a view into Panamint Valley, the site of the next lake downstream in the chain of Pleistocene lakes. To get to this point, return to paved highway and turn north for a distance of about 7 miles. Most of the highway is on modern alluvial washes or older alluvium.

Near the north end of the valley, a mile north of the junction with a road leading right to a quarry (once used as a source of limestone to provide CO_2 to the chemical plant at Westend), steeply dipping orange alluvial gravels are exposed in roadcuts on the right. These are equivalent in age to much of the lacustrine and nonlacustrine section observed on this trip; presumably, therefore, calcareous soils similar to those seen in the south half of the basin should have developed on them. Curiously, the fossil soils developed in this area are all characterized by strong orange staining of the matrix and fragments and a lack of identifiable calcareous (Cca) horizons. This is especially noteworthy in these gravels because the fragments are almost all limestone. The difference in the nature of fossil soils makes it tempting to speculate about possible critical differences in the Pleistocene climates of the north vs. south ends of the valley.

Also near the north end of the valley, in small hills to the left of the highway, on the crests of the Argus and Slate Ranges, and at the divide (known locally as Slate Range Crossing), late Tertiary basaltic rocks and pyroclastics crop out. In the Slate Range and at the divide, they rest on late Paleozoic impure limestones; in the Argus Range they rest mostly on Mesozoic plutonic rocks.



0 1000 2000 3000 ft

	al	Alluvium
Unit C	c3	Lake sand, tan
	c2	Alluvial gravel, gray-orange
	$c1_b$	Lake pebble gravel, brownish-orange
Unit BC	bc	Alluvial gravel, fragments angular, slightly orange stained; locally, massive pebbly sand (colluvium?)
Unit B	b2	Lake sand, very coarse, tan to gray
	b1	Lake silt, calcareous, white to light-green, contains ostracodes
Unit AB	ab3	Alluvial gravel and sand, orange, includes some lake(?) sands
	ab2	Lake sand, tan to dark-brown, well-sorted, well-bedded, beds locally dip steeply; patches of lithoid tufa covered by nodose tufa on top surface
	ab1	Alluvial sand and gravel, tan, lenses of lake(?) sand
Unit A	a	Lake sand, tan to brown, well-sorted

Figure 22. Geologic map and explanation of area along Airport Wash, elevation 2,080 feet.

Stop 2-5b

(Optional; depending on time, may have to be concurrent with Stop 2-5a)

Location: Along the highway toward Death Valley, at the divide between Searles and Panamint Valleys (Slate Range Crossing)

Time: As much as available

Objectives: To view the north half of Panamint Valley, observe the asymmetrical position of the playa on the valley floor, the old shorelines, the large Pleistocene fault scarps, and the locations of archaeology and palynology study sites.

Most of the geographic features to be seen at this stop are shown on the panoramic sketch (fig. 23). To give an idea of the scale of this valley: Ballarat is about 8 miles from the viewpoint, Telescope Peak nearly 20, the north end of the valley about 35, and nearly half of Panamint Valley lies south (to the right) of the segment visible from this point.

As noted by Gale (1914), Panamint Valley has poorly preserved shorelines that document the existence of a Pleistocene lake that was 60 miles long, 5 to 10 miles wide, and over 930 feet deep. It received water chiefly from overflow from Searles Lake (around the south end of the Slate Range), but appreciable volumes of water may have been contributed from the high mountains on both sides (up to 8,839 ft in the Argus Range and 11,049 ft in the Panamint Range). Overflow is suggested by the similarity between the elevation of the poorly preserved highest shoreline and that of the spillway (1,976 ft) near the south end of the valley; overflowing water traveled eastward to Death Valley. A slightly better preserved shoreline exists at 1,800 feet elevation, and several well-preserved shorelines are locally found nearer the elevation of the valley floor (mostly near 1,040 ft).

Drill cores from the playas confirm the former existence of large lakes and intervening dry periods (Smith and Pratt, 1957); lacustrine muds containing diatoms, ostracodes, chara, and forams (P. Smith, 1960) was found beneath the surface of the playa near Ballarat, and several hundred feet of halite was found several miles to the south. Molluscs are found in lacustrine outcrops (Hanna, 1963).

Ages of these lakes are not well known. The poorly preserved nature of the shorelines, plus geologic reconnaissance of exposed lake deposits and the interlayered alluvial gravels and fossil soils, suggest that the largest lakes were of early Wisconsin age and/or older. Carbon-14 dates on heavily weathered tufa give younger ages.

One of the most striking aspects of this part of Panamint Valley is the asymmetrical position of the large central playa (near Ballarat). Alluvial fans on the west side of this part of the valley are 7 to 8 miles long; fans on the east side are mostly ¼ to 2 miles long, and in two places (Warm Sulphur

