# A 10 ka to 1.8 Ma Record of Oxygen-18 and Carbon-13 Variation in Lake Sediments: Searles Lake, Inyo County, California

by
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Book, and Lukefish. Without their support, this project would certainly never have been completed.

## DEDICATION

to my parents, Rock and Wheez
for their love, support and humor

and

to the memory of
Dr. Robert Gernant
for introducing me to thinkin' rocks and laughin' places

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# ABSTRACT

Searles Valley, California has been the site of continuous, yet variable, lacustrine sediment deposition during the past 3.2 million years. A detailed history of fluctuating lake size, reflecting changing climatic conditions, has been recorded in the $^{18}O$ and $^{13}C$ content of primary carbonate sediments at Searles.

The $^{18}O$ and $^{13}C$ content of 247 samples from mud units in the upper 400 meters of Searles Lake lacustrine carbonate sediments (core KM-3) were measured using a timed-extraction technique based on the differing rates of reaction during phosphorolysis of co-existing primary carbonates. An average fractionation between calcite and dolomite of +2.8 per mil $^{18}O$ and +1.0 $^{\text{per mil}}$ $^{13}C$ was determined for the co-existing carbonates.

The samples were assigned ages based on the interpolation of samples between depths having known ages through the $^{14}C$, $^{230}Th$, $^{36}Cl$, and magnetostratigraphic dating of core KM-3 by previous investigators. The resulting stable isotope chronology spans a time period of 10 ka to 1.8 Ma, with a time resolution that ranges from 1,000 to 10,000 years throughout most of the mud units sampled.

An analytical solution of lake volume-isotopic content evolution was used to predict the range of $^{18}O$ variation during extremely wet/cold and dry/warm conditions. The measured $^{18}O$ content of primary carbonates at Searles were within the range predicted by the analytical solution, supporting assumptions of primary origin of the lacustrine carbonates.

Frequencies of lake-size fluctuations on the order of 40 to 50 kyr and 100 kyr are apparent throughout most of the sediments sampled. Searles Lake may have overflowed at approximately 14 ka, 210 ka, 400 ka, 625 ka, 800 ka, and 1.05 Ma. Complete desiccation of the lake is suggested by the stable isotope record at 1.48 Ma, 280 ka, and 27 ka.

Possible origins of the climatic changes producing the lake size fluctuations inferred by the stable isotope record were examined. Lake-size controls may include local or regional controls such as lake topography, lake-atmospheric feedback processes or regional tectonic events such as the uplift of the Sierra Nevada during the Cenozoic. Global controls may include changes in solar insolation due to the Earth's orbital cycles.

Key words: stable isotopes, oxygen-18, carbon-13; paleolake; paleoclimate; California, Searles Lake

# I. INTRODUCTION

## Problem Addressed

Predicting available water supplies for man's use is a difficult task. Growing populations, accompanied by threatened water supplies due to contamination, add stress to already over-allocated fresh water supplies in some areas. Further, the predicted changes in climate due to the accumulation of "greenhouse gases" in the atmosphere has added to the already complex problems of water-resource planners. However, to begin predict future climates and water supplies, and man's impact upon them, we must first establish an understanding of the frequency, extent and cause(s) of climatic changes in the geologic past, and the effects these changes have had on water supply.

In order to examine past climatic changes, a climate recorder must be found which would have been climatically sensitive, continuously active in the past, and suitable for absolute dating techniques. Stable isotope records from deep sea and ice cores have provided detailed climatic records for Quaternary oceanic and polar regions (Williams and others, 1988; Lorius and others, 1985). Analysis of paleolake levels at low latitudes has revealed systematic lake level fluctuations with latitude through the last 18,000 years (Street-Perrott and Roberts, 1983). However, mid-latitude paleoclimate records are scarce, primarily due to the lack of continental depositional systems operating continuously in the past. The closed-basin lakes of the western United States Basin and Range provide one of the most continuous and sensitive record of mid-latitude continental Quaternary climate change currently known.

Lake size fluctuates in response to changes in climate. The relationship between lake area/volume and inflow/outflow is termed a lake's "water balance". Outside of tectonic or volcanic events, changes in a lakes's water balance primarily reflect changes in climate.

Lake levels in closed-basin amplifier lakes respond most sensitively to climatic perturbations. "Closed-basin" refers to those lakes which lack a surface outlet, and "amplifier" implies inflow/influx is dominated by surface runoff rather than precipitation on the lake surface, and groundwater transfer is negligible (Szestay, 1974).

Evidence of fluctuating lake levels can be observed in the sequences of abandoned shorelines and spillways, and wave-cut cliffs surrounding closed-basin lakes. Some of these features may be absolutely dated, allowing development of an absolute chronology. Unfortunately, older geomorphic remnants are frequently removed by the rising waters of a younger lake.

A more detailed climatic record can be found in the sediment sequences of closed-basin lakes. Solutes entering the lake are concentrated by evaporation and lack of surface or groundwater outflow. Consequently, most closed-basin lakes are saline and alkaline. As solute concentrations increase with time or decreasing lake levels, sequences of evaporite minerals are precipitated. With the resumption of large inflows and rising lake levels, non-evaporite minerals are deposited. Thus, lake level fluctuations are recorded in the alternating sequences of muds and evaporites.

In addition to the facies information, the chemical sediment record provides detailed geochemical information. The stable isotope content of lake water is extremely sensitive to inflow/outflow fluxes and their respective isotopic composition. As the lake water balance changes, so will the isotopic composition of the lake water. The temperature, salinity and stable isotope content of the lake water are reflected in the stable isotope content of minerals precipitated in isotopic equilibrium with the lake water. Further, evaporite minerals may be suitable for some absolute dating techniques. Consequently, a continuous record of the stable isotope content of the lake water, together with sediment and geomorphic constraints, can provide a detailed, sensitive record of water balance fluctuations and Quaternary continental climatic change.

Searles Lake, a currently dry, closed-basin amplifier lake in southeastern California (fig. 1), has been the subject of dozens of mineralogic, geochemical and paleohydrologic studies over the past one hundred years. Elevated shorelines and bars in Searles Valley and related

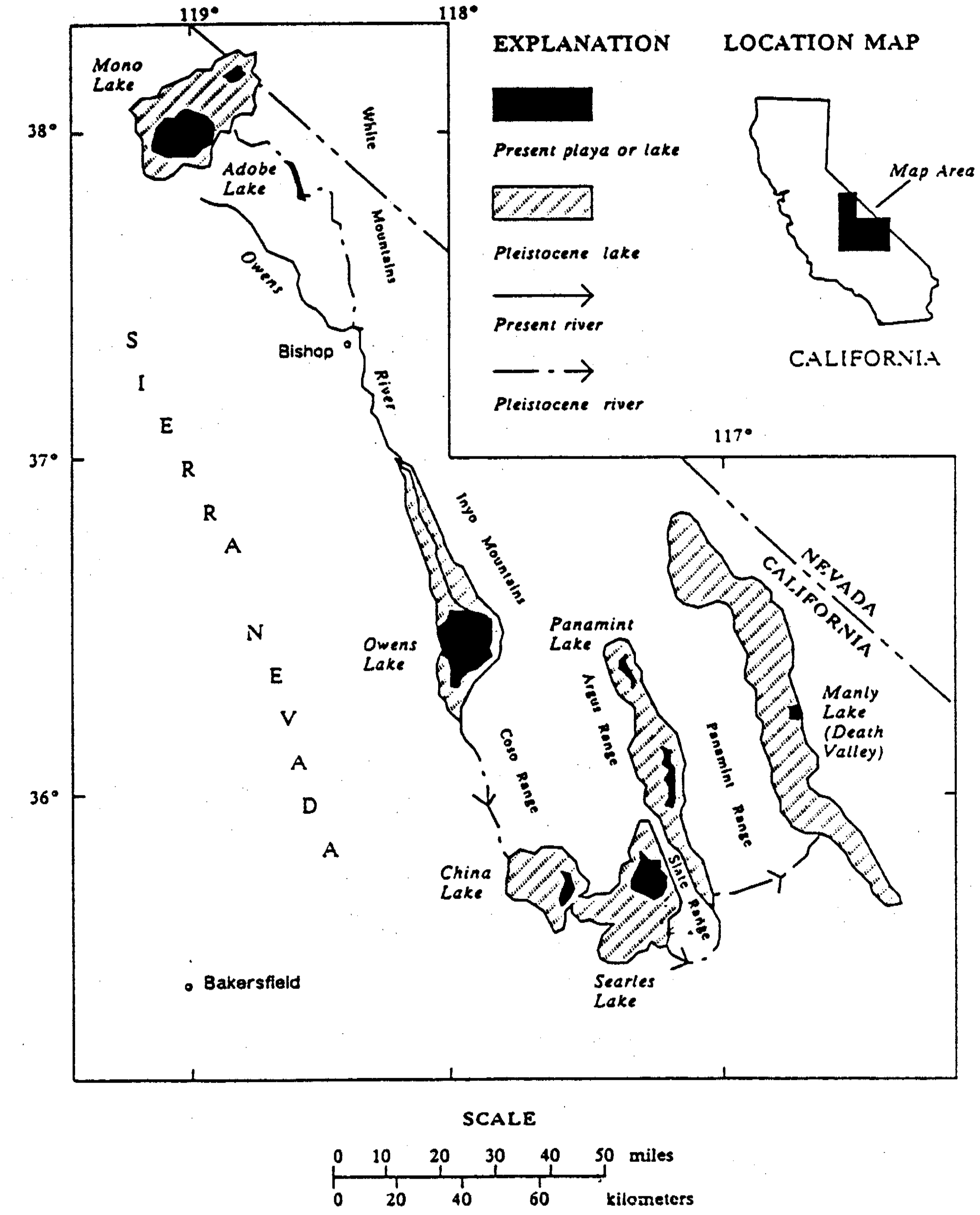

Figure 1 Location of Searles Lake and related Pleistocene lakes. Revised from Smith and others (1983).

basins were recognized by nineteenth-century geologists as evidence of past deep lakes. Early twentieth-century studies revealed the relationship between Searles Lake and four other lakes in the area. Runoff from the eastern Sierra Nevada into the paleo-Owens River created a chain of five paleolakes. Searles Lake was the third and, for most of the Pleistocene, the terminal lake in the chain. Consequently, large amounts of solutes were concentrated in Searles and precipitated as chemical sediments. Exploration cores, drilled by mining companies and the U.S. Geological Survey to define the mineral deposits at Searles, revealed thick sequences of alternating muds and evaporite minerals. The term "muds" has traditionally been used by investigators at Searles to include clays, silts, and marls consisting primarily of alkaline earth carbonates and diagenetic minerals.

Of particular interest is Kerr-McGee core KM-3, a 930 meter core drilled to bedrock in 1968 (Smith and others, 1983). Of the 930 meters of core, 693 meters are believed to be lacustrine deposits which date to the early Pliocene. An absolute chronology for KM-3 has been established by means of numerous carbon-14 (Flint and Gale, 1958) (Stuiver, 1964) (Stuiver and Smith, 1979) , uranium-thorium (Peng and others, 1978) (Bischoff and others, 1985), chlorine-36 (Phillips and others, 1986)(Jannik, 1989) and paleomagnetic (Liddicoat and others, 1980) dates. Therefore, with the benefit of a detailed and lengthy chronology already in place, in addition to geochemical and stratigraphic evidence assembled, core KM-3 can provide a long record of mid-latitude continental climatic change.

## Objective and Approach

The primary objective of this study was to construct a record of stable isotope variation in Searles Lake sediments for the last 2.0 Myr [in this paper I follow the convention of designating ages by 'Ma' (million years before present) or 'ka' (thousand years before present) and periods of time by 'Myr' (million years) or 'kyr' (thousand years) ]. Preliminary interpretation of the record, in addition to comparison with other isotope records, was made. The approach taken to accomplish the objective is as follows:

1) Sample Searles Lake Core KM-3 with enough frequency to determine degree and duration of climatic cycles.

It has been recognized from deep-sea and ice core isotopic records that global climate has fluctuated in a cyclic fashion throughout the Pleistocene (Hays and others, 1986; Dansgaard, 1969). A sampling interval in time comparable to those in deep-sea cores would allow a similar definition of climate frequencies at Searles. Further, detailed sampling would allow time-series analysis of the Searles Lake isotope chronology so that frequencies and possible causes of the climatic fluctuations may be ascertained.

2) Examine composite chronology proposed by Jannik(1989). Evaluate sources of error for

each dating technique. Assign ages to all KM-3 samples using composite chronology.

The chronology proposed by Jannik is a composite of selected $^{14}C$, U-Th, $^{36}Cl$, and paleomagnetic dates, in addition to dates based on accumulation of acid-insoluble residue. An examination of the dating methods, dates selected, and relative error is warranted before time-series analysis, comparison with other paleoclimate records, or numerical modeling of the lake begins.

3) Develope methodologies to separate primary carbonate minerals from diagenetic carbonates, and to separate primary carbonates from each other.

Searles lake sediments contain a variety of primary and diagenetic carbonate minerals. Carbonates termed "primary" include dolomite, calcite, aragonite and northupite. Some gaylussite may also be primary. These minerals are presumed to have precipitated in isotopic equilibrium with the lake water. Diagenetic carbonates are formed through the reaction of infiltrating concentrated brines with primary carbonates to form new minerals, such as gaylussite and pirssonite. Therefore, diagenetic carbonates may not reflect the isotopic composition of the original lake water.

> 4) Perform mass spectrometric analysis of primary carbonates to determine oxygen-18 ($^{18}O$) and carbon-13 ($^{13}C$) content.

Interpreting the $^{13}C$ and $^{18}O$ content of $CO_2$ extracted from primary lake carbonates assumes the $CO_2$ incorporated into the mineral at the time of precipitation was in isotopic equilibrium with the dissolved lake $CO_2$. A second assumption is that the dissolved lake $CO_2$ was in isotopic equilibrium with lake water. If these assumptions are born out, analysis of $^{13}C$ and $^{18}O$ content of carbonates would allow determination of the isotopic content of the paleolake water.

> 5) Estimate paleometeorological parameters such as relative humidity, temperature, net evaporation. Use analytical model to predict range of expected $^{18}O$ and $^{13}C$ during infill, overflow and desiccation episodes. Compare range of values to mass spectrometer results.

Comparison of the isotopic content of the Searles Lake carbonates with the isotopic content predicted by an analytical solution allows evaluation of the methodologies used to separate and extract the carbonates from the lake mud, and the validity of the assumptions of primary origin of the carbonates. Second, the analytical results will allow validation of the numerical model under construction. Finally, the analytical model will allow preliminary interpretation of the Searles Lake isotope chronology.

6) Interpret Searles Lake isotope chronology. Compare Searles Lake isotope chronology to other Great Basin and deep-sea isotope records.

The record of the stable isotope content of the lake water through time will permit interpretation of changes in lake water balance (Phillips and others, in progress). From the water balance, changes in climate may be inferred, and the response of the Searles Lake water balance due to changes in climate may be determined.

Comparison of the Searles Lake isotope record to other paleoclimate records will allow examination of the relationship between oceanic and continental paleoclimates. The geographic extent of climate change affecting Searles may be determined: local or regional changes affecting only Searles, the Great Basin, or global climatic changes. The correlation of climatic changes to other events will be examined: whether the climate changes relate to volcanic or tectonic activity, or to the waxing and waning of global ice volumes, presumably due to changes in solar insolation.

# II. RELATED STUDIES

## Closed Basin Lakes

One of the earliest, most insightful, and possibly the most enjoyable reports on a closed-basin lake of the Great Basin can be found in Russell (1885). Russell recognized that the Quaternary closed-basin lake levels were climate-dependent and hypothesized the changes in humidity and temperature that would have been required to produce the large saline lakes. Meinzer (1922) took a broader approach to paleoclimate reconstructions of closed-basin lakes. All closed-basin lakes in the western U.S. were included in a discussion of the relationships between the water balance of these lakes and their respective locations, geology, bathymetry, and climate.

One of the most extensive quantitative reconstructions of paleoclimates using closed-basin lake records can be found in Mifflin and Wheat (1979). Paleotemperatures were assumed in order to calculate the changes in evaporation, precipitation and runoff necessary to produce the paleolake levels indicated by geomorphic evidence in Lake Lahontan, Nevada.

Smith and Street-Perrott (1983) calculated the required inflow from the Owens River necessary to produce the Owens River system closed-basin paleolakes, including Searles Lake. Assumed paleotemperatures were used to calculate paleo-evaporation and precipitation. Street-Perrott and Harrison (1985) summarized the factors affecting the sensitivity of closed-basin lakes to climatic change, the various approaches to reconstructing lake levels, and evidence used by to investigators accomplish the reconstruction.

This paper is the first part of a study to reconstruct paleo-water balances through the construction of stable isotope records from the sediments of two Pleistocene lakes: Searles Lake in southeastern California (this paper) and Lake San Agustin in west central New Mexico (Johnson, in progress). Some of the previous investigations that used stable isotopes to determine the water balance of lakes can be found summarized in Pearson and Coplen (1978).

A numerical approach to isotopic evolution in closed-basin lakes was taken by Phillips and others (1986). A lumped-parameter numerical model was created to simulate the isotopic evolution of a lake through time, given specified fluxes, meteorological and chemical parameters. The model was validated by simulating the isotopic evolution of Owens Lake (California) during a desiccation episode. The numerical model in development to reconstruct the paleo-water balance of Searles and San Agustin is based on the Phillips and others (1986) model.

The causes of lake level fluctuations have been discussed by several investigators. Kutzbach and Street-

Perrott (1985) correlated fluctuations in tropical lake levels with fluctuations in solar insolation calculated from the Milankovitch theory. Changes in sedimentation in Searles Lake due to orbital forcing have also been suggested by Smith (1984); Bischoff and others (1985); and Jannik (1989). Lake level fluctuations caused by changing atmospheric circulation patterns have been suggested by Street-Perrott and Roberts (1983).

Many records for Quaternary climates have been published. Among the most important are the stable isotope records from ocean cores. Most recently, Martinson and others (1987) presented a 1.8 Myr "stacked" and "orbitally-tuned" $^{18}0$ record: the record was "stacked" in that it was a normalized composite of several ocean cores, and "orbitally-tuned" in that orbital forcing was presumed to be the driving force of sea-level fluctuations, and the chronology was adjusted to be "in sync" with orbital frequencies. Williams and others (1988) presented a 1.8-Myr $^{18}0$ record that was also a normalized composite of several cores, yet was not "orbitally tuned".

Detailed isotope records from polar ice cores have also been published. Dansgaard (1969) presented a deuterium chronology from a Greenland ice core. Isotope records from Antarctica ice cores were published by Barkov and others (1979) and Lorius and others (1985).

Several long paleoclimate records from the Great Basin have been developed in the past few years. Winograd and others (1985) measured the deuterium content in calcite fluid inclusions from eastern Nevada calcite veins. The calcite was precipitated from calcite-saturated groundwater, and therefore, the deuterium content of the fluid inclusions should reflect the deuterium content of the groundwater. A systematic depletion in the deuterium values during the past 2.0 Myr was theorized to be due to the uplift of the Coastal Ranges and the Sierra Nevada during the Quaternary. A 50 ka to 310 ka $^{18}O$ record from a southwestern Nevada calcite vein was reported by Winograd and others (1988). The stable isotope record mimicked ocean and ice core $^{18}O$ records presented by Martinson and others (1987) and Lorius and others (1985) respectively. However, the timing of the $^{18}O$ fluctuations in the Nevada calcite did not correspond to that of the ocean and ice core records. Rather, the isotopic events identified in the Nevada $^{18}O$ record occurred decreasingly earlier through time than the other two records suggest. A mechanism for a systematically decreasing time-lag of climatic events among the three study areas is not apparent. It would appear that some systematic error occurred in the development of the absolutely-dated chronology for at least one of the $^{18}O$ records. The discrepancy in the timing of climatic events suggest by the ocean $^{18}O$ record and the Nevada $^{18}O$ record is of great interest in regard to previously inferred dependence of climatic fluctuations upon orbited forcing (Hays and others, 1976). If the Nevada $^{18}O$ chronology is assumed to be correct, the differences in the timing of events between the Nevada $^{18}O$ chronology and the Martinson and others chronology, which was "orbitally tuned", suggest that solar insolation fluctuations predicted by the Milankovitch (1941) theory are not the primary forces contributing to climatic change (Winograd and others, 1988, p.1279).

A detailed discussion and comparison of the lake level histories in four Great Basin closed-basin lakes is provided in Benson and others (in press). Geomorphic, sedimentological and geochemical evidence of lake level fluctuations for Lake Bonneville, Lake Lahontan, Lake Russell and Searles Lake were discussed, and the lake level fluctuations in the four lake systems were concluded to be penecontemporaneous.

## Searles Lake

An impressive volume of work has been published on the geology, chemistry, and chronology of tectonic and climatic events in Searles Valley. Russell (1885) included the paleolake occupying Searles Valley on Plate 1 of his section on Great Basin paleolakes. Bailey (1902) recognized the relationship between Searles Lake and other Owens River paleolakes. The discovery of large deposits of potash in

Searles Lake drew investigators to the area to define and exploit the mineral deposits in the early twentieth century. Gale (1914) reviewed the known available mineral assemblages at Searles and drew remarkably insightful conclusions as to the history of sedimentation in Searles and related paleolakes.

Investigations at Searles were resumed during the late 1950's with the advent of suitable radiometric dating techniques and a drive by the United States Geological Survey (USGS) to better define the lacustrine deposits beneath Searles Valley. Hundreds of sediment cores were drilled by mining companies and the USGS. Stratigraphic studies based on several of these cores can be found in Smith and Pratt (1957), Flint and Gale (1958), Haines (1959), Smith (1962; 1979) and Smith and others (1983).

Detailed discussions of Searles Lake mineralogy include Droste (1961); Hay and Moiola (1964); Smith and Haines (1964), and Smith (1976; 1979). The geochemistry of Searles Lake deposits and brines include reports by Eugster and Smith (1965), Eugster and Hardie (1978), Smith (1979), Guldman (1984), and Hay and Guldman (1987). The hydrology of Searles Lake is reported in Hardt and others (1972).

The recognition by investigators of the usually favorable opportunity to obtain a detailed record of continental climatic change prompted numerous studies employing isotopic, and paleomagnetic techniques to date

Searles Lake sediments. Investigators took advantage of new developments in radiocarbon techniques to establish a chronology for the shallow sediments beneath Searles Lake. These include Flint and Gale (1957), Stuiver (1964) and Stuiver and Smith (1979). Reasonable agreement of $^{230}$Th ages of upper stratigraphic units with radiocarbon dates (Peng and others, 1978) allowed a continuation of the $^{230}$Th chronology to units at the top of the Mixed Layer (Bischoff and others, 1985). Identification of paleomagnetic boundaries in Searles Lake core KM-3 extended the absolute chronology to 3.15 Ma (Liddicoat and others, 1980). Several halite units were dated by the $^{36}$Cl method (Phillips and others, 1983; Jannik, 1989). A tephra layer in core KM-3 was tentatively correlated with the Lava Creek B ash (Hay and Guldman, 1987). Radiocarbon dates on rock varnish from high-stand shorelines are presented by Dorn (*in* Benson and others, in press).

Paleoclimatic interpretations of Searles Lake based on stable isotope information have been presented in Oana and Deevey (1960), Stuiver (1964), and Horita (1987). Paleoclimatic interpretations based on sedimentological and outcrop evidence have been presented in Smith (1968; 1976; 1979; 1984; 1987), and Smith and others (1983).

# III. STUDY AREA

## Location

Searles Lake is located in the southwestern corner of the Basin and Range physiographic province along the boundaries of Inyo and San Bernadino counties, California (35  45′N, 117  20′W). Currently, Searles Lake is a dry (playa) lake, with standing water only after intense rainfall events (Smith, 1979).

During pluvial periods, Searles Lake was the third in a chain of five paleolakes created by large runoff from the eastern Sierra Nevada into the ancient Owens River. However, Owens Lake was the frequent terminus of the Owens River during interpluvial periods, as it is today. According to Smith and others, (1983) when flow in the Owens River increased, Owens Lake filled until at approximately 64 m in lake depth, Owens Lake overflowed into Indian Wells Valley to form China Lake. Upon reaching a depth of 8 m, China Lake, in turn, overflowed into Searles Valley to form Searles Lake. When Searles Lake deepened to ~180 m, China Lake and Searles Lake coalesced to form one large lake (Searles Lake), which at a depth of 200 m overflowed into Panamint Valley, creating Panamint Lake. During extreme pluvial periods, Panamint Lake would overflow into Death Valley. Lake Manly (Death Valley) was also the ultimate sink for the Armagosa and Mojave River paleolake systems.

In addition, lakes in the Mono Basin, such as Mono Lake and Adobe Lake may have overflowed during extreme pluvial periods, contributing to the flow in the ancestral Owens River system. Figure 1 shows the relationships between all of the paleolakes. Figure 2 is a schematic cross-sectional representation of the Owens River paleolakes.

## Hydrology

Currently, Searles Lake playa, located in the bottom of Searles Valley, has a surface area of approximately 100 $km^2$. According to Smith (1979), Searles Valley floor is 60 km long and up to 15 km wide. The playa surface itself is 15 km long and 11 km wide; approximately 66 percent of the playa is silt covered, and the remaining third is hard salt pan.

Searles Valley has a drainage area of approximately 1600 $km^2$ (Smith, 1979). However, during intense pluvial periods, most of the water in Searles Lake would have originated from eastern Sierra Nevada runoff via the Owens River. Lee (1912) reports that the Owens River has a drainage area of approximately 3300 $mi^2$ (~8550 $km^2$) of which 536 $mi^2$ (1390 $km^2$), in the high altitude area of the eastern Sierra Nevada, contributes most of the runoff reaching Owens River. The remaining drainage area is predominantly either desert or transition slopes. From Lee's work, Jannik (1989) postulated that even during intense pluvial periods, the

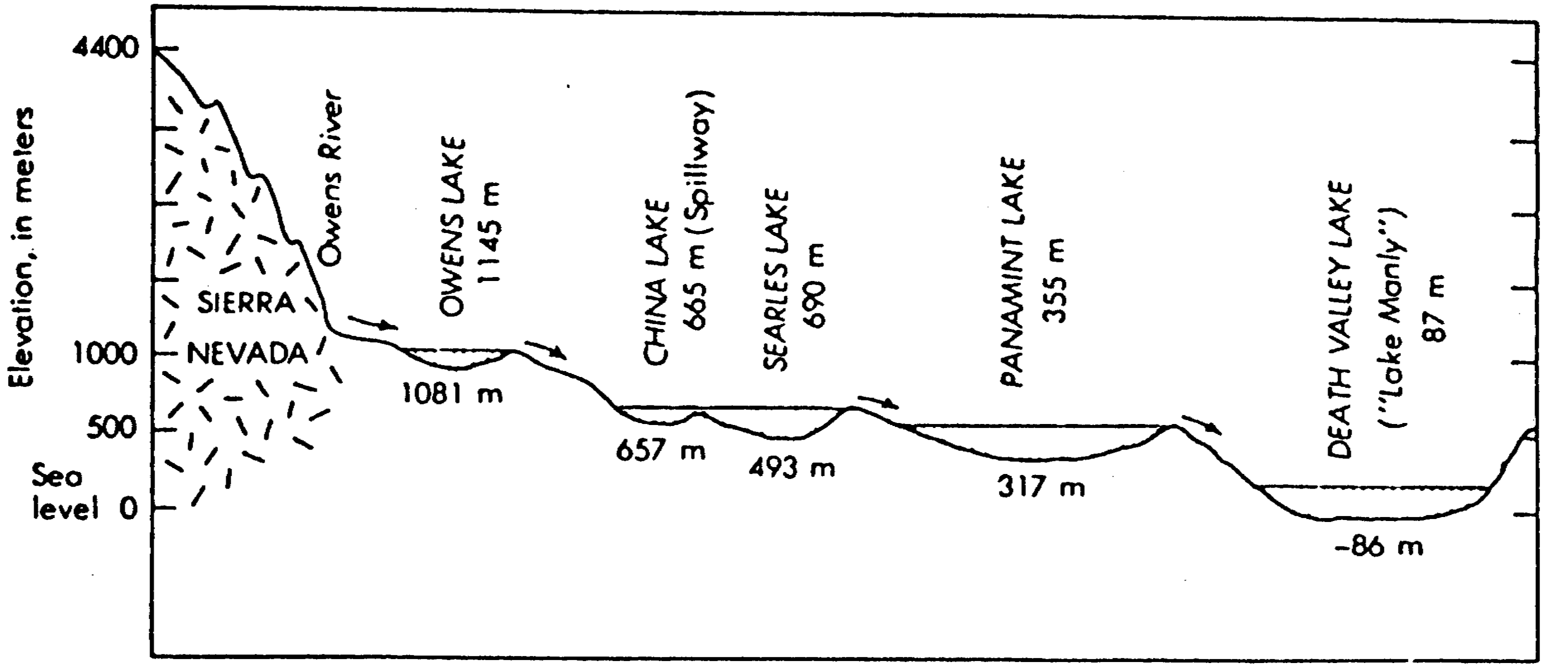

Figure 2 Schematic cross-section of lake basins in the paleo-Owens River Chain. Smith and Street-Perrott (1983).

Sierra Nevada created such a strong rain shadow that most of the water in Searles Lake still originated from the high-altitude section of the eastern Sierra Nevada. Any precipitation falling within Searles Lake's drainage area would have been negligible compared to the inflow into Searles via Owens and China Lakes.

Hydrothermal springs in the Owens Valley area also contributed to the flow in the Owens River paleolake systems (Jannik, 1989). Of equal interest, the springs may have contributed some of the unusual solutes found in Searles Lake evaporite deposits.

## Climate

Most of the following climate information was found in Smith (1979). The climate at Searles Lake is hot and arid. Temperature extremes range from -12.2 C to 47.8 C, with an average annual temperature of 19.1 C (for a 36-year period ending 1973). Annual precipitation during this period averaged 96.3 mm, with extremes ranging from 23 mm to 291 mm per year. Most of the precipitation occurs during the winter. I was not able to acquire relative humidity data, although it is reported (Horita ,1987) that Kerr-McGee Corporation in Trona, California maintains a weather station, and humidity values are recorded. A linear regression of relative humidity data in the surrounding area gave an approximate annual average relative humidity for

Searles Valley of 22 percent (Appendix G).

Searles Valley playa supports no vegetation. Smith (1979) reported vegetation on the surrounding mountains and alluvial fans as typical of the lower Sonoran zone: desert holly (Atriplex hymenelytra), creosote bush (Larrea tridentata), burro-bush (Franseria dumosa), and hop sage (Grayia spinosa). Piñon pine and joshua trees are reported in the surrounding mountain ranges.

## Geology

**Geologic Environment** According to Smith (1979), Searles Valley is a closed tectonic depression of Cenozoic age. The valley floor is surrounded by several mountain ranges: the Argus Range and Spangler Hills to the west, the Slate Range on the north and east, and the Lava Mountains to the south. The Argus Range consists primarily of Mesozoic granites. The Slate Range contains Precambrian metamorphic units, small amounts of Paleozoic limestone, Mesozoic granites and metavolcanics and Cenozoic volcanics (Jennings and others, 1962 in Jannik, 1989). The Lava mountains consist primarily of late Tertiary volcanics and sandstone (Smith, 1968).

**Core KM-3** Numerous sediment cores have been recovered from the lake bed in Searles Valley. A detailed examination of the chemistry and mineralogy of sediments from several cores in Searles Lake is provided in Smith (1979). In 1968, a 930 m exploration core designated KM-3 was drilled to bedrock by Kerr-McGee Corporation. In 1976, the United States Geological Survey (USGS) was granted permission to examine company data on the core, and the core itself, and to publish the results of their investigation, including internal Kerr-McGee data. The findings of the USGS investigation, including detailed core description, chemical analyses, and interpretation can be found in Smith and others (1983).

Detailed geochemical analyses were performed on the KM-3 sediments by Kerr-McGee Corporation. The core was divided up into 254 units based on lithology. Analysis for percent acid-insoluble residue, and ten elements in the acid-soluble fraction. In addition, the percent by weight of important evaporite minerals were calculated, including halite and several carbonate, sulfate, and borate minerals. The results of these analyses (Smith and others, 1983, Plates 2-4) were used as a general guide in selecting samples from core KM-3 for stable isotope analysis.

The following core descriptions, stratigraphic and mineralogic information were obtained from Smith (1979) and Smith and others (1983). Core KM-3 was drilled near the center of Searles Valley (fig. 1). The ~8 cm diameter core consisted of three distinct sections: 1) 15 m of quartz monzonite bedrock of which only ~3 m of core was actually recovered; 2) 212 m of alluvial arkosic sand and gravel, and

3) 693 m of lacustrine sediments. The lacustrine sediments were divided into fourteen informal stratigraphic units based on lithology and mineralogy. The informal stratigraphic units are those that have been used by the mining companies at Searles Lake, and have been adopted by investigators. A copy of the core log summary presented in Smith and others (1983) is shown in table 1, and is shown graphically in figure 3.

In the broadest sense, Searles Lake sediments have been divided into two categories: "muds" and "salts". These are not sedimentologically exact terms, but they are useful in delineating sediments deposited in different environments and have a long history of application to Searles sediments. As mentioned earlier, the "muds" can consist of marl, silt or clay, and are plastic when wet. The muds vary in origin from deep lake marls and oozes to playa sediments, tephra, and possibly paleosols. The marls contain clays as well as alkaline earth carbonates (calcite, dolomite, aragonite), clastics, and diagenetic carbonate minerals such as gaylussite and pirssonite. The saline units can be thin seams of single or multiple evaporite minerals, such as hanksite, borax, tincalconite, thenardite, northupite, nahcolite, and halite, to thick coarsely crystalline units of halite or trona. Many of the saline minerals can also be found disseminated within the mud units.