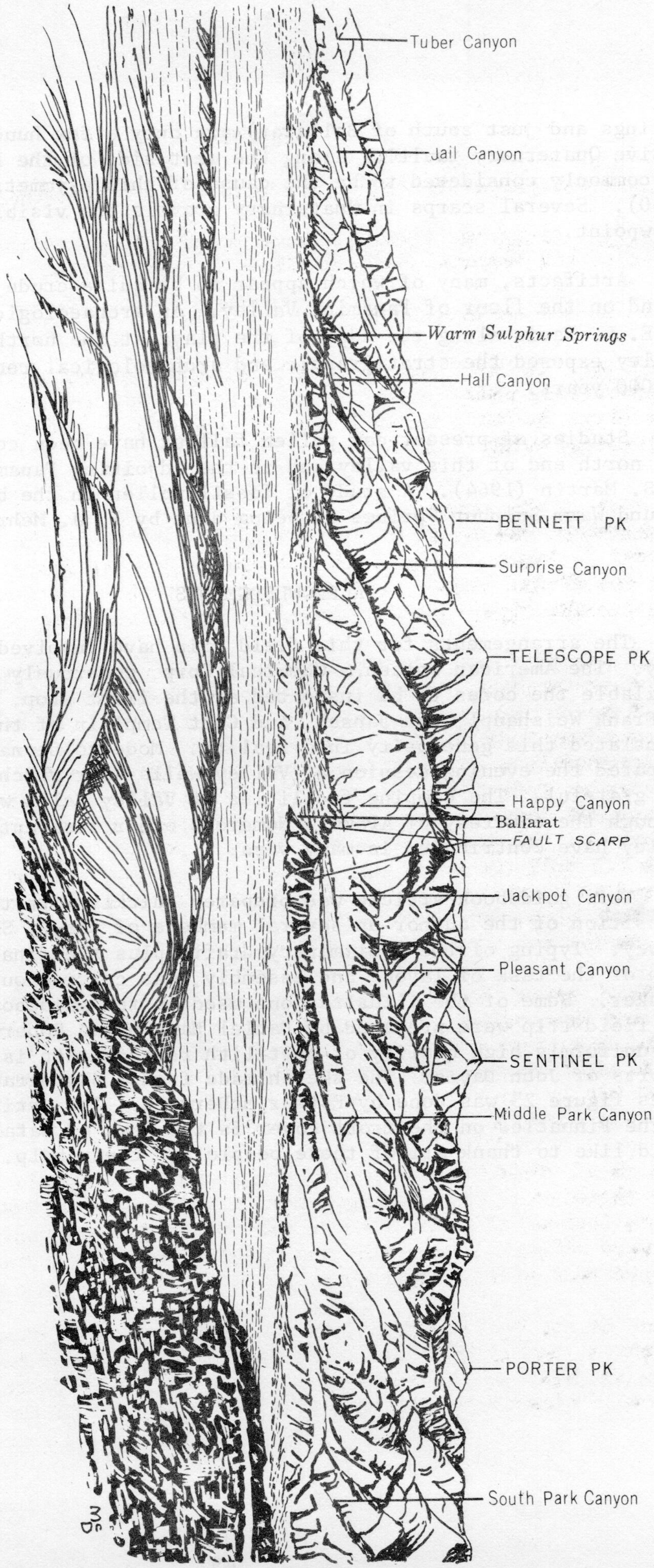


Figure 23. Major geographic features of the Panamint Range and Panamint Valley as seen from Slate Range Crossing. Sketch by Esther McDermott.

Springs and just south of Ballarat) are only a few hundred feet wide. Active Quaternary faulting along the west side of the Panamint Range is commonly considered to be the cause of this asymmetry (see Maxon, 1950). Several scarps in Quaternary gravels are visible from this viewpoint.

Artifacts, many of which appear to be quite crude in form, are found on the floor of Panamint Valley. An archaeological excavation by E. L. Davis along the edge of the playa at the north end of the valley exposed the stratigraphic and archaeological record of the last 10,000 years.

Studies of present-day pollen fallout have been conducted near the north end of this valley and in the adjoining Panamint Range by P. S. Martin (1964). A study of fossil pollen in the bog deposits around Warm Sulphur Springs is being done by P. J. Mehringer, Jr.

ACKNOWLEDGMENTS

The arrangements for this field trip have involved the help of many. The American Potash & Chemical Corp. generously agreed to make available the cores to be inspected at the first stop, and the efforts of Frank Weishaupl, Lou Jansen, and Curt Templain of the corporation translated this generosity into reality. Modesto Leonardi arranged and prepared the evening session at Valley Wells--for which all participants are grateful. The camping facilities at Valley Wells were also offered through the courtesy of AP&CC. Numerous other residents of Searles Valley have contributed in many ways.

This guidebook article was prepared quickly with the inevitable imposition of the author on several members of the U. S. Geological Survey. Typing of the preliminary drafts plus the final text, and much of the task of layout and assembly, was carried out by Frances LeBaker. Some of the illustrations used in the guidebook and during the field trip were prepared by Daniel Hamson and Robert McLaughlin. The uniformly high quality of multilith reproduction is due to the efforts of John Davis. The sketch made from a photograph that constitutes figure 23 was done by Esther McDermott. The artistic portrayal of The Pinnacles on the front cover is the work of Natalie Miller. I would like to thank all of these people for their help.

REFERENCES

Birman, J. H., 1964, Glacial geology across the crest of the Sierra Nevada, California: Geol. Soc. America Spec. Paper 75, 80 p.

Blackwelder, Eliot, 1931, Pleistocene in the Sierra Nevada and Basin ranges: Geol. Soc. America Bull., v. 42, p. 865-922.

Broecker, W. S., and Kaufman, Aaron, 1965, Radiocarbon chronology of Lake Lahontan and Lake Bonneville II, Great Basin: Geol. Soc. America Bull., v. 76, p. 537-566.

Broecker, W. S., and Orr, P. C., 1958, Radiocarbon chronology of Lake Lahontan and Lake Bonneville: Geol. Soc. America Bull., v. 69, p. 1009-1032.

Broecker, W. S., Turekian, K. K., and Heezen, B. C., 1958, The relation of deep sea [Atlantic Ocean] sedimentation rates to variations in climate: Am. Jour. Sci., v. 256, p. 503-517.

Emiliani, Cesare, 1955, Pleistocene temperatures: Jour. Geology, v. 63, p. 538-578.

Ericson, D. B., Ewing, Maurice, and Wollin, Goesta, 1964, The Pleistocene epoch in deep-sea sediments: Science, v. 146, p. 723-732.

Eugster, H. P., and Smith, G. I., 1965, Mineral equilibria in the Searles Lake evaporites, California: Jour. Petrology, v. 6, no. 3, p. 473-522.

Flint, R. F., and Gale, W. A., 1958, Stratigraphy and radiocarbon dates at Searles Lake, California: Am. Jour. Sci., v. 256, p. 689-714.

Gale, H. S., 1914, Salines in the Owens, Searles, and Panamint basins, southeastern California: U.S. Geol. Survey Bull. 580-L, p. 251-323.

Haines, D. V., 1959, Core logs from Searles Lake, San Bernardino County, California: U.S. Geol. Survey Bull. 1045-E, p. 139-317.

Hanna, G. D., 1963, Some Pleistocene and Pliocene freshwater mollusca from California and Oregon: California Acad. Sci. Occasional Papers, no. 43, 20 p.

Martin, P. S., 1964, Pollen analysis and the full-glacial landscape, in Hester, J. J., and Schoenwetter, J., eds., Reconstruction of past environments: Fort Burgwin Research Center, Toas, N. Mex., Pub. 3, p. 66-74.

Maxson, J. H., 1950, Physiographic features of the Panamint Range, California: Geol. Soc. America Bull., v. 61, p. 99-114.

Morrison, R. B., 1965, Quaternary geology of the Great Basin, p. 265-285 in Wright, H. E., Jr., and Frey, D. G., eds., The Quaternary of the United States--a review volume for the VII Congress of the International Association for Quarternary Research: Princeton, N. J., Princeton Univ. Press, 922 p.

Scholl, D. W., 1960, Pleistocene algal pinnacles at Searles Lake, California: Jour. Sed. Petrology, v. 30, no. 3, p. 414-431.

Sharp, R. P., and Birman, J. H., 1963, Additions to classical sequence of Pleistocene glaciations, Sierra Nevada, California: Geol. Soc. America Bull., v. 74, p. 1079-1086.

Smith, G. I., 1962, Subsurface stratigraphy of late Quaternary deposits, Searles Lake, California--a summary: U.S. Geol. Survey Prof. Paper 450-C, p. C65-C69.

_____1965, Late Quaternary geologic and climatic history of Searles Lake, southeastern California [abs.]: Internat. Assoc. Quaternary Research, 7th Cong., Boulder and Denver, Colo., 1965, Gen. Sess., p. 436.