Table 1. Generalized Searles Lake core KM-3 log (Smith and others, 1983).

| Depth to base of unit (m) | Thickness of unit (m) | Description |
|---|---|---|
| 5.8 | 5.8 | Not cored. Overburden Mud is included in this zone. |
| 19.9 | 14.1 | *Upper Salt.*—Salines, mostly trona and halite; abundant hanksite near top, borax at base; light- to medium-gray (N6-8) and yellowish-gray (5Y8/1), with some thin interbeds of olive-gray (5Y4/1) mud; mostly indistinctly bedded to massive, locally vuggy. |
| 25.0 | 5.1 | *Parting Mud.*—Megascopic crystals of gaylussite and pirssonite in soft mud composed of microscopic crystals of dolomite, halite, aragonite, other evaporite minerals, and clastic silicates; light- to moderate-olive gray (5Y3-6/1-4); upper part finely laminated, lower part massive. |
| 37.9 | 12.9 | *Lower Salt.*—Seven saline layers interbedded with six mud layers; salines are mostly halite and trona in upper two layers, trona, halite, and burkeite in underlying two layers, and trona in lower three layers; interbedded mud layers contain megascopic crystals of gaylussite and pirssonite; salines range in color from white through dark gray to yellowish orange (N5-8, 10YR6/6), mud from dark olive gray to brown (5Y4-6/1-4); salts poorly bedded to massive; some mud layers have thin laminar bedding. |
| 69.0 | 31.1 | *Bottom Mud.*—Mud containing megascopic gaylussite crystals; mud is composed of microscopic crystals of dolomite, aragonite, calcite, and other carbonate minerals, and about 30 percent acid-insoluble silicates and organic residues; thin-bedded to massive, with some laminar bedding; medium- to dark-brown, brownish-gray, and olive (5YR4/4 to 5Y3-4/1-2). Discontinuous saline layers at 41.4 m (0.5 m thick), 48.5 m (0.4 m thick), and 54.4 m (0.8 m thick). |
| 90.8 | 21.8 | Interval of poor core recovery; recovered core (3.4 m) is composed of mud containing megascopic gaylussite crystals, massive, medium- to dark-brown and olive (5YR5/2 to 5Y3/2). Top of interval probably represents top of Mixed Layer. This and following three units probably represent Units A and B of Mixed Layer, of which most of the saline layers were lost during drilling (see text). |
| 95.4 | 4.6 | Salines, mostly trona, containing mud; faintly bedded to massive; moderate-brown to olive (5YR4/4 to 5Y5/1). |
| 99.8 | 4.4 | Mud, mostly acid-insoluble material, some dolomite; light-olive-gray (5Y5-6/1-2), thin-bedded. |
| 114.0 | 14.2 | Salines, mostly trona, with small amounts of other minerals and extensive mud impurities; light- to dark-green and brown (5GY5/1, 5Y4-6/1, 5YR3/4); faint bedding in lighter colored salines, with interbeds of mud common near base. Contact between Units B and C of Mixed Layer is at base of this interval. |
| 124.0 | 10.0 | Salines, with some interbedded mud; saline minerals are mostly halite, with smaller amounts of trona and other evaporite minerals; indistinct bedding, beds mostly 1 to 2 cm thick; salines light- to dark-olive-gray (5Y4-7/1-2) and moderate-brown (10YR4-6/2-4). |
| 130.4 | 6.4 | Salines and some mud; salines are about two-thirds halite and one-third trona, with some thenardite; yellowish-gray (5Y5-7/2); upper part of unit contains largest percentage of mud impurities. |
| 135.6 | 5.2 | Salines, mostly halite, with minor trona and thenardite; dark- to medium-gray (N3-5); upper part of unit contains mud impurities. |
| 151.2 | 15.6 | Interbedded mud and salines; salines are mostly halite, with some trona; salines olive-gray (5Y4/1 to 5Y6/1), mud brownish-black (5YR2/1); saline layers, 0.3 to 0.6 m thick, constitute about one-third of zone. |
| 166.4 | 15.2 | Salines, mostly halite, with smaller amounts of trona and thenardite, nearly pure in lower part; mostly gray to yellowish-gray (N4-7 to 5Y4-6/1); bedding 1 to 2 cm thick, some zones porous but most nonporous. Contact between Units C and D+E of Mixed Layer is at base of this interval. |
| 178.6 | 12.2 | Mud containing megascopic crystals of gaylussite and pirssonite, microscopic crystals of |

| Depth to base of unit (m) | Thickness of unit (m) | Description |
|---|---|---|
| | | dolomite, halite, and probably other acid-soluble minerals; brownish-black (5YR2/1) in upper and lower part, moderate-brown (5YR3/4) in middle. |
| 186.5 | 7.9 | Mud, with interbedded salts at 179 and 181 m; salts, in beds 0.1 and 0.6 m thick, are mostly halite and trona, with some thenardite and northupite; mud is composed largely of microscopic crystals of dolomite and other carbonates; olive to brownish-black (5Y2/1 to 5YR2/1). |
| 192.0 | 5.5 | Salines interbedded with mud containing scattered saline crystals; salines are mostly halite, with subordinate trona, thenardite, and other minerals; salines olive-gray and medium- to dark-gray (5Y6/1 to N4-6), mud dark-olive-black (5Y1-2/1). |
| 196.1 | 4.1 | Mud, dark-olive-black (5Y1-2/1). |
| 196.6 | 0.5 | Salines, mostly halite; olive-gray (5Y4/1). |
| 204.5 | 7.9 | Mostly mud, with some disseminated saline crystals; brown (5YR3/4) in upper part, olive-gray (5Y4/1) in lower. |
| 207.4 | 2.9 | Salines, with interbedded mud; salines are mostly halite, distinctly bedded, averaging 1 cm in thickness; salines yellowish-gray (5Y7/2), mud olive-gray (5Y4/1). |
| 210.9 | 3.5 | Mud, moderate-brown (5YR4/4) in upper half, olive-black (5Y2/1) in lower part. |
| 213.6 | 2.7 | Salines, mostly halite, with mud impurities; olive-black (5Y2/1) to light-olive-gray (5Y6/1); upper part faintly bedded, lower part massive to mottled. |
| 218.4 | 4.7 | Mud, massive, olive-black (5Y3/1). |
| 218.5 | 0.1 | Salines, trona and halite. |
| 227.4 | 8.9 | Mud, massive, olive-black (5Y2/1). |
| 227.7 | 0.3 | Salines, trona and halite. Contact between Units D+E and F of Mixed Layer is at base of this interval. |
| 248.1 | 20.4 | Mud, mostly grayish-olive (5GY4/1), with a grayish-brown (5YR3/2) zone at 236-238 m and a greenish-gray (5GY6/2) zone at 244-245 m. |
| 249.5 | 1.4 | Mud, dark-greenish-gray (5GY4/1), mottled to faintly bedded; lower half extremely hard (limestone). |
| 271.4 | 21.9 | Mud, with irregular concentrations of a few mottled areas caused by light-colored dolomite or salts; mostly pale- to grayish-green (10G4-6/2), upper 3 m grayish-olive-green (5GY3/2); massive except near 260 and 268 m, where thin to laminar bedding is defined by pale-orange (10YR6-8/2-4) layers (dolomite?). |
| 276.9 | 6.5 | Mud, similar to interval above but containing searlesite. |
| 291.1 | 14.2 | Mud, similar to that at 249.5 m. Contact between Units F and G (new) of Mixed Layer is at base of this interval. |
| 294.4 | 3.3 | Impure salines with mud impurities similar to interval above; salines, mostly halite and thenardite, are mottled aggregates surrounded by mud. |
| 299.3 | 4.9 | Mud, dusky-yellow-green (5GY5/2); upper part mottled, lower part has buff laminae and thin beds. |
| 306.3 | 7.0 | Salines and some mud; salines are chiefly halite and thenardite, white to light-gray (N5-8); mud pale-green (10G6/2); upper part faintly bedded, lower part mottled. |
| 324.3 | 18.0 | Two saltbeds separated by mudbeds (see pl. 1); salts, largely halite, massive, light-greenish-gray (5GY6-8/1); muds massive, greenish-gray (5G6/1). |
| 333.1 | 8.8 | Three mud and two impure salt layers (pl. 1); mud pale-green (10G6/2), massive, with dispersed salts; saline layers, consisting of mottled zones of lighter colored secondary crystals oriented randomly in mud matrix, are halite, with some thenardite, glauberite, and anhydrite. |
| 334.7 | 1.6 | Impure salts, halite; dark-greenish-gray (5GY4/1). |
| 337.3 | 2.6 | Mud containing some halite; brownish-gray (5YR4/1). |
| 341.1 | 3.8 | Muddy salt grading downward into impure mud; salts largely halite and anhydrite; mud dark-greenish-gray (5GY4/1). |
| 345.3 | 4.2 | Mud with some dispersed salts; massive, faint mottled coloring; olive-gray (5Y4/1). |
| 405.7 | 60.4 | Nine alternating salt and mud layers in nearly equal volumes, with individual layers generally 4 to 6 m thick (see pl. 1); salts are halite and other saline minerals, mostly light- through medium-gray (N5-7) to light-olive-gray (5Y6/1) and grayish-orange-pink (5YR7/2); mud greenish-gray (5G4-6/1) to dark-greenish-gray (5GY4/1); mud is massive except in 0.5-m-thick zone below saltbeds, where it is thin bedded; salts are faintly bedded to massive. |
| 413.3 | 7.6 | Mud; inadvertently not photographed, but reported by field log as green to brown. |
| 422.5 | 19.3 | Core not recovered. |
| 425.5 | 22.3 | Mud, soft and plastic, olive-black (5Y2/1). Contact between Units G and H (new) of Mixed Layer is at base of this interval. |
| 437.7 | 12.2 | Mud, with small crystals of thenardite dispersed randomly; more coherent than interval above; average moderate-brown (5YR3/4). |
| 444.6 | 6.9 | Mud, soft and plastic, olive-black (5Y2/1). |

| Depth to base of unit (m) | Thickness of unit (m) | Description |
|---|---|---|
| 449.6 | 5.0 | Mud, more coherent than interval above; moderate-brown (5YR3/4). |
| 451.4 | 1.8 | Salts and mud; salts in thin beds and mottled areas, yellowish-gray (5Y8/1), chiefly glauberite and anhydrite, with some halite; mud massive, olive-gray (5Y4/1). |
| 482.5 | 31.1 | Mud, moderate-brown (5YR3/4), with some zones of light-olive-gray (5Y5-6/1-2); salts largely halite and anhydrite, both dispersed and concentrated in mottled zones. |
| 483.4 | 0.9 | Mud and some salts; mud olive-gray (5Y4/1), thin bedded; salts are chiefly anhydrite and halite. |
| 494.4 | 11.0 | Mud, moderate-yellowish- to pale-brown (10YR5/2-4), massive. |
| 507.5 | 13.1 | Mud, light-olive-gray (5Y5/2) to pale-yellowish-brown(10YR/2), 2-m-thick zone at 502 m is pale brown (5YR5/2). |
| 507.8 | 0.3 | Mud and salt; mud light-olive-gray (5Y5/2); salts are mostly glauberite. |
| 516.6 | 8.8 | Mud and disseminated salts; light-olive gray (5Y6/1) to pale-yellowish-brown (10YR6/2). |
| 524.0 | 7.4 | Mud; moderate-brown (5YR4/4) in upper part, yellowish-brown (10YR6/2) to pale-brown (5YR5/2) in lower part. |
| 530.1 | 6.1 | Mud; upper part greenish-gray (5GY6/1), mottled, thin-bedded to massive; lower part yellowish-brown (10YR6/2), thin-bedded. |
| 541.6 | 11.5 | Mud, mottled, pale-brown (5YR5/2) to pale-yellowish-brown (10YR6/2). Contact between Units II and I (new) of Mixed Layer is at base of this interval. |
| 582.2 | 40.6 | Mud, olive-gray (5Y4/1) down to 558 m, light-olive-gray (5Y6/1) below that depth, with 2-m-thick pale-brown (5YR5/2) zone at base. |
| 634.0 | 51.8 | Mud, light-olive-gray (5Y5-6/1-2). |
| 640.1 | 6.1 | Mud, brownish- black (5YR2/1) to olive-black (5Y2/1). |
| 649.2 | 9.1 | Mud, light-olive-gray (5Y5-6/1-2) and pale-olive (10Y6/2). |
| 658.7 | 9.5 | Mud; grayish-olive (10Y4/2) in upper part, yellowish-gray (5Y6/2) in lower part. |
| 681.5 | 22.8 | Mud, mostly pale-olive (10Y6/2) to yellowish-gray (5Y7/2), with zones near-olive-gray (5Y4/1) at 662, 665, and 669 m. |
| 684.0 | 2.4 | Tuff mixed with mud, grading down into pure tuff; impure tuff is olive-gray (5Y4/1), pure tuff yellowish-gray (5Y7/2); well indurated in basal 40 cm. |
| 690.4 | 6.4 | Mud, silt- to sand-size; mottled, ranging in color from olive gray (5Y4/1) to dark yellowish brown (10YR4/2) |
| 690.9 | 0.5 | Tuff, yellowish-gray (5Y6-8/1), well-indurated, crossbedded. |
| 693.4 | 2.5 | Mud and sand; faint to conspicuous thin beds, light-olive-gray (5Y5/2), with streaks of pale-brown (5YR5/2). Contact between Unit I of Mixed Layer and alluvial sand and gravel is at base of this interval. |
| 915.3 | 211.9 | Pebbly arkosic sand and gravel, most commonly moderate brown (5YR3-4/4), with zones that average light brown (5YR6/4) in color between 726-740 and 748-798 m; mostly coarse to very coarse sand, poorly sorted, containing quartz monzonite and volcanic-rock fragments, as large as 15 cm in diameter; faintly bedded to massive; not cored between 748.3–793.4, 804.7–826.3, and 839.1-903.1 m. |
| 929.6 | 14.3 | Quartz monzonite, light- to medium-gray (N5–7), with pale-brown (5YR5/2) stains along fractures extending through cored interval; rock bit was used from 915.3 to 926.3 m, and so no core was recovered. |

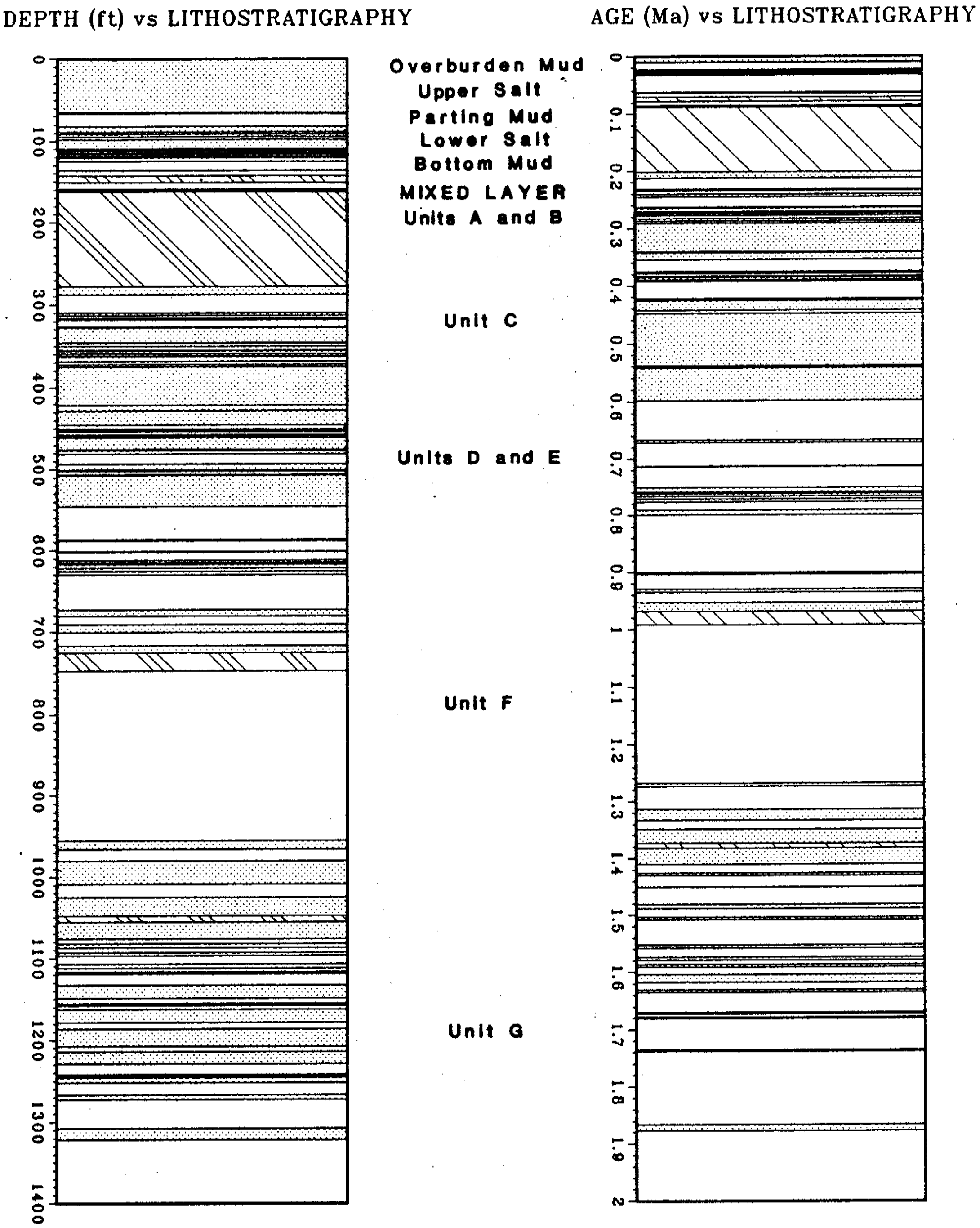

Figure 3 A comparison of core KM-3 stratigraphy with depth and with age. Cross-hatching indicates poor core recovery; stippling, intervals of predominantly evaporite minerals; and absence of pattern, predominantly lacustrine mud.

**Mineralogy** The buildup of solutes in Searles Lake water provided an unusual environment for the accumulation of thick sequences of evaporite minerals. These minerals, and the accompanying brines, have been the target of mining companies at Searles Lake for the last 100 years. A list of evaporite minerals and the diagenetic products of some of the minerals (Smith, 1979) is shown in table 2. Of greatest interest, for the purposes of this paper, are primary and diagenetic carbonates. Those carbonates assumed to be of primary origin are dolomite, calcite, aragonite, and northupite. Gaylussite and pirssonite are assumed to be of diagenetic origin, although fine-grained gaylussite may be primary.

Assumptions of diagenetic or primary origin of these carbonates are crucial in attempting to reconstruct lake history by stable isotope records. If isotopic exchange had occurred with interstitial brines, or by any other mechanism, paleohydrologic information from the isotopic record may be lost. Therefore, a brief discussion of the evidence leading to conclusions of primary or diagenetic origin is warranted.

The mineral of greatest interest in this paper is dolomite. Smith and others (1983) reported dolomite to exist throughout most of core KM-3, and its abundance and frequent occurrence makes the mineral very attractive in constructing a detailed and consistent isotope record at

Table 2. Names and composition of the non-clastic minerals found in the KM-3 core. (Smith and others, 1983).

| *Mineral* | *Composition* |
|---|---|
| Analcime | $NaAlSi_2O_6 \cdot H_2O$ |
| Anhydrite | $CaSO_4$ |
| Aragonite | $CaCO_3$ |
| Borax | $Na_2B_4O_7 \cdot 10H_2O$ |
| Burkeite | $2Na_2SO_4 \cdot Na_2CO_3$ |
| Calcite | $CaCO_3$ |
| Celestite | $(Sr, Ba)\,SO_4$ |
| Dolomite | $CaMg\,(CO_3)_2$ |
| Gaylussite | $CaCO_3 \cdot Na_2CO_3 \cdot 5H_2O$ |
| Glauberite | $Na_2SO_4 \cdot CaSO_4$ |
| Gypsum | $CaSO_4 \cdot 2H_2O$ |
| Halite | $NaCl$ |
| Hanksite | $9Na_2SO_4 \cdot 2Na_2CO_3 \cdot KCl$ |
| Heulandite | $CaO \cdot Al_2O_3 \cdot 6SiO_2 \cdot 5H_2O$ |
| Magnesite | $MgCO_3$ |
| Nahcolite | $NaHCO_3$ |
| Northupite | $Na_2CO_3 \cdot MgCO_3 \cdot NaCl$ |
| Pirssonite | $CaCO_3 \cdot Na_2CO_3 \cdot 2H_2O$ |
| Searlesite | $NaBSi_2O_6 \cdot H_2O$ |
| Thenardite | $Na_2SO_4$ |
| Tincalconite | $Na_2B_4O_7 \cdot 5H_2O$ |
| Trona | $Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$ |

Searles. Smith (1979) suggested a primary origin for dolomite based on several factors: 1) the mineral occurs only in microscopic form, 2) it is found in lake bed outcrops surrounding the valley floor, where other minerals of diagenetic origin are missing, 3) dolomite occurs in distinct zones, suggesting it occurred only when the lake chemistry was conducive to dolomite formation, 4) the magnesium content of interstitial brines is very low, and other minerals occurring with dolomite contain very small amounts of magnesium; the source of magnesium during the possible alteration of calcium carbonate to dolomite is not readily apparent, and 5) dolomite does not occur in areas where minerals present could react diagenetically to form dolomite.

That dolomite occurs as a primary evaporite mineral in some lakes has been proven by several investigators (Clayton and others, 1968; De Decker and Last, 1988). Of great interest is the evidence presented by Clayton and others (1968), following Jones (1965), of modern dolomite formation in Deep Springs Lake, California. Smith (1979) suggested that current dolomite formation in Deep Springs may be a modern analog of dolomite formation in Searles Lake, as the two lakes are presumed to be chemically very similar. Calcite in core KM-3 is also assumed to be of primary origin. Calcite occurs less frequently than dolomite in core KM-3, yet is predominant in a few sections of the core, most notably in the Parting Mud and very deep in the core (Units G through I). Calcite is well known as a primary precipitate from lake waters, and no compelling evidence suggests a diagenetic origin. However, Smith (1979) strongly suggested that some of the calcite may be recrystallized metastable aragonite.

Aragonite occurs only in the upper stratigraphic units, mainly the Parting Mud and the Bottom Mud. As aragonite is thermodynamically metastable near the earth's surface, any aragonite that may have been precipitated earlier in the lake's history has probably been altered to calcite, or reacted with the interstitial brines to form gaylussite or pirssonite. No evidence suggests that the aragonite present in KM-3 is of any but primary origin.

Megascopic and microscopic northupite occurs in discrete intervals throughout most units of the Mixed Layer. Primary northupite is thought to have originated by the mixing of magnesium-bearing waters with concentrated sodium carbonate and chloride brines (Smith and Haines, 1964). However, Smith (1979) suggested that microcrystalline northupite may have a diagenetic origin in some sections of the core. As no northupite/water fractionation factor has been published, northupite was not used in the stable isotope analysis of core KM-3.

Several carbonate minerals are considered to be of at least partially diagenetic origin in Searles Lake, including gaylussite and pirssonite. The alteration of calcium carbonate by percolating sodium and carbonate-rich brines is suggested by the inverse relative proportions of the diagenetic carbonates to the primary calcium carbonates (Smith, 1979). Textural evidence, such as growth of macrocrystalline gaylussite across mud laminae without deformation of the laminae suggests that the diagenetic minerals formed after compaction of the lake sediments. Gaylussite is known to occur as a primary mineral in Owens Lake (Smith and others, 1987), and disseminated crystals in the sediment may be of primary origin.

**Brines** The interstitial brines have been classified by Eugster and Hardie (1978) as being of the $Na-CO_3-SO_4-Cl$ type. The origin of the brines has been discussed at length in Eugster and Hardie (1978). Figure 4 graphically displays the chemical evolution of the brines at Searles.

Hardt and others (1973) described the relationship of the relatively fresh water in the alluvial fans to the brines. The authors showed that the hydrostatic head of the brines is, and perhaps generally has been, higher than the head in the surrounding freshwater aquifers. Brine movement is therefore down, through the lake sediments, and possibly eventually moving out laterally from the basin (Friedman and others, 1982).

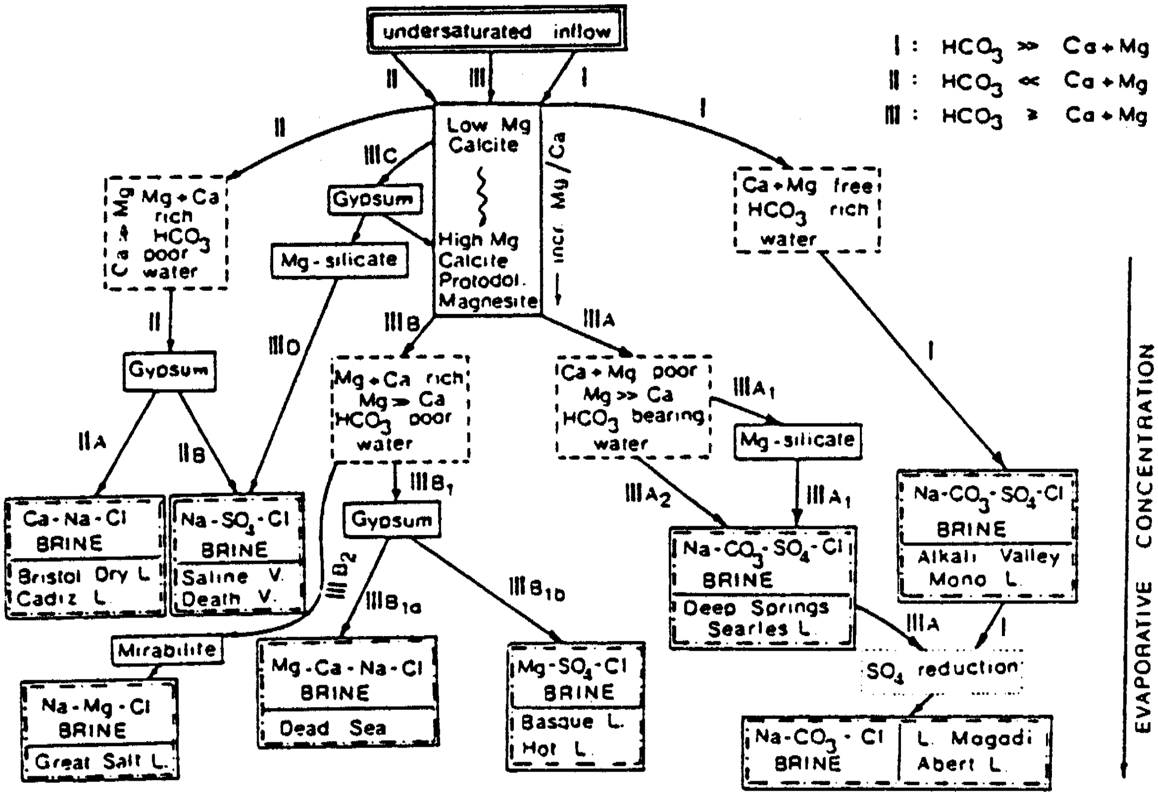

Figure 4 Water quality path of Searles Lake brines during evaporative concentration (Eugster and Hardie, 1978).

# IV. CHRONOLOGY DEVELOPMENT

## Carbon-14

During the late 1950's and 1960's, numerous investigators used radiocarbon techniques to obtained numerical age-estimates of lake sediments at Searles Lake (Flint and Gale, 1958; Stuiver, 1964; Stuiver and Smith, 1979). Eighty-eight radiocarbon dates for sediment in the Overburden Mud, Upper Salt, Parting Mud, Lower Salt and the Bottom Mud have been published; a summary of these dates can be found in Benson and others (1989). Materials used for radiocarbon age-estimates include wood, disseminated organic carbon, and primary and diagenetic carbonate minerals.

The reliability of the materials for radiocarbon dating at Searles has been debated at length (Benson and others, in press; Stuiver and Smith, 1979). Potentially diagenetic carbonate minerals are not considered to be useful except as a supplement to more suitable materials. Briefly, the likely contamination of diagenetic carbonates with carbon from interstitial brines casts considerable doubt on the reliability of these minerals for radiocarbon dating.

Debate over the reliability of radiocarbon dates from primary carbonates is due to several factors. First, non-equilibrium of the $^{14}C/^{12}C$ ratio between the lake water and atmosphere, the "reservoir effect", can cause the lake water to have an apparent age of hundreds to thousands of years

(Broecker and Walton, 1965; Peng and others, 1978; Stuiver and Smith 1979). Therefore, radiocarbon age-estimates of carbonates precipitated in isotopic equilibrium with lake water will be too "old". Second, re-crystallization or the isotopic re-equilibration of carbonate minerals with interstitial brines may have occurred. Depending upon the source of the brine, either from above or below the sediment, the radiocarbon ages could be too "old" or too "young". However, the possibility that isotopic re-equilibrium or exchange with interstitial brines has occurred cannot be ruled out. A third source of error in the radiocarbon age-estimates of inorganic carbonates could be the assumption that the carbonate minerals were precipitated in isotopic equilibrium with the lake water. This problem is most likely to occur at low lake levels where kinetic effects due to supersaturation of carbonates can produce non-equilibrium precipitates (Stiller and others, 1985). However, resulting errors in radiocarbon ages are likely to be small in comparison with other sources of error. Finally, Stuiver and Smith (1979) list substantial evidence that possible reworking of older sediments has occurred, especially in the Overburden Mud and the Upper Salt. Re-deposition of older sediments could lead to $^{14}C$ dates that are too "old". Further, the dissolution of dead carbon into the lake would also cause precipitating carbonates to appear too "old".

Disseminated organic radiocarbon dates would be affected by many of the same processes as inorganic carbonates. The $^{14}C/^{12}C$ ratio of organisms utilizing dissolved carbon in the lake water will reflect the "apparent age" of the water. Similarly, isotopic exchange with interstitial fluids will produce errors in the radiocarbon age-estimates of organic sediments. Finally, bacterial contamination of wet-sediment cores may produce radiocarbon age-estimates of organic sediments that are too "young" (Geyh and others, 1974 in Benson and others, in press).

Radiocarbon age-estimates on wood are probably the most reliable (Stuiver and Smith, 1979). Only two wood dates are available at Searles Lake: one in the Overburden Mud and one in a lower mud unit in the Lower Salt. No evidence to cast doubt the reliability of these dates has been put forward.

Inorganic carbonate minerals are least reliable for radiocarbon dating due to "reservoir effects", possible isotopic exchange with interstitial fluids, and re-deposition of older sediments. Stuiver and Smith (1979) estimate errors associated with the $^{14}C$ dates of carbonate minerals range from ±500 to ±2500 years, in addition to reported counting errors. Estimated errors for disseminated organic dates range from 500-2500 years too "old", in addition to counting errors. As there are sufficient disseminated organic carbon and wood dates available, the inorganic dates will not be considered further in this paper.

**Uranium/Thorium**

To expand the absolute-age chronology of Searles Lake sediments, Peng and others (1978) compared radiocarbon dates of Lower Salt muds (Stuiver and Smith, 1979) with $^{230}$Th dates on the surrounding salt beds. Nineteen $^{230}$Th dates were published on halite and trona samples from two cores. The uranium-thorium dates were in general agreement with the radiocarbon dates. This fact encouraged further uranium-series dating of the Bottom Mud and Mixed Layer Unit A+B by Bischoff and others (1985). An additional nineteen $^{230}$Th dates on trona, gaylussite and dolomite were published, extending the absolute-age chronology to approximately 230 ka.

The reliability of the $^{230}$Th age-estimates depends upon how well the technique satisfies two basic assumptions: 1) all $^{230}$Th present in the sample resulted from post depositional in situ decay of uranium (it is assumed that there is no non-radiogenic $^{230}$Th present), and 2) the sediment has remain a geochemically closed system; there has been no gain/loss or exchange of uranium or thorium (Ku and Liang, 1984). In Peng and others (1978), several additional assumptions were made in calculating the $^{230}$Th age. First, an estimated correction factor for non-radiogenic $^{230}$Th was arrived at by assuming that the initial $^{230}Th/^{232}Th$ ratio was the same for all salt units in the Lower Salt. Second, it was assumed that the salt units had been precipitated in an extremely short amount of time.

Varying degrees of error are introduced by the above assumptions. Fluctuations in initial $^{230}Th/^{232}Th$ ratios are expected. Isotopic exchange with interstitial brines is possible, though difficult to determine. Age-estimates of the Lower Salt based on the accumulation of acid-insoluble residue (Jannik, 1989) support the assumption that the salt units were deposited in less than 1000 years and possibly less than 100 years.

A potential problem of post-depositional contamination also exists with the age-estimates presented by Bischoff and others (1985). Finally, because intervals of core loss were not always noted during drilling, there may be uncertainly concerning the sample depth. With all possible errors in mind, the counting errors associated with the $^{230}Th$ dates for Searles Lake salts represent only a minimum error estimate.

## Magnetostratigraphy

Interpretation of paleomagnetic polarities from Searles Lake core KM-3 allowed development of a magnetostratigraphy for the paleolake sediments (Liddicoat and others, 1980). Using the revised time scale of Mankinen and Dalrymple (1979), the deepest lacustrine sediments were correlated with the base of the Mammoth subchron of the Gauss chron (3.15 Ma). The youngest boundary defined was the Brunhes-Matuyama (~730 ka). A total of twenty-four polarity boundaries were described, including five zones that were not included in the Mankinen and Dalrymple time scale.

Possible interpretation errors due to core sections reversed in the core boxes were discussed by the investigators. Only deep in the core, beyond the maximum depth of stable isotope analysis, was this problem suspected to exist. Reported errors associated with zone definition ranged from ±0.4 m to ±10.6 m. Using an average sedimentation rate for the core of 45 yr/cm, a minimum age error of ±1.8 kyr to ±45.5 kyr may be assumed for these paleomagnetic age-estimates.

## Tephrochronology

Series of ash units were deposited in Searles Lake sediments as a result of widespread Cenozoic volcanic activity. Fourteen tephra layers were identified in core KM-3 (Hay and Guldman, 1987). One ash unit, at ~168.6 m, was tentatively identified, and was correlated with the Lava Creek B (formerly 'Pearlette Type O') ash. The most recent age-estimate for the Lava Creek B ash is 610 ka (J.D. Obradovich, written communication in Izett, 1981). The age is based on a mean of several K-Ar dates. No error associated with this date has been published. Fission-track ages of zircons within the Lava Creek B ash from several localities are 0.6 ±0.07 Ma (Naeser and others, 1973) and 0.6 ±0.15 Ma (Christiansen and Blank , 1972 in Naeser and others, 1973). These ages are in close agreement with the K-Ar date of 0.610 Ma.

The correlation of the tephra unit in Core KM-3 with the Lava Creek B ash was made partially due to its stratigraphic position relative to the Brunhes-Matuyama paleomagnetic boundary. There appears to be some circular reasoning with this correlation, as the paleomagnetic boundary was originally identified partially based on its proximity to this tephra unit, then assumed to be the Bishop Tuff (Liddicoat and others, 1980). However, additional mineralogic information supports the identification of this ash unit as the Lava Creek B.

## Chlorine-36

Absolute age-estimates based on the decay of $^{36}$Cl in halite have extended the chronology of sediments at Searles Lake. Six $^{36}$Cl dates on halite units from 14.2 m to 401.3 m in depth ranged from 10 ka to 1.95 Ma (Phillips and others, 1983). The $^{36}$Cl dates were in general agreement with radiocarbon, uranium-series, and paleomagnetic age-estimates of the same units. Based on the success of Phillips and others (1983), Jannik (1989), determined an additional fourteen $^{36}$Cl age-estimates on halite units in core KM-3 from 3.0 m to 401.3 m in depth. $^{36}$Cl dates on these new samples ranges from 6.7 ka to 1.27 Ma. The deepest sample at 401.3 m (1.95 Ma) had previously been suspected of contamination by Phillips and others (1983), and the new date (1.25 Ma) of this depth confirmed earlier suspicions. A summary of all $^{36}$Cl age-estimates can be found in Jannik (1989).

As the $^{36}$Cl method is somewhat new, a brief discussion of $^{36}$Cl theory as it applies to the Searles Lake sediments is warranted. The hydrophilic nature of chlorine allows the chloride ion to travel through a hydrologic system with minimal chemical interaction. As Searles Lake was the frequent terminus of the Owens River paleolake system, chloride accumulated in the lake water and eventually precipitated out in evaporite minerals during arid periods. Upon deposition, the decay of $^{36}$Cl began.

The various sources of $^{36}$Cl in the evaporite minerals are discussed in great detail in Jannik (1989). Briefly, there are three main sources of $^{36}$Cl. First, the initial $^{36}$Cl input to a hydrologic system is through the inclusion of atmospheric-produced $^{36}$Cl in precipitation. Second, surface production of $^{36}$Cl in rocks is caused by cosmic-ray spallation of calcium and potassium and neutron activation of $^{35}$Cl. The weathering of these rocks will add $^{36}$Cl to surface or groundwater sytems. Third, post-deposition production of $^{36}$Cl due to activation of $^{35}$Cl by cosmic-ray neutrons, in addition to neutron activation by the decay of uranium and thorium in the sediments, can occur, increasing the $^{36}Cl/Cl$ ratio in the evaporite minerals. Phillips and others (1983) estimated the $^{36}Cl/Cl$ input from the three different sources for the halite units in the upper Salt. Approximately thirty percent of the $^{36}Cl$ in the halite is derived from atmospheric sources, about seventeen percent from subsurface production, and apparently more than fifty percent from surface production.

In addition to the production of $^{36}Cl$ by the three sources mentioned above, several other site-specific sources or sinks of chloride bear mentioning. The mixing ratios of the various source waters, especially thermal springs in the Owens Valley, can alter the final $^{36}Cl/Cl$ ratio in the Owens River water and its related paleolakes. Second, the inflow/overflow/desiccation history of each lake will affect the $^{36}Cl/Cl$ ratio of evaporite minerals precipitating out of a given lake.

In light of all the possible contributions of $^{36}Cl$ to the eventual $^{36}Cl/Cl$ ratio of the Searles Lake halite units, the determination of age-estimates based on the $^{36}Cl$ method depends upon several conditions. First, the $^{36}Cl/Cl$ ratio of inflow waters at Searles Lake was constant or known. Second, subsurface production of $^{36}Cl$ is assumed to be negligible. And finally, no post-deposition transfer of chloride to or from the halite crystal has occurred. The general agreement of the $^{36}$Cl age-estimates with other radiocarbon, uranium-series, and paleomagnetic age-estimates support these assumptions. However, a few $^{36}$Cl measurements from Searles Lake showed abnormally high $^{36}$Cl/Cl ratios. Jannik (1989) suggested that some sort of laboratory contamination had taken place, yet she did not rule out other sources of error.

Analytical errors on the Searles Lake $^{36}$Cl dates ranged from ±1.0 kyr in shallow samples to ±176 kyr for deep samples. As with all other methods described previously, these analytical errors represent only a minimum error.

### AIR-Interpolated Ages

With a detailed absolute chronology established, assigning ages to samples between absolutely-dated points usually involves a linear interpolation of ages based on an assumption of constant sedimentation rates. However, large variations in sedimentation rates at Searles Lake are expected due to the extreme fluctuations between deep-water muds and shallow-water evaporite sequences. Therefore, Jannik (1989) developed a technique to minimize the errors associated with interpolated ages. This technique is based on evidence for a relatively constant accumuluation of acid-insoluble residue (AIR) in lake sediments.

The variability of sedimentation rates in Searles is largely due to the accumulation of solutes in the lake water during non-overflow periods of the lake's history. During low lake level or desiccation episodes, accumulated solutes precipitated out of the water rapidly as thick sequences of evaporite minerals. Conversely, the AIR component of inflow waters had a relatively short residence time in the lake water, and therefore accumulated at a relatively constant rate through time.

Results from detailed geochemical analyses of core KM-3 were presented by Smith and others (1983). The core was divided up into 254 intervals according to lithology; geochemical analysis, including determining of acid-insoluble residue (AIR), was performed on each interval. Jannik (1989) calculated cumulative AIR versus time and concluded that the accumulation of the AIR component of the sediments varied smoothly through time. A plot of "AIR vs. Depth" displayed a "stair-step" pattern reflecting the change in sedimentation rates from pluvial (low sedimentation) to more arid (high sedimentation) periods. AIR data were assigned ages by linearly interpolating between absolutely-dated points. The AIR ages were then correlated with AIR depths to create "AIR-interpolated ages" for the lithologic intervals. Analyses of some of the intervals were combined due to similar geochemical characteristics. A total of 144 intervals were assigned AIR-interpolated ages.

It should be emphasized that the AIR values are merely a method for interpolating ages between absolute radiometric and paleomagnetic dates. The purpose of using the AIR-interpolation procedure (instead of depth interpolation) is to compensate for drastic fluctuations in sedimentation rate caused by alternation of evaporite and marl-depositing conditions. A very high deposition rate for the Upper Salt can be demonstrated by $^{14}C$ dating (discussed above). It seems reasonable to infer that similar evaporites deeper in the core were deposited under similar conditions. The AIR interpolation avoids unrealistically long deposition times for these evaporites. Errors assumed for this technique are difficult to quantify. The AIR technique has, however, substantially decreased errors that would have resulted had a simple linear interpolation between absolutely-dated points been used.

## Composite Chronology

With all the possible errors in mind using absolute dating techniques, the chronology for Searles Lake is remarkably detailed, especially in the upper units. Following Jannik (1989), a composite chronology of core KM-3 is presented below according to the informal (but generally accepted) stratigraphic unit names. Slight revisions of the Jannik chronology have been made, and a discussion of these revisions are included in the following section.

**Overburden Mud** Evidence presented by Stuiver and Smith (1979) indicates most of the mud in this unit is reworked older sediment. Therefore, no dates on carbonate minerals or organic sediments are thought to be reliable. A $^{36}$Cl date of 67 ka ±10 kyr is clearly much too old and also will not be used. The only reliable date available is a $^{14}$C date on wood at 2.4 m in depth with an age of 3.52 ka ±0.19 kyr. One AIR-interpolated age at the Overburden Mud/Upper Salt boundary implies an age of 6 ka.

**Upper Salt** Twelve radiocarbon dates (Stuiver and Smith, 1979) for this unit are from inorganic carbonates and are considered unreliable. Four radiocarbon dates on disseminated organic carbon ranged from 11.4 ka ±0.6 kyr near the top of the unit to 9.72 ka ±0.2 kyr at the base of the unit. All other dates fell within the 10 ka to 11 ka range for the bottom 80% of the unit.

As discussed by previous investigators, (Stuiver, 1964; Benson and others, in press) the reversals in age and the small range of ages throughout the bottom 80% of the Lower Salt indicate rapid precipitation of this salt unit. The AIR data also support this conclusion.

Two U-Th age-estimates (Peng and others, 1978) near the top and base of the Lower Salt zone gave "corrected" $^{230}$Th ages of 5.3 ka ±1.2 kyr and 8.7 ka ±0.2 kyr respectively. The age-estimates are in general agreement with AIR and $^{14}$C dates.

Again, as stable isotope analysis was not made on samples above the Parting Mud, age-estimates for the Upper Salt are not crucial to this report. I have used an approximate average of the $^{14}C$ values for the Parting Mud/Upper Salt boundary, of 10 ka, which is in general agreement with all other age-estimates. AIR dates for locations within the unit have been used as they are stratigraphically consistent while the radiocarbon dates are not.

**Parting Mud** Thirty-nine $^{14}C$ dates for the Parting Mud are summarized in Stuiver and Smith (1979); fourteen radiocarbon dates were from inorganic carbonates and, therefore, unreliable. Twenty-five radiocarbon dates from disseminated organic carbon were presented; the radiocarbon age-estimates on these samples range from 10.06 ka ±90 yr to 10.9 ka ±90 yr at the top of the unit, and 22.4 ka ±1.0 kyr to 24.69 ka ±1.07 kyr at the base. Following Stuiver and Smith (1979), an age-estimate of 23 ka for the base of the Parting Mud is chosen here, although the age could range from ~21 ka to 24 ka.

**Lower Salt** Twenty-seven radiocarbon dates for this unit are summarized in Stuiver and Smith (1979): seven are from inorganic carbon, nineteen are from disseminated organic carbon, and one radiocarbon date on wood is available. As before, radiocarbon·dates on inorganic carbonates are probably unreliable and will not be considered further. The uppermost radiocarbon date is on sub-unit M-7, with an age estimate of 23.75 ka ±400 yr. The deepest reliable date is from sub-unit M-2, with an age-estimate of 32.6 ka ±500 yr. Sub-unit M-3 is the most uncertain, with two disseminated organic radiocarbon dates of 32.0ka ±1 kyr and 29.5 ka ±2 kyr. The wood radiocabon date for M-3 is 26.7 ka ±2 kyr. Between M-6 and M-2, several radicarbon dates are stratigraphically inconsistent. Detailed AIR dates are available in the Lower Salt units; these data again support conclusions by previous authors that most of the salt sub-units were deposited in a very short amount of time.

Eighteen U-Th age-estimates are available for the salt sub-units of the Lower Salt; sixteen "corrected" $^{230}$Th dates were published in Peng and others (1978) and one $^{230}$Th age-estimate for the S-1 submit was presented in Bischoff and others (1985). A few $^{230}$Th age-estimates were stratigaphically inconsistent. $^{230}$Th dates ranged from 23.8 ka ±1.4 kyr for subunit S-7, to 33.0 ka ±1.5 kyr for sub-unit S-1 (Peng and others, 1978). The $^{230}$Th age-estimate for S-1 in Bishoff and others (1985) was 35.3 ka $^{+2.7-2.4}$ kyr.

Selecting a chronology for the Lower Salt was problematic. Overall, both $^{14}$C and $^{230}$Th dates were in general agreement. However, data that were stratigraphically reversed, in addition to doubts concerning "reservior effects" and Peng's $^{232}$Th corrections, made choosing the best dates difficult. Therefore, I have chosen to assign a "probable" age to the Lower Salt/Bottom Mud boundary of 33.0 ka. This age is within the reported confidence intervals of all $^{14}$C and $^{230}$Th age-estimates. Using the "probable age" of the LS/BM boundary of 33 ka, the "probable age" of the PM/LS boundary of 23 ka, and AIR data, I interpolated a chronology for the subunits of the Lower Salt. In general, the new AIR interpolated-ages for the subunits are in agreement with $^{14}$C and $^{230}$Th age-estimates. A problem immediately apparent with this AIR-interpolated chronology is that the AIR ages for the submit M-3 boundaries are not within the confidence interval of the radiocarbon age-estimate on the wood from submit M-3, presumably the most reliable date in the Lower Salt. Therefore, the confidence intervals for assigned sample ages within this unit should probably be as large as ±5 kyr.

**Bottom Mud** Four $^{14}$C age-estimates are available for the Bottom Mud; three of the four dates are on disseminated organic carbon. Two of the three organic dates are near the top of the Bottom Mud, and the previously assigned "probable age" of the LS/BM boundary is within the confidence interval of both dates.

Five $^{230}$Th age-estimates for the Bottom Mud were presented in Bischoff and others (1985). Ages ranged from 58.4 ka $^{+1.5-1.1}$ kyr near the top of the Bottom Mud, to 122.3 $^{+3.6-3.0}$ kyr approximately 30% above the base of the unit.

AIR data are available for the Bottom Mud. Of greatest interest is one point at the base of the unit. If the first $^{230}$Th date of 58.4 ka is incorporated into the chronology, a sedimentation rate of less than 1 cm/100 yr is inferred from the LS/BM boundary to this sample. This sedimenatation rate is more than an order of magnitude less that the rates in the intervals above and below. Therefore, only the lower four $^{230}$Th age-estimates are used. AIR data are also incorporated into the Bottom Mud chronology. An age-estimate of 153.8 ka is interpolated for the BM/Mixed Layer boundary.

**Mixed Layer: A+B** Four $^{230}$Th age-estimates for the A+B unit were presented by Bischoff and others (1985). The A+B/C boundary was dated by the $^{36}$Cl method to yield an age of 286 ka ±47 ka (Jannik, 1989). Seven AIR intervals are also available for this unit.

I have chosen not to use two of the four $^{230}$Th age-estimates available for the A+B unit. The uppermost sample (Bischoff sample 7) yields an extremely low calculated sedimentation rate. The deepest $^{230}$Th date (Bischoff sample 11) also yields a low sedimentation rate, and has a very large analytical uncertainty. Two $^{230}$Th ages were available for Bischoff sample 8, and, following Jannik (1989), I have averaged the two dates for an age-estimage of 160.5 ka at 70.86 m in KM-3. All AIR data were used.

**Mixed Layer: Unit C** Four $^{36}$Cl age-estimates and twenty six AIR-interpolated ages are available for Unit C (Jannik, 1989). All available data were incorporated into the unit C chronology. The AIR interpolated age at the Unit C/D+E boundary is 598 ka.

**Mixed Layer: Units D+E** Four $^{36}$Cl age-estimates are available for unit D+E (Phillips and others, 1983; Jannik, 1989). One of the four (SLC-6) represented a reversal, and therefore, was not included in this chronology. An ash layer at 168.6 m was correlated with the Lava Creek B ash (610 ka) (Hay and Guldman, 1986). The first three paleomagnetic boundaries in KM-3 were defined in the D+E unit (Liddicoat and others, 1980): the Brunhes-Matuyama (730 ka) at 185 m, the Matuyama-Jaramillo (900 ka) at 204.9, and the Jaramillo-Matuyama (970 ka) at 221.2 m. Thirteen AIR ages are also available in D+E (Jannik, 1989).

All available age-estimates, with the exception of the one $^{36}$Cl date previously mentioned, are incorporated into the D+E chronology presented in this paper. No data are available for the D+E/F boundary, but a linear interpolation between the last absolutely-dated point at 221.2 m (970 ka) and the AIR age below the boundary (1.06 Ma at 248.11 m) gives an approximate age of 992 ka for the D+E/F boundary.

**Mixed Layer: Unit F** Only seven AIR-interpolated ages (Jannik, 1989) are available for Unit F. The deepest AIR interval, located at the F/G boundary, gives an approximate age of 1.268 Ma for the stratigraphic boundary. Two palemoagnetic boundaries were defined in Unit F, but as they are not included in the Mankinen and Dalrymple (1979) time scale, they will not be used in this chronology.

**Mixed Layer: Unit G** This is the deepest stratigraphic unit presented in this report that was sampled for stable isotope analysis. One $^{36}$Cl date and thirty-four AIR-interpolated ages are available for this unit (Jannik, 1989). Six paleomagnetic ages are also available (Liddicoat & others, 1980). Two of the six paleomagnetic ages are undefined boundaries, and therefore will not be used in this chronology. The four defined paleomagnetic boundaries that are used are 1) the Matuyama-Olduvai (1.67 Ma) at 378.6 m; 2) the Olduvai-Matuyama (1.87 Ma) at 403.25m; 3) The Matuyama-Reunion (2.01 Ma) at 408.3 m; 4) and the Reunion-Matuyama (2.04 Ma) at 424.7 m near the G/H stratigraphic boundary.

The $^{36}$Cl date, the four previously mentioned paleomagnetic dates and all AIR ages are used in Unit G chronology. An approximate age of the G/H stratigraphic boundary is 2.04 Ma.

**Composite Chronology** All $^{14}$C, $^{230}$Th, $^{36}$Cl, AIR-interpolated and paleomagnetic age-estimates used in this chronology are listed in Appendix A. Graphical representations of KM-3 stratigraphy vs. core depth and age are shown in figures 5 and 6. KM-3 mud samples prepared for stable isotope analysis were assigned ages using linear interpolation between absolutely dated isotope, AIR and paleomagnetic points.

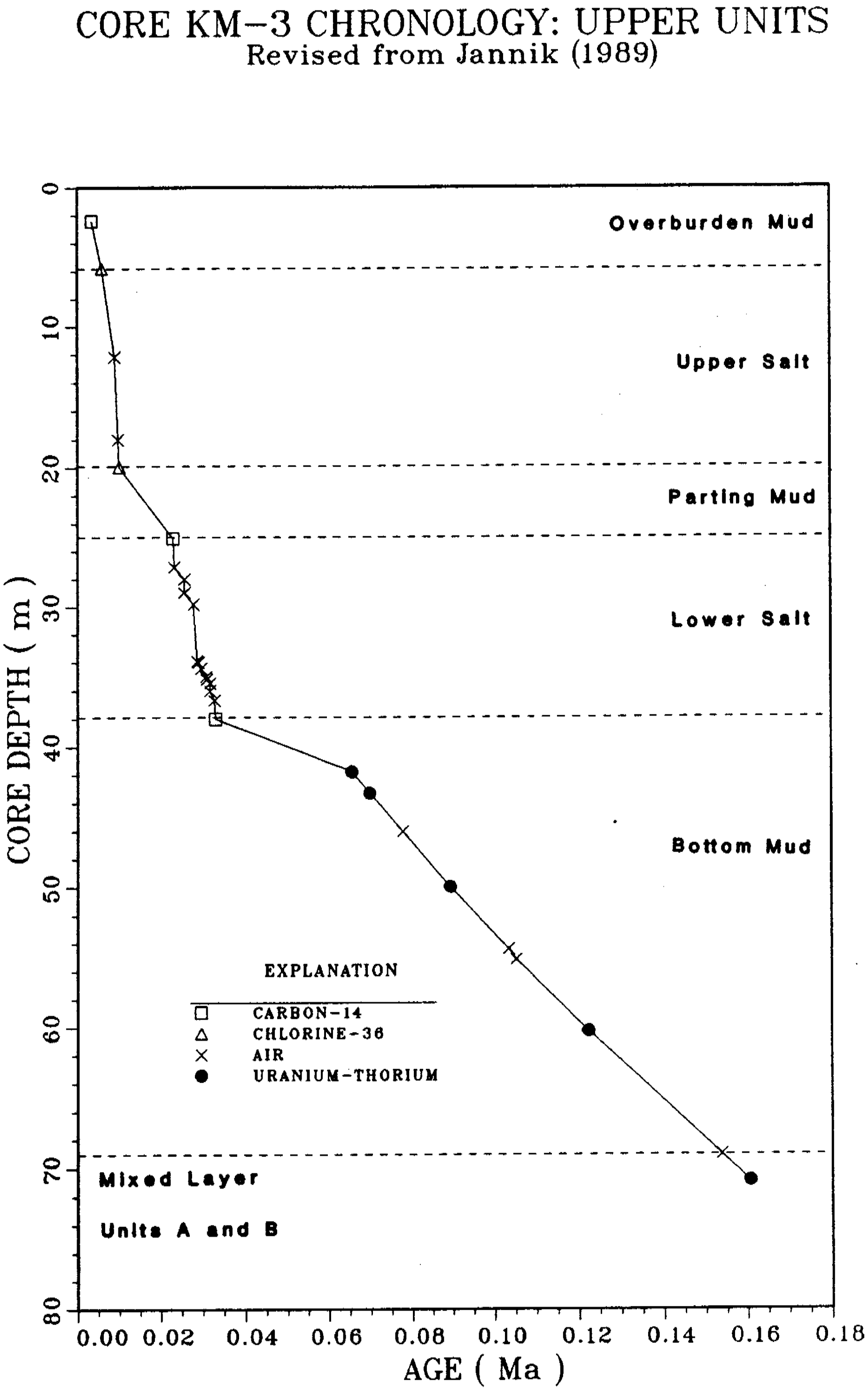

Figure 5 Age versus depth relationship for upper portion (0-80 m depth) of core KM-3, using carbon-14, thorium-230, and chlorine-36 dates and acid-insoluble residue (AIR) interpolation. Revised from Jannik (1989).

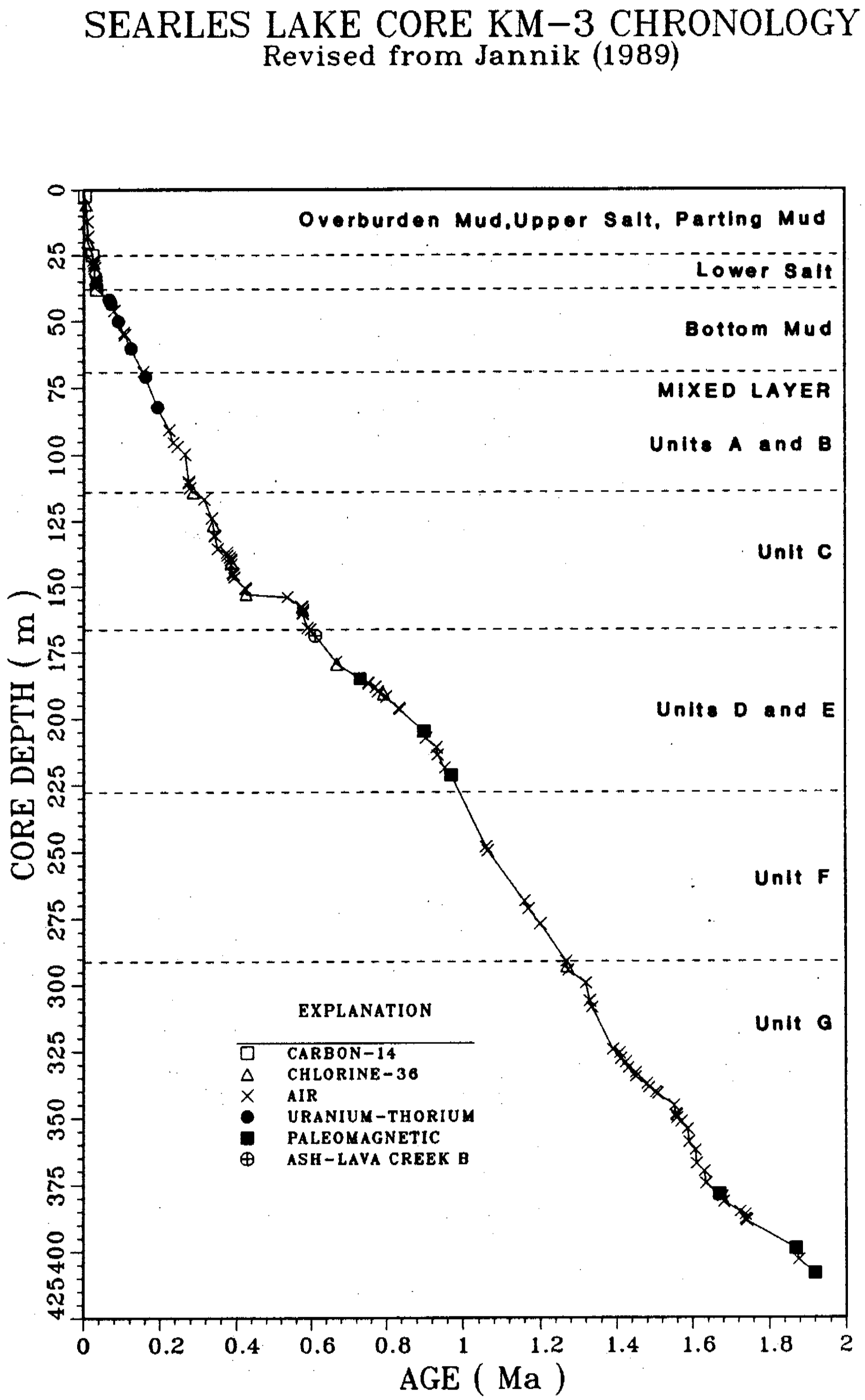

Figure 6 Age versus depth relationship for the upper 425 m of core KM-3, using carbon-14, thorium-230, chlorine-36, paleomagnetic dates, and acid-insoluble residue (AIR) interpolation. Revised from Jannik (1989).

# V. METHODS AND PROCEDURES

## Introduction

A detailed sampling scheme was developed in order to achieve a high time-resolution record of stable isotope variation in Searles Lake paleowaters. Care was taken in sampling the core to minimize location errors. Once the core was been sampled, the relative amounts and types of minerals were determined. Any substances which would interfere with mass spectrometer analysis of primary carbonates was removed from the samples. Following this, a methodology was developed to separate primary carbonates from each other, as each mineral has its own water-carbonate fractionation factor and phosphoric acid fractionation factor.

## Sampling

247 samples were collected from core KM-3 mud units during October of 1986. The desired sampling frequency was approximately one sample every one to two thousand years. Using Smith and others' (1983) core log and calculated sedimentation rates as a guide, approximately fifty grams of sample were taken every one to two feet in most intervals from the Parting Mud through Unit G of the Mixed Layer. Sample descriptions and field notes are listed in Appendix B. Care was taken to remove large macroscopic salt crystals

and to scrape off the outside of the core to minimize contamination. Severe "telescoping" had occurred in several core boxes; the core boxes with this problem are noted in Appendix B. Sample depths are listed to the tenth of a foot, but this should not be interpreted to imply confidence in the depths to this degree, especially in intervals with severe "telescoping" problems.

## Sample Preparation

Core samples contain a variety of primary and secondary authigenic minerals as described in an earlier section. In order to obtain a good stable isotopic analysis of the primary carbonate (principally dolomite), minerals which could interfere with the analysis of the carbonate had to be removed. The samples also contain detrital silicates; however, it was not necessary to remove the silicates as only carbonate minerals react with the phosphoric acid to release $CO_2$ in the acid extraction technique.

Both physical and chemical methods were used to achieve the separation of the primary carbonate from interfering minerals. First, macroscopic crystals of unwanted salts were removed from the sample by hand-picking. These crystals included secondary carbonate (gaylussite and pirssonite), bicarbonates, sulfates and halite. Halite needed to be removed from the samples as it was found to react with phosphoric acid to produce HCl gas; the HCl gas creates severe problems during the mass spectrometry analysis.

Due to the much greater solubility of the unwanted minerals than the primary carbonates, water leaching was used as a second step to dissolve the remaining unwanted minerals. This procedure is described in Appendix C. X-ray diffraction (XRD) techniques were used to determine the success of the leaching procedure. Scanning parameters and XRD results are listed in Appendix B.

An unexpected problem with the leaching procedure was raised by the XRD results. Although the diagenetic carbonates identified by XRD in bulk samples dissolved, calcite appeared to have precipitated during the leaching process. An experiment was conducted to determine the origin of this calcite which I have dubbed "mongrel" calcite due to its uncertain parentage. Clean gaylussite and pirssonite crystals were placed in water to dissolve overnight. The solid collected by filtration was identified by XRD as calcite and confirmed that calcite had resulted from the dissolution of the two diagenetic carbonates. This phenomenon was previously observed by G.I. Smith (pers. comm). Whether the calcite was the result of incongruent dissolution or a later precipitate is not known.

A second problem with the leaching process was the occasional persistence of pirssonite and, more often, northupite. Repeated leaching could not remove all of these

| AGE ( Ma ) | DEPTH (m) | DEPTH (ft) | DATE TYPE |
|---|---|---|---|
| 0.57680 | 159.000 | 521.652 | AIR |
| 0.57700 | 160.000 | 524.933 | AIR |
| 0.57700 | 160.300 | 525.918 | AIR |
| 0.59000 | 165.800 | 543.962 | AIR |
| 0.59800 | 166.420 | 545.996 | AIR |
| 0.61000 | 168.600 | 553.148 | ASH |
| 0.66700 | 178.640 | 586.088 | AIR |
| 0.66800 | 179.410 | 588.614 | CL-36 |
| 0.73000 | 185.000 | 606.954 | Paleo-Mag |
| 0.75100 | 186.540 | 612.007 | AIR |
| 0.75200 | 186.900 | 613.188 | AIR |
| 0.77100 | 188.150 | 617.289 | AIR |
| 0.77800 | 189.950 | 623.194 | AIR |
| 0.79200 | 190.700 | 625.655 | CL-36 |
| 0.79900 | 192.020 | 629.986 | AIR |
| 0.83400 | 196.140 | 643.503 | AIR |
| 0.83500 | 196.660 | 645.209 | AIR |
| 0.89600 | 204.520 | 670.996 | AIR |
| 0.90000 | 204.900 | 672.243 | Paleo-Mag |
| 0.90400 | 207.450 | 680.609 | AIR |
| 0.93200 | 210.920 | 691.993 | AIR |
| 0.93500 | 213.660 | 700.983 | AIR |
| 0.95300 | 218.540 | 716.993 | AIR |
| 0.97000 | 221.200 | 725.720 | Paleo-Mag |
| 1.06000 | 248.110 | 814.008 | AIR |
| 1.06400 | 249.480 | 818.502 | AIR |
| 1.16000 | 268.530 | 881.002 | AIR |
| 1.17000 | 271.420 | 890.484 | AIR |
| 1.20000 | 276.910 | 908.496 | AIR |
| 1.26800 | 291.080 | 954.985 | AIR |
| 1.27000 | 293.000 | 961.284 | CL-36 |
| 1.27300 | 294.440 | 966.009 | AIR |
| 1.32000 | 299.310 | 981.986 | AIR |
| 1.33000 | 306.020 | 1004.001 | AIR |
| 1.33500 | 308.460 | 1012.006 | AIR |
| 1.39000 | 324.310 | 1064.007 | AIR |
| 1.40800 | 325.530 | 1068.010 | AIR |
| 1.41000 | 327.960 | 1075.982 | AIR |
| 1.42400 | 329.180 | 1079.985 | AIR |
| 1.43000 | 331.320 | 1087.006 | AIR |
| 1.45000 | 333.150 | 1093.010 | AIR |
| 1.45000 | 334.670 | 1097.996 | AIR |
| 1.48000 | 337.260 | 1106.494 | AIR |
| 1.48500 | 338.630 | 1110.989 | AIR |
| 1.50300 | 340.310 | 1116.500 | AIR |
| 1.50800 | 341.070 | 1118.994 | AIR |
| 1.55200 | 345.340 | 1133.003 | AIR |
| 1.55500 | 348.690 | 1143.994 | AIR |
| 1.55700 | 349.150 | 1145.503 | AIR |
| 1.55800 | 350.220 | 1149.013 | AIR |
| 1.57000 | 351.430 | 1152.983 | AIR |
| 1.58600 | 354.180 | 1162.005 | AIR |
| 1.59000 | 359.050 | 1177.983 | AIR |
| 1.60700 | 362.100 | 1187.990 | AIR |
| 1.61000 | 367.130 | 1204.492 | AIR |
| 1.63000 | 370.030 | 1214.007 | AIR |
| 1.63500 | 374.750 | 1229.492 | AIR |
| 1.67000 | 378.560 | 1241.992 | Paleo-Mag |
| 1.67200 | 379.170 | 1243.994 | AIR |
| 1.67800 | 379.630 | 1245.503 | AIR |
| 1.68100 | 381.610 | 1251.999 | AIR |
| 1.72400 | 385.270 | 1264.007 | AIR |
| 1.73700 | 386.330 | 1267.484 | AIR |
| 1.73800 | 388.010 | 1272.996 | AIR |
| 1.74000 | 388.620 | 1274.997 | AIR |
| 1.87000 | 398.980 | 1308.987 | Paleo-Mag |
| 1.87700 | 403.250 | 1322.996 | AIR |
| 1.92000 | 408.300 | 1339.564 | Paleo-Mag |

# Appendix B

## Core Sampling Field Notes and X-Ray Diffraction Results

# APPENDIX B

## FIELD NOTES and X-RAY DIFFRACTION RESULTS

Field Notes: Kerr-McGee core shed, Trona, California
October 28-30, 1986

### ABBREVIATIONS USED

lt=light
xtals=crystals
CAL=calcite
GAY=gaylussite
THEN=thenardite

dk=dark
mass=massive
ARAG=aragonite
PIRS=pirsonnite
HAL=halite

lam=laminated
DOL=dolomite
TRON=trona
NORT=northupite

X-Ray Diffraction results from runs at NMIMT
Samples scanned from 25-35 degrees 2-theta

M= major phase
I= intermediate phase
TR= trace phase

| CORE DEPTH ( ft.) | CORE DEPTH ( m ) | FIELD DESCRIPTION | XRD LEACHED SAMPLES | XRD BULK SAMPLES |
|---|---|---|---|---|
| 65.5 | 20.18 | mud, dk green lam; GAY xtals | M-calcite | M-gaylussite |
| 66.1 | 20.34 | mud, alternating green/ white (ARAG?)finely lam; | M-calcite,<br>TR-dolomite | |
| 66.6 | 20.49 | as 66.6 | I-aragonite,<br>TR-calcite<br>TR-dolomite | |
| 68.1 | 20.95 | mud, green finely lam; GAY xtals, borax | M-calcite,<br>TR-Gaylussite(?)<br>TR-dolomite | |
| 68.6 | 21.11 | mud, green/white finely lam; | I-dolomite,<br>TR-calcite<br>TR-aragonite(?) | |
| 69.1 | 21.26 | mud, lt green/white lam; | I-dolomite,<br>TR-calcite | |
| 69.6 | 21.42 | mud, green/white lam; | TR-calcite,<br>TR-dolomite<br>TR-aragonite(?) | |
| 70.1 | 21.57 | mud, green/white lam, lam more widely spaced than above; | I-calcite,<br>TR-aragonite,<br>TR-calcite | |
| 70.6 | 21.72 | as 70.1 | TR-calcite,<br>TR-aragonite,<br>TR-dolomite | |
| 71.0 | 21.85 | as 70.1<br>** possible depth error (.7 ft too deep last 7 samples)***** | I-aragonite,<br>TR-calcite<br>TR-dolomite | |
| 71.6 | 22.03 | mud, green/white lam, lam more frequent than 70.1-71.0; | I-aragonite,<br>TR-calcite | |

| CORE DEPTH ( ft.) | CORE DEPTH ( m ) | FIELD DESCRIPTION | XRD LEACHED SAMPLES | XRD BULK SAMPLES |
|---|---|---|---|---|
| 72.1 | 22.18 | mud, white/green lam white lam thicker than above; | I-aragonite,<br>TR-calcite | |
| 72.6 | 22.34 | mud, dk green/white lam, white lam less frequent than above (several mm apart); | I-aragonite,<br>TR-calcite | |
| 73.1 | 22.49 | mud, yellow-green/ white lam, lam finer than 72.6; | I-aragonite,<br>TR-calcite,<br>TR-dolomite | |
| 73.6 | 22.65 | mud, green/white lam, lam as 72.6; | I-aragonite,<br>TR-dolomite | |
| 74.1 | 22.80 | mud, lt green/white lam, white lam (~2 mm) parted from green; | I-aragonite,<br>TR-calcite | |
| 74.6 | 22.95 | as 74.1; possible GAY xtals | I-aragonite,<br>TR-dolomite,<br>TR-calcite | |
| 75.3 | 23.17 | as 74.1; | I-aragonite,<br>TR-calcite | |
| 75.8 | 23.32 | mud, lt grey-green, friable;GAY xtals | I-calcite,<br>I-dolomite | |
| 80.0 | 24.62 | mud, lt grey, friable; GAY xtals<br>**** HAND SAMPLE **** | I-calcite,<br>I-dolomite | |
| 81.0 | 24.92 | mud, lt grey,dense; | I-calcite,<br>TR-dolomite<br>TR-pirssonite(?) | |
| 81.6 | 25.11 | mud, dk green,friable; large borax xtals, small (PIRS?) xtals | I-calcite,<br>TR-dolomite<br>TR-pirssonite(?) | |
| 81.9 | 25.20 | mud, dk green;borax xtals, large (PIRS?) xtals, sm trona (?) | I-calcite,<br>TR-dolomite<br>TR-pirssonite?<br>TR-trona | M-pirssonite<br>I-trona<br>TR-dolomite |
| | | ********* BOTTOM OF PARTING MUD ********* | | |
| 89.5 | 27.54 | mud, dk green; GAY(?) xtals | M-calcite | |
| 90.7 | 27.91 | mud, dk green lam; GAY xtals | M-calcite | |
| 91.5 | 28.15 | mud,dk green; mainly HAL(?)xtals,few large borax xtals | TR-calcite,<br>TR-aragonite(?) | |
| 95.5 | 29.38 | mud, lt green-yellow lam; GAY xtals | I-calcite | |
| 96.6 | 29.72 | mud, dk green; mainly GAY xtals | M-calcite | I-gaylussite<br>I-burkeite |

| CORE DEPTH ( ft.) | CORE DEPTH ( m ) | FIELD DESCRIPTION | XRD LEACHED SAMPLES | XRD BULK SAMPLES |
|---|---|---|---|---|
| 104.9-<br>115.5 | | ****PHOTOS**** | trona and halite units | |
| 111.7 | 34.37 | mud, lt green finely lam; no salt xtals (above large trona seam) | I-calcite | |
| 113.3 | 34.86 | mud, lt green finely lam;(below trona seam) | TR-aragonite,<br>TR-calcite | |
| 114.5 | 35.23 | mud, very lt green lam; | I-calcite,<br>TR-aragonite | |
| 115.9 | | ****HAND SAMPLE**** | Algal mats(?) | |
| 116.4 | 35.82 | mud, green, finely lam; some small borax xtals | M-calcite | |
| 118.5 | 36.46 | mud ,finely lam; | I-calcite,<br>TR-aragonite | |
| 120.0 | 36.92 | mud, lt grey-green; small trona xtals | I-calcite | |
| | | ************ TOP OF BOTTOM MUD ************************ | | |
| 124.9 | 38.43 | mud, lt green/orange lam; | M-calcite,<br>TR-dolomite | |
| 125.7 | 38.68 | mud, green lam; possible borax | M-calcite | |
| 126.3 | 38.86 | mud, green finely lam; coarse GAY xtals | I-calcite,<br>I-dolomite | |
| 126.9 | 39.05 | mud, buff, lam; GAY xtals | I-dolomite,<br>TR-calcite | |
| 127.7 | 39.29 | mud, dk green, lam; GAY xtals,HAND SAMPLE | I-calcite,<br>TR-dolomite | |
| 128.7 | 39.60 | mud, dk green; ~95% GAY xtals | TR-dolomite,<br>TR-calcite | |
| 128.9 | 39.66 | mud, buff/green lam; NO macroscopic GAY xtals | I-dolomite,<br>TR-calcite,<br>TR-aragonite(?) | |
| 129.8 | 39.94 | mud, lt green/buff lam; small GAY xtals | M-calcite, | |
| 130.1 | 40.03 | mud, lt green/buff finely lam;( above THEN seam) | I-dolomite,<br>TR-calcite | |
| 130.4 | 40.12 | mud, buff,crudely lam; ( below THEN seam) | M-calcite,<br>I-dolomite | I-gaylussite<br>I-dolomite |
| 131.5 | 40.46 | mud, dk green/buff lam; | I-aragonite,<br>TR-calcite<br>TR-dolomite | |

| CORE DEPTH ( ft.) | CORE DEPTH ( m ) | FIELD DESCRIPTION | XRD LEACHED SAMPLES | XRD BULK SAMPLES |
|---|---|---|---|---|
| 132.3 | 40.71 | mud, dk green lam; ~80% GAY xtals | TR-dolomite,<br>TR-calcite<br>TR-aragonite | |
| 134.4 | 41.35 | mud, lt green, mass; | M-calcite,<br>TR-dolomite | M-gaylussite<br>TR-dolomite |
| 136.4 | 41.97 | mud, grey, mass; THEN(?) xtals (above THEN seam) | M-calcite,<br>TR-dolomite | |
| 137.5 | 42.31 | mud, green-grey finely lam; (below THEN seam) | M-calcite,<br>TR-dolomite | |
| 139.0 | 42.77 | mud, dk green/white lam; | I-aragonite,<br>TR-calcite<br>TR-dolomite | I-aragonite<br>TR-calcite<br>TR-dolomite |
| 140.5 | 43.23 | as 139.0, lam spaced further apart; coarse GAY xtals | M-dolomite,<br>Tr-calcite | M-dolomite<br>TR-calcite |
| 141.8 | 43.63 | mud, dk green/white lam, lam spaced further apart than 140.5; | I-aragonite,<br>I-dolomite<br>TR-calcite | I-dolomite<br>I-aragonite<br>TR-calcite |
| 142.8 | 43.94 | mud, dk green, finely lam; | I-dolomite<br>TR-calcite<br>TR-aragonite | |
| ***** | LOTS OF TELESCOPING IN CORE BOXES (150-200 ft); DEPTHS DUBIOUS! ***** ( MEASUREMENTS RECORDED TO TENTH OF FOOT DOES NOT IMPLY CONFIDENCE AT THIS LEVEL!!!!!!!!) | | | |
| 151.1 | 46.49 | mud, grey-green; mainly GAY xtals | I-dolomite,<br>I-calcite | |
| 153.0 | 47.08 | as 151.1; | I-calcite | |
| 154.1 | 47.42 | as 151.1; | I-calcite | |
| 158.6 | 48.80 | mud, lt green, finely lam; | M-dolomite | |
| 164.0 | 50.46 | mud, lt green, mass; | M-dolomite | |
| 170.0 | 52.31 | mud, dk green; small salt(?) xtals | I-dolomite | |
| 178.5 | 54.92 | mud, green, mass; | TR-calcite,<br>TR-dolomite | |
| 183.0 | 56.31 | mud, lt green, finely lam; few salt(?) xtals | I-calcite,<br>I-dolomite | |
| 187.4 | 57.66 | mud, lt to dk green, finely lam; small salt(?) xtals | I-calcite,<br>I-dolomite | |
| 189.4 | 58.28 | as 187.4; more salt(?) xtals | M-calcite,<br>TR-dolomite | |

| CORE DEPTH ( ft.) | CORE DEPTH ( m ) | FIELD DESCRIPTION | XRD LEACHED SAMPLES | XRD BULK SAMPLES |
|---|---|---|---|---|
| 191.9 | 59.05 | mud, dk grey-green,<br>lam; GAY xtals | M-calcite | |
| 194.9 | 59.97 | mud, green, lam; | I-dolomite | |
| 199.9 | 61.51 | as 194.9;GAY xtals | I-dolomite,<br>TR-calcite | |
| 205.0 | 63.08 | mud, green,lam;<br>GAY xtals | M-calcite,<br>I-dolomite | |
| 211.1 | 64.95 | mud, green;<br>GAY xtals | I-calcite | |
| 218.0 | 67.08 | mud, dk green-black;<br>few salt(?) xtals | I-dolomite | |
| 221.0 | 68.00 | mud, dk green/buff<br>lam, lam 2-10mm @;<br>small salt(?) xtals | M-dolomite | M-dolomite |
| 224.1 | 68.95 | as 221.0; | I-dolomite | |
| 226.6 | 69.72 | mud, dk green-black,<br>finely laminated,<br>orange stained; | I-dolomite | |
| 256.1 | 78.80 | mud, green-buff;<br>salt(?) xtals | TR-dolomite,<br>TR-calcite | |
| 257.0 | 79.08 | mud, lt green,<br>orange stained;<br>salt(?) xtals | I-calcite,<br>TR-dolomite | |