Smith, G. I., 1967(?), Late Quaternary geologic and climatic history of Searles Lake, southeastern California: Utah Univ., in press.

Smith, G. I., and Haines, D. V., 1964, Character and distribution of nonclastic minerals in the Searles Lake evaporite deposit, California: U.S. Geol. Survey Bull. 1181-P, p. P1-P58.

Smith, G. I., and Pratt, W. P., 1957, Core logs from Owens, China, Searles, and Panamint basins, California: U.S. Geol. Survey Bull. 1045-A, p. 1-62.

Smith, P. B., 1960, Fossil Foraminifera from the southeastern California deserts, in Geological Survey Research 1960: U.S. Geol. Survey Prof. Paper 400-B, art. 127, p. B278-B279.

Stuiver, Minze, 1964, Carbon isotopic distribution and correlated chronology of Searles Lake sediments: Am. Jour. Sci., v. 262, p. 377-392.

SUMMARY OF PALYNOLOGICAL DATA FROM SEARLES LAKE

By

Estella B. Leopold

U. S. Geological Survey, Denver, Colorado

CONTENTS

SUMMARY OF PALYNOLOGICAL DATA FROM SEARLES LAKE

By Estella B. Leopold

VEGETATION ZONES OF SEARLES LAKE AREA

The present vegetation of the Searles Lake basin may be briefly outlined as occupying the following zones:

(1) Bare areas: elevations below 1,621 feet, or sometimes below 1,630 feet depending on local topography; lack of vegetation due either to excessive salinity or to minimal ground-water supply.

(2) Phreatophytes around edge of salt pan: intermittent between elevations 1,621 and 1,630 feet; pickleweed (*Allenrolfea occidentalis*), saltgrass (*Distichlis stricta*), and in washes, red molly (*Kochia americana*) and Parry saltbush (*Atriplex parryi*).

(3) Desert scrub on fans and dunes, elevations above 1,630 or 1,680 feet to about 1,900 feet: dominant plants include desert holly (*Atriplex hymenelytra*) and creosote bush (*Larrea tridentata*). Common forms include spiny hop sage (*Grayia spinosa*), burrowweed (*Franseria dumosa*), skeleton-weed (*Eriogonum deflexum*), Bigelow cholla (*Optunia bigelowi*); lower in washes, Mohave saltbush (*Atriplex spinifera*).

(4) Desert scrub on mountain slopes above 1,900 feet to about 4,000 feet: dominant plant is creosote bush (*Larrea tridentata*), subdominant is burrowweed (*Franseria dumosa*); common plants include bisnaga or barrel cactus (*Echinocactus acanthodes*), mormon's tea or mountain joint fir (*Ephedra viridis*), desert alyssum (*Lepidium fremontii*), and brittle-bush (*Encelia farinosa*). In washes: rabbitbush (*Chrysothamnus*), desert plume (*Stanleya pinnata*), and mesquite (*Prosopis*).

(5) Southern Argus Mountains, 4,000 to 6,000 feet; buckbrush (*Ceanothus*), mormon's tea, *Baccharis*, and *Eriogonum*; at upper edge of this zone is the lowest occurrence of *Juniperus*, pinyon pine (*Pinus monophylla*), sagebrush (*Artemisia*), and probably *Coleogyne*. Only a few scattered pinyons occur in the highest parts of the southern Argus Mountains. In the Panamints, juniper occurs in this zone without pinyon. In the southern Argus Mountains, pinyon occurs without juniper.

Pinyon-juniper woodland is not represented in the southern Argus Mountains or Slate Range; but this zone is represented above 6,500 or 7,000 feet in the Panamint Mountains, some 20 miles northeast of Searles Lake and in the northern Argus Mountains 20 miles northwest of Searles Lake. Associated with this zone are mountain mahogany (Cercocarpus), cliff rose (Cowania), sage (Artemisia), and mistletoe (Arceuthobium).

MODERN POLLEN RAIN AT SEARLES LAKE

In 1963, a series of modern pollen traps were placed in an east-west transect across the south end of Searles Lake basin along an abandoned trackway (see G. I. Smith, fig. 2). The traps are standard rain gages equipped with filters of 10-micron mesh set in the funnel of the gages. The instruments were set up in October when few plants were blooming, and the pollen filters were collected in 1964, exactly a year later. Samples thus obtained are assumed to represent aerial pollen rain for a while year's interval. Trap samples were analyzed for relative composition and for total numbers of pollen grains trapped per square centimeter per year. Soil samples from each site were analyzed for contained pollen. The purpose of this transect was to determine the absolute number and composition of the modern pollen rain at both basin and mountain sites, and to compare airborne pollen rain with pollen in local modern soils, and with the subsurface pollen stratigraphy.

The results of this study are summarized in figure 1. Absolute numbers of pollen per square cm/yr ranged from about 200 to 1,200. The higher fallout occurred on the divides (see bottom of fig. 1). The most common pollen types found in the pollen traps for the year 1963-1964 were found to represent groups that grow in Searles Valley. Pollen types probably from local plants include:

Chenopodiaceae, saltbush family: 10-30 percent of the counts with the higher percentages occurring on the fans where members of this family are best represented. Members of this family cannot be assigned to genus, except for greasewood (Sarcobatus) (a rare pollen type growing in Death Valley), and hence one cannot say which local genera of Chenopodiaceae are represented. Best representation of Chenopodiaceae pollen both in absolute numbers per square centimeters per year and in percentages of the counts is in the fan areas where members of this family dominate the vegetation.

Compositae, daisy family: between 10 and 32 percent of counts. The Franseria pollen type, which can be recognized by its long spines, is best represented on the ridgetops where this plant is most abundant. Percentages of short-spined Compositae are about the same across the transect. Absolute numbers of Compositae pollen are greatest on the ridgetops, in part due to a higher representation of Franseria pollen fallout, but also because total fallout was greatest there. Artemisia (sage) of this family is excluded from the Compositae counts in figure 1 and is discussed later.