**************** LIMITED CORE RECOVERY; DEPTH DUBIOUS!!!!!*********

| CORE DEPTH ( ft.) | CORE DEPTH ( m ) | FIELD DESCRIPTION | XRD LEACHED SAMPLES | XRD BULK SAMPLES |
|---|---|---|---|---|
| 277.5 | 85.38 | mud, lt grey/dk green<br>crumbled mud; salt(?)<br>xtals | TR-dolomite,<br>TR-calcite | |

**************** END OF LIMITED CORE RECOVERY ********************

| CORE DEPTH ( ft.) | CORE DEPTH ( m ) | FIELD DESCRIPTION | XRD LEACHED SAMPLES | XRD BULK SAMPLES |
|---|---|---|---|---|
| 288.1 | 88.65 | mud, lt grey-green,<br>mass; salt(?) xtals | TR-calcite | |
| 298.1 | 91.72 | as 288.1, less<br>consolidated; | I-calcite | |
| 308.0 | 94.77 | mud, lt green,<br>mass; small salt(?)<br>xtals | I-calcite | |
| 326.5 | 100.46 | mud, lt green,<br>orange-stained;<br>~ 50% salts | TR-calcite,<br>TR-aragonite(?) | I-gaylussite<br>TR-Northupite<br>TR-aragonite? |
| 349.9 | 107.66 | as 326.5;<br>more salt | I-northupite | I-northupite |
| 359.3 | 110.55 | as 326.5; | TR-calcite<br>Unknown peaks<br>25-28 2-theta | |
| 369.5 | 113.69 | mud, lt green;<br>small salt xtals | TR-aragonite<br>TR-calcite?<br>unknown peaks | |

| CORE DEPTH ( ft.) | CORE DEPTH ( m ) | FIELD DESCRIPTION | XRD LEACHED SAMPLES | XRD BULK SAMPLES |
|---|---|---|---|---|
| 370.5 | 114.00 | mud, lt green, orange staining; small salt xtals | TR-calcite | |
| 371.8 | 114.40 | mud, lt green; trona | TR-calcite | |
| 373.3 | 114.86 | as 371.8; | TR-calcite | |
| 375.0 | 115.38 | mud, lt green; | I-calcite | |
| 446.1 | 137.26 | mud, green-black; few salt(?) xtals | TR-calcite<br>TR-thenardite? | |
| 447.5 | 137.69 | mud, lt green, orange stained; few salt(?) xtals | TR-calcite | |
| 448.5 | 138.00 | as 447.5; less salt | TR-calcite<br>TR-thenardite? | |
| 449.4 | 138.28 | as 447.5; | I-calcite | |
| 453.0 | 139.38 | mud, dk green; mainly salt | TR-dolomite | |
| 455.5 | 140.15 | as 453.0; | M-northupite<br>TR-dolomite | |
| 457.0 | 140.62 | mud, dk green; trona,other salts(?) | I-northupite<br>TR-calcite? | |
| 459.5 | 141.38 | mud, green; salts(?) | TR-calcite | |
| 476.0 | 146.46 | as 459.6; | I-calcite | |
| 481.0 | 148.00 | mud, green-grey; more salt than 459.6; | I-calcite, | |
| 483.4 | 148.74 | mud, lt green, orange-stained; large salt(?) xtals | I-calcite | |
| 484.4 | 149.05 | as 483.4; trona | I-calcite | |
| 485.7 | 149.45 | mud, green, orange-stained; large salt(?) xtals | I-calcite,<br>TR-pirssonite | |
| 486.0 | 149.54 | as 485.7; | I-calcite | |
| 487.8 | 150.09 | mud, dk green; small salt(?) xtals | I-calcite | |
| 489.0 | 150.46 | mud, lt green; small salt(?) xtals | I-calcite | |
| 490.0 | 150.77 | mud, lt green, orange-stained; large salt(?) xtals | TR-northupite<br>TR-dolomite<br>TR-calcite(?) | |

| CORE DEPTH ( ft.) | CORE DEPTH ( m ) | FIELD DESCRIPTION | XRD LEACHED SAMPLES | XRD BULK SAMPLES |
|---|---|---|---|---|
| 491.2 | 151.14 | mud, lt green, orange-stained; smaller salt(?) xtals than above | M-calcite | |
| 492.0 | 151.38 | as 491.2; more salt(?) than 491.2 | M-calcite<br>TR-pirssonite? | |
| 493.2 | 151.75 | as 491.2; | I-calcite | |
| 493.9 | 151.97 | mud, green; from thin bed of mud in between halite seams (@~6-8 cm) | I-calcite | |
| 502.1 | 154.49 | mud, green; large halite xtals | TR-calcite | |
| 546.1 | 168.03 | mud, dk green; PIRS xtals | I-calcite | |
| 547.4 | 168.43 | as 546.1; | M-calcite | |
| 547.7 | 168.52 | mud, dk green-black; less PIRS xtals than 546.1 | I-calcite | |
| 548.5 | 168.77 | mud, green; many small salt(?) xtals | M-calcite | |
| 549.5 | 169.08 | as 548.5; | I-calcite | |
| 550.5 | 169.38 | mud, lt green; large PIRS(?) xtals | M-calcite,<br>TR-dolomite | I-dolomite<br>I-pirssonite |
| 551.7 | 169.75 | mud, green; PIRS(?) xtals | M-calcite | |
| 552.6 | 170.03 | mud, dk green, orange-stained; small PIRS? xtals | I-calcite | |
| 553.8 | 170.40 | as 552.6; | I-calcite<br>Tr-pirssonite? | |
| 555.0 | 170.77 | mud, green, finely lam; little salt | M-calcite<br>TR-dolomite | |
| 556.0 | 171.08 | mud, lt green; small salt? xtals | M-calcite<br>TR-dolomite | |
| 557.1 | 171.42 | mud, lt green, orange-stained; small salt? xtals | I-calcite<br>TR-dolomite | |
| 558.2 | 171.75 | mud, dk green-black; small salt? xtals | I-calcite<br>TR-dolomite | |
| 559.2 | 172.06 | mud, green;white powdery substance, small salt? | TR-calcite<br>TR-dolomite | |
| 560.1 | 172.34 | mud, green, finely lam; some salts? | I-calcite<br>I-dolomite<br>TR-thenardite<br>TR-northupite? | |

| CORE DEPTH ( ft.) | CORE DEPTH ( m ) | FIELD DESCRIPTION | XRD LEACHED SAMPLES | XRD BULK SAMPLES |
|---|---|---|---|---|
| 561.0 | 172.62 | as 560.1; | I-calcite,<br>TR-dolomite | |
| 562.2 | 172.98 | mud, dk green-black;PIRS xtals | M-calcite,<br>TR-dolomite | |
| 563.2 | 173.29 | mud, green;PIRS xtals | I-calcite,<br>TR-dolomite | |
| 564.3 | 173.63 | mud, dk green, finely lam;salt? xtals | I-calcite,<br>I-dolomite | |
| 565.3 | 173.94 | mud, green;mainly PIRS? xtals | M-calcite,<br>I-dolomite | I-dolomite<br>TR-pirssonite |
| 567.0 | 174.46 | as 565.3; | I-calcite,<br>TR-dolomite | |
| 568.7 | 174.98 | mud, dk green; mainly PIRS? xtals | I-calcite,<br>TR-dolomite | |
| 569.9 | 175.35 | mud, lt green, orange-stained; few salt? xtals | M-dolomite,<br>TR-northupite? | |
| 571.2 | 175.75 | mud, lt green, orange-stained; large salt? xtals | I-dolomite,<br>TR-calcite | |
| 572.5 | 176.15 | as 569.9; | I-dolomite | |
| 573.8 | 176.55 | mud, yellow-black, finely lam; | TR-dolomite | |
| 574.9 | 176.89 | as 573.8; | I-dolomite | |
| 575.4 | 177.05 | mud, lt green-yellow, finely lam; large salt? xtals | M-dolomite,<br>I-calcite<br>TR-northupite | |
| 576.4 | 177.35 | as 575.4; | TR-dolomite | |
| 577.6 | 177.72 | mud, green-grey, hard,dense; small salt? xtals | M-calcite | |
| 578.6 | 178.03 | as 577.6, some orange-staining | I-calcite,<br>TR-dolomite | |
| 579.5 | 178.31 | mud, yellow-green, hard, dense, finely lam;few small salt? xtals | I-calcite,<br>TR-dolomite | |
| 580.7 | 178.68 | as 579.5; | I-calcite,<br>TR-dolomite | |
| 582.2 | 179.14 | mud, yellow-black, hard, dense; white stringers?, small salt? xtals | I-calcite,<br>TR-dolomite? | |
| 583.3 | 179.48 | mud, green-grey, hard,dense, some orange-staining; | TR-thenardite<br>TR-trona<br>Tr-calcite | |

| CORE DEPTH ( ft.) | CORE DEPTH ( m ) | FIELD DESCRIPTION | XRD LEACHED SAMPLES | XRD BULK SAMPLES |
|---|---|---|---|---|
| 584.2 | 179.75 | mud, orange-black; some salt? xtals, trona? | TR-calcite,<br>TR-dolomite? | |
| 587.8 | 180.86 | mud, dk green-black, orange-stained; large salt? xtals,(below 2ft seam of halite) | TR-calcite | |
| 590.9 | 181.82 | mud, yellow-dk green, lam; small salt? xtals | I-dolomite | |
| 592.6 | 182.34 | as 590.9; salt? xtals larger, more frequent | M-northupite,<br>TR-dolomite,<br>TR-calcite | |
| 594.8 | 183.02 | mud, lt green-yellow, salt? xtals | M-dolomite | |
| 598.5 | 184.15 | mud, lt green-yellow, hard, orange-stained, small salt? xtals | I-calcite,<br>I-dolomite | I-dolomite<br>TR-pirssonite |
| 601.5 | 185.08 | mud, orange-green; large salt? xtals | TR-thenardite | |
| 603.0 | 185.54 | as 601.5;(just below thin trona seam) | I-northupite,<br>I-pirssonite<br>TR-calcite,<br>TR-dolomite | |
| 605.0 | 186.15 | mud, orange-green; ~50% salt xtals | I-pirssonite<br>TR-calcite | |
| 607.9 | 187.05 | mud, green-grey; large salt? xtals | TR-northupite<br>TR-calcite<br>TR-dolomite? | |
| 609.9 | 187.66 | mud, orange-green; ~50% salt? xtals | M-pirssonite<br>M-northupite<br>TR-dolomite | |
| 611.5 | 188.15 | as 609.9; (0.7 ft above trona seam) | TR-thenardite<br>TR-dolomite | |
| 615.0 | 189.23 | mud, orange-green; samll xtals | TR-northupite | |
| 624.0 | 192.00 | as 615.0; small PIRS? xtals | I-calcite | |
| 631.8 | 194.40 | mud, dk green-orange, hard, dense; small salt? xtals | TR-calcite | |
| 634.2 | 195.14 | mud, dk green-black, hard, dense, orange staining; small salt? xtals | I-calcite,<br>TR-dolomite | |
| 636.4 | 195.82 | as 634.2; less salt? | TR-calcite,<br>TR-dolomite | |

| CORE DEPTH ( ft.) | CORE DEPTH ( m ) | FIELD DESCRIPTION | XRD LEACHED SAMPLES | XRD BULK SAMPLES |
|---|---|---|---|---|
| 638.5 | 196.46 | mud, lt green, hard, dense, orange stained; salt? stringers | TR-northupite<br>TR-calcite | |
| 641.1 | 197.26 | as 638.5; | TR-dolomite,<br>TR-calcite | |
| 642.5 | 197.69 | mud, lt green, less dense than above; ~50% salts | M-calcite,<br>TR-dolomite | |
| 645.2 | 198.52 | mud, green, crumbly; ~30% salts (below 1.5 ft halite seam) | M-calcite,<br>TR-dolomite | |
| 647.4 | 199.20 | mud, dk green; ~20% salts | M-calcite,<br>TR-pirssonite | |
| 651.4 | 200.43 | as 647.4; | M-calcite | |
| 653.6 | 201.11 | mud, grey; little salt | M-calcite<br>I-dolomite | I-dolomite<br>I-pirssonite |
| 659.2 | 202.83 | mud, green-grey; little salt | TR-calcite<br>TR-dolomite | |
| 661.7 | 203.60 | as 659.2; | TR-calcite<br>TR-dolomite | |
| 664.8 | 204.55 | mud, dk green; few salt? xtals | I-dolomite | |
| 666.5 | 205.08 | as 664.8; | TR-calcite<br>TR-dolomite<br>TR-northupite? | |
| 668.4 | 205.66 | mud, green-grey, orange-stained; few salts | I-calcite<br>I-dolomite | |
| 670.2 | 206.22 | mud, dk green-orange; few salt stringers | TR-dolomite<br>TR-northupite? | |
| 671.5 | 206.62 | mud, grey-black; small salt? xtals | TR-dolomite?<br>TR-northupite? | |
| 680.7 | 209.45 | mud, yellow-green; little salt | M-dolomite | |
| 684.7 | 210.68 | mud, white, soft; no salt | M-dolomite | |
| 690.3 | 212.40 | mud, lt green-orange; PIRS? xtals | TR-dolomite<br>TR-calcite | |
| 701.2 | 215.75 | mud, green-brown; ~60% salts?(just below coarse halite) | I-northupite<br>I-dolomite | |
| 706.2 | 217.29 | mud, green; large salt? xtals | M-calcite<br>TR-pirssonite | |
| 710.2 | 218.52 | as 706.2; | M-calcite<br>TR-pirssonite | |

| CORE DEPTH ( ft.) | CORE DEPTH ( m ) | FIELD DESCRIPTION | XRD LEACHED SAMPLES | XRD BULK SAMPLES |
|---|---|---|---|---|
| 713.4 | 219.51 | as 706.2; | I-calcite<br>TR-pirssonite | |
| 717.0 | 220.62 | mud, dk green; salt? xtals | I-calcite<br>TR-pirssonite | |
| 724.9 | 223.05 | as 717.0; | I-calcite<br>Tr-pirssonite | |
| 727.5 | 223.85 | mud, green, crumbly; small PIRS? xtals | I-calcite | |
| 747.2 | 229.91 | mud, lt grey-orange, lam w/ salts;(just above minor halite seam) | I-dolomite<br>TR-calcite | |
| 750.0 | 230.77 | mud, lt green; little salt | I-dolomite | |
| 752.5 | 231.54 | mud, buff/black lam; salt? xtals | TR-calcite<br>TR-northupite<br>TR-dolomite | TR-pirssonite<br>TR-northupite<br>TR-dolomite |
| 758.0 | 233.23 | as 752.5;less salt | I-dolomite<br>TR-calcite | |
| 762.4 | 234.58 | mud, grey/buff lam; little salt | M-dolomite | |
| 766.5 | 235.85 | mud, green/buff lam; more salt than 762.4 | M-calcite<br>TR-dolomite | I-pirssonite<br>TR-dolomite |
| 772.2 | 237.60 | mud, buff/orange lam; little salt | TR-calcite<br>TR-dolomite | |
| 775.8 | 238.71 | mud, green-orange, lam; minor salt | I-dolomite | |
| 780.8 | 240.25 | mud, green-dk orange; PIRS? xtals | M-calcite<br>I-dolomite | |
| 785.9 | 241.82 | mud, green, mass; | I-dolomite | |
| 794.2 | 244.37 | mud, green-orange, mass; | I-dolomite | |
| 798.7 | 245.75 | as 780.8; | I-calcite<br>I-dolomite | |
| 805.0 | 247.69 | mud, dk green-orange; minor salts | I-calcite<br>TR-dolomite | |
| 814.0 | 250.46 | mud, lt green; large amounts of salts? | I-calcite<br>TR-dolomite | |
| 818.2 | 251.75 | mud, green-orange, hard, dense; minor amounts of salt | M-calcite<br>TR-dolomite | M-calcite<br>I-pirssonite<br>I-dolomite |
| 823.6 | 253.42 | as 818.2; | TR-calcite | |

| CORE DEPTH ( ft.) | CORE DEPTH ( m ) | FIELD DESCRIPTION | XRD LEACHED SAMPLES | XRD BULK SAMPLES |
|---|---|---|---|---|
| 827.0 | 254.46 | mud, dk green/orange lam, hard; minor salts | TR-calcite<br>TR-dolomite | |
| 831.7 | 255.91 | mud, dk green/orange lam, hard, dense; little salt | TR-dolomite<br>TR-calcite | |
| 837.0 | 257.54 | mud, green/buff lam; no salt<br>***HAND SAMPLE**** | M-dolomite | M-dolomite |
| 841.6 | 258.95 | mud, green-orange; minor salt | I-dolomite<br>TR-calcite | |
| 846.6 | 260.49 | mud, buff;mainly PIRS xtals | M-calcite<br>TR-dolomite<br>TR-pirsonnite | I-pirssonite<br>I-dolomite<br>TR-calcite |
| 859.8 | 264.55 | mud, green-orange, hard,dense; salt stringers | TR-calcite<br>TR-dolomite | |
| 864.0 | 265.85 | mud, lt green-buff; minor salt | I-dolomite | |
| 876.2 | 269.60 | mud, lt green/buff lam; no salt | M-dolomite | |
| 887.6 | 273.11 | mud, green-orange, hard, dense; large amounts of salt | M-calcite<br>TR-dolomite | |
| 893.9 | 275.05 | mud, dk green, hard, dense,orange-stained; minor salt | I-calcite | |
| 898.9 | 276.58 | as 893.9; | I-calcite | |
| 903.1 | 277.88 | mud, green-orange; large amount of salt | I-calcite<br>I-dolomite | |
| 908.6 | 279.57 | mud, green-orange, hard, dense;minor salts | I-calcite<br>TR-dolomite | |
| 917.1 | 282.18 | mud, grey-buff, hard, dense; salt stringers | M-calcite | |
| 922.0 | 283.69 | mud, grey-orange,hard dense; minor salt | M-calcite<br>TR-dolomite | M-calcite<br>TR-dolomite |
| 930.0 | 286.15 | mud, lt green-orange; minor salt | TR-calcite<br>TR-dolomite | |
| 935.7 | 287.91 | as 930.0; | TR-calcite<br>TR-dolomite | |
| 939.9 | 289.20 | mud, green/orange lam; hard, dense; salt xtals | TR-calcite<br>TR-dolomite | |
| 948.0 | 291.69 | mud, green-orange, hard, dense; salt xtals | M-calcite | |

| CORE DEPTH ( ft.) | CORE DEPTH ( m ) | FIELD DESCRIPTION | XRD LEACHED SAMPLES | XRD BULK SAMPLES |
|---|---|---|---|---|
| 955.0 | 293.85 | mud, dk green, hard, dense;minor salt | I-calcite<br>TR-dolomite | |
| 959.0 | 295.08 | mud, green, hard, dense; minor salt | M-calcite | |
| 966.0 | 297.23 | mud, green/buff lam; salt stringers | M-calcite | M-calcite |
| 972.1 | 299.11 | mud, dk green,mass; | TR-dolomite | |
| 977.0 | 300.62 | mud, green/buff lam; | I-calcite<br>TR-dolomite | I-calcite<br>TR-dolomite |
| 986.0 | 303.38 | mud, green,mass; | I-calcite | |
| 1006.0 | 309.54 | mud, green, mass; minor salt | I-aragonite?<br>TR-calcite<br>TR-dolomite? | |
| 1012.0 | 311.38 | mud, dk green,mass; | I-calcite | |
| 1017.0 | 312.92 | as 1012.0; | I-calcite<br>I-dolomite | |
| 1034.2 | 318.22 | mud, green,mass; large HAL xtals | M-dolomite | |
| 1068.0 | 328.62 | mud, dk green, hard, dense; large HAL xtals | TR-dolomite<br>TR-calcite | |
| 1076.0 | 331.08 | mud, green/orange lam; hard,dense; some salt | I-calcite | I-calcite |
| 1080.4 | 332.43 | mud, green, hard,dense; minor salt | TR-calcite | |
| 1089.0 | 335.08 | mud, green, lam; | I-calcite | |
| 1093.0 | 336.31 | mud, green-orange, hard, dense; large HAL xtals | M-calcite | |
| 1099.0 | 338.15 | mud, green, hard, dense; | TR-calcite | |
| 1104.0 | 339.69 | mud, grey/buff lam; minor salt | TR-calcite | |
| 1106.5 | 340.46 | mud, grey-buff, lam;minor salt | TR-calcite | |
| 1110.6 | 341.72 | mud, grey-black lam; little salt | TR-calcite | |
| 1115.3 | 343.17 | mud, grey-buff; **HAND SAMPLE** | TR-calcite | |
| 1120.0 | 344.62 | mud, grey lam; minor salt | I-calcite | |
| 1125.5 | 346.31 | mud, green-brown; no salt | TR-calcite | |

| CORE DEPTH ( ft.) | CORE DEPTH ( m ) | FIELD DESCRIPTION | XRD LEACHED SAMPLES | XRD BULK SAMPLES |
|---|---|---|---|---|
| 1130.5 | 347.85 | mud, white/green lam, orange-stained; minor halite | M-calcite<br>I-dolomite | M-calcite<br>I-dolomite |
| 1132.7 | 348.52 | mud, green, lam; minor halite | M-dolomite<br>TR-calcite | |
| 1156.5 | 355.85 | mud, grey/brown lam;minor salt | TR-calcite | |
| 1210.7 | 372.52 | mud, grey-buff, hard, dense; no salt | I-calcite | |
| 1294.0 | 398.15 | mud, grey-buff, hard, dense; **HAND SAMPLE** | TR-calcite | |

# Appendix C

## Water-leaching Procedure

# APPENDIX C

## WATER-LEACHING PROCEDURE

Materials needed:

tweezers
Mortar and Pestle
50 ml centrifuge tubes with caps
distilled water
centrifuge
watch glasses
oven
2-drams vials with lids

**Procedure**

1) Carefully inspect each sample for macroscopic salts crystals (gaylussite, pirssonite, trona, thenardite, borax, northupite, halite, etc. ). Remove all macroscopic salts crystals with tweezers.

2) Grind remaining sample in mortar until it would pass ˜100 mesh.

3) Place approximately five grams of ground mud sample into a 50 ml centrifuge tube. Fill tube with distilled water and cap ( no air pockets should be in the tube).

4) Shake centrifuge tube. Leave sample for 24 hours, shaking periodically, to dissolve soluble salts.

5) After ˜24 hours, check sample. If the sample is cloudy, centrifuge sample until liquid is clear. Carefully decant liquid. Add fresh distilled water, cap, and shake sample to rinse mud. Centrifuge sample until liquid is clear and, again, carefully decant liquid. Repeat the rinsing process at least three times or until liquid shows no signs of color ( the 'leachate' was usually a dark yellow to brown color ).

6) Carefully scrape the centrifuged mud ( not easy ) from the bottom of the centrifuge tube. Place mud on a watch glass. [NOTE: At this point the sample was checked to make sure no tiny salt crystals were visible. If there were crystals visible, the entire leaching process for that sample was repeated.] Place in the oven overnight at a low temperature to dry the mud.

7) Remove sample from oven. [NOTE: again, another check for salt was made. If an efflourescence was

observed, the entire leaching process was repeated.] Remove dried sample from watch glass and crush in mortar until the sample will pass ˜ 200 mesh. Place sample in vial for mass spectrometric analysis.

# Appendix D

## EDTA Dissolution Procedure

# APPENDIX D

## EDTA DISSOLUTION PROCEDURE AND RESULTS

### Introduction

Following Glover (1961) and Bodine and Fernalld (1973), an attempt was made to separate calcite from dolomite using a high pH aqueous solution of the complexing agent EDTA (ethylenedinitrilotetraacetic acid ). The chemical processes governing the dissolution of alkaline earth carbonates by EDTA can be found in Bodine and Fernalld (1973; after Welcher, 1958).

### Materials Needed

Tetrasodium EDTA dihydrate powder
50 ml vials (centrifuge tubes used here) with caps
pH paper or meter
shaker
watch glasses
centrifuge
distilled water
oven
containers for leached sample (2-dram vials used here)

### Procedure Followed

1) A .25M ( near saturation ) solution of EDTA (using tetrasodium EDTA, pH should be ˜10.5) was prepared.

2) Searles Lake sample 127.7 ( a fairly equal mixture of "mongrel calcite and dolomite, and about 30 weight percent carbonate) was selected as a test sample. Four aliquots of water-leached mud sample (passing 100 mesh) at ˜two grams each were placed into 50 ml centrifuge tubes. ˜50 ml of EDTA solution were added to the sample, and the centrifuge tube was capped.

3) The four samples were placed on a shaker for 1,2,4,and

8 hours respectively at room temperature ( ~20° C ). High temperture used by previous investigators were not used due to the extreme rapidity of the complexing reaction.

4) After each time interval had passed, one sample was removed from the shaker. The pH was measured (all samples had a pH between 9.5-10.5).

5) The sample was placed in a centrifuge briefly to spin down solids. The EDTA solution was carefully decanted. The sample was rinsed with distilled water several times to remove all EDTA. The mud was carefully removed from the centrifuge tube and placed on a watch glass. The watch glass was placed in a low temperature oven overnight to dry.

6) Mortar and pestle were used to crush the dried sample until it passed 200 mesh. Samples were placed in vials for XRD analysis.

7) The steps one through six were repeated until eight samples were created (A and B): two 1-hour, two 2-hour, two 4-hour, and two 8-hour samples.

8) X-Ray Diffraction analysis was performed on the eight samples. The samples were scanned from 25-32 degrees 2-$\Theta$ Cu K$\alpha$ for the primary carbonate peaks. The calcite peak gradually disappeared, and the primary dolomite peak diminished slightly by 4 hours and was significantly reduced at 8 hours.

9) The eight samples were analyzed for $^{18}$O and $^{13}$C content at the University of New Mexico (Albuquerque) isotope lab following the methods of McCrea (1950). The UNM lab reported difficulties in the mass spectrometric analyses of these samples: samples 1A, 4A, and 8B were reported "contaminated". The stable isotope content of the remaining samples is shown graphically is fig. 34.

   No acid fraction factors were assigned to the samples. The stable isotope content of the bulk water-leached sample and the dolomite ( determined later) values are included in fig. 34 for illustrative purposes.

## Discussion

The isotopic content of the 1-hour sample is very similar to that of the bulk sample, as would be expected.

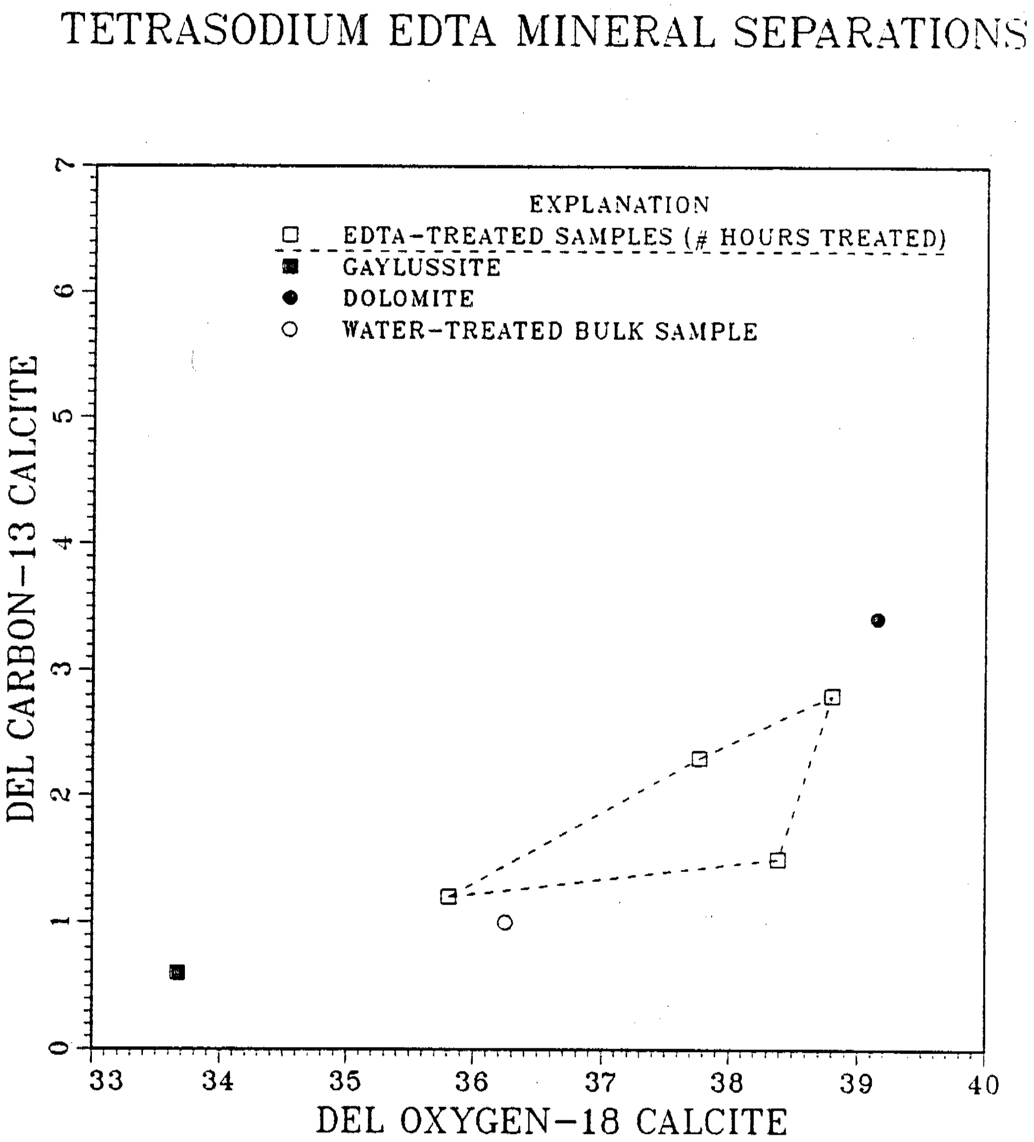

Figure 34. EDTA chemical separation of KM-3 sample 127.7 (feet).

The isotopic content of the 2-hour sample approaches the dolomite values. However, it appears that the EDTA had begun to complex with the dolomite by the 4-hour sample, and by eight hours the isotopic content of the sample had essentially returned to that of the 1-hour sample. It appears that the same relative proportion of calcite/dolomite existed after eight hours of EDTA dissolution as had existed in the 1-hour sample.

The money available for the stable isotope analysis did not permit the detailed mole% calite and dolomite determination nor exhaustive grain size analysis that would have been required to calibrate this procedure. Further, the 'dolomite endpoint' might not be acheived as the EDTA began to complex with the dolomite in the sample.

# Appendix E

## Hierarchical Statistics Analysis of Uncertainty for $^{18}O$ and $^{13}C$ Analyses

```
c
c       PROGRAM RUNS ANALYSIS OF VARIANCE FOR DATA SET
c
        program anova
        character fname*80
        character fname2*20
        character desc*50
        dimension yhia(1000),yhiabar(1000)
        dimension yhi(1000),yhibar(1000),nhi(1000)
        dimension yh(1000),yhbar(1000),nh(1000)
        dimension min(1000),maj(1000)
        DIMENSION EHI(1000),THI(1000),RMHI(1000)

        write(6,*)'enter the input file name'
        read(5,'(a)')fname
        open(unit=99,file=fname,status='old')
        write(6,*)'enter output file name'
        read(5,'(a)')fname2
        open(unit=96,file=fname2,status='new')


        read(99,*)n,nmhi,nmh
        if(n.gt.1000 .or.nmhi.gt.1000 .or. nmh.gt.1000)then
           write(6,*)'program dimensioned to 1000',n,nmhi,nmh
           stop
        endif
        write(6,*)'input number of cycles per minor group'
        read(5,*)k

        do 100 i = 1,n
           read(99,*)yhia(i),min(i),maj(i)
           nhi(min(i)) = nhi(min(i)) + 1
           nh(maj(i)) = nh(maj(i)) + 1
100     continue

        write(96,*)
        write(96,*)
        write(96,*)
        write(96,*)
        write(96,*)
        write(96,*)
        write(6,*)'enter decription'
        read(5,'(a)')desc
        write(96,*)desc
        write(96,*)'_________________________'
        write(96,*)
        write(96,*)'number of points:      ',n
        write(96,*)'number of minor groups:',nmhi
        write(96,*)'number of major groups:',nmh
        write(96,*)

C   data has been input, compute the totals for each minor and major group

        do 200 i = 1,n
           yhi(min(i)) = yhi(min(i)) + yhia(i)
           yh(maj(i)) = yh(maj(i)) + yhia(i)
           y = y + yhia(i)
200     continue
        DO 300 I = 1,NMHI*nmh
           YHIBAR(I) = YHI(I) / FLOAT(NHI(I) )
           WRITE(96,10)' MINOR GROUP #, SIZE, TOTAL, MEAN',
     1                  I,NHI(I),YHI(I),YHIBAR(I)
300     CONTINUE
        WRITE(96,*)
        DO 400 I = 1,NMH
           YHBAR(I) = YH(I) / FLOAT(NH(I) )
        WRITE(96,10)' MAJOR GROUP #, SIZE, TOTAL, MEAN',
     1                  I,NH(I),YH(I),YHBAR(I)
```

```
400     CONTINUE
        YBAR = Y/FLOAT(N)
        write(96,*)
        WRITE(96,10)' TOTAL RUN      SIZE, TOTAL, MEAN',1,N,Y,YBAR
10      FORMAT(1X,A,I5,1X,I5,1X,1PE12.4,1X,1PE12.4)
        WRITE(96,*)
        WRITE(96,*)

C    OK SO THE YH... AND NH ARRAYS HAVE BEEN FILLED
C    SO NOW COMPUTE THE A,B1,B2,C STUFF:

        A = 0.
        DO 500 I = 1,N
           A = A + YHIA(I)*YHIA(I)
500     CONTINUE
        B1 = 0.
        DO 600 I = 1,(NMHI*nmh)
           B1 = B1 + YHI(I)*YHI(I)/float(k)
600     CONTINUE
        B2 = 0.
        DO 700 I = 1,NMH
           B2 = B2 + YH(I)*YH(I)/(float(k)*float(nmhi))
700     CONTINUE
        C = Y*Y/FLOAT(N)

C     NOW WE HAVE THE A,B1,B2,C SO COMPUTE THE SSQ STUFF

        SSQW = A-B1
        SSQB = B1 - B2
        SSQH = B2 - C
        SSQT = A - C

C        IN ALLAN'S NOTATION I = NMH
C                            J = NMHI
C                            K = K
C      COMPUTE DEGREES OF FREEDOM

        IHDF=NMH-1
        IBDF=NMH*(NMHI-1)
        IWDF=NMH*NMHI*(K-1)

C     COMPUTE THE MEAN SUM SQUARES (DIVIDE SUM SQUARES BY DEGREES OF FREEDOM)
C
        ESSQW= SSQW/FLOAT(IWDF)
        ESSQB = SSQB/FLOAT(IBDF)
        ESSQH = SSQH/FLOAT(IHDF)

        WRITE(96,*)
        write(96,*)
        WRITE(96,*)'               ____________________________________________'
        write(96,*)'                                ANOVA                      '
        WRITE(96,*)'               ____________________________________________'
        write(96,*)

C      COMPUTE THE VARIANCE OF MEAN SUM SQUARES FOR EXPECTATION CALCULATIONS

        SIGSQW=ESSQW
        SIGSQB=(ESSQB-ESSQW)/FLOAT(K)
        SIGSQH=(ESSQH-ESSQB)/(FLOAT(K*NMHI))
        WRITE(96,30)'SUM SQUARES','DEG FRDM','MEAN SUM SQUARES','VARIANCE'
30      FORMAT(22x,A11,4x,A8,4x,A16,2X,A8)
40      FORMAT(1x,A19,4x,f8.4,8x,I4,10x,f8.4,7x,f8.4)
        WRITE(96,*)
        WRITE(96,40)'BTWN SAMPLES       ',SSQH,IHDF,ESSQH,SIGSQH
        WRITE(96,*)
        WRITE(96,40)'BTWN GAS ALIQUOTS  ',SSQB,IBDF,ESSQB,SIGSQB
        WRITE(96,*)
        WRITE(96,40)'BTWN MACHINE CYCLES',SSQW,IWDF,ESSQW,SIGSQW

        END
```

```
SAMPLE 690.3  OXYGEN-18
_____________________________

number of points:              150
number of minor groups:          5
number of major groups:          5

 MINOR GROUP #, SIZE, TOTAL, MEAN    1      6    1.4449E+02    2.4082E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    2      6    1.4366E+02    2.3943E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    3      6    1.4320E+02    2.3866E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    4      6    1.4308E+02    2.3846E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    5      6    1.4321E+02    2.3868E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    6      6    1.4750E+02    2.4583E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    7      6    1.4807E+02    2.4679E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    8      6    1.4814E+02    2.4690E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    9      6    1.4813E+02    2.4689E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   10      6    1.4813E+02    2.4688E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   11      6    1.5090E+02    2.5150E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   12      6    1.4941E+02    2.4901E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   13      6    1.4892E+02    2.4820E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   14      6    1.4892E+02    2.4820E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   15      6    1.4907E+02    2.4845E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   16      6    1.4845E+02    2.4742E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   17      6    1.4764E+02    2.4607E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   18      6    1.4765E+02    2.4608E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   19      6    1.4739E+02    2.4565E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   20      6    1.4747E+02    2.4578E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   21      6    1.3855E+02    2.3091E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   22      6    1.3964E+02    2.3274E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   23      6    1.3950E+02    2.3249E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   24      6    1.3935E+02    2.3225E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   25      6    1.3914E+02    2.3191E+01

 MAJOR GROUP #, SIZE, TOTAL, MEAN    1     30    7.1763E+02    2.3921E+01
 MAJOR GROUP #, SIZE, TOTAL, MEAN    2     30    7.3997E+02    2.4666E+01
 MAJOR GROUP #, SIZE, TOTAL, MEAN    3     30    7.4721E+02    2.4907E+01
 MAJOR GROUP #, SIZE, TOTAL, MEAN    4     30    7.3859E+02    2.4620E+01
 MAJOR GROUP #, SIZE, TOTAL, MEAN    5     30    6.9618E+02    2.3206E+01

 TOTAL RUN      SIZE, TOTAL, MEAN    1    150    3.6396E+03    2.4264E+01


                       ____________________________________
                                      ANOVA
                       ____________________________________

                       SUM SQUARES    DEG FRDM    MEAN SUM SQUARES   VARIANCE

BTWN SAMPLES             58.1719          4           14.5430          0.4831

BTWN GAS ALIQUOTS         1.0000         20            0.0500          0.0072

BTWN MACHINE CYCLES       0.8359        125            0.0067          0.0067
```