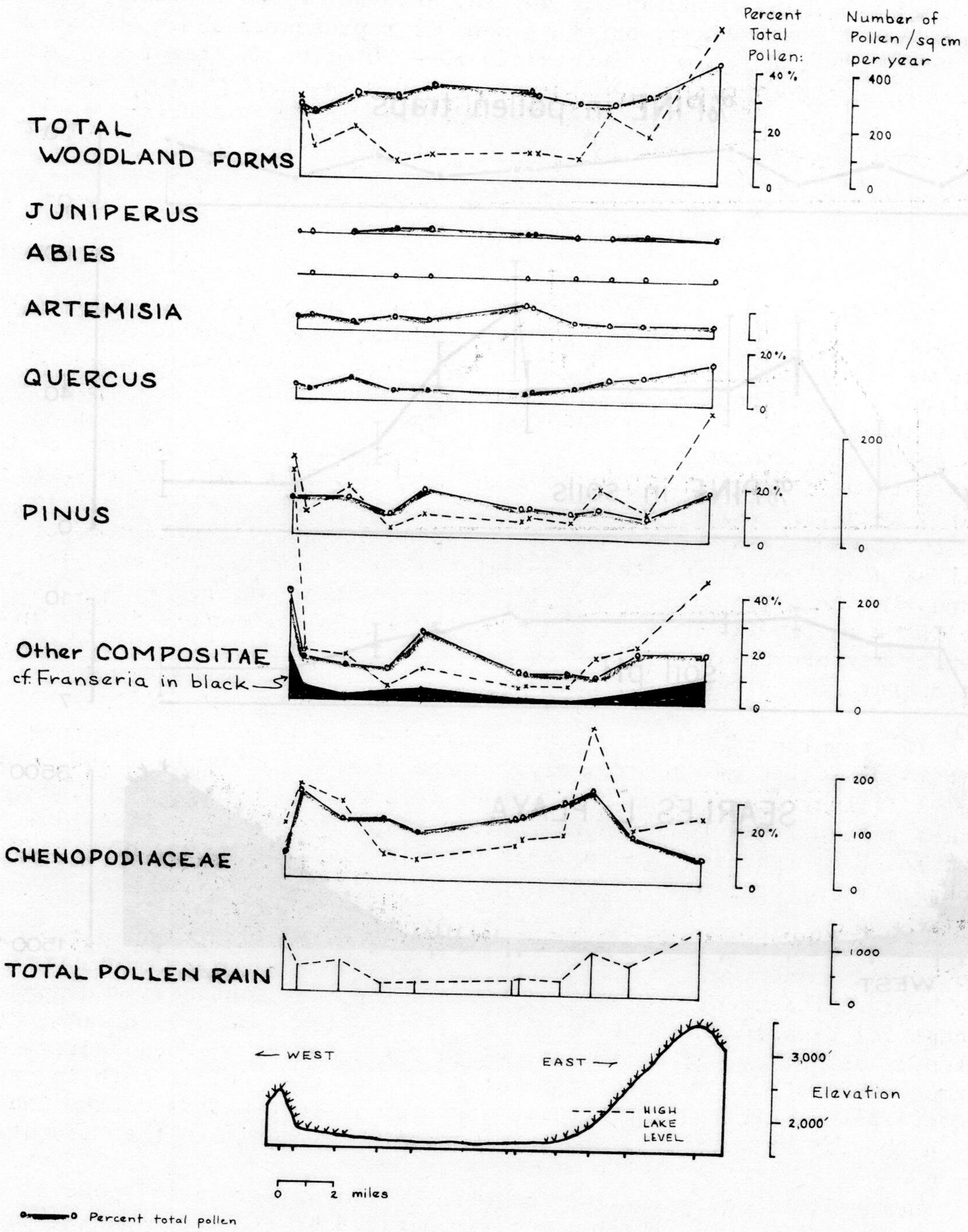


Figure 1. Modern pollen trap transect at Searles Lake; showing relative numbers of pollen (percent composition) as solid lines, and showing absolute numbers of pollen per square centimeter per year as dotted lines. This figure only includes numbers for the common types. Profile of Searles Valley along east-west transect is shown at bottom.

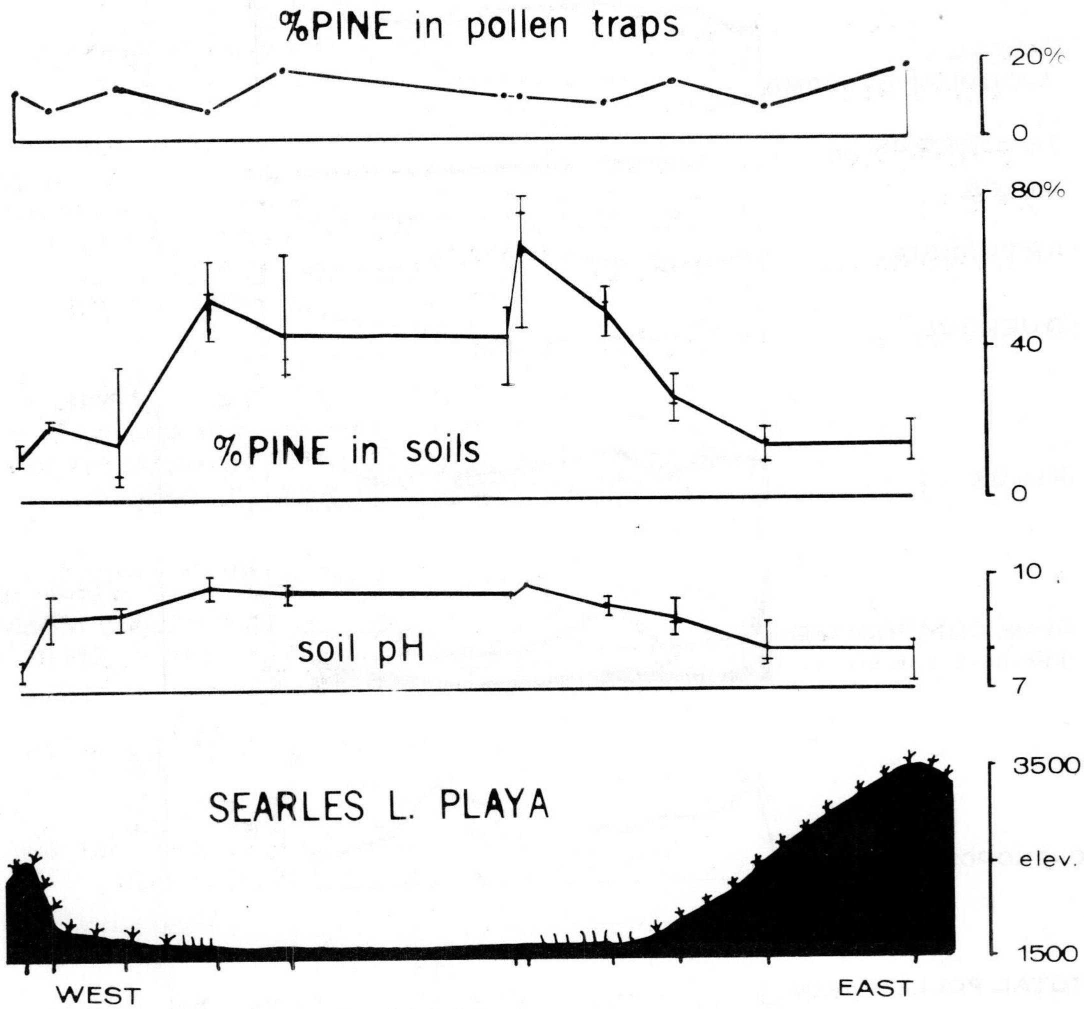


Figure 2. Pollen from surface soil transect, Searles Lake, showing percentages of pine pollen from three soil samples at each trapping station, and mean pine content at each station (middle graph). Lower graph shows pH readings from same soil samples and range of readings at each station (lower graph). Top graph indicates percent pine pollen found in aerial pollen rain samples in rain gage traps. Note discrepancy between pine percentages in soils and in traps, and note general relationship to curve showing increasing basicity of soils toward middle of valley (see text discussion).

Other local plants are represented meagerly in the pollen rain: for example, Ephedra, Rhamnus, Ceanothus, Pontentilla, Prosopis, Larrea, Plantago, and Lythrum.

Pollen types that clearly represent groups foreign to the Searles basin include the following:

Pinus: 8 to 18 percent across the transect, average 11.6 percent. About a third of the pine count are small grains assignable to the pinyon pine type, and about two-thirds are therefore probably other species such as P. ponderosa which grow farther away than 35 miles--for example, in the Sierra Nevada. Differences in absolute numbers of pine per square centimeter at different stations conform to the pattern of the total pollen rain.

Quercus-Cercocarpus type: 5 to 16 percent of the count. Although there may be some Cercocarpus type (Rosaceae) pollen in this count, I feel that most of it is assignable to Quercus. Both of these plants are prolific pollen producers, but only Cercocarpus is known to exist in desert woodland zone of this area.

Artemisia: 4 to 10 percent of the count. This plant is a member of the pinyon-juniper woodland, and grows with juniper on open slopes at the lower limit of the tree line. Therefore its pollen comes from at least 20 miles distance.

Pollen of other nonlocal plants are represented sparsely but occur in nearly all the trap sites; examples are:

Ulmus: planted at China Lake (18 miles west) Naval Station and in various towns west of the Sierra Nevada. Not native to California.

Carya: planted in Great Valley, not native.

Juglans: native in San Bernardino Mountains, Arizona, and north-central California, planted in Great Valley and near Owens Lake.

Fremontia: native to San Bernardino Mountains and west flanks of Sierras.

Abies: nearest occurrence 95 miles to northeast, Spring Mountains, Nevada.

Picea: nearest occurrence in northern California, 300 miles to the northwest.

Also: Tsuga, Pseudotsuga, Sequoia, Fremontia (from the Sierras); Fraxinus, Populus, Typha, Eleagnus from desert mountains or Sierras.

General provenance of pollen rain at Searles: about 70 percent probably comes from the Searles basin and 30 percent comes from 20 to 300 or more miles away.

POLLEN IN SURFACE SOILS

Along the same transect described above, three soil samples from each modern pollen-trapping site were analyzed for percentages of contained pollen, and the pH of each was taken with a Beckman meter. The results are shown in figure 2 compared with the results from the pollen traps.

In soil collections from the rim of the basin, the percentages of pine pollen in relation to the total pollen count are about 11 to 20 percent with an average of 13 percent. These percentages show some scatter, but the pine content is very similar to pine percentages found inside the traps locally (11.6 percent). However, the soil samples from the valley floor show large scatter at individual sites, and the range and the mean pine pollen content there is significantly larger than that found in any traps. In the center of the basin the average for soil samples is 50 percent pine, and ranges from 30 to 80 percent in different samples.

The pH of surface soils on the rim of the basin ranges from 7 to 8 and shows a progressive increase toward the center of the basin, where pH ranges from 9 to 10. A general relationship between alkaline soils and high pine content is suggested.

If the pollen traps reveal the nature of the modern pollen rain, then the surface soils in the middle of Searles Valley do not. The pollen contained in the soil samples from the margins of the valley are quite well preserved, while those in the center of the valley tend to be poorly preserved. Since pine is one of the more sturdy pollen types, differential degradation of the more fragile pollen types under basic pH may account for the results here. Reworking of pine-rich sediments of Wisconsin age exposed on the flanks of the valley may have occurred too.

Similar relationships are seen in the surface soil transect taken from Panamint Valley by Paul Martin. The right-hand portion of figure 3 was published by Martin (1964). Note that pine-rich soils are located in the woodland zone in the Panamint Mountains and in the center of Panamint Playa. Soils on the desert fans, however, contain preponderantly desert pollen types just as at Searles Lake. Two pH readings on pine-rich soils from near the center of Panamint Valley were pH 9, suggesting that the same physical situation may exist in that playa.

SUBSURFACE POLLEN STRATIGRAPHY

Pollen analysis of three long subsurface cores has been completed by the Geological Survey (Leopold, 1965) and one short core by Mrs. Aino Roosma (1958). The long cores extend from the Bottom Mud to the surface, and Roosma's core penetrates only the Parting Mud and the Upper Salt. All cores are from near the center of the Searles Lake basin.