## RAW OXYGEN_18 CYCLE DATA: SAMPLE 690.3

| CYCLE | MINOR GROUP | MAJOR GROUP |
|---|---|---|
| 24.087 | 1 | 1 |
| 24.069 | 1 | 1 |
| 23.995 | 1 | 1 |
| 24.125 | 1 | 1 |
| 24.216 | 1 | 1 |
| 24.001 | 1 | 1 |
| 23.652 | 2 | 1 |
| 24.025 | 2 | 1 |
| 24.019 | 2 | 1 |
| 23.910 | 2 | 1 |
| 23.974 | 2 | 1 |
| 24.076 | 2 | 1 |
| 23.867 | 3 | 1 |
| 23.742 | 3 | 1 |
| 23.907 | 3 | 1 |
| 23.824 | 3 | 1 |
| 23.909 | 3 | 1 |
| 23.949 | 3 | 1 |
| 23.815 | 4 | 1 |
| 23.842 | 4 | 1 |
| 23.769 | 4 | 1 |
| 23.779 | 4 | 1 |
| 24.010 | 4 | 1 |
| 23.863 | 4 | 1 |
| 23.839 | 5 | 1 |
| 23.857 | 5 | 1 |
| 23.955 | 5 | 1 |
| 23.968 | 5 | 1 |
| 23.856 | 5 | 1 |
| 23.730 | 5 | 1 |
| 24.461 | 6 | 2 |
| 24.547 | 6 | 2 |
| 24.769 | 6 | 2 |
| 24.512 | 6 | 2 |
| 24.532 | 6 | 2 |
| 24.676 | 6 | 2 |
| 24.563 | 7 | 2 |
| 24.701 | 7 | 2 |
| 24.676 | 7 | 2 |
| 24.758 | 7 | 2 |
| 24.665 | 7 | 2 |
| 24.710 | 7 | 2 |
| 24.686 | 8 | 2 |
| 24.722 | 8 | 2 |
| 24.725 | 8 | 2 |
| 24.695 | 8 | 2 |
| 24.650 | 8 | 2 |
| 24.659 | 8 | 2 |
| 24.684 | 9 | 2 |
| 24.699 | 9 | 2 |
| 24.692 | 9 | 2 |
| 24.754 | 9 | 2 |
| 24.695 | 9 | 2 |
| 24.608 | 9 | 2 |
| 24.697 | 10 | 2 |
| 24.625 | 10 | 2 |
| 24.704 | 10 | 2 |
| 24.635 | 10 | 2 |
| 24.728 | 10 | 2 |
| 24.738 | 10 | 2 |
| 25.194 | 11 | 3 |
| 25.190 | 11 | 3 |
| 25.063 | 11 | 3 |
| 25.060 | 11 | 3 |
| 25.209 | 11 | 3 |
| 25.184 | 11 | 3 |

| CYCLE | MINOR GROUP | MAJOR GROUP |
|---|---|---|
| 24.848 | 12 | 3 |
| 24.823 | 12 | 3 |
| 24.866 | 12 | 3 |
| 24.977 | 12 | 3 |
| 24.947 | 12 | 3 |
| 24.946 | 12 | 3 |
| 24.728 | 13 | 3 |
| 24.911 | 13 | 3 |
| 24.786 | 13 | 3 |
| 24.866 | 13 | 3 |
| 24.771 | 13 | 3 |
| 24.857 | 13 | 3 |
| 24.841 | 14 | 3 |
| 24.838 | 14 | 3 |
| 24.775 | 14 | 3 |
| 24.767 | 14 | 3 |
| 24.869 | 14 | 3 |
| 24.830 | 14 | 3 |
| 24.867 | 15 | 3 |
| 24.865 | 15 | 3 |
| 24.846 | 15 | 3 |
| 24.760 | 15 | 3 |
| 24.795 | 15 | 3 |
| 24.935 | 15 | 3 |
| 24.800 | 16 | 4 |
| 24.779 | 16 | 4 |
| 24.771 | 16 | 4 |
| 24.690 | 16 | 4 |
| 24.629 | 16 | 4 |
| 24.780 | 16 | 4 |
| 24.610 | 17 | 4 |
| 24.574 | 17 | 4 |
| 24.642 | 17 | 4 |
| 24.615 | 17 | 4 |
| 24.733 | 17 | 4 |
| 24.465 | 17 | 4 |
| 24.561 | 18 | 4 |
| 24.618 | 18 | 4 |
| 24.654 | 18 | 4 |
| 24.603 | 18 | 4 |
| 24.512 | 18 | 4 |
| 24.699 | 18 | 4 |
| 24.520 | 19 | 4 |
| 24.518 | 19 | 4 |
| 24.688 | 19 | 4 |
| 24.563 | 19 | 4 |
| 24.493 | 19 | 4 |
| 24.609 | 19 | 4 |
| 24.573 | 20 | 4 |
| 24.576 | 20 | 4 |
| 24.659 | 20 | 4 |
| 24.604 | 20 | 4 |
| 24.577 | 20 | 4 |
| 24.476 | 20 | 4 |
| 22.855 | 21 | 5 |
| 22.988 | 21 | 5 |
| 23.179 | 21 | 5 |
| 23.160 | 21 | 5 |
| 23.159 | 21 | 5 |
| 23.206 | 21 | 5 |
| 23.287 | 22 | 5 |
| 23.102 | 22 | 5 |
| 23.209 | 22 | 5 |
| 23.331 | 22 | 5 |
| 23.288 | 22 | 5 |
| 23.425 | 22 | 5 |

| CYCLE | MINOR GROUP | MAJOR GROUP |
|---|---|---|
| 23.287 | 23 | 5 |
| 23.383 | 23 | 5 |
| 23.291 | 23 | 5 |
| 22.991 | 23 | 5 |
| 23.284 | 23 | 5 |
| 23.259 | 23 | 5 |
| 23.241 | 24 | 5 |
| 23.220 | 24 | 5 |
| 23.203 | 24 | 5 |
| 23.167 | 24 | 5 |
| 23.303 | 24 | 5 |
| 23.218 | 24 | 5 |
| 23.223 | 25 | 5 |
| 23.214 | 25 | 5 |
| 23.173 | 25 | 5 |
| 23.109 | 25 | 5 |
| 23.242 | 25 | 5 |
| 23.182 | 25 | 5 |

```
SAMPLE 690.3  CARBON-13
_______________________________

number of points:              150
number of minor groups:          5
number of major groups:          5

 MINOR GROUP #, SIZE, TOTAL, MEAN    1     6   2.6780E+02   4.4633E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    2     6   2.6750E+02   4.4583E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    3     6   2.6751E+02   4.4585E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    4     6   2.6750E+02   4.4583E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    5     6   2.6793E+02   4.4655E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    6     6   2.6807E+02   4.4679E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    7     6   2.6854E+02   4.4756E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    8     6   2.6837E+02   4.4729E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    9     6   2.6890E+02   4.4817E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   10     6   2.6856E+02   4.4759E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   11     6   2.6943E+02   4.4905E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   12     6   2.6906E+02   4.4844E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   13     6   2.6917E+02   4.4862E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   14     6   2.6887E+02   4.4812E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   15     6   2.6898E+02   4.4830E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   16     6   2.6845E+02   4.4742E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   17     6   2.6838E+02   4.4730E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   18     6   2.6854E+02   4.4757E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   19     6   2.6857E+02   4.4762E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   20     6   2.6851E+02   4.4752E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   21     6   2.6615E+02   4.4358E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   22     6   2.6691E+02   4.4485E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   23     6   2.6672E+02   4.4453E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   24     6   2.6689E+02   4.4482E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   25     6   2.6669E+02   4.4448E+01

 MAJOR GROUP #, SIZE, TOTAL, MEAN    1    30   1.3382E+03   4.4608E+01
 MAJOR GROUP #, SIZE, TOTAL, MEAN    2    30   1.3424E+03   4.4748E+01
 MAJOR GROUP #, SIZE, TOTAL, MEAN    3    30   1.3455E+03   4.4851E+01
 MAJOR GROUP #, SIZE, TOTAL, MEAN    4    30   1.3425E+03   4.4749E+01
 MAJOR GROUP #, SIZE, TOTAL, MEAN    5    30   1.3334E+03   4.4445E+01

 TOTAL RUN      SIZE, TOTAL, MEAN    1   150   6.7020E+03   4.4680E+01



                ____________________________________________
                                   ANOVA
                ____________________________________________

                    SUM SQUARES    DEG FRDM    MEAN SUM SQUARES   VARIANCE

BTWN SAMPLES           3.0000          4             0.7500         0.0247

BTWN GAS ALIQUOTS      0.1563         20             0.0078         0.0008

BTWN MACHINE CYCLES    0.4063        125             0.0033         0.0033
```

## RAW CARBON-13 CYCLE DATA: SAMPLE 690.3

| CYCLE | MINOR GROUP | MAJOR GROUP |
|---|---|---|
| 44.667 | 1 | 1 |
| 44.531 | 1 | 1 |
| 44.551 | 1 | 1 |
| 44.678 | 1 | 1 |
| 44.690 | 1 | 1 |
| 44.684 | 1 | 1 |
| 44.542 | 2 | 1 |
| 44.575 | 2 | 1 |
| 44.519 | 2 | 1 |
| 44.506 | 2 | 1 |
| 44.690 | 2 | 1 |
| 44.666 | 2 | 1 |
| 44.578 | 3 | 1 |
| 44.536 | 3 | 1 |
| 44.498 | 3 | 1 |
| 44.608 | 3 | 1 |
| 44.712 | 3 | 1 |
| 44.578 | 3 | 1 |
| 44.639 | 4 | 1 |
| 44.557 | 4 | 1 |
| 44.617 | 4 | 1 |
| 44.478 | 4 | 1 |
| 44.635 | 4 | 1 |
| 44.572 | 4 | 1 |
| 44.625 | 5 | 1 |
| 44.608 | 5 | 1 |
| 44.643 | 5 | 1 |
| 44.702 | 5 | 1 |
| 44.646 | 5 | 1 |
| 44.706 | 5 | 1 |
| 44.654 | 6 | 2 |
| 44.666 | 6 | 2 |
| 44.726 | 6 | 2 |
| 44.671 | 6 | 2 |
| 44.638 | 6 | 2 |
| 44.716 | 6 | 2 |
| 44.704 | 7 | 2 |
| 44.765 | 7 | 2 |
| 44.747 | 7 | 2 |
| 44.749 | 7 | 2 |
| 44.755 | 7 | 2 |
| 44.815 | 7 | 2 |
| 44.733 | 8 | 2 |
| 44.729 | 8 | 2 |
| 44.708 | 8 | 2 |
| 44.776 | 8 | 2 |
| 44.705 | 8 | 2 |
| 44.721 | 8 | 2 |
| 44.800 | 9 | 2 |
| 44.816 | 9 | 2 |
| 44.844 | 9 | 2 |
| 44.846 | 9 | 2 |
| 44.789 | 9 | 2 |
| 44.804 | 9 | 2 |
| 44.744 | 10 | 2 |
| 44.712 | 10 | 2 |
| 44.672 | 10 | 2 |
| 44.808 | 10 | 2 |
| 44.816 | 10 | 2 |
| 44.803 | 10 | 2 |
| 44.937 | 11 | 3 |
| 44.938 | 11 | 3 |
| 44.908 | 11 | 3 |
| 44.911 | 11 | 3 |
| 44.881 | 11 | 3 |
| 44.855 | 11 | 3 |

| CYCLE | MINOR GROUP | MAJOR GROUP |
|---|---|---|
| 44.791 | 12 | 3 |
| 44.765 | 12 | 3 |
| 44.849 | 12 | 3 |
| 44.914 | 12 | 3 |
| 44.949 | 12 | 3 |
| 44.794 | 12 | 3 |
| 44.838 | 13 | 3 |
| 44.922 | 13 | 3 |
| 44.812 | 13 | 3 |
| 44.896 | 13 | 3 |
| 44.849 | 13 | 3 |
| 44.853 | 13 | 3 |
| 44.825 | 14 | 3 |
| 44.808 | 14 | 3 |
| 44.846 | 14 | 3 |
| 44.846 | 14 | 3 |
| 44.783 | 14 | 3 |
| 44.766 | 14 | 3 |
| 44.860 | 15 | 3 |
| 44.892 | 15 | 3 |
| 44.792 | 15 | 3 |
| 44.830 | 15 | 3 |
| 44.792 | 15 | 3 |
| 44.816 | 15 | 3 |
| 44.690 | 16 | 4 |
| 44.790 | 16 | 4 |
| 44.757 | 16 | 4 |
| 44.711 | 16 | 4 |
| 44.768 | 16 | 4 |
| 44.737 | 16 | 4 |
| 44.739 | 17 | 4 |
| 44.687 | 17 | 4 |
| 44.711 | 17 | 4 |
| 44.708 | 17 | 4 |
| 44.789 | 17 | 4 |
| 44.745 | 17 | 4 |
| 44.739 | 18 | 4 |
| 44.695 | 18 | 4 |
| 44.761 | 18 | 4 |
| 44.790 | 18 | 4 |
| 44.772 | 18 | 4 |
| 44.783 | 18 | 4 |
| 44.702 | 19 | 4 |
| 44.735 | 19 | 4 |
| 44.829 | 19 | 4 |
| 44.809 | 19 | 4 |
| 44.740 | 19 | 4 |
| 44.758 | 19 | 4 |
| 44.775 | 20 | 4 |
| 44.805 | 20 | 4 |
| 44.710 | 20 | 4 |
| 44.720 | 20 | 4 |
| 44.789 | 20 | 4 |
| 44.711 | 20 | 4 |
| 44.227 | 21 | 5 |
| 44.353 | 21 | 5 |
| 44.374 | 21 | 5 |
| 44.361 | 21 | 5 |
| 44.444 | 21 | 5 |
| 44.390 | 21 | 5 |
| 44.401 | 22 | 5 |
| 44.518 | 22 | 5 |
| 44.538 | 22 | 5 |
| 44.441 | 22 | 5 |
| 44.521 | 22 | 5 |
| 44.493 | 22 | 5 |

| CYCLE | MINOR GROUP | MAJOR GROUP |
|---|---|---|
| 44.353 | 23 | 5 |
| 44.492 | 23 | 5 |
| 44.535 | 23 | 5 |
| 44.449 | 23 | 5 |
| 44.483 | 23 | 5 |
| 44.405 | 23 | 5 |
| 44.432 | 24 | 5 |
| 44.420 | 24 | 5 |
| 44.549 | 24 | 5 |
| 44.605 | 24 | 5 |
| 44.459 | 24 | 5 |
| 44.429 | 24 | 5 |
| 44.426 | 25 | 5 |
| 44.522 | 25 | 5 |
| 44.398 | 25 | 5 |
| 44.374 | 25 | 5 |
| 44.485 | 25 | 5 |
| 44.483 | 25 | 5 |

```
SAMPLE 375.0  OXYGEN-18
________________________

number of points:              150
number of minor groups:          5
number of major groups:          5

 MINOR GROUP #, SIZE, TOTAL, MEAN    1     6   1.0872E+02    1.8120E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    2     6   1.0946E+02    1.8243E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    3     6   1.0917E+02    1.8194E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    4     6   1.0845E+02    1.8074E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    5     6   1.0858E+02    1.8097E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    6     6   1.1005E+02    1.8341E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    7     6   1.0977E+02    1.8295E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    8     6   1.0965E+02    1.8275E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    9     6   1.0930E+02    1.8217E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   10     6   1.1006E+02    1.8344E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   11     6   1.1317E+02    1.8861E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   12     6   1.1392E+02    1.8987E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   13     6   1.1268E+02    1.8780E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   14     6   1.1264E+02    1.8774E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   15     6   1.1347E+02    1.8912E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   16     6   1.0823E+02    1.8039E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   17     6   1.0870E+02    1.8117E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   18     6   1.0996E+02    1.8327E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   19     6   1.0874E+02    1.8124E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   20     6   1.0990E+02    1.8316E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   21     6   1.1293E+02    1.8821E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   22     6   1.1407E+02    1.9011E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   23     6   1.1332E+02    1.8887E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   24     6   1.1437E+02    1.9062E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   25     6   1.1418E+02    1.9031E+01

 MAJOR GROUP #, SIZE, TOTAL, MEAN    1    30   5.4437E+02    1.8146E+01
 MAJOR GROUP #, SIZE, TOTAL, MEAN    2    30   5.4883E+02    1.8294E+01
 MAJOR GROUP #, SIZE, TOTAL, MEAN    3    30   5.6589E+02    1.8863E+01
 MAJOR GROUP #, SIZE, TOTAL, MEAN    4    30   5.4554E+02    1.8185E+01
 MAJOR GROUP #, SIZE, TOTAL, MEAN    5    30   5.6887E+02    1.8962E+01

 TOTAL RUN      SIZE, TOTAL, MEAN    1   150   2.7735E+03    1.8490E+01



                    ________________________________________
                                     ANOVA
                    ________________________________________

                         SUM SQUARES     DEG FRDM     MEAN SUM SQUARES   VARIANCE

BTWN SAMPLES                18.3867           4               4.5967        0.1515

BTWN GAS ALIQUOTS            1.0430          20               0.0521        0.0030

BTWN MACHINE CYCLES          4.2969         125               0.0344        0.0344
```

## RAW OXYGEN-18 CYCLE DATA: SAMPLE 375.0

| CYCLE | MINOR GROUP | MAJOR GROUP |
|---|---|---|
| 18.209 | 1 | 1 |
| 18.111 | 1 | 1 |
| 18.073 | 1 | 1 |
| 18.211 | 1 | 1 |
| 18.033 | 1 | 1 |
| 18.085 | 1 | 1 |
| 17.883 | 2 | 1 |
| 18.127 | 2 | 1 |
| 18.149 | 2 | 1 |
| 19.185 | 2 | 1 |
| 18.015 | 2 | 1 |
| 18.100 | 2 | 1 |
| 17.917 | 3 | 1 |
| 18.198 | 3 | 1 |
| 18.361 | 3 | 1 |
| 18.364 | 3 | 1 |
| 18.231 | 3 | 1 |
| 18.094 | 3 | 1 |
| 17.969 | 4 | 1 |
| 17.848 | 4 | 1 |
| 18.147 | 4 | 1 |
| 18.297 | 4 | 1 |
| 18.202 | 4 | 1 |
| 17.983 | 4 | 1 |
| 18.134 | 5 | 1 |
| 18.328 | 5 | 1 |
| 18.216 | 5 | 1 |
| 17.804 | 5 | 1 |
| 18.156 | 5 | 1 |
| 17.942 | 5 | 1 |
| 18.555 | 6 | 2 |
| 18.128 | 6 | 2 |
| 18.443 | 6 | 2 |
| 18.179 | 6 | 2 |
| 18.317 | 6 | 2 |
| 18.424 | 6 | 2 |
| 18.089 | 7 | 2 |
| 18.356 | 7 | 2 |
| 18.332 | 7 | 2 |
| 18.389 | 7 | 2 |
| 18.341 | 7 | 2 |
| 18.262 | 7 | 2 |
| 18.104 | 8 | 2 |
| 18.276 | 8 | 2 |
| 18.301 | 8 | 2 |
| 18.424 | 8 | 2 |
| 18.352 | 8 | 2 |
| 18.194 | 8 | 2 |
| 17.988 | 9 | 2 |
| 18.349 | 9 | 2 |
| 18.258 | 9 | 2 |
| 18.325 | 9 | 2 |
| 18.330 | 9 | 2 |
| 18.049 | 9 | 2 |
| 18.317 | 10 | 2 |
| 18.254 | 10 | 2 |
| 18.205 | 10 | 2 |
| 18.444 | 10 | 2 |
| 18.307 | 10 | 2 |
| 18.536 | 10 | 2 |
| 18.463 | 11 | 3 |
| 18.849 | 11 | 3 |
| 18.718 | 11 | 3 |
| 19.181 | 11 | 3 |
| 18.929 | 11 | 3 |
| 19.026 | 11 | 3 |

| CYCLE | MINOR GROUP | MAJOR GROUP |
|---|---|---|
| 18.859 | 12 | 3 |
| 18.759 | 12 | 3 |
| 19.057 | 12 | 3 |
| 19.130 | 12 | 3 |
| 18.959 | 12 | 3 |
| 19.159 | 12 | 3 |
| 18.811 | 13 | 3 |
| 18.727 | 13 | 3 |
| 18.985 | 13 | 3 |
| 18.954 | 13 | 3 |
| 18.555 | 13 | 3 |
| 18.649 | 13 | 3 |
| 18.844 | 14 | 3 |
| 18.819 | 14 | 3 |
| 18.744 | 14 | 3 |
| 18.750 | 14 | 3 |
| 18.768 | 14 | 3 |
| 18.718 | 14 | 3 |
| 18.952 | 15 | 3 |
| 18.922 | 15 | 3 |
| 18.835 | 15 | 3 |
| 18.866 | 15 | 3 |
| 18.907 | 15 | 3 |
| 18.991 | 15 | 3 |
| 17.900 | 16 | 4 |
| 17.868 | 16 | 4 |
| 18.235 | 16 | 4 |
| 18.126 | 16 | 4 |
| 17.883 | 16 | 4 |
| 18.221 | 16 | 4 |
| 17.962 | 17 | 4 |
| 17.952 | 17 | 4 |
| 18.165 | 17 | 4 |
| 18.382 | 17 | 4 |
| 18.139 | 17 | 4 |
| 18.101 | 17 | 4 |
| 18.069 | 18 | 4 |
| 18.226 | 18 | 4 |
| 18.636 | 18 | 4 |
| 18.429 | 18 | 4 |
| 18.414 | 18 | 4 |
| 18.190 | 18 | 4 |
| 17.966 | 19 | 4 |
| 18.070 | 19 | 4 |
| 18.440 | 19 | 4 |
| 18.014 | 19 | 4 |
| 18.015 | 19 | 4 |
| 18.238 | 19 | 4 |
| 18.176 | 20 | 4 |
| 18.083 | 20 | 4 |
| 18.373 | 20 | 4 |
| 18.603 | 20 | 4 |
| 18.512 | 20 | 4 |
| 18.151 | 20 | 4 |
| 18.683 | 21 | 5 |
| 18.796 | 21 | 5 |
| 19.017 | 21 | 5 |
| 18.727 | 21 | 5 |
| 18.751 | 21 | 5 |
| 18.952 | 21 | 5 |
| 18.895 | 22 | 5 |
| 19.014 | 22 | 5 |
| 19.148 | 22 | 5 |
| 19.189 | 22 | 5 |
| 18.808 | 22 | 5 |
| 19.015 | 22 | 5 |

| CYCLE | MINOR GROUP | MAJOR GROUP |
|---|---|---|
| 18.562 | 23 | 5 |
| 18.877 | 23 | 5 |
| 18.914 | 23 | 5 |
| 18.827 | 23 | 5 |
| 18.913 | 23 | 5 |
| 19.226 | 23 | 5 |
| 18.876 | 24 | 5 |
| 19.187 | 24 | 5 |
| 19.057 | 24 | 5 |
| 18.921 | 24 | 5 |
| 19.170 | 24 | 5 |
| 19.158 | 24 | 5 |
| 19.330 | 25 | 5 |
| 19.061 | 25 | 5 |
| 18.906 | 25 | 5 |
| 19.231 | 25 | 5 |
| 18.746 | 25 | 5 |
| 18.910 | 25 | 5 |

```
SAMPLE 375.0  CARBON-13
_______________________________

number of points:              150
number of minor groups:          5
number of major groups:          5

 MINOR GROUP #, SIZE, TOTAL, MEAN    1     6    2.6720E+02    4.4533E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    2     6    2.6723E+02    4.4538E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    3     6    2.6732E+02    4.4553E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    4     6    2.6719E+02    4.4532E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    5     6    2.6734E+02    4.4557E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    6     6    2.6840E+02    4.4734E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    7     6    2.6818E+02    4.4696E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    8     6    2.6804E+02    4.4674E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    9     6    2.6830E+02    4.4717E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   10     6    2.6826E+02    4.4709E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   11     6    2.6906E+02    4.4844E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   12     6    2.6979E+02    4.4964E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   13     6    2.6929E+02    4.4882E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   14     6    2.6945E+02    4.4908E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   15     6    2.6958E+02    4.4930E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   16     6    2.6799E+02    4.4665E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   17     6    2.6917E+02    4.4862E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   18     6    2.6844E+02    4.4740E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   19     6    2.6862E+02    4.4770E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   20     6    2.6903E+02    4.4839E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   21     6    2.6998E+02    4.4997E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   22     6    2.6968E+02    4.4947E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   23     6    2.7016E+02    4.5027E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   24     6    2.7000E+02    4.5000E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   25     6    2.7042E+02    4.5070E+01

 MAJOR GROUP #, SIZE, TOTAL, MEAN    1    30    1.3363E+03    4.4543E+01
 MAJOR GROUP #, SIZE, TOTAL, MEAN    2    30    1.3412E+03    4.4706E+01
 MAJOR GROUP #, SIZE, TOTAL, MEAN    3    30    1.3472E+03    4.4906E+01
 MAJOR GROUP #, SIZE, TOTAL, MEAN    4    30    1.3433E+03    4.4775E+01
 MAJOR GROUP #, SIZE, TOTAL, MEAN    5    30    1.3502E+03    4.5008E+01

 TOTAL RUN      SIZE, TOTAL, MEAN    1   150    6.7181E+03    4.4787E+01


                    __________________________________________
                                       ANOVA
                    __________________________________________

                     SUM SQUARES    DEG FRDM    MEAN SUM SQUARES   VARIANCE

BTWN SAMPLES            3.7813          4            0.9453          0.0312

BTWN GAS ALIQUOTS       0.1875         20            0.0094         -0.0011

BTWN MACHINE CYCLES     2.0313        125            0.0162          0.0162
```

## RAW CARBON-13 CYCLE DATA: SAMPLE 375.0

| CYCLE | MINOR GROUP | MAJOR GROUP |
|---|---|---|
| 44.462 | 1 | 1 |
| 44.607 | 1 | 1 |
| 44.542 | 1 | 1 |
| 44.465 | 1 | 1 |
| 44.504 | 1 | 1 |
| 44.621 | 1 | 1 |
| 44.449 | 2 | 1 |
| 44.655 | 2 | 1 |
| 44.417 | 2 | 1 |
| 44.583 | 2 | 1 |
| 44.497 | 2 | 1 |
| 44.627 | 2 | 1 |
| 44.526 | 3 | 1 |
| 44.588 | 3 | 1 |
| 44.567 | 3 | 1 |
| 44.580 | 3 | 1 |
| 44.541 | 3 | 1 |
| 44.515 | 3 | 1 |
| 44.603 | 4 | 1 |
| 44.435 | 4 | 1 |
| 44.448 | 4 | 1 |
| 44.566 | 4 | 1 |
| 44.627 | 4 | 1 |
| 44.513 | 4 | 1 |
| 44.487 | 5 | 1 |
| 44.603 | 5 | 1 |
| 44.563 | 5 | 1 |
| 44.421 | 5 | 1 |
| 44.606 | 5 | 1 |
| 44.660 | 5 | 1 |
| 44.904 | 6 | 2 |
| 44.659 | 6 | 2 |
| 44.876 | 6 | 2 |
| 44.588 | 6 | 2 |
| 44.651 | 6 | 2 |
| 44.727 | 6 | 2 |
| 44.651 | 7 | 2 |
| 44.591 | 7 | 2 |
| 44.745 | 7 | 2 |
| 44.714 | 7 | 2 |
| 44.661 | 7 | 2 |
| 44.814 | 7 | 2 |
| 44.679 | 8 | 2 |
| 44.573 | 8 | 2 |
| 44.698 | 8 | 2 |
| 44.651 | 8 | 2 |
| 44.769 | 8 | 2 |
| 44.674 | 8 | 2 |
| 44.572 | 9 | 2 |
| 44.651 | 9 | 2 |
| 44.776 | 9 | 2 |
| 44.676 | 9 | 2 |
| 44.800 | 9 | 2 |
| 44.825 | 9 | 2 |
| 44.566 | 10 | 2 |
| 44.638 | 10 | 2 |
| 44.647 | 10 | 2 |
| 44.740 | 10 | 2 |
| 44.781 | 10 | 2 |
| 44.884 | 10 | 2 |
| 44.955 | 11 | 3 |
| 44.777 | 11 | 3 |
| 44.603 | 11 | 3 |
| 44.975 | 11 | 3 |
| 44.854 | 11 | 3 |
| 44.897 | 11 | 3 |

| CYCLE | MINOR GROUP | MAJOR GROUP |
|---|---|---|
| 45.105 | 12 | 3 |
| 44.927 | 12 | 3 |
| 44.831 | 12 | 3 |
| 44.964 | 12 | 3 |
| 44.905 | 12 | 3 |
| 45.053 | 12 | 3 |
| 44.766 | 13 | 3 |
| 44.851 | 13 | 3 |
| 44.955 | 13 | 3 |
| 44.972 | 13 | 3 |
| 44.959 | 13 | 3 |
| 44.787 | 13 | 3 |
| 44.857 | 14 | 3 |
| 45.029 | 14 | 3 |
| 45.007 | 14 | 3 |
| 44.840 | 14 | 3 |
| 44.774 | 14 | 3 |
| 44.941 | 14 | 3 |
| 44.990 | 15 | 3 |
| 44.949 | 15 | 3 |
| 44.821 | 15 | 3 |
| 45.025 | 15 | 3 |
| 44.994 | 15 | 3 |
| 44.802 | 15 | 3 |
| 44.486 | 16 | 4 |
| 44.525 | 16 | 4 |
| 44.570 | 16 | 4 |
| 44.672 | 16 | 4 |
| 45.005 | 16 | 4 |
| 44.733 | 16 | 4 |
| 44.839 | 17 | 4 |
| 44.887 | 17 | 4 |
| 44.920 | 17 | 4 |
| 45.018 | 17 | 4 |
| 44.802 | 17 | 4 |
| 44.704 | 17 | 4 |
| 44.806 | 18 | 4 |
| 44.802 | 18 | 4 |
| 44.997 | 18 | 4 |
| 44.784 | 18 | 4 |
| 44.612 | 18 | 4 |
| 44.440 | 18 | 4 |
| 44.599 | 19 | 4 |
| 44.783 | 19 | 4 |
| 44.747 | 19 | 4 |
| 45.033 | 19 | 4 |
| 44.826 | 19 | 4 |
| 44.633 | 19 | 4 |
| 44.936 | 20 | 4 |
| 44.783 | 20 | 4 |
| 44.793 | 20 | 4 |
| 44.873 | 20 | 4 |
| 44.949 | 20 | 4 |
| 44.698 | 20 | 4 |
| 44.814 | 21 | 5 |
| 45.220 | 21 | 5 |
| 44.953 | 21 | 5 |
| 44.790 | 21 | 5 |
| 45.008 | 21 | 5 |
| 45.194 | 21 | 5 |
| 45.018 | 22 | 5 |
| 45.041 | 22 | 5 |
| 44.753 | 22 | 5 |
| 44.870 | 22 | 5 |
| 44.927 | 22 | 5 |
| 45.072 | 22 | 5 |

| CYCLE | MINOR GROUP | MAJOR GROUP |
|---|---|---|
| 44.865 | 23 | 5 |
| 44.779 | 23 | 5 |
| 45.200 | 23 | 5 |
| 45.077 | 23 | 5 |
| 45.088 | 23 | 5 |
| 45.155 | 23 | 5 |
| 44.964 | 24 | 5 |
| 45.082 | 24 | 5 |
| 45.037 | 24 | 5 |
| 44.994 | 24 | 5 |
| 44.978 | 24 | 5 |
| 44.946 | 24 | 5 |
| 45.060 | 25 | 5 |
| 44.969 | 25 | 5 |
| 44.875 | 25 | 5 |
| 45.485 | 25 | 5 |
| 45.243 | 25 | 5 |
| 44.786 | 25 | 5 |

```
SAMPLE 127.7- OXYGEN-18
______________________________

number of points:              150
number of minor groups:          5
number of major groups:          5

 MINOR GROUP #, SIZE, TOTAL, MEAN    1      6    1.7868E+02    2.9780E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    2      6    1.7832E+02    2.9719E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    3      6    1.7861E+02    2.9768E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    4      6    1.7869E+02    2.9782E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    5      6    1.7874E+02    2.9791E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    6      6    1.7879E+02    2.9798E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    7      6    1.7864E+02    2.9773E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    8      6    1.7855E+02    2.9758E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    9      6    1.7844E+02    2.9740E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   10      6    1.7843E+02    2.9738E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   11      6    1.8324E+02    3.0540E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   12      6    1.8350E+02    3.0583E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   13      6    1.8339E+02    3.0565E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   14      6    1.8310E+02    3.0517E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   15      6    1.8324E+02    3.0539E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   16      6    1.7972E+02    2.9954E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   17      6    1.8004E+02    3.0006E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   18      6    1.8010E+02    3.0017E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   19      6    1.7962E+02    2.9937E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   20      6    1.8000E+02    3.0000E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   21      6    1.7953E+02    2.9922E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   22      6    1.7956E+02    2.9926E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   23      6    1.7898E+02    2.9830E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   24      6    1.7892E+02    2.9819E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   25      6    1.7907E+02    2.9845E+01

 MAJOR GROUP #, SIZE, TOTAL, MEAN    1     30    8.9304E+02    2.9768E+01
 MAJOR GROUP #, SIZE, TOTAL, MEAN    2     30    8.9284E+02    2.9761E+01
 MAJOR GROUP #, SIZE, TOTAL, MEAN    3     30    9.1647E+02    3.0549E+01
 MAJOR GROUP #, SIZE, TOTAL, MEAN    4     30    8.9949E+02    2.9983E+01
 MAJOR GROUP #, SIZE, TOTAL, MEAN    5     30    8.9606E+02    2.9869E+01

 TOTAL RUN      SIZE, TOTAL, MEAN    1    150    4.4979E+03    2.9986E+01


                   ________________________________________
                                    ANOVA
                   ________________________________________

                     SUM SQUARES    DEG FRDM    MEAN SUM SQUARES   VARIANCE

BTWN SAMPLES            12.9375          4             3.2344        0.1076

BTWN GAS ALIQUOTS        0.1563         20             0.0078        0.0005

BTWN MACHINE CYCLES      0.5781        125             0.0046        0.0046
```