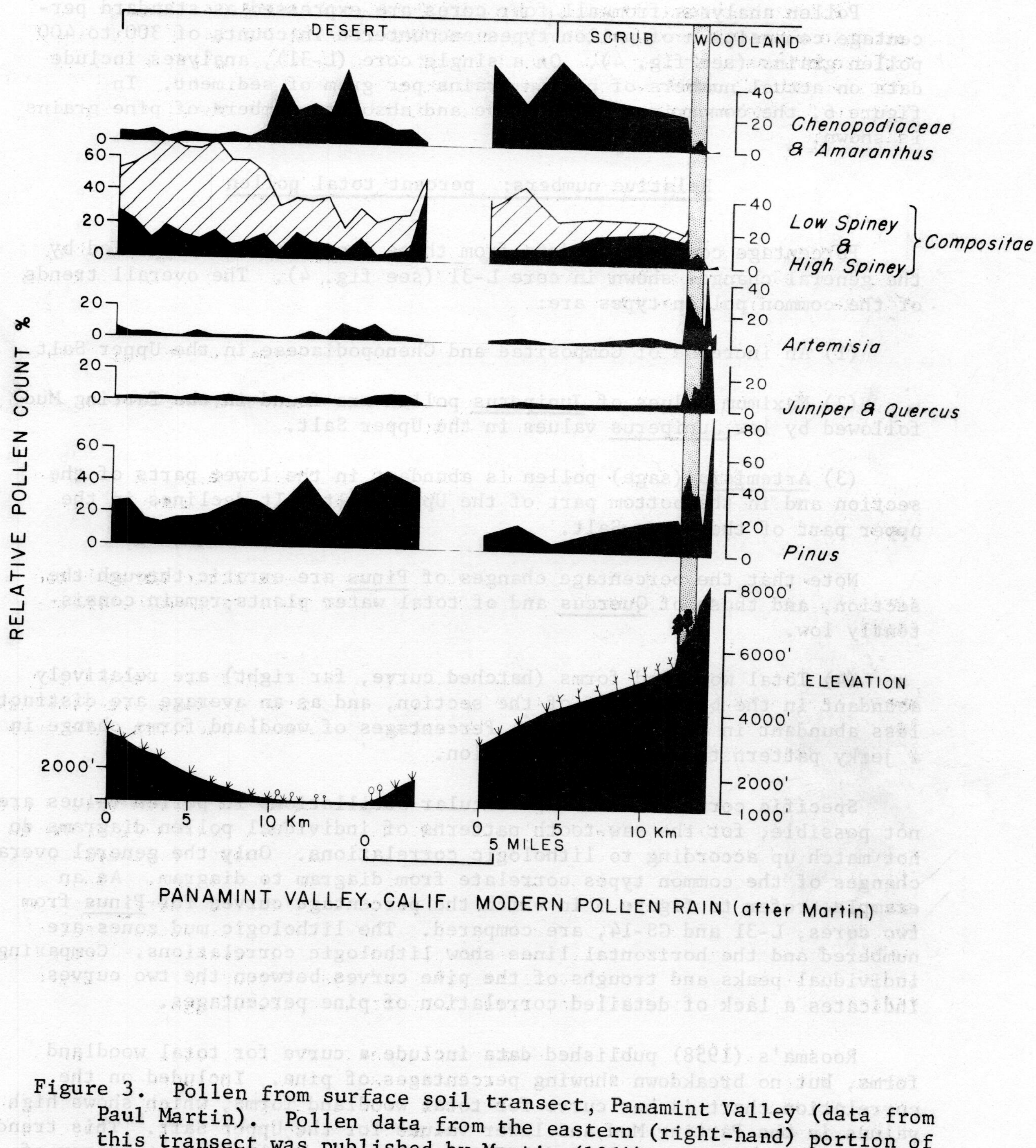


Figure 3. Pollen from surface soil transect, Panamint Valley (data from Paul Martin). Pollen data from the eastern (right-hand) portion of this transect was published by Martin (1964).

Pollen analyses from all four cores are expressed as standard percentage composition of pollen types encountered in counts of 300 to 400 pollen grains (see fig. 4). On a single core (L-31), analyses include data on actual numbers of pollen grains per gram of sediment. In figure 6, the comparison of relative and absolute numbers of pine grains is shown.

Relative numbers: percent total pollen

Percentage composition data from three long cores are typified by the general changes shown in core L-31 (see fig. 4). The overall trends of the common pollen types are:

(1) An increase of Compositae and Chenopodiaceae in the Upper Salt.

(2) Maximum values of *Juniperus* pollen are found in the Parting Mud, followed by low *Juniperus* values in the Upper Salt.

(3) *Artemisia* (sage) pollen is abundant in the lower parts of the section and in the bottom part of the Upper Salt. It declines in the upper part of the Upper Salt.

Note that the percentage changes of *Pinus* are erratic through the section, and those of *Quercus* and of total water plants remain consistently low.

(4) Total woodland forms (hatched curve, far right) are relatively abundant in the bottom half of the section, and as an average are distinctly less abundant in the Upper Salt. Percentages of woodland forms change in a jerky pattern throughout the section.

Specific correlations of particular oscillations in pollen values are not possible, for the saw-tooth patterns of individual pollen diagrams do not match up according to lithologic correlations. Only the general overall changes of the common types correlate from diagram to diagram. As an example, refer to figure 5 in which the percentage curves for *Pinus* from two cores, L-31 and GS-14, are compared. The lithologic mud zones are numbered and the horizontal lines show lithologic correlations. Comparing individual peaks and troughs of the pine curves between the two curves indicates a lack of detailed correlation of pine percentages.

Roosma's (1958) published data include a curve for total woodland forms, but no breakdown showing percentages of pine. Included on the correlation chart is her curve for total woodland forms, which shows high values in the Parting Mud and lower values for the Upper Salt. This trend is reflected by the total woodland curve in core L-31, but not by any of the percent pine curves. In other words, the general decrease in woodland forms in the late Pleistocene at Searles is due to a decrease in woodland forms other than pine.

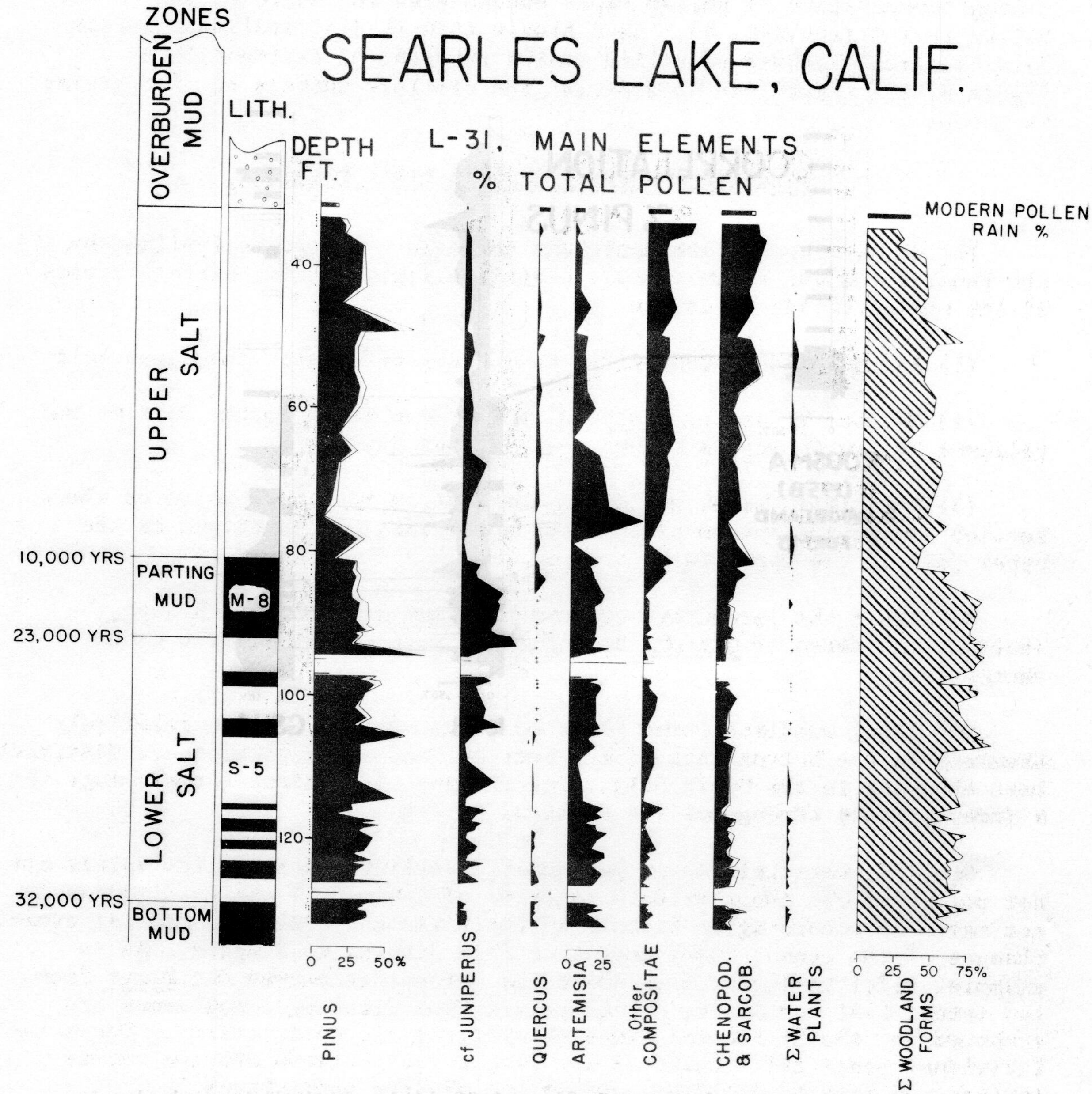


Figure 4. Pollen diagram of core L-31 showing percent composition of pollen counts, and showing only common forms. Histogram bars entered at top of section reveal nature of modern pollen rain and relative importance of these common forms. Hatched curve on far right include total woodland forms, for example, herbs, shrubs, or trees that are known to be associated with woodland or forest communities, and these therefore have a provenance outside Searles basin. Pinyon-type pine pollen is indicated by the white area at the top of the pine curve (observations available only above S-5).

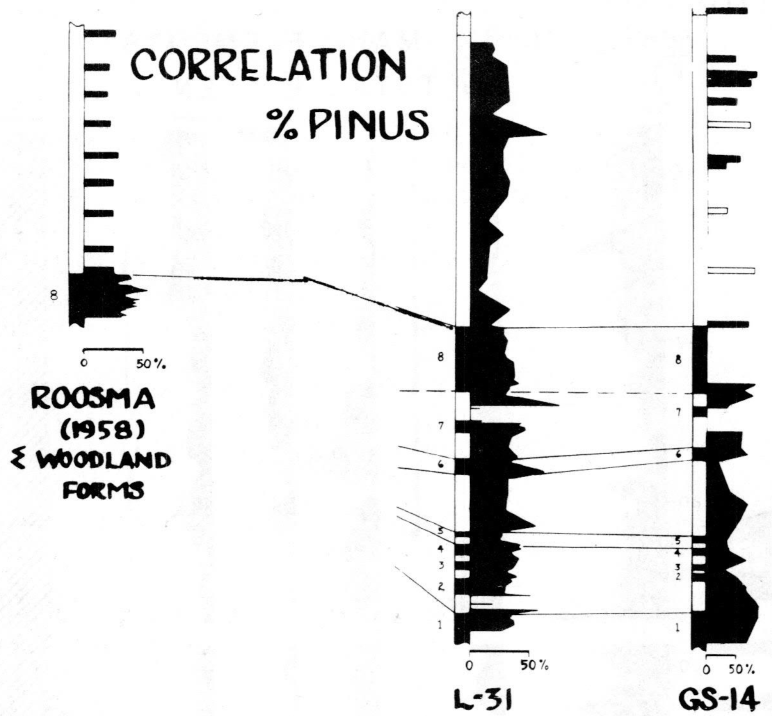


Figure 5. Correlation of cores L-31 and GS-14 by lithology and showing pattern of pine curves (percentages of pine). Roosma's core entered at left shows only total woodland forms, since percent pine figures were not published by her. Note the lack of correlation of the sawtooth pine oscillations between the two cores at right.

Meaning of the relative pollen numbers in terms of vegetation change

The meaning of the fossil materials can best be viewed in relation to the modern pollen rain data obtained from the pollen traps. At the top of figure 4, histogram bars are entered to show the mean percentages for each pollen type observed in the modern pollen traps.

The modern composition of the pollen rain at Searles Lake includes only 11.8 percent pine, which is lower than any time during the last 30,000 years, except for certain levels in the early postglacial (for example, base of Upper Salt in three cores). In core L-31, the average pine percentage in the Upper Salt is 25 percent; in the Parting Mud, 33 percent; in the Lower Salt, 39 percent; and in the Bottom Mud, 33 percent. Average percentages of pine vary widely, however, between the three cores.

Juniperus pollen occupies only 1 percent of the modern pollen rain, but had a peak percentage of 33 percent during the late glacial and averaged about 15 percent in the lower part of the section.

Oak (Quercus) is now 7 percent of the pollen rain and ranged from zero to 7 percent during the late Wisconsin.

Artemisia is now 7 percent of the pollen rain, but was 2 to 4 times better represented during late Wisconsin and early postglacial interval.

Compositae and Chenopodiaceae (16 and 21 percent, respectively, in modern pollen rain) were better represented during the early postglacial than now, and less well represented during the late Wisconsin than now.

The total sum of woodland forms (now 30 percent of modern rain) was 2 to 2½ times higher than now during the late Wisconsin, and was about like now during the early postglacial.

From these facts we conclude that woodland communities probably occupied more area in the Searles region during the late Wisconsin than since. Because only two-thirds of the present pollen rain is of local origin, we feel that an important fraction of the fossil pollen may have drifted into Searles Basin from great distances then as it does now.

Absolute numbers: pollen grains per gram of sediment

On a single core, pollen analyses included determinations of absolute numbers of pollen grains per gram of sediment. The results are given for core L-31 on figure 6, where numbers of pollen per gram are shown on the left as two curves; one is the outer line representing numbers of total pollen per gram, and an inner line showing total numbers of pine per gram. These data are compared with relative numbers (percent total pollen) of pine shown on the right. Note the change of vertical scale for core depths at base of Upper Salt.

A comparison of the absolute numbers of pine with percent pine indicates that there is no relationship between the two in L-31. The absolute numbers of pollen per gram are very high in each of the mud layers, and are quite low (lower in fact by a factor of 40,000) for all the salt layers. Undoubtedly these trends are largely a reflection of sedimentation rates.

The percentages of pine (right-hand curve, fig. 6) seem to reach maximum values in the salt beds, especially at the tops and bottoms of salt beds, at least for layers older than the Parting Mud. Hence high pine percentages (more than 40 percent) are not associated with pluvial intervals during which mud was deposited, but instead are associated with beginnings and ends of interpluvials. An explanation of this strange relationship at Searles might be that during times of lake desiccation, dry conditions inhibited the blooming of the desert scrub and woodland species, but did not seriously hamper pollen production of montane woodland in the Sierra Nevada. The Sierra Nevada pine stands may have been the source area for most fossil pine pollen during the late Wisconsin. One supporting fact is that the pine curve throughout the late Wisconsin here is mainly composed of pine pollen other than that of the desert pinyon, and may have drifted into the Searles Basin from the Sierra Nevada, some 35 miles upwind, just as it does today.