## RAW OXYGEN-18 CYCLE DATA: SAMPLE 127.7

| CYCLE | MINOR GROUP | MAJOR GROUP |
|---|---|---|
| 29.818 | 1 | 1 |
| 29.858 | 1 | 1 |
| 29.864 | 1 | 1 |
| 29.700 | 1 | 1 |
| 29.745 | 1 | 1 |
| 29.697 | 1 | 1 |
| 29.863 | 2 | 1 |
| 29.752 | 2 | 1 |
| 29.618 | 2 | 1 |
| 29.587 | 2 | 1 |
| 29.776 | 2 | 1 |
| 29.721 | 2 | 1 |
| 29.667 | 3 | 1 |
| 29.790 | 3 | 1 |
| 29.830 | 3 | 1 |
| 29.760 | 3 | 1 |
| 29.816 | 3 | 1 |
| 29.747 | 3 | 1 |
| 29.746 | 4 | 1 |
| 29.820 | 4 | 1 |
| 29.872 | 4 | 1 |
| 29.761 | 4 | 1 |
| 29.759 | 4 | 1 |
| 29.734 | 4 | 1 |
| 29.841 | 5 | 1 |
| 29.866 | 5 | 1 |
| 29.822 | 5 | 1 |
| 29.743 | 5 | 1 |
| 29.792 | 5 | 1 |
| 29.680 | 5 | 1 |
| 29.822 | 6 | 2 |
| 29.751 | 6 | 2 |
| 29.853 | 6 | 2 |
| 29.819 | 6 | 2 |
| 29.720 | 6 | 2 |
| 29.820 | 6 | 2 |
| 29.742 | 7 | 2 |
| 29.749 | 7 | 2 |
| 29.774 | 7 | 2 |
| 29.815 | 7 | 2 |
| 29.775 | 7 | 2 |
| 29.786 | 7 | 2 |
| 29.720 | 8 | 2 |
| 29.818 | 8 | 2 |
| 29.736 | 8 | 2 |
| 29.752 | 8 | 2 |
| 29.705 | 8 | 2 |
| 29.818 | 8 | 2 |
| 29.841 | 9 | 2 |
| 29.703 | 9 | 2 |
| 29.740 | 9 | 2 |
| 29.746 | 9 | 2 |
| 29.716 | 9 | 2 |
| 29.693 | 9 | 2 |
| 29.809 | 10 | 2 |
| 29.750 | 10 | 2 |
| 29.717 | 10 | 2 |
| 29.693 | 10 | 2 |
| 29.699 | 10 | 2 |
| 29.762 | 10 | 2 |
| 30.444 | 11 | 3 |
| 30.522 | 11 | 3 |
| 30.521 | 11 | 3 |
| 30.605 | 11 | 3 |
| 30.570 | 11 | 3 |
| 30.578 | 11 | 3 |

| CYCLE | MINOR GROUP | MAJOR GROUP |
|---|---|---|
| 30.636 | 12 | 3 |
| 30.540 | 12 | 3 |
| 30.683 | 12 | 3 |
| 30.668 | 12 | 3 |
| 30.441 | 12 | 3 |
| 30.530 | 12 | 3 |
| 30.495 | 13 | 3 |
| 30.584 | 13 | 3 |
| 30.519 | 13 | 3 |
| 30.618 | 13 | 3 |
| 30.609 | 13 | 3 |
| 30.566 | 13 | 3 |
| 30.617 | 14 | 3 |
| 30.460 | 14 | 3 |
| 30.473 | 14 | 3 |
| 30.492 | 14 | 3 |
| 30.539 | 14 | 3 |
| 30.521 | 14 | 3 |
| 30.411 | 15 | 3 |
| 30.395 | 15 | 3 |
| 30.648 | 15 | 3 |
| 30.587 | 15 | 3 |
| 30.592 | 15 | 3 |
| 30.603 | 15 | 3 |
| 29.976 | 16 | 4 |
| 29.931 | 16 | 4 |
| 29.953 | 16 | 4 |
| 29.901 | 16 | 4 |
| 29.992 | 16 | 4 |
| 29.971 | 16 | 4 |
| 29.997 | 17 | 4 |
| 30.019 | 17 | 4 |
| 30.001 | 17 | 4 |
| 29.988 | 17 | 4 |
| 30.032 | 17 | 4 |
| 29.998 | 17 | 4 |
| 30.057 | 18 | 4 |
| 30.084 | 18 | 4 |
| 30.017 | 18 | 4 |
| 30.023 | 18 | 4 |
| 29.897 | 18 | 4 |
| 30.026 | 18 | 4 |
| 29.902 | 19 | 4 |
| 29.853 | 19 | 4 |
| 30.067 | 19 | 4 |
| 29.958 | 19 | 4 |
| 29.868 | 19 | 4 |
| 29.975 | 19 | 4 |
| 29.876 | 20 | 4 |
| 30.016 | 20 | 4 |
| 30.074 | 20 | 4 |
| 29.970 | 20 | 4 |
| 30.062 | 20 | 4 |
| 30.002 | 20 | 4 |
| 29.848 | 21 | 5 |
| 29.870 | 21 | 5 |
| 29.947 | 21 | 5 |
| 29.984 | 21 | 5 |
| 29.970 | 21 | 5 |
| 29.911 | 21 | 5 |
| 29.816 | 22 | 5 |
| 29.842 | 22 | 5 |
| 29.973 | 22 | 5 |
| 29.996 | 22 | 5 |
| 29.986 | 22 | 5 |
| 29.943 | 22 | 5 |
| 29.766 | 23 | 5 |

| CYCLE | MINOR GROUP | MAJOR GROUP |
|---|---|---|
| 29.868 | 23 | 5 |
| 29.824 | 23 | 5 |
| 29.874 | 23 | 5 |
| 29.817 | 23 | 5 |
| 29.833 | 23 | 5 |
| 29.819 | 24 | 5 |
| 29.746 | 24 | 5 |
| 29.726 | 24 | 5 |
| 29.945 | 24 | 5 |
| 29.816 | 24 | 5 |
| 29.863 | 24 | 5 |
| 29.849 | 25 | 5 |
| 29.962 | 25 | 5 |
| 29.886 | 25 | 5 |
| 29.885 | 25 | 5 |
| 29.823 | 25 | 5 |
| 29.668 | 25 | 5 |

```
SAMPLE 127.7- CARBON-13
________________________

number of total points:                    150
number of minor groups/major groups:         5
number of major groups:                      5

 MINOR GROUP #, SIZE, TOTAL, MEAN    1     6    2.6201E+02    4.3668E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    2     6    2.6203E+02    4.3672E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    3     6    2.6172E+02    4.3620E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    4     6    2.6225E+02    4.3708E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    5     6    2.6232E+02    4.3719E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    6     6    2.6214E+02    4.3689E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    7     6    2.6225E+02    4.3708E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    8     6    2.6232E+02    4.3720E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN    9     6    2.6209E+02    4.3682E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   10     6    2.6212E+02    4.3687E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   11     6    2.6093E+02    4.3488E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   12     6    2.6089E+02    4.3481E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   13     6    2.6080E+02    4.3467E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   14     6    2.6094E+02    4.3489E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   15     6    2.6093E+02    4.3489E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   16     6    2.6221E+02    4.3702E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   17     6    2.6239E+02    4.3732E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   18     6    2.6222E+02    4.3703E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   19     6    2.6201E+02    4.3669E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   20     6    2.6204E+02    4.3673E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   21     6    2.6203E+02    4.3672E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   22     6    2.6218E+02    4.3696E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   23     6    2.6201E+02    4.3668E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   24     6    2.6181E+02    4.3635E+01
 MINOR GROUP #, SIZE, TOTAL, MEAN   25     6    2.6191E+02    4.3652E+01

 MAJOR GROUP #, SIZE, TOTAL, MEAN    1    30    1.3103E+03    4.3677E+01
 MAJOR GROUP #, SIZE, TOTAL, MEAN    2    30    1.3109E+03    4.3697E+01
 MAJOR GROUP #, SIZE, TOTAL, MEAN    3    30    1.3045E+03    4.3483E+01
 MAJOR GROUP #, SIZE, TOTAL, MEAN    4    30    1.3109E+03    4.3696E+01
 MAJOR GROUP #, SIZE, TOTAL, MEAN    5    30    1.3099E+03    4.3665E+01

 TOTAL RUN      SIZE, TOTAL, MEAN    1   150    6.5465E+03    4.3644E+01


                   _______________________________________
                                    ANOVA
                   _______________________________________

                        SUM SQUARES    DEG FRDM    MEAN SUM SQUARES   VARIANCE

BTWN SAMPLES               1.0938          4              0.2734         0.0090

BTWN GAS ALIQUOTS          0.0938         20              0.0047         0.0007

BTWN MACHINE CYCLES        0.0938        125              0.0008         0.0008
```

## RAW CARBON-13 CYCLE DATA: SAMPLE 127.7

| CYCLE | MINOR GROUP | MAJOR GROUP |
|---|---|---|
| 43.690 | 1 | 1 |
| 43.683 | 1 | 1 |
| 43.629 | 1 | 1 |
| 43.607 | 1 | 1 |
| 43.699 | 1 | 1 |
| 43.700 | 1 | 1 |
| 43.672 | 2 | 1 |
| 43.691 | 2 | 1 |
| 43.673 | 2 | 1 |
| 43.671 | 2 | 1 |
| 43.691 | 2 | 1 |
| 43.634 | 2 | 1 |
| 43.595 | 3 | 1 |
| 43.546 | 3 | 1 |
| 43.671 | 3 | 1 |
| 43.610 | 3 | 1 |
| 43.653 | 3 | 1 |
| 43.643 | 3 | 1 |
| 43.723 | 4 | 1 |
| 43.686 | 4 | 1 |
| 43.725 | 4 | 1 |
| 43.669 | 4 | 1 |
| 43.757 | 4 | 1 |
| 43.690 | 4 | 1 |
| 43.735 | 5 | 1 |
| 43.748 | 5 | 1 |
| 43.688 | 5 | 1 |
| 43.684 | 5 | 1 |
| 43.746 | 5 | 1 |
| 43.714 | 5 | 1 |
| 43.703 | 6 | 2 |
| 43.678 | 6 | 2 |
| 43.689 | 6 | 2 |
| 43.735 | 6 | 2 |
| 43.689 | 6 | 2 |
| 43.641 | 6 | 2 |
| 43.748 | 7 | 2 |
| 43.704 | 7 | 2 |
| 43.626 | 7 | 2 |
| 43.686 | 7 | 2 |
| 43.763 | 7 | 2 |
| 43.720 | 7 | 2 |
| 43.770 | 8 | 2 |
| 43.717 | 8 | 2 |
| 43.700 | 8 | 2 |
| 43.668 | 8 | 2 |
| 43.711 | 8 | 2 |
| 43.756 | 8 | 2 |
| 43.770 | 9 | 2 |
| 43.621 | 9 | 2 |
| 43.673 | 9 | 2 |
| 43.667 | 9 | 2 |
| 43.721 | 9 | 2 |
| 43.637 | 9 | 2 |
| 43.716 | 10 | 2 |
| 43.756 | 10 | 2 |
| 43.732 | 10 | 2 |
| 43.678 | 10 | 2 |
| 43.586 | 10 | 2 |
| 43.656 | 10 | 2 |
| 43.415 | 11 | 3 |
| 43.478 | 11 | 3 |
| 43.509 | 11 | 3 |
| 43.546 | 11 | 3 |
| 43.481 | 11 | 3 |
| 43.498 | 11 | 3 |

| CYCLE | MINOR GROUP | MAJOR GROUP |
|---|---|---|
| 43.550 | 12 | 3 |
| 43.527 | 12 | 3 |
| 43.431 | 12 | 3 |
| 43.468 | 12 | 3 |
| 43.433 | 12 | 3 |
| 43.479 | 12 | 3 |
| 43.426 | 13 | 3 |
| 43.387 | 13 | 3 |
| 43.543 | 13 | 3 |
| 43.495 | 13 | 3 |
| 43.450 | 13 | 3 |
| 43.500 | 13 | 3 |
| 43.493 | 14 | 3 |
| 43.503 | 14 | 3 |
| 43.562 | 14 | 3 |
| 43.473 | 14 | 3 |
| 43.419 | 14 | 3 |
| 43.485 | 14 | 3 |
| 43.464 | 15 | 3 |
| 43.460 | 15 | 3 |
| 43.557 | 15 | 3 |
| 43.472 | 15 | 3 |
| 43.411 | 15 | 3 |
| 43.571 | 15 | 3 |
| 43.668 | 16 | 4 |
| 43.712 | 16 | 4 |
| 43.675 | 16 | 4 |
| 43.684 | 16 | 4 |
| 43.712 | 16 | 4 |
| 43.762 | 16 | 4 |
| 43.758 | 17 | 4 |
| 43.750 | 17 | 4 |
| 43.665 | 17 | 4 |
| 43.750 | 17 | 4 |
| 43.732 | 17 | 4 |
| 43.739 | 17 | 4 |
| 43.709 | 18 | 4 |
| 43.717 | 18 | 4 |
| 43.660 | 18 | 4 |
| 43.705 | 18 | 4 |
| 43.739 | 18 | 4 |
| 43.688 | 18 | 4 |
| 43.633 | 19 | 4 |
| 43.715 | 19 | 4 |
| 43.691 | 19 | 4 |
| 43.634 | 19 | 4 |
| 43.654 | 19 | 4 |
| 43.684 | 19 | 4 |
| 43.645 | 20 | 4 |
| 43.664 | 20 | 4 |
| 43.695 | 20 | 4 |
| 43.601 | 20 | 4 |
| 43.726 | 20 | 4 |
| 43.708 | 20 | 4 |
| 43.585 | 21 | 5 |
| 43.686 | 21 | 5 |
| 43.715 | 21 | 5 |
| 43.682 | 21 | 5 |
| 43.648 | 21 | 5 |
| 43.718 | 21 | 5 |
| 43.696 | 22 | 5 |
| 43.712 | 22 | 5 |
| 43.734 | 22 | 5 |
| 43.682 | 22 | 5 |
| 43.675 | 22 | 5 |
| 43.678 | 22 | 5 |
| 43.681 | 23 | 5 |

| CYCLE | MINOR GROUP | MAJOR GROUP |
|---|---|---|
| 43.669 | 23 | 5 |
| 43.681 | 23 | 5 |
| 43.636 | 23 | 5 |
| 43.658 | 23 | 5 |
| 43.681 | 23 | 5 |
| 43.657 | 24 | 5 |
| 43.696 | 24 | 5 |
| 43.627 | 24 | 5 |
| 43.588 | 24 | 5 |
| 43.634 | 24 | 5 |
| 43.607 | 24 | 5 |
| 43.663 | 25 | 5 |
| 43.686 | 25 | 5 |
| 43.659 | 25 | 5 |
| 43.597 | 25 | 5 |
| 43.609 | 25 | 5 |
| 43.700 | 25 | 5 |

# Appendix F

## Searles Lake core KM-3 Isotopic Results and Isotopic Correction Factors

# APPENDIX F

## SEARLES LAKE CORE KM-3: DEPTH, AGE, O-18 & C-13 RESULTS and CORRECTIONS
SAMPLES MARKED WITH 'XX' NOT USED IN RECONSTRUCTION DUE TO MINERALOGY

| CORE | CORE | C-13 | O-18 | C-13 | O-18 | C-13 | O-18 | AGE |
|---|---|---|---|---|---|---|---|---|
| DEPTH ( ft ) | DEPTH ( m ) | DOL. (PDB) | DOL. (SMOW) | CORRECTIONS ( per mil ) | | FINAL (PDB) | FINAL (SMOW) | (Ma) |
| 65.6 | 19.99 | 0.004 | 30.018 | 0.800 | 2.800 | 0.804 | 32.818 | 0.0102 |
| 66.1 | 20.15 | 2.383 | 36.988 | ----- | 1.000 | 2.383 | 37.988 | 0.0106 |
| 66.6 | 20.30 | 2.905 | 34.463 | ----- | ----- | 2.905 | 34.463 | 0.0109 |
| 68.1 | 20.76 | 0.331 | 33.558 | ----- | 1.000 | 0.331 | 34.558 | 0.0121 |
| 68.6 | 20.91 | 1.657 | 34.889 | ----- | ----- | 1.657 | 34.889 | 0.0125 |
| 69.1 | 21.06 | 0.677 | 35.569 | ----- | ----- | 0.677 | 35.569 | 0.0129 |
| 69.6 | 21.21 | 1.047 | 32.623 | ----- | ----- | 1.047 | 32.623 | 0.0133 |
| 70.1 | 21.37 | 1.357 | 34.228 | ----- | ----- | 1.357 | 34.228 | 0.0137 |
| 70.6 | 21.52 | 0.965 | 32.802 | ----- | ----- | 0.965 | 32.802 | 0.0141 |
| 71.0 | 21.64 | 1.961 | 32.964 | ----- | ----- | 1.961 | 32.964 | 0.0144 |
| 71.6 | 21.82 | 2.188 | 32.704 | 0.800 | 2.800 | 2.988 | 35.504 | 0.0149 |
| 72.1 | 21.98 | 2.701 | 33.525 | 0.800 | 2.800 | 3.501 | 36.325 | 0.0153 |
| 72.6 | 22.13 | 2.804 | 34.929 | 0.800 | 2.800 | 3.604 | 37.729 | 0.0156 |
| 73.1 | 22.28 | 3.122 | 35.847 | ----- | ----- | 3.122 | 35.847 | 0.0160 |
| 73.6 | 22.43 | 3.386 | 36.617 | ----- | ----- | 3.386 | 36.617 | 0.0164 |
| 74.1 | 22.59 | 3.424 | 34.055 | 0.800 | 2.800 | 4.224 | 36.855 | 0.0168 |
| 74.6 | 22.74 | 3.845 | 36.239 | ----- | ----- | 3.845 | 36.239 | 0.0172 |
| 75.3 | 22.95 | 4.491 | 37.373 | 0.800 | 2.800 | 5.291 | 40.173 | 0.0178 |
| 75.8 | 23.10 | 3.416 | 32.154 | ----- | ----- | 3.416 | 32.154 | 0.0182 |
| 80.0 | 24.38 | 3.515 | 37.715 | ----- | ----- | 3.515 | 37.715 | 0.0214 |
| 81.0 | 24.69 | 4.370 | 39.140 | ----- | ----- | 4.370 | 39.140 | 0.0222 |
| 81.6 | 24.87 | 3.719 | 35.356 | ----- | ----- | 3.719 | 35.356 | 0.0227 |
| 81.9 | 24.96 | 1.719 | 31.829 | ----- | ----- | 1.719 | 31.829 | 0.0229 |
| 89.5 | 27.28 | 3.537 | 32.878 | 0.800 | 2.800 | 4.337 | 35.678 | 0.0236 |
| 90.7 | 27.65 | 3.764 | 35.804 | 0.800 | 2.800 | 4.564 | 38.604 | 0.0247 |
| 91.5 | 27.89 | 3.890 | 36.372 | 0.800 | 2.800 | 4.690 | 39.172 | 0.0253 |
| 95.5 | 29.11 | 2.617 | 28.411 | 0.800 | 2.800 | 3.417 | 31.211 | 0.0260 |
| 96.6 | 29.44 | 1.830 | 26.935 | 0.800 | 2.800 | 2.630 | 29.735 | 0.0269 |
| 111.7 | 34.05 | 3.152 | 32.440 | 0.800 | 2.800 | 3.952 | 35.240 | 0.0290 |
| 113.3 | 34.53 | 3.799 | 33.907 | 0.800 | 2.800 | 4.599 | 36.707 | 0.0298 |
| 114.5 | 34.90 | 4.754 | 32.632 | 0.800 | 2.800 | 5.554 | 35.432 | 0.0306 |
| 116.4 | 35.48 | 4.245 | 33.476 | 0.800 | 2.800 | 5.045 | 35.276 | 0.0317 |
| 118.5 | 36.12 | 3.861 | 35.465 | 0.800 | 2.800 | 4.661 | 38.265 | 0.0319 |
| 120.0 | 36.58 | 4.081 | 35.993 | 0.800 | 2.800 | 4.881 | 38.793 | 0.0326 |
| 124.9 | 38.07 | 4.006 | 38.129 | ----- | 1.000 | 4.006 | 39.129 | 0.0335 |
| 125.7 | 38.31 | 4.706 | 32.652 | 0.800 | 2.800 | 5.506 | 35.452 | 0.0356 |
| 126.3 | 38.50 | 4.070 | 38.909 | ----- | ----- | 4.070 | 38.909 | 0.0372 |
| 126.9 | 38.68 | 4.354 | 40.755 | ----- | ----- | 4.354 | 40.755 | 0.0388 |
| 127.7 | 38.92 | 3.412 | 38.345 | ----- | ----- | 3.412 | 38.345 | 0.0409 |
| 128.7 | 39.23 | 2.841 | 35.474 | ----- | ----- | 2.841 | 35.474 | 0.0435 |
| 128.9 | 39.29 | 3.775 | 39.432 | ----- | ----- | 3.775 | 39.432 | 0.0440 |
| 129.8 | 39.56 | 3.980 | 36.587 | 0.800 | 2.800 | 4.780 | 39.387 | 0.0464 |
| 130.1 | 39.65 | 3.412 | 39.934 | ----- | ----- | 3.412 | 39.934 | 0.0471 |
| 130.4 | 39.75 | 3.962 | 40.348 | ----- | ----- | 3.962 | 40.348 | 0.0480 |
| 131.5 | 40.08 | 3.575 | 37.927 | ----- | ----- | 3.575 | 37.927 | 0.0508 |
| 132.3 | 40.33 | 1.831 | 37.379 | ----- | ----- | 1.831 | 37.379 | 0.0530 |
| 134.4 | 40.97 | 3.659 | 36.075 | ----- | 1.000 | 3.659 | 37.075 | 0.0585 |
| 136.4 | 41.57 | 3.407 | 37.320 | ----- | 1.000 | 3.407 | 38.320 | 0.0637 |
| 137.5 | 41.91 | 4.278 | 37.353 | ----- | 1.000 | 4.278 | 38.353 | 0.0659 |
| 139.0 | 42.37 | 2.226 | 36.486 | ----- | ----- | 2.226 | 36.486 | 0.0672 |
| 140.5 | 42.82 | 3.124 | 40.365 | ----- | ----- | 3.124 | 40.365 | 0.0685 |
| 141.8 | 43.22 | 2.885 | 37.364 | ----- | ----- | 2.885 | 37.364 | 0.0696 |
| 142.8 | 43.53 | 3.078 | 40.448 | ----- | ----- | 3.078 | 40.448 | 0.0705 |
| 151.1 | 46.06 | 4.981 | 39.621 | ----- | ----- | 4.981 | 39.621 | 0.0779 |
| 153.0 | 46.63 | 3.571 | 33.188 | 0.800 | 2.800 | 4.371 | 35.988 | 0.0796 |
| 154.1 | 46.97 | 3.589 | 33.052 | 0.800 | 2.800 | 4.389 | 35.852 | 0.0806 |
| 158.6 | 48.34 | 6.557 | 41.891 | ----- | ----- | 6.557 | 41.891 | 0.0846 |
| 164.0 | 49.99 | 6.237 | 41.768 | ----- | ----- | 6.237 | 41.768 | 0.0894 |
| 170.0 | 51.82 | 4.521 | 40.515 | ----- | ----- | 4.521 | 40.515 | 0.0952 |

| CORE DEPTH ( ft ) | CORE DEPTH ( m ) | C-13 DOL. (PDB) | O-18 DOL. (SMOW) | CORRECTIONS ( per mil ) | | C-13 FINAL (PDB) | O-18 FINAL (SMOW) | AGE (Ma) |
|---|---|---|---|---|---|---|---|---|
| | | | | C-13 | O-18 | | | |
| 178.5 | 54.41 | 4.568 | 37.689 | ----- | ----- | 4.568 | 37.689 | 0.1034 |
| 183.0 | 55.78 | 4.749 | 37.390 | ----- | ----- | 4.749 | 37.390 | 0.1072 |
| 187.4 | 57.12 | 5.592 | 38.764 | ----- | ----- | 5.592 | 38.764 | 0.1117 |
| 189.4 | 57.73 | 4.347 | 34.780 | ----- | 1.000 | 4.347 | 35.780 | 0.1138 |
| 191.9 | 58.49 | 2.984 | 30.941 | 0.800 | 2.800 | 3.784 | 33.741 | 0.1163 |
| 194.9 | 59.41 | 5.319 | 40.123 | ----- | ----- | 5.319 | 40.123 | 0.1194 |
| 199.9 | 60.93 | 5.999 | 41.715 | ----- | ----- | 5.999 | 41.715 | 0.1247 |
| 205.0 | 62.48 | 5.098 | 38.463 | ----- | ----- | 5.098 | 38.463 | 0.1303 |
| 211.1 | 64.34 | 3.507 | 33.198 | 0.800 | 2.800 | 4.307 | 35.998 | 0.1370 |
| 218.0 | 66.45 | 5.956 | 40.727 | ----- | ----- | 5.956 | 40.727 | 0.1446 |
| 221.0 | 67.36 | 5.763 | 40.267 | ----- | ----- | 5.763 | 40.267 | 0.1479 |
| 224.1 | 68.31 | 6.425 | 41.175 | ----- | ----- | 6.425 | 41.175 | 0.1513 |
| 226.6 | 69.07 | 6.566 | 42.131 | ----- | ----- | 6.566 | 42.131 | 0.1540 |
| 256.1 | 78.06 | 5.590 | 38.712 | ----- | ----- | 5.590 | 38.712 | 0.1806 |
| 257.0 | 78.33 | 5.282 | 36.223 | ----- | ----- | 5.282 | 36.223 | 0.1814 |
| 277.5 | 84.58 | 4.921 | 34.702 | ----- | ----- | 4.921 | 34.702 | 0.2006 |
| 288.1 | 87.81 | 6.406 | 23.423 | 0.800 | 2.800 | 7.206 | 26.223 | 0.2122 |
| 298.1 | 90.86 | 2.369 | 24.906 | 0.800 | 2.800 | 3.169 | 27.706 | 0.2231 |
| 308.0 | 93.88 | 3.768 | 30.120 | 0.800 | 2.800 | 4.568 | 32.920 | 0.2303 |
| XX 326.5 | 99.52 | 4.465 | 26.841 | 0.800 | 2.800 | 5.265 | 29.641 | 0.2629 |
| XX 349.9 | 106.65 | 4.730 | 32.428 | ----- | ----- | 4.730 | 32.428 | 0.2710 |
| XX 359.3 | 109.51 | 5.381 | 29.988 | ----- | ----- | 5.381 | 29.988 | 0.2735 |
| 369.5 | 112.62 | 4.890 | 23.163 | 0.800 | 2.800 | 5.690 | 25.963 | 0.2788 |
| 370.5 | 112.93 | 3.558 | 23.247 | 0.800 | 2.800 | 4.358 | 26.047 | 0.2804 |
| 371.8 | 113.32 | 4.073 | 21.541 | 0.800 | 2.800 | 4.873 | 24.342 | 0.2825 |
| 373.3 | 113.78 | 4.732 | 31.709 | 0.800 | 2.800 | 5.532 | 34.509 | 0.2849 |
| 375.0 | 114.30 | 4.965 | 27.420 | 0.800 | 2.800 | 5.765 | 30.220 | 0.2893 |
| 446.1 | 135.97 | 4.102 | 30.735 | 0.800 | 2.800 | 4.902 | 33.535 | 0.3552 |
| 447.5 | 136.40 | 3.892 | 28.274 | 0.800 | 2.800 | 4.692 | 31.074 | 0.3620 |
| 448.5 | 136.70 | 3.560 | 28.514 | 0.800 | 2.800 | 4.360 | 31.314 | 0.3668 |
| 449.4 | 136.98 | 3.599 | 26.006 | 0.800 | 2.800 | 4.399 | 28.806 | 0.3711 |
| 453.0 | 138.07 | 6.623 | 35.706 | ----- | ----- | 6.623 | 35.706 | 0.3760 |
| XX 455.5 | 138.84 | 5.429 | 37.563 | ----- | ----- | 5.429 | 37.563 | 0.3810 |
| XX 457.0 | 139.29 | 3.624 | 29.094 | ----- | ----- | 3.624 | 29.094 | 0.3828 |
| 459.5 | 140.06 | 4.951 | 26.749 | 0.800 | 2.800 | 5.751 | 29.544 | 0.3852 |
| 476.0 | 145.09 | 4.457 | 31.139 | 0.800 | 2.800 | 5.257 | 33.939 | 0.3905 |
| 481.0 | 146.61 | 3.899 | 32.837 | 0.800 | 2.800 | 4.699 | 35.637 | 0.3930 |
| 483.4 | 147.34 | 4.741 | 30.302 | 0.800 | 2.800 | 5.541 | 33.102 | 0.3985 |
| 484.4 | 147.65 | 4.372 | 30.112 | 0.800 | 2.800 | 5.172 | 32.912 | 0.4008 |
| 485.7 | 148.04 | 4.883 | 25.332 | 0.800 | 2.800 | 5.683 | 28.132 | 0.4038 |
| 486.0 | 148.13 | 4.848 | 28.408 | 0.800 | 2.800 | 5.648 | 31.208 | 0.4045 |
| 487.8 | 148.68 | 4.377 | 28.848 | 0.800 | 2.800 | 5.177 | 31.648 | 0.4087 |
| 489.0 | 149.05 | 3.761 | 31.085 | 0.800 | 2.800 | 4.561 | 33.885 | 0.4115 |
| XX 490.0 | 149.35 | 4.079 | 31.244 | ----- | ----- | 4.079 | 31.000 | 0.4138 |
| 491.2 | 149.72 | 3.755 | 31.014 | 0.800 | 2.800 | 4.555 | 33.814 | 0.4165 |
| 492.0 | 149.96 | 2.985 | 30.480 | 0.800 | 2.800 | 3.785 | 33.280 | 0.4184 |
| 493.2 | 150.33 | 3.429 | 30.686 | 0.800 | 2.800 | 4.229 | 33.486 | 0.4212 |
| 493.9 | 150.54 | 2.711 | 35.253 | 0.800 | 2.800 | 3.511 | 38.053 | 0.4228 |
| 502.1 | 153.04 | 3.311 | 30.935 | 0.800 | 2.800 | 4.111 | 33.735 | 0.4301 |
| 546.1 | 166.45 | 2.765 | 31.910 | 0.800 | 2.800 | 3.565 | 34.710 | 0.5982 |
| 547.4 | 166.85 | 2.214 | 32.187 | 0.800 | 2.800 | 3.014 | 34.987 | 0.6004 |
| 547.7 | 166.94 | 1.945 | 32.628 | 0.800 | 2.800 | 2.745 | 35.428 | 0.6009 |
| 548.5 | 167.18 | 1.455 | 35.075 | 0.800 | 2.800 | 2.255 | 37.875 | 0.6022 |
| 549.5 | 167.49 | 2.285 | 33.221 | 0.800 | 2.800 | 3.085 | 36.021 | 0.6039 |
| 550.5 | 167.79 | 1.591 | 33.215 | ----- | 1.000 | 1.591 | 33.415 | 0.6056 |
| 551.7 | 168.16 | 3.607 | 31.163 | 0.800 | 2.800 | 4.407 | 33.963 | 0.6076 |
| 552.6 | 168.43 | 1.878 | 28.600 | 0.800 | 2.800 | 2.678 | 31.400 | 0.6091 |
| 553.8 | 168.80 | 3.271 | 31.311 | 0.800 | 2.800 | 4.071 | 34.111 | 0.6111 |
| 555.0 | 169.16 | 1.634 | 32.290 | ----- | 1.000 | 1.634 | 33.290 | 0.6132 |
| 556.0 | 169.47 | 3.003 | 32.705 | ----- | 1.000 | 3.003 | 33.705 | 0.6149 |
| 557.1 | 169.80 | 4.053 | 38.224 | ----- | ----- | 4.053 | 38.224 | 0.6168 |
| 558.2 | 170.14 | 1.280 | 27.901 | ----- | ----- | 1.280 | 27.901 | 0.6187 |
| 559.2 | 170.44 | 1.964 | 32.186 | ----- | ----- | 1.964 | 32.186 | 0.6205 |
| 560.1 | 170.72 | 3.577 | 32.874 | ----- | ----- | 3.577 | 32.874 | 0.6220 |
| 561.0 | 170.99 | 2.147 | 35.478 | ----- | ----- | 2.147 | 35.478 | 0.6236 |

|  | CORE DEPTH ( ft ) | CORE DEPTH ( m ) | C-13 DOL. (PDB) | 0-18 DOL. (SMOW) | C-13 CORRECTIONS ( per mil ) | 0-18 | C-13 FINAL (PDB) | 0-18 FINAL (SMOW) | AGE (Ma) |
|---|---|---|---|---|---|---|---|---|---|
|  | 562.2 | 171.36 | 1.121 | 34.479 | ----- | 1.000 | 1.121 | 35.479 | 0.6257 |
|  | 563.2 | 171.66 | 1.296 | 30.667 | ----- | ----- | 1.296 | 30.667 | 0.6274 |
|  | 564.3 | 172.00 | 2.333 | 32.120 | ----- | ----- | 2.333 | 32.120 | 0.6293 |
|  | 565.3 | 172.30 | 2.461 | 31.986 | ----- | ----- | 2.461 | 31.986 | 0.6310 |
|  | 567.0 | 172.82 | 2.027 | 33.316 | ----- | ----- | 2.027 | 33.316 | 0.6340 |
|  | 568.7 | 173.34 | 3.073 | 35.171 | ----- | ----- | 3.073 | 35.171 | 0.6369 |
|  | 569.9 | 173.71 | 6.209 | 40.770 | ----- | ----- | 6.209 | 40.770 | 0.6390 |
|  | 571.2 | 174.10 | 3.738 | 34.551 | ----- | ----- | 3.738 | 34.551 | 0.6412 |
|  | 572.5 | 174.50 | 4.834 | 39.142 | ----- | ----- | 4.834 | 39.142 | 0.6435 |
|  | 573.8 | 174.89 | 4.646 | 37.815 | ----- | ----- | 4.646 | 37.815 | 0.6457 |
|  | 574.9 | 175.23 | 5.332 | 39.691 | ----- | ----- | 5.332 | 39.691 | 0.6476 |
|  | 575.4 | 175.38 | 4.182 | 35.143 | ----- | ----- | 4.182 | 35.143 | 0.6485 |
|  | 576.4 | 175.69 | 4.677 | 37.685 | ----- | ----- | 4.677 | 37.685 | 0.6502 |
|  | 577.6 | 176.05 | 4.320 | 36.589 | 0.800 | 2.800 | 5.120 | 39.389 | 0.6523 |
|  | 578.6 | 176.36 | 4.971 | 30.339 | ----- | ----- | 4.971 | 30.339 | 0.6540 |
|  | 579.5 | 176.63 | 4.037 | 32.522 | ----- | ----- | 4.037 | 32.522 | 0.6556 |
|  | 580.7 | 177.00 | 4.475 | 34.149 | ----- | ----- | 4.475 | 34.149 | 0.6577 |
|  | 582.2 | 177.45 | 4.201 | 33.392 | 0.800 | 2.800 | 5.001 | 36.192 | 0.6603 |
| XX | 583.3 | 177.79 | 4.681 | 31.669 | ----- | ----- | 4.681 | 31.669 | 0.6622 |
| XX | 584.2 | 178.06 | 3.562 | 21.455 | ----- | ----- | 3.562 | 21.455 | 0.6637 |
|  | 587.8 | 179.16 | 2.644 | 32.359 | 0.800 | 2.800 | 3.444 | 35.159 | 0.6697 |
|  | 590.9 | 180.11 | 5.838 | 41.693 | ----- | ----- | 5.838 | 41.693 | 0.6794 |
| XX | 592.6 | 180.62 | 4.184 | 33.944 | ----- | ----- | 4.184 | 33.944 | 0.6848 |
|  | 594.8 | 181.30 | 5.488 | 42.246 | ----- | ----- | 5.488 | 42.246 | 0.6917 |
|  | 598.5 | 182.42 | 4.162 | 30.279 | ----- | ----- | 4.162 | 30.279 | 0.7034 |
| XX | 601.5 | 183.34 | 6.636 | 23.732 | ----- | ----- | 6.636 | 23.732 | 0.7128 |
| XX | 603.0 | 183.79 | 5.326 | 36.755 | ----- | ----- | 5.326 | 36.755 | 0.7175 |
| XX | 605.0 | 184.40 | 4.765 | 27.429 | ----- | ----- | 4.765 | 27.429 | 0.7238 |
| XX | 607.9 | 185.29 | 5.768 | 34.523 | ----- | ----- | 5.768 | 34.523 | 0.7339 |
| XX | 609.9 | 185.90 | 6.254 | 39.206 | ----- | ----- | 6.254 | 39.206 | 0.7422 |
| XX | 611.5 | 186.39 | 6.349 | 27.093 | ----- | ----- | 6.349 | 27.093 | 0.7489 |
| XX | 615.0 | 187.45 | 6.030 | 31.304 | ----- | ----- | 6.030 | 31.304 | 0.7604 |
|  | 624.0 | 190.20 | 4.279 | 28.077 | 0.800 | 2.800 | 5.079 | 30.877 | 0.7826 |
|  | 631.8 | 192.57 | 3.304 | 31.200 | 0.800 | 2.800 | 4.104 | 34.000 | 0.8037 |
|  | 634.2 | 193.30 | 4.220 | 25.842 | ----- | ----- | 4.220 | 25.842 | 0.8099 |
|  | 636.4 | 193.98 | 4.679 | 26.805 | ----- | ----- | 4.679 | 26.805 | 0.8156 |
| XX | 638.5 | 194.62 | 4.470 | 28.589 | ----- | ----- | 4.470 | 28.589 | 0.8210 |
|  | 641.1 | 195.41 | 5.353 | 30.612 | ----- | ----- | 5.353 | 30.612 | 0.8278 |
|  | 642.5 | 195.83 | 4.143 | 32.740 | ----- | 1.000 | 4.143 | 33.740 | 0.8314 |
|  | 645.2 | 196.66 | 4.076 | 32.534 | ----- | 1.000 | 4.076 | 33.534 | 0.8350 |
|  | 647.4 | 197.33 | 2.675 | 35.727 | 0.800 | 2.800 | 3.475 | 38.527 | 0.8402 |
|  | 651.4 | 198.55 | 3.440 | 36.050 | 0.800 | 2.800 | 4.240 | 38.850 | 0.8496 |
|  | 653.6 | 199.22 | 4.500 | 35.557 | ----- | ----- | 4.500 | 35.557 | 0.8548 |
|  | 659.2 | 200.92 | 4.736 | 33.899 | ----- | ----- | 4.736 | 33.899 | 0.8681 |
|  | 661.7 | 201.69 | 4.498 | 31.425 | ----- | ----- | 4.498 | 31.425 | 0.8740 |
|  | 664.8 | 202.63 | 5.707 | 38.055 | ----- | ----- | 5.707 | 38.055 | 0.8813 |
|  | 666.5 | 203.15 | 3.960 | 35.178 | ----- | ----- | 3.960 | 35.178 | 0.8854 |
|  | 668.4 | 203.73 | 5.562 | 39.513 | ----- | ----- | 5.562 | 39.513 | 0.8899 |
|  | 670.2 | 204.28 | 6.449 | 33.316 | ----- | ----- | 6.449 | 33.316 | 0.8941 |
|  | 671.5 | 204.67 | 3.988 | 31.171 | ----- | ----- | 3.988 | 31.171 | 0.8976 |
|  | 680.7 | 207.48 | 5.768 | 38.904 | ----- | ----- | 5.768 | 38.904 | 0.9042 |
|  | 684.7 | 208.70 | 6.016 | 39.346 | ----- | ----- | 6.016 | 39.346 | 0.9141 |
|  | 690.3 | 210.40 | 4.673 | 32.509 | ----- | ----- | 4.673 | 32.509 | 0.9278 |
| XX | 701.2 | 213.73 | 5.930 | 38.156 | ----- | ----- | 5.930 | 38.156 | 0.9352 |
|  | 706.2 | 215.25 | 3.374 | 34.371 | 0.800 | 2.800 | 4.174 | 37.171 | 0.9409 |
|  | 710.2 | 216.47 | 2.598 | 33.392 | 0.800 | 2.800 | 3.398 | 36.192 | 0.9454 |
|  | 713.4 | 217.44 | 3.035 | 36.275 | 0.800 | 2.800 | 3.835 | 39.075 | 0.9490 |
|  | 717.0 | 218.54 | 2.861 | 28.766 | 0.800 | 2.800 | 3.661 | 32.566 | 0.9530 |
|  | 724.9 | 220.95 | 3.403 | 29.145 | 0.800 | 2.800 | 4.203 | 31.945 | 0.9684 |
|  | 727.5 | 221.74 | 3.625 | 24.522 | 0.800 | 2.800 | 4.425 | 27.322 | 0.9718 |
|  | 747.2 | 227.75 | 6.008 | 34.406 | ----- | ----- | 6.008 | 34.406 | 0.9919 |
|  | 750.0 | 228.60 | 5.971 | 41.628 | ----- | ----- | 5.971 | 41.628 | 0.9948 |
| XX | 752.5 | 229.36 | 4.160 | 24.314 | ----- | ----- | 4.160 | 24.314 | 0.9973 |