DISCUSSION AND CONCLUSIONS

The representation of woodland forms in the pollen rain during the late Wisconsin was 2 to 2½ times higher than now. This evidence alone suggests an expansion of woodland during the late Wisconsin.

Evidence from C-14-dated fossil rat middens in which fossil wood has been found indicates that during the late glacial xerophilous juniper woodlands descended to an elevation of about 3,600 feet (1,100 m), some 2,000 feet below the present lower limit of woodland in the latitude of Frenchman Flat. Similar evidence indicates that the more mesophytic phase of pinyon-juniper woodland was confined to montane habitats at elevations above 4,900 feet (1,500 m) in the same area (Wells and Berger, 1967). Rat midden C-14 dates are discussed by Wells (1966), Mehringer (1966), Wells and Jorgensen (1964), and Wells and Berger (1967).

The fact that juniper is frequently found at lower elevations than pinyon pine on the higher mountains of this region might lead one to expect juniper woodland to reach lower elevations during pluvial intervals than pinyon-juniper woodland.

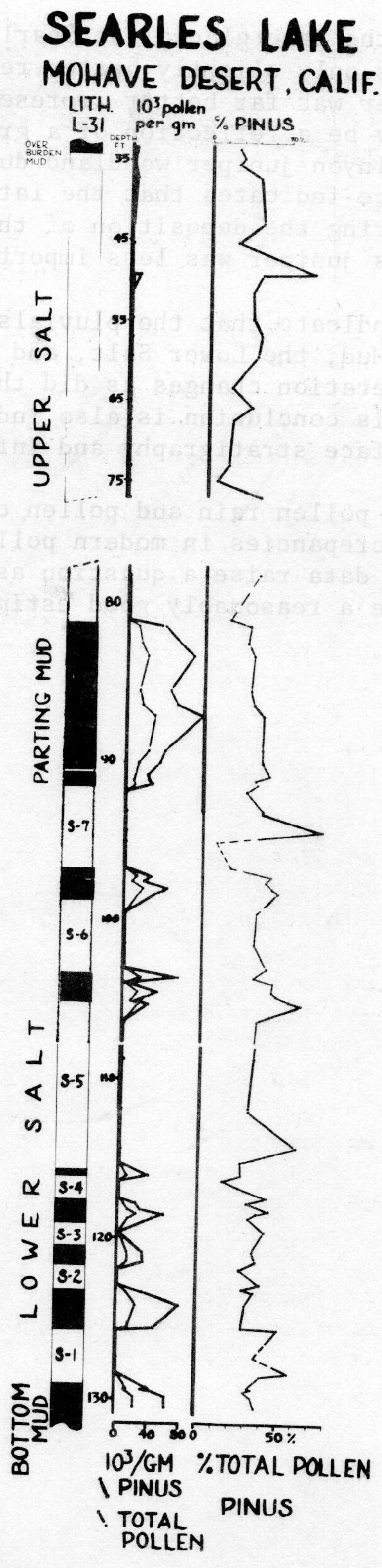


Figure 6. Absolute numbers of pollen (left) compared with relative counts (right) in core L-31. Absolute numbers of total pollen and pine pollen (outer and inner lines on left) per gram dry weight of sediment are plotted along with percent pine (right). Lithology is indicated on far left.

Pollen evidence from the late glacial at Searles Lake indicates that pinyon-type pine pollen was only slightly better represented in the pollen rain than now, while juniper was far better represented in the pollen rain than now. This pattern may be a reflection of a greater expansion of juniper woodland than of pinyon-juniper woodland during that period. In any case the pollen evidence indicates that the late glacial pollen rain was different from that during the deposition of the Lower Salt and Bottom Mud, for during those times juniper was less important.

The pollen diagrams indicate that the pluvials and interpluvials represented by the Bottom Mud, the Lower Salt, and the Parting Mud did not provide such great vegetation changes as did the climatic warming of the early postglacial. This conclusion is also indicated by the details of the Searles Lake subsurface stratigraphy and inferred lake history.

Comparisons of aerial pollen rain and pollen contained in surface soils indicate serious discrepancies in modern pollen data from the alkaline playa flats. The data raise a question as to whether surface soil samples always provide a reasonably good estimate of the nature of modern pollen rain.

REFERENCES

Martin, P. S., 1964, Pollen analysis and the full-glacial landscape, in Hester, J. J., and Schoenwetter, J., eds., Reconstruction of past environments: Fort Burgwin Research Center, Toas, N. Mex., Pub. 3, p. 66-74.

Mehringer, P. J., 1966, Some notes on the late Quaternary biogeography of the Mohave Desert: Arizona Univ., Geochronology Labs., Interim Research Report No. 11, p. 1-17.

Leopold, Estella B., 1965, Late Quaternary and modern pollen rain at Searles Lake, California [abs.]: Internat. Assoc. Quaternary Research, 7th Cong., Boulder and Denver, Colo., 1965, Gen. Sess., p. 289.

Wells, P. V., 1966, Late Pleistocene vegetation and degree of pluvial climatic change in the Chihuauan Desert: Science, v. 153, p. 970-975.

Wells, P. V., and Berger, Rainer, 1967, Late Pleistocene history of coniferous woodland in the Mohave Desert: Science, v. 155, p. 1640-1647.

Wells, P. V., and Jorgensen, C. D., 1964, Pleistocene wood rat middens and climatic change in Mohave Desert: A record of juniper woodlands: Science, v. 143, p. 1171-1174.

Roosma, Aino, 1958, A climatic record from Searles Lake, California: Science, v. 128, p. 716.

ARCHAEOLOGY OF THE MOJAVE DESERT AND ITS PLAYAS: SELECTED REFERENCES

Compiled by E. L. Davis
San Diego Museum of Man
San Diego, California

Panamint Area

Clements, Lydia, 1956, Inferences regarding the ancient inhabitants of Panamint Valley: Southwest Museum Masterkey, Los Angeles, Calif., v. 30, no. 6, p. 184-190.

Davis, E. L., and Winslow, Sylvia, 1965, Giant ground figures of the prehistoric deserts: Am. Philos. Soc., v. 109, no. 1, p. 8-21, Philadelphia.

Death Valley Area

Wallace, William, 1958, Archaeological investigations in the Death Valley National Monument: California Univ., Berkeley, Archaeol. Survey Rept. No. 42.

_____1962, Prehistoric cultural development in the southern California deserts: Am. Antiquity, Salt Lake City, Utah, v. 28, no. 2, p. 172-180.

Hunt, Alice, 1960, Archaeology of the Death Valley Salt Pan: Utah Univ., Salt Lake City, Anthropol. Papers, No. 47.

Soda Lake Area

Campbell, E.W.C., and others, 1937, The archaeology of Pleistocene Lake Mohave: Southwest Museum Papers, Los Angeles, Calif., No. 11.

General

Rogers, Malcolm J., and others, 1966, Ancient hunters of the Far West: Copley Press, San Diego, Calif.