| CORE DEPTH ( ft ) | CORE DEPTH ( m ) | C-13 DOL. (PDB) | O-18 DOL. (SMOW) | C-13 CORRECTIONS ( per mil ) | O-18 | C-13 FINAL (PDB) | O-18 FINAL (SMOW) | AGE (Ma) |
|---|---|---|---|---|---|---|---|---|
| 758.0 | 231.04 | 6.272 | 39.973 | ----- | ----- | 6.272 | 39.973 | 1.0029 |
| 762.4 | 232.38 | 6.394 | 40.565 | ----- | ----- | 6.394 | 40.565 | 1.0074 |
| 766.5 | 233.63 | 3.581 | 35.114 | ----- | 1.000 | 3.581 | 36.114 | 1.0116 |
| 772.2 | 235.37 | 6.234 | 38.277 | ----- | ----- | 6.234 | 38.277 | 1.0174 |
| 775.8 | 236.46 | 5.773 | 38.988 | ----- | ----- | 5.773 | 38.988 | 1.0211 |
| 780.8 | 237.99 | 4.861 | 30.802 | ----- | ----- | 4.861 | 30.802 | 1.0261 |
| 785.9 | 239.54 | 5.964 | 38.269 | ----- | ----- | 5.964 | 38.269 | 1.0313 |
| 794.2 | 242.07 | 6.178 | 40.195 | ----- | ----- | 6.178 | 40.195 | 1.0398 |
| 798.7 | 243.44 | 6.063 | 38.766 | ----- | ----- | 6.063 | 38.766 | 1.0444 |
| 805.0 | 245.36 | 4.262 | 32.830 | ----- | ----- | 4.262 | 32.830 | 1.0508 |
| 814.0 | 248.11 | 4.546 | 33.949 | ----- | ----- | 4.546 | 33.949 | 1.0600 |
| 818.2 | 249.39 | 5.270 | 33.377 | ----- | 1.000 | 5.270 | 34.377 | 1.0637 |
| 823.6 | 251.03 | 4.384 | 32.283 | 0.800 | 2.800 | 5.184 | 35.083 | 1.0718 |
| 827.0 | 252.07 | 5.173 | 33.282 | ----- | ----- | 5.173 | 33.282 | 1.0771 |
| 831.7 | 253.50 | 5.348 | 36.596 | ----- | ----- | 5.348 | 36.596 | 1.0843 |
| 837.0 | 255.12 | 6.809 | 37.489 | ----- | ----- | 6.809 | 37.489 | 1.0924 |
| 841.6 | 256.52 | 6.166 | 37.373 | ----- | ----- | 6.166 | 37.373 | 1.0995 |
| 846.6 | 258.04 | 4.465 | 35.381 | ----- | 1.000 | 4.465 | 36.381 | 1.1072 |
| 859.8 | 262.07 | 4.366 | 33.866 | ----- | ----- | 4.366 | 33.866 | 1.1274 |
| 864.0 | 263.35 | 6.830 | 40.501 | ----- | ----- | 6.830 | 40.501 | 1.1339 |
| 876.2 | 267.07 | 6.735 | 38.187 | ----- | ----- | 6.735 | 38.187 | 1.1526 |
| XX 880.9 | 268.50 | NO CARBONATE | | ----- | ----- | ----- | ----- | 1.1598 |
| 887.6 | 270.54 | 4.786 | 33.328 | ----- | 1.000 | 4.786 | 34.328 | 1.1670 |
| 893.9 | 272.46 | 4.384 | 31.279 | 0.800 | 2.800 | 5.184 | 34.079 | 1.1757 |
| 898.9 | 273.99 | 4.473 | 29.276 | 0.800 | 2.800 | 5.273 | 32.076 | 1.1840 |
| 903.1 | 275.27 | 6.496 | 36.371 | ----- | ----- | 6.496 | 36.371 | 1.1910 |
| XX 908.6 | 276.94 | 4.099 | 33.032 | ----- | ----- | 4.099 | 33.032 | 1.2002 |
| 917.1 | 279.53 | 5.022 | 34.559 | 0.800 | 2.800 | 5.822 | 37.359 | 1.2126 |
| 922.0 | 281.03 | 4.839 | 34.751 | ----- | 1.000 | 4.839 | 35.751 | 1.2198 |
| 930.0 | 283.46 | 4.408 | 34.554 | ----- | ----- | 4.408 | 34.554 | 1.2315 |
| 935.7 | 285.20 | 2.905 | 35.058 | ----- | ----- | 2.905 | 35.058 | 1.2398 |
| 939.9 | 286.48 | 2.759 | 32.046 | ----- | ----- | 2.759 | 32.046 | 1.2459 |
| 948.0 | 288.95 | 2.330 | 34.153 | 0.800 | 2.800 | 3.130 | 36.953 | 1.2578 |
| 955.0 | 291.08 | 3.307 | 35.125 | ----- | ----- | 3.307 | 35.125 | 1.2680 |
| 959.0 | 292.30 | 1.909 | 35.548 | 0.800 | 2.800 | 2.709 | 38.348 | 1.2693 |
| 966.0 | 294.44 | 0.290 | 32.647 | 0.800 | 2.800 | 1.090 | 35.447 | 1.2730 |
| 972.1 | 296.30 | 2.091 | 29.356 | ----- | ----- | 2.091 | 29.356 | 1.2909 |
| 977.0 | 297.79 | 0.439 | 33.098 | ----- | ----- | 0.439 | 33.098 | 1.3053 |
| 986.0 | 300.53 | -0.045 | 34.680 | 0.800 | 2.800 | 0.755 | 37.480 | 1.3218 |
| 1006.0 | 306.63 | 3.369 | 33.397 | 0.800 | 2.800 | 4.169 | 36.197 | 1.3312 |
| 1012.0 | 308.46 | -0.076 | 31.653 | 0.800 | 2.800 | 0.724 | 34.453 | 1.3350 |
| 1017.0 | 309.98 | 4.825 | 31.282 | ----- | ----- | 4.825 | 31.282 | 1.3403 |
| 1034.2 | 315.22 | 5.640 | 36.016 | ----- | ----- | 5.640 | 36.016 | 1.3585 |
| 1068.0 | 325.53 | -9.314 | 23.058 | ----- | ----- | -9.314 | 23.058 | 1.4080 |
| 1076.0 | 327.97 | -1.436 | 29.713 | 0.800 | 2.800 | -0.636 | 32.513 | 1.4101 |
| 1080.4 | 329.31 | -2.507 | 27.552 | 0.800 | 2.800 | -1.707 | 30.352 | 1.4244 |
| 1089.0 | 331.93 | -0.672 | 31.240 | 0.800 | 2.800 | 0.128 | 34.040 | 1.4366 |
| 1093.0 | 333.15 | 4.686 | 40.200 | 0.800 | 2.800 | 5.486 | 43.000 | 1.4500 |
| 1099.0 | 334.98 | -5.207 | 28.305 | 0.800 | 2.800 | -4.407 | 31.105 | 1.4535 |
| 1104.0 | 336.50 | -5.748 | 26.033 | 0.800 | 2.800 | -4.948 | 28.833 | 1.4712 |
| 1106.5 | 337.26 | -4.479 | 25.626 | 0.800 | 2.800 | -3.679 | 28.426 | 1.4800 |
| 1110.6 | 338.51 | -6.709 | 28.633 | 0.800 | 2.800 | -5.909 | 31.433 | 1.4846 |
| 1115.3 | 339.94 | -4.257 | 24.794 | 0.800 | 2.800 | -3.457 | 27.594 | 1.4991 |
| 1120.0 | 341.38 | -3.085 | 27.424 | 0.800 | 2.800 | -2.285 | 30.224 | 1.5112 |
| 1125.5 | 343.05 | -0.470 | 29.556 | 0.800 | 2.800 | 0.330 | 32.356 | 1.5284 |
| 1130.5 | 344.58 | 3.095 | 33.892 | ----- | ----- | 3.095 | 33.892 | 1.5441 |
| 1132.7 | 345.25 | 3.498 | 34.063 | ----- | ----- | 3.498 | 34.063 | 1.5510 |
| 1156.5 | 352.50 | -0.116 | 29.908 | 0.800 | 2.800 | 0.684 | 32.708 | 1.5762 |
| 1210.7 | 369.02 | 0.422 | 32.659 | 0.800 | 2.800 | 1.222 | 35.459 | 1.6230 |
| 1294.0 | 394.41 | -1.131 | 28.458 | 0.800 | 2.800 | -0.331 | 31.258 | 1.8127 |

# Appendix G

## Searles Lake Core KM-3 Isotopic Results for Bulk Leached Samples Run at University of Missouri-Columbia

# APPENDIX G

## SEARLES LAKE CORE KM-3: DEPTH, AGE, O-18 & C-13 RESULTS FOR BULK LEACHED SAMPLES RUN AT UNIVERSITY OF MISSOURI-COLUMBIA.

| CORE DEPTH (ft) | CORE DEPTH (m) | C-13 DOL (PDB) | O-18 DOL (SMOW) | AGE (Ma) |
|---|---|---|---|---|
| 96.6 | 29.44 | 2.38 | 29.59 | .0269 |
| 124.9 | 38.07 | 4.06 | 34.99 | .0335 |
| 125.7 | 38.31 | 4.04 | 31.161 | .0356 |
| 126.3 | 38.50 | 2.52 | 33.34 | .0372 |
| 126.9 | 38.68 | 3.93 | 38.92 | .0388 |
| 127.7 | 38.92 | 2.964 | 36.033 | .0409 |
| 128.7 | 39.29 | 2.83 | 34.22 | .0440 |
| 130.1 | 39.65 | 2.51 | 28.35 | .0471 |
| 130.4 | 39.75 | 3.6 | 37.65 | .0480 |
| 132.3 | 40.33 | 1.75 | 33.21 | .0530 |
| 134.4 | 40.97 | 3.40 | 34.44 | .0585 |
| 136.4 | 41.57 | 2.63 | 35.71 | .0637 |
| 137.5 | 41.91 | 4.05 | 34.61 | .0659 |
| 139.0 | 42.37 | 1.52 | 34.15 | .0672 |
| 140.5 | 42.82 | 2.79 | 38.084 | .0685 |
| 141.8 | 43.22 | 3.77 | 35.93 | .0696 |
| 142.8 | 43.53 | 2.82 | 38.97 | .0705 |
| 481.0 | 146.61 | 3.34 | 31.97 | .3930 |
| 481.0 | 146.61 | 3.36 | 31.36 | .3930 |
| 492.0 | 149.96 | 1.88 | 29.21 | .4148 |
| 493.9 | 150.54 | 2.14 | 32.24 | .4228 |
| 502.1 | 153.04 | 2.204 | 28.63 | .4301 |
| 546.1 | 166.45 | 2.56 | 30.94 | .5982 |
| 547.4 | 166.85 | 2.00 | 30.14 | .6004 |
| 547.7 | 166.94 | 1.364 | 30.88 | .6009 |
| 548.5 | 167.18 | 1.62 | 31.95 | .6022 |
| 548.5 | 167.18 | 1.36 | 32.11 | .6022 |
| 549.5 | 167.49 | 1.63 | 30.76 | .6039 |
| 550.5 | 167.79 | 1.518 | 29.558 | .6056 |
| 551.7 | 168.16 | 3.36 | 30.15 | .6076 |
| 552.6 | 168.43 | 2.54 | 29.08 | .6091 |
| 553.8 | 168.80 | 2.85 | 29.29 | .6111 |
| 555.0 | 169.16 | 1.76 | 30.61 | .6132 |
| 556.0 | 169.47 | 2.88 | 28.56 | .6149 |
| 557.1 | 169.80 | 3.71 | 35.12 | .6168 |
| 558.2 | 170.14 | 1.07 | 27.13 | .6187 |
| 559.2 | 170.44 | 1.34 | 21.52 | .6205 |
| 560.1 | 170.72 | 3.32 | 30.79 | .6220 |
| 561.0 | 170.99 | 1.13 | 30.81 | .6236 |
| 562.2 | 171.36 | 2.31 | 33.41 | .6257 |
| 562.2 | 171.36 | 2.58 | 33.14 | .6257 |
| 563.2 | 171.66 | 1.04 | 28.27 | .6274 |
| 564.3 | 172.00 | 1.56 | 28.19 | .6293 |
| 564.3 | 172.00 | 1.475 | 28.924 | .6293 |
| 565.3 | 172.30 | 2.67 | 30.98 | .6310 |
| 567.0 | 172.82 | 1.73 | 29.70 | .6340 |
| 568.7 | 173.34 | 2.90 | 31.64 | .6369 |
| 569.9 | 173.71 | 7.19 | 41.13 | .6390 |
| 571.2 | 174.10 | 1.88 | 28.45 | .6412 |
| 572.5 | 174.50 | 4.94 | 38.40 | .6435 |
| 574.9 | 175.23 | 4.51 | 36.31 | .6476 |
| 575.4 | 175.38 | 3.19 | 30.94 | .6485 |
| 576.4 | 175.69 | 4.58 | 36.02 | .6502 |
| 577.6 | 176.05 | 3.68 | 33.66 | .6523 |
| 578.6 | 176.36 | 4.19 | 27.37 | .6540 |
| 578.6 | 176.36 | 4.46 | 37.68 | .6540 |
| 580.7 | 177.00 | 3.95 | 30.20 | .6577 |

| CORE DEPTH (ft) | CORE DEPTH (m) | C-13 DOL (PDB) | O-18 DOL (SMOW) | AGE (Ma) |
|---|---|---|---|---|
| 582.2 | 177.45 | 3.62 | 31.19 | .6603 |
| 583.3 | 177.79 | 6.05 | 32.22 | .6622 |
| 584.2 | 178.06 | 2.56 | 19.57 | .6637 |
| 587.8 | 179.16 | 2.36 | 28.75 | .6697 |
| 590.9 | 180.11 | 5.38 | 39.7 | .6794 |
| 590.9 | 180.11 | 5.73 | 40.35 | .6794 |
| 592.6 | 180.62 | 3.426 | 30.436 | .6848 |
| 636.4 | 193.98 | 1.28 | 23.00 | .8156 |
| 636.4 | 193.98 | 2.82 | 25.15 | .8156 |
| 638.5 | 194.62 | 3.49 | 27.60 | .8210 |
| 641.1 | 195.41 | 4.21 | 28.59 | .8278 |
| 642.5 | 195.83 | 2.94 | 31.28 | .8314 |
| 651.4 | 198.55 | 3.32 | 32.73 | .8496 |
| 653.6 | 199.22 | 3.17 | 30.02 | .8548 |
| 659.2 | 200.92 | 4.06 | 29.87 | .8681 |
| 661.7 | 201.69 | 3.72 | 29.62 | .8740 |
| 666.5 | 203.15 | 4.36 | 31.58 | .8854 |
| 668.4 | 203.73 | 4.52 | 35.82 | .8899 |
| 671.5 | 204.67 | 3.64 | 28.63 | .8976 |
| 701.2 | 213.73 | 4.51 | 34.32 | .9352 |
| 706.2 | 215.25 | 1.43 | 28.98 | .9409 |
| 710.2 | 216.47 | 1.87 | 30.40 | .9454 |
| 713.4 | 217.44 | 2.95 | 42.30 | .9490 |
| 750.0 | 228.60 | 5.80 | 40.00 | .9948 |
| 766.5 | 233.63 | 2.25 | 30.48 | 1.0116 |
| 772.2 | 235.37 | 5.17 | 35.01 | 1.0174 |
| 798.7 | 243.44 | 4.74 | 34.43 | 1.0444 |
| 1006.0 | 306.63 | 3.84 | 33.11 | 1.3312 |
| 1012.0 | 308.46 | 0.78 | 32.05 | 1.3350 |
| 1017.0 | 309.98 | 4.17 | 29.86 | 1.3403 |
| 1076.0 | 327.97 | -0.95 | 30.24 | 1.4101 |
| 1080.4 | 329.31 | -1.91 | 29.03 | 1.4244 |
| 1089.0 | 331.93 | 0.63 | 33.13 | 1.4366 |
| 1093.0 | 333.15 | 4.75 | 38.95 | 1.4500 |
| 1099.0 | 334.98 | -5.14 | 27.06 | 1.4535 |

# Appendix H

# Analytical-Solution Lake Isotope Evolution Model and Results

```
C*****************************************************************************
C*                                                                           *
C*    THIS PROGRAM COMPUTES FRED'S ANALYTICAL SOLUTIONS FOR CLOSED-BASIN     *
C*    LAKE VOLUMES AND ISOTOPIC COMPOSITION.  YOU WILL BE ASKED TO INPUT     *
C*    ALL PARAMETERS- PAY CAREFUL ATTENTION TO UNITS!                        *
C*                                                                           *
C*****************************************************************************
        PROGRAM CBLAKES
        CHARACTER FNAME*50,ANS*1,ANS2*1
C
        WRITE(6,*)'THIS PROGRAM COMPUTES FREDS ANALYTICAL
     1 SOLUTIONS FOR'
        WRITE(6,*)'CLOSED-BASIN  LAKE VOLUMES AND ISOTOPIC COMPOSITION.'
        WRITE(6,*)'YOU WILL BE ASKED TO INPUT  ALL PARAMETERS- PAY
     1 CAREFUL'
        WRITE(6,*)' ATTENTION TO UNITS!'
C
C
C
        WRITE(6,*)'ENTER OUTPUT FILE NAME'
        READ(5,'(A)')FNAME
        OPEN(UNIT=95,FILE=FNAME,STATUS='NEW',CARRIAGECONTROL='LIST')

  10    WRITE(6,*)'INPUT TYPE OF EQUATIONS USED (R,I,E)'
        WRITE(6,*)'     R=    RAMP INFLOW EQUATIONS'
        WRITE(6,*)'     I=    INSTANTANEOUS INFLOW EQUATIONS'
        WRITE(6,*)'     E=    EXIT PROGRAM'
        READ(5,'(A)')ANS
        IF((ANS.EQ.'R').OR.(ANS.EQ.'r'))THEN
                WRITE(6,*)'STATE SITUATION (I,D,E)'
                WRITE(6,*)'   I=  INCREASING OR DECREASING INFLOW'
                WRITE(6,*)'   D=  DESSICATION:INITIAL AND FINAL INFLOW=0'
                WRITE(6,*)'   E=  EXIT RAMP EQUATIONS'
                READ(5,'(A)')ANS2
                IF((ANS2.EQ.'I').OR.(ANS2.EQ.'i'))THEN
                        CALL RAMP
                ELSEIF((ANS2.EQ.'D').OR.(ANS2.EQ.'d'))THEN
                        CALL DESSICATE
                ELSEIF((ANS2.EQ.'E').OR.(ANS2.EQ.'e'))THEN
                        GO TO 10
                ENDIF
        ELSEIF((ANS.EQ.'I').OR.(ANS.EQ.'i'))THEN
                WRITE(6,*)'STATE SITUATION (I,D,E)'
                WRITE(6,*)'   I=  INCREASING OR DECREASING INFLOW'
                WRITE(6,*)'   D=  DESSICATION:INITIAL AND FINAL INFLOW=0'
                WRITE(6,*)'   E=  EXIT INSTANTANEOUS INFLOW EQUATIONS'
                READ(5,'(A)')ANS2
                IF((ANS2.EQ.'I').OR.(ANS2.EQ.'i'))THEN
                        CALL INSTANT
                ELSEIF((ANS2.EQ.'D').OR.(ANS2.EQ.'d'))THEN
                        CALL DESSICATE
                ELSEIF((ANS2.EQ.'E').OR.(ANS2.EQ.'e'))THEN
                        GO TO 10
                ENDIF
        ELSEIF((ANS.EQ.'E').OR.(ANS.EQ.'e'))THEN
                GO TO 100
 100    ENDIF
        STOP
        END
C
C*****************************************************************************
C
        SUBROUTINE RAMP
c       COMMON /STUFF/ TEMP,ELVS,EVAP,AREA,VOL,DK,H,DELO,VO,DELC,CAREPS
c       COMMON /RAMPSTUFF/ QIO,QF,LRAMP,BETA
c       COMMON /BOTH/ DELI
cC
c       CHARACTER TITLE*60,ANS3*1
c       DIMENSION RVOL(0:1000),DLAKE(0:1000),DELOF(0:1000)
c       DIMENSION CARB(0:1000)
```

```
C       COMING TO A THEATRE NEAR YOU...
        RETURN
        END
C
C*******************************************************************************
C*******************************************************************************
        SUBROUTINE INSTANT
        COMMON /STUFF/ TEMP,ELVS,EVAP,AREA,VOL,DK,H,DELO,VO,DELC,CAREPS
        COMMON /QINSTANT/ QI
        COMMON /BOTH/ DELI
C
        CHARACTER TITLE*60,ANS2*1
        DIMENSION RVOL(0:3000),DLAKE(0:3000),DELOF(0:3000)
        DIMENSION CARB(0:3000)
C
        WRITE(6,*)'DESCRIBE SITUATION (60 CHARACTERS OR LESS)'
        READ(5,'(A)')TITLE
        WRITE(95,*)'************************************************************'
        WRITE(95,*)
        WRITE(95,*)TITLE
        WRITE(95,*)
        WRITE(95,*)'************************************************************'

        CALL PARAMS
C
C
C       *****  DETERMINE IF OVERFLOW WILL OCCUR WITH INFLOW  ********
C
 12     FORMAT(1x,A5,7x,A6,7x,A12,4x,A8)
 13     FORMAT(1x,I5,3x,1e13.7,5x,f11.7,9x,f8.5)

        V=QI/((1-H)*DK)
        IF(VOL.EQ.VO)THEN
        KOFTIM=LOG((VOL-V)/(VO-V))/(-(1-H)*DK)
                WRITE(5,*)'LAKE WILL OVERFLOW'
        WRITE(95,*)
        WRITE(95,12)'TIME ','VOLUME','DEL O-18 H2O','   O-18 CARB'
        WRITE(95,12)'(yrs)',' (m^3)','   (SMOW)   ','     (SMOW)    '
        WRITE(95,*)
                WRITE(95,*)
                WRITE(95,*)'************ OVERFLOW ******************'
                WRITE(95,*)
C
C               COMPUTE ISOTOPIC COMPOSITION OF OVERFLOWING LAKE
C
                QO=QI-DK*VOL*(1-H)
                KTIM=0
                P1=DK/(ELVS+1) + QO/VOL
                P2=QI*DELI/VOL + DK*(ELVS/(ELVS+1) + H*DELC)
                DO 250 J=0,500,10
                        RVOL(J)=(VO-V)*EXP(-(1-H)*DK*KTIM)+V
                        DELOF(J)=(P2/P1 + (DELO-P2/P1)
    1                          *EXP((-P1)*KTIM))*1000.
                        CARB(J)=CAREPS + DELOF(J)
                        WRITE(95,13)KTIM,VOL,DELOF(J),CARB(J)
                        KTIM=KTIM+10
                        IF(RVOL(J).LT.VOL)THEN
                           DELBSW=DELOF(J)/1000.
                                KBSW=2000-KTIM+10
                                GO TO 251

                        ENDIF
 250            CONTINUE
C
C               COMPUTE LAKE VOLUME AND ISO COMP. LAKE BENEATH SPILLWAY
C
 251            WRITE(95,*)
                WRITE(95,*)'******** LAKE LEVEL BENEATH SPILLWAY *******'
                WRITE(95,*)
                KTIM=0
                        A=(ELVS+1)/DK
```

```
                        B=(ELVS+DELC*H*(ELVS+1))/(1-(ELVS+1)*(1-H))
                        D2=QI*(DELI*A+B*(VO-QI*A))
                DO 260 J=0,KBSW,100
                        RVOL(J)=(VO-V)*EXP(-(1-H)*DK*KTIM) + V
                        C=EXP(-(DK*KTIM/(ELVS+1)))
                        DLAKE(J)=((QI*A*(DELI-B)+(VO*(DELBSW-B)-QI*A
     1                          *(DELI-B))*C)/RVOL(J)+B)*1000.
                        CARB(J)=CAREPS + DLAKE(J)
                        WRITE(95,13)KTIM,RVOL(J),DLAKE(J),CARB(J)
                        KTIM=KTIM+100
                        IF(KTIM.GE.KBSW)THEN
                             RVOL(KBSW)=(VO-V)*EXP(-(1-H)*DK*KBSW) + V
                             C=EXP(-(DK*KBSW/(ELVS+1)))
                             DLAKE(KBSW)=((QI*A*(DELI-B)+(VO*(DELBSW-B)
     1                         -QI*A*(DELI-B))*C)/RVOL(KBSW)+B)*1000.
                             CARB(KBSW)=CAREPS+DLAKE(KBSW)
                             WRITE(95,13)KBSW,RVOL(KBSW),DLAKE(KBSW),
     1                          CARB(KBSW)
                        ENDIF
 260            CONTINUE
C
C               COMPUTE STEADY STATE DEL LAKE
C
                FV=QI/((1-H)*DK)
                SS1=QI*DELI*(ELVS+1)/(DK*FV) + ELVS + H*DELC*(ELVS+1)
                SS=SS1*1000.
                DOLSS=CAREPS + SS
                WRITE(95,*)'          STEADY STATE VALUES:NON-OVERFLOW'
                WRITE(95,*)
                WRITE(95,*)'                        LAKE VOLUME',FV
                WRITE(95,*)'               STEADY STATE DEL H2O',SS
                WRITE(95,*)'             STEADY STATE CARBONATE',DOLSS
        ELSEIF(V.GT.VOL)THEN
        KOFTIM=LOG((VOL-V)/(VO-V))/(-(1-H)*DK)
                WRITE(5,*)'LAKE WILL OVERFLOW'
C
C               COMPUTE LAKE VOLUME AND ISO COMPOSITION UNTIL OVERFLOW
C
                WRITE(95,*)
        WRITE(95,12)'TIME ','VOLUME','DEL O-18 H2O','   O-18 CARB'
        WRITE(95,12)'(yrs)',' (m^3)','   (SMOW)   ','    (SMOW)    '
                WRITE(95,*)
                        KTIM=0
                        A=(ELVS+1)/DK
                        B=(ELVS+DELC*H*(ELVS+1))/(1-(ELVS+1)*(1-H))
                DO 150 J=0,KOFTIM+1,10
                        RVOL(J)=(VO-V)*EXP(-(1-H)*DK*KTIM) + V
                        C=EXP(-(DK*KTIM/(ELVS+1)))
                        IF((VO.EQ.0).AND.(KTIM.EQ.0))THEN
                        DLAKE(0)=DELI*1000.
                        CARB(0)=CAREPS+DLAKE(0)
                        ELSE
                        DLAKE(J)=((QI*A*(DELI-B)+(VO*(DELO-B)-QI*A
     1                          *(DELI-B))*C)/RVOL(J)+B)*1000.
                        CARB(J)=CAREPS+DLAKE(J)
                        ENDIF
                        WRITE(95,13)KTIM,RVOL(J),DLAKE(J),CARB(J)
                        KTIM=KTIM+10
                        IF(KTIM.GE.KOFTIM+1)THEN
                             RVOL(KOFTIM+1)=(VO-V)*
     1                          EXP(-(1-H)*DK*(KOFTIM+1))+V
                             C=EXP(-(DK*(KOFTIM+1)/(ELVS+1)))
                             DLAKE(KOFTIM+1)=((QI*A*(DELI-B)+(VO*(DELO
     1                         -B)-QI*A*(DELI-B))*C)/RVOL(KOFTIM+1)+B)
     1                         *1000.
                             CARB(KOFTIM+1)=CAREPS+DLAKE(KOFTIM+1)
                             WRITE(95,13)KOFTIM,RVOL(KOFTIM+1),
     1                            DLAKE(KOFTIM+1),CARB(KOFTIM+1)
                             DELOV=(DLAKE(KOFTIM+1))/1000.
                        ENDIF
```

```
 150            CONTINUE
C
C               COMPUTE ISOTOPIC COMPOSITION OF OVERFLOWING LAKE
C
                WRITE(95,*)
                WRITE(95,*)' ***************  OVERFLOW  ********************'
                WRITE(95,*)
                QO=QI-DK*VOL*(1-H)
                KTIM=0
                P1=DK/(ELVS+1) + QO/VOL
                P2=QI*DELI/VOL + DK*(ELVS/(ELVS+1) + H*DELC)
                DO 160 J=0,500,50
                        DELOF(J)=(P2/P1 + (DELOV-P2/P1)
     1                          *EXP((-P1)*KTIM))*1000.
                        CARB(J)=CAREPS+DELOF(J)
                        WRITE(95,13)KTIM,VOL,DELOF(J),CARB(J)
                        KTIM=KTIM+50
 160            CONTINUE
C
C               COMPUTE STEADY STATE DEL LAKE-OVERFLOW
C
                SS1=QI*DELI + DK*VOL*((ELVS/(ELVS+1)) + H*DELC)
                SS2=QI + DK*VOL*(H-1+(1/(ELVS+1)))
                SSDELO=(SS1/SS2)*1000.
                DOL=CAREPS+SSDELO
                WRITE(95,*)'              STEADY STATE VALUES-OVERFLOW'
                WRITE(95,*)
                WRITE(95,*)'                     OVERFLOW TIME',KOFTIM
                WRITE(95,*)'                       LAKE VOLUME',VOL
                WRITE(95,*)'              STEADY STATE DEL H2O',SSDELO
                WRITE(95,*)'            STEADY STATE CARBONATE',DOL
                WRITE(95,*)'                      OUTFLOW RATE',QO
C
C       COMPUTE LAKE VOLUME FOR NON-OVERFLOWING LAKE'
C
        ELSE
        WRITE(95,*)
        WRITE(95,12)'TIME ','VOLUME','DEL O-18 H2O','   O-18 CARB'
        WRITE(95,12)'(yrs)',' (m^3)','   (SMOW)    ','    (SMOW)    '
        WRITE(95,*)
                KTIM=0
                        A=(ELVS+1)/DK
                        B=(ELVS+DELC*H*(ELVS+1))/(1-(ELVS+1)*(1-H))
                DO 170 J=0,2500,100
                        RVOL(J)=(VO-V)*EXP(-(1-H)*DK*KTIM) + V
                        C=EXP(-(DK*KTIM/(ELVS+1)))
                        IF((VO.EQ.0).AND.(KTIM.EQ.0))THEN
                        DLAKE(J)=DELI*1000.
                        CARB(J)=CAREPS+DLAKE(J)
                        ELSE
                        DLAKE(J)=((QI*A*(DELI-B) + (VO*(DELO-B)-
     1                     QI*A*(DELI-B))*C)/RVOL(J) + B)*1000.
                        CARB(J)=CAREPS+DLAKE(J)
                        ENDIF
                        WRITE(95,13)KTIM,RVOL(J),DLAKE(J),CARB(J)
                        KTIM=KTIM+100
                        IF(KTIM.GT.2500)THEN
                        ENDIF
 170            CONTINUE
C
C               COMPUTE STEADY STATE DEL LAKE
C

                FV=QI/((1-H)*DK)
                SS1=QI*DELI*(ELVS+1)/(DK*FV) + ELVS + H*DELC*(ELVS+1)
                SSDELO=SS1*1000.
                DOL=CAREPS+SSDELO
                WRITE(95,*)'         STEADY STATE VALUES:NON-OVERFLOW'
                WRITE(95,*)
```

```
               WRITE(95,*)'                       LAKE VOLUME',FV
               WRITE(95,*)'              STEADY STATE DEL H2O',SSDELO
               WRITE(95,*)'            STEADY STATE CARBONATE',DOL
        ENDIF
        RETURN
        END
C*****************************************************************************
C*****************************************************************************
        SUBROUTINE DESSICATE
        COMMON /STUFF/ TEMP,ELVS,EVAP,AREA,VOL,DK,H,DELO,VO,DELC,CAREPS
C
        CHARACTER TITLE*60
        DIMENSION RVOL(0:2100),DLAKE(0:2100),CARB(0:2100)
C
        WRITE(6,*)'DESCRIBE SITUATION (60 CHARACTERS OR LESS)'
        READ(5,'(A)')TITLE
        WRITE(95,*)'*********************************************************'
        WRITE(95,*)
        WRITE(95,*)TITLE
        WRITE(95,*)
        WRITE(95,*)'*********************************************************'
C
        CALL PARAMS
C
C               COMPUTE VOLUME AND ISO COMP OF DESSICATING LAKE
C
 12     FORMAT(1x,A5,7x,A6,7x,A12,4x,A8)
 13     FORMAT(1x,I5,3x,1e13.7,5x,f11.7,9x,f8.5)
        KTIM=0
        A=(ELVS+DELC*H*(ELVS+1))/(1-(ELVS+1)*(1-H))
        WRITE(95,*)
        WRITE(95,12)'TIME ','VOLUME','DEL O-18 H2O','  O-18 CARB'
        WRITE(95,12)'(YRS)',' (M^3)','   (SMOW)   ','    (SMOW)   '
        WRITE(95,*)
        DO 180 J=0,2000,100
                RVOL(J)=VO*EXP(-(1-H)*DK*KTIM)
                DLAKE(J)=((1/RVOL(J))*(VO*(DELO-A)*EXP(-DK*KTIM/(ELVS+1
    1                    )))+A)*1000.
                CARB(J)=CAREPS+DLAKE(J)
                WRITE(95,13)KTIM,RVOL(J),DLAKE(J),CARB(J)
                KTIM=KTIM+100
  180   CONTINUE
        RETURN
        END
C*****************************************************************************
C*****************************************************************************
C
        SUBROUTINE PARAMS
C
        COMMON /STUFF/ TEMP,ELVS,EVAP,AREA,VOL,DK,H,DELO,VO,DELC,CAREPS
        COMMON /RAMPSTUFF/ QIO,QF,LRAMP,BETA
        COMMON /QINSTANT/ QI
        COMMON /BOTH/ DELI
C
        CHARACTER ANS*1,ANS3*1,ANS4*1,ANS5*1
C
C
C       INPUT TEMPERATURE AND COMPUTE ELV ACCORDING TO BOTTINGA AND CRAIG(1969)
C
        WRITE(6,*)'ENTER TEMPERATURE IN DEGREES CELCIUS'
        READ(5,*)TEMP
        write(95,*)'TEMPERATURE IN DEGREES CELCIUS IS',TEMP
        TEMP=TEMP + 273.4
        ELV=1.534*(1e6/TEMP**2)-3.206*(1e3/TEMP)+2.644
        WRITE(95,*)'ELV =',ELV
        WRITE(6,*)'IS THIS RUN ASSUMING DELC=DELI?(Y,N)'
        READ(5,'(A)')ANS5
                IF((ANS5.EQ.'Y').OR.(ANS5.EQ.'y'))THEN
        WRITE(6,*)'ENTER ISOTOPIC COMP. OF BACK CONDENS. FLUX(PER MIL)'
        READ(5,*)DELC
                ELSEIF((ANS5.EQ.'N').OR.(ANS5.EQ.'n'))THEN
```

```
      WRITE(6,*)'ENTER ISOTOPIC COMPOSITION OF ATMOSPHERE'
      READ(5,*)DELA
      DELC=ELV*(1+(DELA/1000))+DELA
              ENDIF
      WRITE(95,*)'ISOTOPIC COMP. OF BACK CONDENSATION FLUX IS ',DELC
      DELC=DELC/1000.
      WRITE(6,*)'ENTER RELATIVE HUMIDITY'
      READ(5,*)H
      WRITE(95,*)'RELATIVE HUMIDITY IS',H
      ALPHA=EXP(ELV/1000)
      ELVS=((1.0/ALPHA)*(1.0 - 0.0069)/(1.0-0.0069*H))-1
      ELVS=ELVS*(-1)
      WRITE(95,*)'ELV-STAR =',ELVS
C
      WRITE(6,*)' COMPUTE CARBONATE VALUES ALONG WITH WATER? (Y,N)'
      READ(5,'(A)')ANS3
      IF((ANS3.EQ.'Y').OR.(ANS3.EQ.'y'))THEN
              WRITE(6,*)'CALCITE OR DOLOMITE? (C,D)'
              READ(5,'(A)')ANS4
              IF((ANS4.EQ.'D').OR.(ANS4.EQ.'d'))THEN
              WRITE(95,*)'COMPUTED CARBONATE VALUES FOR DOLOMITE'
C
C             COMPUTE DOLOMITE ELV ACCORDING TO NORTHROP & CLAYTON (1966)
C
                      CAREPS=3.20*(1.E6)/(TEMP**2) - 1.50
C
              ELSEIF((ANS4.EQ.'C').OR.(ANS4.EQ.'c'))THEN
              WRITE(95,*)'COMPUTED CARBONATE VALUES FOR CALCITE'
C
C     COMPUTE CALCITE EPSILON ACCORDING TO O'NEIL,CLAYTON & MAYEDA(1969)
C
                      CAREPS=2.78*(1.E6)/(TEMP**2)-2.89
              ENDIF
      ELSEIF((ANS3.EQ.'N').OR.(ANS3.EQ.'n'))THEN
      ENDIF
C
C             INPUT OTHER INITIAL PARAMETERS
C
      WRITE(6,*)'ENTER EVAPORATION RATE (m/yr)'
      read(5,*)EVAP
      WRITE(95,*)'EVAPORATION RATE IS (m/yr) ',EVAP
C
C             INPUT LAKE GEOMETRY
C
      WRITE(6,*)'ENTER MAX. LAKE SURFACE AREA(EST. HIGH LAKE STAND)(m^2)'
      read(5,*)AREA
      WRITE(95,*)'ESTIMATED MAXIMUM LAKE SURFACE AREA IS(m^2)',AREA
      WRITE(6,*)'ENTER MAX. LAKE VOLUME (EST. HIGH LAKE STAND)(m^3)'
      READ(5,*)VOL
      WRITE(95,*)'ESTIMATED MAXIMUM LAKE VOLUME IS (m^3)',VOL
C
C             COMPUTE K
C
      DK=(AREA/VOL)*EVAP
      WRITE(95,*)'K= ',DK
C
C             ENTER YET MORE INITIAL PARAMETERS
C
      WRITE(6,*)'ENTER INITIAL LAKE ISO COMPOSITION (PER MIL)'
      READ(5,*)DELO
      WRITE(95,*)'INITIAL LAKE ISO COMPOSITION IS(PER MIL)',DELO
      DELO=DELO/1000.
      WRITE(6,*)'ENTER INITIAL LAKE VOLUME(FLUID IN LAKE)(m^3)'
      READ(5,*)VO
      WRITE(95,*)'INITIAL LAKE VOLUME (m^3) IS',VO
C
C
C
      WRITE(6,*)'INPUT TYPE EQUATIONS USED ( R,I,D )'
      WRITE(6,*)'     R =  RAMP EQUATIONS'
```

```
        WRITE(6,*)'      I =  INSTANTANEOUS INFLOW'
        WRITE(6,*)'      D =  DESSICATION:INITIAL & FINAL INFLOW=0'
        READ(5,'(A)')ANS
        IF((ANS.EQ.'R').OR.(ANS.EQ.'r'))THEN
                WRITE(6,*)'ENTER INITIAL INFLOW RATE (m^3/yr)'
                read(5,*)QIO
                WRITE(95,*)'INITIAL INFLOW RATE IS (m^3/yr)',QIO
                WRITE(6,*)'ENTER FINAL INFLOW RATE (m^3/yr)'
                READ(5,*)QF
                WRITE(95,*)'FINAL INFLOW RATE IS (m^3/yr)',QF
                WRITE(6,*)'ENTER TIME RAMP (YEARS)'
                READ(5,*)LRAMP
                WRITE(95,*)'TIME RAMP IN YEARS IS',LRAMP
C
C               COMPUTE BETA
C
                BETA=(QF-QIO)/LRAMP
                WRITE(95,*)'BETA =',BETA
                WRITE(6,*)'INPUT ISOTOPIC COMP.
     6                          OF INFLOW WATER(PER MIL)'
                READ(5,*)DELI
                WRITE(95,*)'ISOTOPIC COMP OF INFLOW WATER IS',DELI
                DELI=DELI/1000.
        ELSEIF((ANS.EQ.'I').OR.(ANS.EQ.'i'))THEN
                WRITE(6,*)'ENTER  INFLOW RATE (m^3/yr)'
                read(5,*)QI
                WRITE(95,*)' INFLOW RATE IS (m^3/yr)',QI
                WRITE(6,*)'INPUT ISOTOPIC COMP.OF INFLOW WATER(PER MIL)'
                READ(5,*)DELI
                WRITE(95,*)'ISOTOPIC COMP OF INFLOW WATER IS',DELI
                DELI=DELI/1000.
        ELSEIF((ANS.EQ.'D').OR.(ANS.EQ.'d'))THEN
        ENDIF
        RETURN
        END
C*****************************************************************************
```

```
**********************************************************

INFILL OWENS FROM DRY LAKE; DELI=DELC

**********************************************************
TEMPERATURE IN DEGREES CELCIUS IS   15.50000
ELV =   9.926092
ISOTOPIC COMP. OF BACK CONDENSATION FLUX IS   -16.25000
RELATIVE HUMIDITY IS  0.2780000
ELV-STAR =  1.4819145E-02
COMPUTED CARBONATE VALUES FOR DOLOMITE
EVAPORATION RATE IS (m/yr)    1.177000
ESTIMATED MAXIMUM LAKE SURFACE AREA IS(m^2)  6.9400000E+08
ESTIMATED MAXIMUM LAKE VOLUME IS (m^3)  3.0020000E+10
K=   2.7209796E-02
INITIAL LAKE ISO COMPOSITION IS(PER MIL)  -16.25000
INITIAL LAKE VOLUME (m^3) IS  0.0000000E+00
INFLOW RATE IS (m^3/yr)  3.7000000E+09
ISOTOPIC COMP OF INFLOW WATER IS  -16.25000

TIME        VOLUME        DEL O-18 H2O        O-18 CARB
(yrs)        (m^3)           (SMOW)             (SMOW)

    0   0.0000000E+00     -16.2500000         20.59025
    8   0.3052221E+11     -14.5784540         22.26180

 ***************  OVERFLOW  ********************

    0   0.3002000E+11     -14.5784540         22.26180
   50   0.3002000E+11     -13.2548151         23.58543
  100   0.3002000E+11     -13.2528658         23.58738
  150   0.3002000E+11     -13.2528629         23.58739
  200   0.3002000E+11     -13.2528629         23.58739
  250   0.3002000E+11     -13.2528629         23.58739
  300   0.3002000E+11     -13.2528629         23.58739
  350   0.3002000E+11     -13.2528629         23.58739
  400   0.3002000E+11     -13.2528629         23.58739
  450   0.3002000E+11     -13.2528629         23.58739
  500   0.3002000E+11     -13.2528629         23.58739
               STEADY STATE VALUES-OVERFLOW

                   OVERFLOW TIME           8
                     LAKE VOLUME   3.0020000E+10
              STEADY STATE DEL H2O  -13.25286
            STEADY STATE CARBONATE   23.58739
                    OUTFLOW RATE   3.1102428E+09
```

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************************************************************

INFILL CHINA LAKE FROM DRY LAKE; DELI=DELC

************************************************************
TEMPERATURE IN DEGREES CELCIUS IS   18.40000
ELV =   9.672875
ISOTOPIC COMP. OF BACK CONDENSATION FLUX IS   -13.25286
RELATIVE HUMIDITY IS  0.2320000
ELV-STAR =  1.4882922E-02
COMPUTED CARBONATE VALUES FOR DOLOMITE
EVAPORATION RATE IS (m/yr)    1.413000
ESTIMATED MAXIMUM LAKE SURFACE AREA IS(m^2)  1.5500000E+08
ESTIMATED MAXIMUM LAKE VOLUME IS (m^3)  6.9600000E+08
K=   0.3146767
INITIAL LAKE ISO COMPOSITION IS(PER MIL)  -13.25286
INITIAL LAKE VOLUME (m^3) IS  0.0000000E+00
INFLOW RATE IS (m^3/yr)  3.1100001E+09
ISOTOPIC COMP OF INFLOW WATER IS  -13.25286

TIME          VOLUME          DEL O-18 H2O          O-18 CARB
(yrs)          (m^3)             (SMOW)               (SMOW)

    0    0.0000000E+00      -13.2528601           22.82910
    0    0.2762729E+10      -11.1157265           24.96623

 ***************  OVERFLOW  ********************

    0    0.6960000E+09      -11.1157265           24.96623
   50    0.6960000E+09      -12.2491808           23.83278
  100    0.6960000E+09      -12.2491808           23.83278
  150    0.6960000E+09      -12.2491808           23.83278
  200    0.6960000E+09      -12.2491808           23.83278
  250    0.6960000E+09      -12.2491808           23.83278
  300    0.6960000E+09      -12.2491808           23.83278
  350    0.6960000E+09      -12.2491808           23.83278
  400    0.6960000E+09      -12.2491808           23.83278
  450    0.6960000E+09      -12.2491808           23.83278
  500    0.6960000E+09      -12.2491808           23.83278
                STEADY STATE VALUES-OVERFLOW

                       OVERFLOW TIME            0
                         LAKE VOLUME  6.9600000E+08
                STEADY STATE DEL H2O  -12.24918
              STEADY STATE CARBONATE   23.83278
                         OUTFLOW RATE  2.9417966E+09
```

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**********************************************************

INFILL SEARLES LAKE FROM DRY LAKE; DELI=DELC

**********************************************************
TEMPERATURE IN DEGREES CELCIUS IS   19.10000
ELV =   9.613042
ISOTOPIC COMP. OF BACK CONDENSATION FLUX IS   -12.24918
RELATIVE HUMIDITY IS  0.2210000
ELV-STAR =  1.4898777E-02
COMPUTED CARBONATE VALUES FOR DOLOMITE
EVAPORATION RATE IS (m/yr)    1.685000
ESTIMATED MAXIMUM LAKE SURFACE AREA IS(m^2)  9.9400000E+08
ESTIMATED MAXIMUM LAKE VOLUME IS (m^3)  8.5279998E+10
K=   1.9639893E-02
INITIAL LAKE ISO COMPOSITION IS(PER MIL)  -12.24918
INITIAL LAKE VOLUME (m^3) IS  0.0000000E+00
INFLOW RATE IS (m^3/yr)  2.9417999E+09
ISOTOPIC COMP OF INFLOW WATER IS  -12.24918

TIME         VOLUME          DEL O-18 H2O          O-18 CARB
(yrs)         (m^3)            (SMOW)               (SMOW)

    0    0.0000000E+00     -12.2491798             23.65311
   10    0.2727811E+11     -10.8798704             25.02242
   20    0.5068638E+11      -9.6160879             26.28621
   30    0.7077383E+11      -8.4522257             27.45007
   38    0.8640402E+11      -7.4856467             28.41665

 ***************  OVERFLOW  *******************

    0    0.8528000E+11      -7.4856467             28.41665
   50    0.8528000E+11      -5.2432985             30.65900
  100    0.8528000E+11      -4.9169765             30.98532
  150    0.8528000E+11      -4.8694882             31.03281
  200    0.8528000E+11      -4.8625770             31.03972
  250    0.8528000E+11      -4.8615713             31.04072
  300    0.8528000E+11      -4.8614249             31.04087
  350    0.8528000E+11      -4.8614039             31.04089
  400    0.8528000E+11      -4.8614006             31.04089
  450    0.8528000E+11      -4.8614001             31.04089
  500    0.8528000E+11      -4.8614001             31.04089
              STEADY STATE VALUES-OVERFLOW

                     OVERFLOW TIME          38
                       LAKE VOLUME   8.5279998E+10
              STEADY STATE DEL H2O   -4.861401
            STEADY STATE CARBONATE    31.04089
                       OUTFLOW RATE   1.6370606E+09
```

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**********************************************************

SEARLES OVERFLOW TO BENEATH SPILLWAY; DELI=DELC

**********************************************************
TEMPERATURE IN DEGREES CELCIUS IS   19.10000
ELV =   9.613042
ISOTOPIC COMP. OF BACK CONDENSATION FLUX IS   -12.24918
RELATIVE HUMIDITY IS  0.2210000
ELV-STAR =  1.4898777E-02
COMPUTED CARBONATE VALUES FOR DOLOMITE
EVAPORATION RATE IS (m/yr)    1.685000
ESTIMATED MAXIMUM LAKE SURFACE AREA IS(m^2)  9.9400000E+08
ESTIMATED MAXIMUM LAKE VOLUME IS (m^3)  8.5279998E+10
K=   1.9639893E-02
INITIAL LAKE ISO COMPOSITION IS(PER MIL)  -4.861401
INITIAL LAKE VOLUME (m^3) IS  8.5279998E+10
INFLOW RATE IS (m^3/yr)  1.0000000E+09
ISOTOPIC COMP OF INFLOW WATER IS  -12.24918

TIME        VOLUME        DEL O-18 H2O        O-18 CARB
(yrs)        (m^3)           (SMOW)             (SMOW)


*********** OVERFLOW *****************

    0   0.8528000E+11      -4.8614011          31.04089
   10   0.8528000E+11      -3.3052216          32.59707

******** LAKE LEVEL BENEATH SPILLWAY *******

    0   0.8528000E+11      -3.3052227          32.59707
  100   0.6967496E+11       2.5928617          38.49516
  200   0.6629573E+11       2.7469881          38.64928
  300   0.6556398E+11       2.5650747          38.46737
  400   0.6540551E+11       2.4936721          38.39597
  500   0.6537120E+11       2.4736226          38.37592
  600   0.6536377E+11       2.4686158          38.37091
  700   0.6536216E+11       2.4674423          38.36974
  800   0.6536181E+11       2.4671741          38.36947
  900   0.6536174E+11       2.4671144          38.36941
 1000   0.6536172E+11       2.4670997          38.36939
 1100   0.6536172E+11       2.4670959          38.36939
 1200   0.6536172E+11       2.4670959          38.36939
 1300   0.6536172E+11       2.4670959          38.36939
 1400   0.6536172E+11       2.4670959          38.36939
 1490   0.6536172E+11       2.4670959          38.36939
           STEADY STATE VALUES:NON-OVERFLOW

                         LAKE VOLUME  6.5361715E+10
                STEADY STATE DEL H2O   2.467098
              STEADY STATE CARBONATE   38.36939
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************************************************************

SEARLES HIGH LAKE LEVEL TO LOW LEVEL; DELI=DELC

************************************************************
TEMPERATURE IN DEGREES CELCIUS IS   19.10000
ELV =   9.613042
ISOTOPIC COMP. OF BACK CONDENSATION FLUX IS   -12.24918
RELATIVE HUMIDITY IS  0.2210000
ELV-STAR =  1.4898777E-02
COMPUTED CARBONATE VALUES FOR DOLOMITE
EVAPORATION RATE IS (m/yr)    1.685000
ESTIMATED MAXIMUM LAKE SURFACE AREA IS(m^2)  9.9400000E+08
ESTIMATED MAXIMUM LAKE VOLUME IS (m^3)  8.5279998E+10
K=   1.9639893E-02
INITIAL LAKE ISO COMPOSITION IS(PER MIL)   2.467098
INITIAL LAKE VOLUME (m^3) IS  6.5361719E+10
INFLOW RATE IS (m^3/yr)  3.0000000E+08
ISOTOPIC COMP OF INFLOW WATER IS  -12.24918

TIME        VOLUME       DEL O-18 H2O        O-18 CARB
(yrs)        (m^3)          (SMOW)            (SMOW)

    0    0.6536172E+11     2.4670959          38.36939
  100    0.2951623E+11     8.6809998          44.58329
  200    0.2175400E+11     5.5103006          41.41259
  300    0.2007311E+11     3.3718011          39.27409
  400    0.1970912E+11     2.6946478          38.59694
  500    0.1963030E+11     2.5206320          38.42293
  600    0.1961323E+11     2.4792888          38.38158
  700    0.1960954E+11     2.4698229          38.37212
  800    0.1960874E+11     2.4676993          38.37000
  900    0.1960856E+11     2.4672225          38.36952
 1000    0.1960852E+11     2.4671257          38.36942
 1100    0.1960852E+11     2.4671032          38.36940
 1200    0.1960851E+11     2.4670959          38.36939
 1300    0.1960851E+11     2.4670959          38.36939
 1400    0.1960851E+11     2.4670959          38.36939
 1500    0.1960851E+11     2.4670959          38.36939
 1600    0.1960851E+11     2.4670959          38.36939
 1700    0.1960851E+11     2.4670959          38.36939
 1800    0.1960851E+11     2.4670959          38.36939
 1900    0.1960851E+11     2.4670959          38.36939
 2000    0.1960851E+11     2.4670959          38.36939
          STEADY STATE VALUES:NON-OVERFLOW

                        LAKE VOLUME  1.9608515E+10
               STEADY STATE DEL H2O   2.467099
             STEADY STATE CARBONATE   38.36939
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***********************************************************

 DESSICATE SEARLES LAKE; DELI=DELC

 ***********************************************************
 TEMPERATURE IN DEGREES CELCIUS IS   19.10000
 ELV =   9.613042
 ISOTOPIC COMP. OF BACK CONDENSATION FLUX IS   -12.24918
 RELATIVE HUMIDITY IS  0.2950000
 ELV-STAR =  1.4394820E-02
 COMPUTED CARBONATE VALUES FOR DOLOMITE
 EVAPORATION RATE IS (m/yr)    1.685000
 ESTIMATED MAXIMUM LAKE SURFACE AREA IS(m^2)  9.9400000E+08
 ESTIMATED MAXIMUM LAKE VOLUME IS (m^3)  8.5279998E+10
 K=   1.9639893E-02
 INITIAL LAKE ISO COMPOSITION IS(PER MIL)   2.467098
 INITIAL LAKE VOLUME (m^3) IS  1.9608515E+10

 TIME          VOLUME          DEL O-18 H2O          O-18 CARB
 (YRS)          (M^3)            (SMOW)               (SMOW)

     0    0.1960851E+11        2.4670997            38.36939
    50    0.9812506E+10       10.9500923            46.85239
   100    0.4910380E+10       17.3886890            53.29099
   150    0.2457255E+10       22.2755814            58.17788
   200    0.1229661E+10       25.9847355            61.88703
   250    0.6153478E+09       28.7999821            64.70228
   300    0.3079328E+09       30.9367580            66.83905
   350    0.1540960E+09       32.5585709            68.46087
   400    0.7711277E+08       33.7895241            69.69182
   450    0.3858883E+08       34.7238235            70.62612
   500    0.1931064E+08       35.4329491            71.33524
   550    0.9663446E+07       35.9711800            71.87347
   600    0.4835787E+07       36.3796997            72.28200
   650    0.2419927E+07       36.6897621            72.59206
   700    0.1210982E+07       36.9250984            72.82739
   750    0.6060003E+06       37.1037254            73.00602
   800    0.3032550E+06       37.2392998            73.14159
   850    0.1517550E+06       37.3421974            73.24449
   900    0.7594140E+05       37.4202995            73.32259
   950    0.3800263E+05       37.4795799            73.38187
  1000    0.1901730E+05       37.5245743            73.42687
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**********************************************************

INFILL OWENS FROM DRY LAKE; DELI > DELC

**********************************************************
TEMPERATURE IN DEGREES CELCIUS IS   15.50000
ELV =   9.926092
ISOTOPIC COMP. OF BACK CONDENSATION FLUX IS   -21.68460
RELATIVE HUMIDITY IS  0.2780000
ELV-STAR =  1.4819145E-02
COMPUTED CARBONATE VALUES FOR DOLOMITE
EVAPORATION RATE IS (m/yr)    1.177000
ESTIMATED MAXIMUM LAKE SURFACE AREA IS(m^2)  6.9400000E+08
ESTIMATED MAXIMUM LAKE VOLUME IS (m^3)  3.0020000E+10
K=   2.7209796E-02
INITIAL LAKE ISO COMPOSITION IS(PER MIL)  -16.25000
INITIAL LAKE VOLUME (m^3) IS  0.0000000E+00
INFLOW RATE IS (m^3/yr)  3.7000000E+09
ISOTOPIC COMP OF INFLOW WATER IS  -16.25000

TIME         VOLUME          DEL O-18 H2O          O-18 CARB
(yrs)         (m^3)             (SMOW)              (SMOW)

    0    0.0000000E+00      -16.2500000           20.59025
    8    0.3052221E+11      -14.7542467           22.08600

 ***************  OVERFLOW  *******************

    0    0.3002000E+11      -14.7542467           22.08600
   50    0.3002000E+11      -13.5698185           23.27043
  100    0.3002000E+11      -13.5680752           23.27217
  150    0.3002000E+11      -13.5680723           23.27218
  200    0.3002000E+11      -13.5680723           23.27218
  250    0.3002000E+11      -13.5680723           23.27218
  300    0.3002000E+11      -13.5680723           23.27218
  350    0.3002000E+11      -13.5680723           23.27218
  400    0.3002000E+11      -13.5680723           23.27218
  450    0.3002000E+11      -13.5680723           23.27218
  500    0.3002000E+11      -13.5680723           23.27218
              STEADY STATE VALUES-OVERFLOW

                     OVERFLOW TIME            8
                       LAKE VOLUME   3.0020000E+10
              STEADY STATE DEL H2O   -13.56807
            STEADY STATE CARBONATE    23.27218
                      OUTFLOW RATE   3.1102428E+09
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**********************************************************

INFILL CHINA LAKE FROM DRY LAKE; DELI > DELC

**********************************************************
TEMPERATURE IN DEGREES CELCIUS IS   18.40000
ELV =   9.672875
ISOTOPIC COMP. OF BACK CONDENSATION FLUX IS   -13.75154
RELATIVE HUMIDITY IS  0.2320000
ELV-STAR =  1.4882922E-02
COMPUTED CARBONATE VALUES FOR DOLOMITE
EVAPORATION RATE IS (m/yr)    1.413000
ESTIMATED MAXIMUM LAKE SURFACE AREA IS(m^2)  1.5500000E+08
ESTIMATED MAXIMUM LAKE VOLUME IS (m^3)  6.9600000E+08
K=   0.3146767
INITIAL LAKE ISO COMPOSITION IS(PER MIL)  -13.56807
INITIAL LAKE VOLUME (m^3) IS  0.0000000E+00
INFLOW RATE IS (m^3/yr)  3.1100001E+09
ISOTOPIC COMP OF INFLOW WATER IS  -13.56807

TIME         VOLUME          DEL O-18 H2O          O-18 CARB
(yrs)         (m^3)             (SMOW)               (SMOW)

    0    0.0000000E+00      -13.5680704            22.51389
    0    0.2762729E+10      -11.4379120            24.64405

 ***************  OVERFLOW  *******************

    0    0.6960000E+09      -11.4379120            24.64405
   50    0.6960000E+09      -12.5676632            23.51430
  100    0.6960000E+09      -12.5676632            23.51430
  150    0.6960000E+09      -12.5676632            23.51430
  200    0.6960000E+09      -12.5676632            23.51430
  250    0.6960000E+09      -12.5676632            23.51430
  300    0.6960000E+09      -12.5676632            23.51430
  350    0.6960000E+09      -12.5676632            23.51430
  400    0.6960000E+09      -12.5676632            23.51430
  450    0.6960000E+09      -12.5676632            23.51430
  500    0.6960000E+09      -12.5676632            23.51430
              STEADY STATE VALUES-OVERFLOW

                     OVERFLOW TIME           0
                       LAKE VOLUME   6.9600000E+08
                STEADY STATE DEL H2O   -12.56766
              STEADY STATE CARBONATE    23.51430
                      OUTFLOW RATE   2.9417966E+09
```

```
***********************************************************

INFILL SEARLES LAKE FROM DRY LAKE; DELI > DELC

***********************************************************
TEMPERATURE IN DEGREES CELCIUS IS   19.10000
ELV =   9.613042
ISOTOPIC COMP. OF BACK CONDENSATION FLUX IS   -13.80998
RELATIVE HUMIDITY IS  0.2210000
ELV-STAR =  1.4898777E-02
COMPUTED CARBONATE VALUES FOR DOLOMITE
EVAPORATION RATE IS (m/yr)    1.685000
ESTIMATED MAXIMUM LAKE SURFACE AREA IS(m^2)  9.9400000E+08
ESTIMATED MAXIMUM LAKE VOLUME IS (m^3)  8.5279998E+10
K=   1.9639893E-02
INITIAL LAKE ISO COMPOSITION IS(PER MIL)  -12.56766
INITIAL LAKE VOLUME (m^3) IS  0.0000000E+00
INFLOW RATE IS (m^3/yr)  2.9417966E+09
ISOTOPIC COMP OF INFLOW WATER IS  -12.56766

TIME         VOLUME         DEL O-18 H2O          O-18 CARB
(yrs)         (m^3)           (SMOW)               (SMOW)

    0   0.0000000E+00     -12.5676603            23.33463
   10   0.2727808E+11     -11.2246838            24.67761
   20   0.5068633E+11      -9.9852495            25.91705
   30   0.7077375E+11      -8.8438129            27.05848
   38   0.8640392E+11      -7.8958535            28.00644

 ***************  OVERFLOW  ********************

    0   0.8528000E+11      -7.8958535            28.00644
   50   0.8528000E+11      -5.6966844            30.20561
  100   0.8528000E+11      -5.3766456            30.52565
  150   0.8528000E+11      -5.3300710            30.57222
  200   0.8528000E+11      -5.3232932            30.57900
  250   0.8528000E+11      -5.3223071            30.57999
  300   0.8528000E+11      -5.3221631            30.58013
  350   0.8528000E+11      -5.3221426            30.58015
  400   0.8528000E+11      -5.3221393            30.58015
  450   0.8528000E+11      -5.3221388            30.58016
  500   0.8528000E+11      -5.3221388            30.58016
             STEADY STATE VALUES-OVERFLOW

                   OVERFLOW TIME          38
                     LAKE VOLUME   8.5279998E+10
              STEADY STATE DEL H2O   -5.322138
            STEADY STATE CARBONATE    30.58016
                     OUTFLOW RATE   1.6370573E+09
```

```
***********************************************************

SEARLES OVERFLOW TO BENEATH SPILLWAY; DELI > DELC

***********************************************************
TEMPERATURE IN DEGREES CELCIUS IS   19.10000
ELV =   9.613042
ISOTOPIC COMP. OF BACK CONDENSATION FLUX IS   -13.80998
RELATIVE HUMIDITY IS  0.2210000
ELV-STAR =  1.4898777E-02
COMPUTED CARBONATE VALUES FOR DOLOMITE
EVAPORATION RATE IS (m/yr)    1.685000
ESTIMATED MAXIMUM LAKE SURFACE AREA IS(m^2)  9.9400000E+08
ESTIMATED MAXIMUM LAKE VOLUME IS (m^3)  8.5279998E+10
K=   1.9639893E-02
INITIAL LAKE ISO COMPOSITION IS(PER MIL)  -5.322138
INITIAL LAKE VOLUME (m^3) IS  8.5279998E+10
INFLOW RATE IS (m^3/yr)  1.0000000E+09
ISOTOPIC COMP OF INFLOW WATER IS  -12.56766

TIME          VOLUME          DEL O-18 H2O           O-18 CARB
(yrs)          (m^3)             (SMOW)                (SMOW)


*********** OVERFLOW *****************

    0    0.8528000E+11       -5.3221383            30.58016
   10    0.8528000E+11       -3.7959268            32.10637

******** LAKE LEVEL BENEATH SPILLWAY *******

    0    0.8528000E+11       -3.7959256            32.10637
  100    0.6967496E+11        1.9885786            37.89087
  200    0.6629573E+11        2.1397359            38.04203
  300    0.6556398E+11        1.9613206            37.86361
  400    0.6540551E+11        1.8913001            37.79359
  500    0.6537120E+11        1.8716305            37.77393
  600    0.6536377E+11        1.8667244            37.76902
  700    0.6536216E+11        1.8655733            37.76787
  800    0.6536181E+11        1.8653088            37.76760
  900    0.6536174E+11        1.8652492            37.76754
 1000    0.6536172E+11        1.8652343            37.76753
 1100    0.6536172E+11        1.8652306            37.76752
 1200    0.6536172E+11        1.8652306            37.76752
 1300    0.6536172E+11        1.8652306            37.76752
 1400    0.6536172E+11        1.8652306            37.76752
 1490    0.6536172E+11        1.8652306            37.76752
           STEADY STATE VALUES:NON-OVERFLOW

                       LAKE VOLUME   6.5361715E+10
              STEADY STATE DEL H2O    1.865230
           STEADY STATE CARBONATE    37.76752
```

```
****************************************************

SEARLES HIGH LAKE LEVEL TO LOW LEVEL; DELI > DELC

****************************************************
TEMPERATURE IN DEGREES CELCIUS IS   19.10000
ELV =   9.613042
ISOTOPIC COMP. OF BACK CONDENSATION FLUX IS    -13.80998
RELATIVE HUMIDITY IS  0.2210000
ELV-STAR =  1.4898777E-02
COMPUTED CARBONATE VALUES FOR DOLOMITE
EVAPORATION RATE IS (m/yr)     1.685000
ESTIMATED MAXIMUM LAKE SURFACE AREA IS(m^2)   9.9400000E+08
ESTIMATED MAXIMUM LAKE VOLUME IS (m^3)  8.5279998E+10
K=   1.9639893E-02
INITIAL LAKE ISO COMPOSITION IS(PER MIL)    1.865231
INITIAL LAKE VOLUME (m^3) IS  6.5361715E+10
INFLOW RATE IS (m^3/yr)  3.0000000E+08
ISOTOPIC COMP OF INFLOW WATER IS  -12.56766

TIME         VOLUME          DEL O-18 H2O          O-18 CARB
(yrs)         (m^3)             (SMOW)               (SMOW)

    0    0.6536172E+11        1.8652267            37.76752
  100    0.2951623E+11        7.9594703            43.86176
  200    0.2175400E+11        4.8498325            40.75213
  300    0.2007311E+11        2.7525201            38.65482
  400    0.1970912E+11        2.0884016            37.99070
  500    0.1963030E+11        1.9177384            37.82003
  600    0.1961323E+11        1.8771924            37.77949
  700    0.1960954E+11        1.8679053            37.77020
  800    0.1960874E+11        1.8658266            37.76812
  900    0.1960856E+11        1.8653609            37.76765
 1000    0.1960852E+11        1.8652604            37.76756
 1100    0.1960852E+11        1.8652380            37.76753
 1200    0.1960851E+11        1.8652343            37.76753
 1300    0.1960851E+11        1.8652343            37.76753
 1400    0.1960851E+11        1.8652343            37.76753
 1500    0.1960851E+11        1.8652343            37.76753
 1600    0.1960851E+11        1.8652343            37.76753
 1700    0.1960851E+11        1.8652343            37.76753
 1800    0.1960851E+11        1.8652343            37.76753
 1900    0.1960851E+11        1.8652343            37.76753
 2000    0.1960851E+11        1.8652343            37.76753
         STEADY STATE VALUES:NON-OVERFLOW

                          LAKE VOLUME  1.9608515E+10
                 STEADY STATE DEL H2O    1.865231
               STEADY STATE CARBONATE    37.76752
```

```
************************************************************

DESSICATE SEARLES LAKE; DELI > DELC

************************************************************
TEMPERATURE IN DEGREES CELCIUS IS   19.10000
ELV =   9.613042
ISOTOPIC COMP. OF BACK CONDENSATION FLUX IS   -13.80998
RELATIVE HUMIDITY IS  0.2950000
ELV-STAR =  1.4394820E-02
COMPUTED CARBONATE VALUES FOR DOLOMITE
EVAPORATION RATE IS (m/yr)    1.685000
ESTIMATED MAXIMUM LAKE SURFACE AREA IS(m^2)  9.9400000E+08
ESTIMATED MAXIMUM LAKE VOLUME IS (m^3)  8.5279998E+10
K=   1.9639893E-02
INITIAL LAKE ISO COMPOSITION IS(PER MIL)   1.865231
INITIAL LAKE VOLUME (m^3) IS  1.9600001E+10

TIME         VOLUME         DEL O-18 H2O          O-18 CARB
(YRS)         (M^3)            (SMOW)               (SMOW)

    0    0.1960000E+11       1.8652306           37.76752
   50    0.9808245E+10      10.0981112           46.00040
  100    0.4908248E+10      16.3468742           52.24917
  150    0.2456189E+10      21.0896816           56.99198
  200    0.1229128E+10      24.6894760           60.59177
  250    0.6150807E+09      27.4217167           63.32401
  300    0.3077991E+09      29.4954910           65.39779
  350    0.1540291E+09      31.0694866           66.97178
  400    0.7707929E+08      32.2641487           68.16644
  450    0.3857208E+08      33.1708984           69.07320
  500    0.1930226E+08      33.8591194           69.76141
  550    0.9659251E+07      34.3814774           70.28378
  600    0.4833687E+07      34.7779503           70.68024
  650    0.2418876E+07      35.0788765           70.98117
  700    0.1210457E+07      35.3072739           71.20957
  750    0.6057372E+06      35.4806290           71.38293
  800    0.3031233E+06      35.6122055           71.51450
  850    0.1516891E+06      35.7120743           71.61437
  900    0.7590842E+05      35.7878723           71.69017
  950    0.3798613E+05      35.8454056           71.74770
 1000    0.1900904E+05      35.8890686           71.79137
```

# Appendix I

## Climatological Data for Southeastern California Weather Stations

```
********************************************************************************
*                                                                              *
*   This file contains climatological data for SE California weather           *
*   stations east of the Sierra Nevada divide.                                 *
*                                                                              *
*   Data from White Mountain stations are from info compiled by UC-Davis       *
*   for the BARCROFT(white Mountain2)  1953-1973 and CROOKED CREEK             *
*   (white mountain1) 1949-1973 reseach stations.                              *
*                                                                              *
*   Relative humidity data for Bishop is from:                                 *
*   Ruffner,J.A. (ed.?),1985,CLimates of the States:Gale Research Co.          *
*       Detroit, Michigan.  Vol. 1                                             *
*   (compilation from NOAA climatological data QE 983 .C56 1985 v.1)           *
*                                                                              *
*   All other elevation,temp and precip data are from "Monthly normals of      *
*   Temperature, Precipitation, and Heating and Cooling Degree Days            *
*   1951-1980 no.81 (California):NOAA,National Climatic Center, Asheville,     *
*   North Carolina,1982."                                                      *
*                                                                              *
*   Evaporation data (following Smith,G.I. and Street-Perrott,F.A.) are        *
*   interpolations between "evaporation from lake surfaces-Plate 3"            *
*   IN Meyers,J.S.,1962, Evaporation from the 17 Western States, USGS          *
*   Professional Paper 272-D: USGS etc....                                     *
*                                                                              *
*                                                                              *
********************************************************************************
```

| STATION NAME /LOCATION | ELEVATION (METERS) | TEMP DEG C 30*YR MEAN | ANNUAL PRECIP 30yr MEAN (cm) | REL HUMIDITY 30yr av annual |
|---|---|---|---|---|
| DEATH VALLEY | -59.69 | 24.83 | 5.16 | ---- |
| TRONA | 521.54 | 19.0 | 10.03 | ---- |
| INYOKERN | 750.77 | 17.39 | 10.57 | ---- |
| INDEPENDENCE | 1215.39 | ----- | 13.69 | ---- |
| BISHOP | 1264.0 | 13.33 | ---- | 0.29 |
| MONO LAKE | 1984.62 | 8.72 | ---- | ---- |
| WHITE MOUNTAIN1 | 3123.08 | 1.28 | 34.70 | 0.529 |
| WHITE MOUNTAIN2 | 3836.92 | -2.44 | 49.61 | 0.558 |

| LOCATION | ELEVATION (METERS) | EVAPORATION FROM LAKE SURFACES ANNUAL GROSS (m/yr) |
|---|---|---|
| LAKE MANLY | -86 | 2.13 |
| LAKE PANAMINT | 317 | 1.93 |
| SEARLES LAKE | 493 | 1.78 |
| CHINA LAKE | 657 | 1.52 |
| OWENS LAKE | 1081 | 1.33 |
| HAIWEE RESEV | 1177 | 1.025 |
| INDEPENDENCE | 1215.39 | 1.025 |
| BISHOP | 1264.0 | 0.77 |

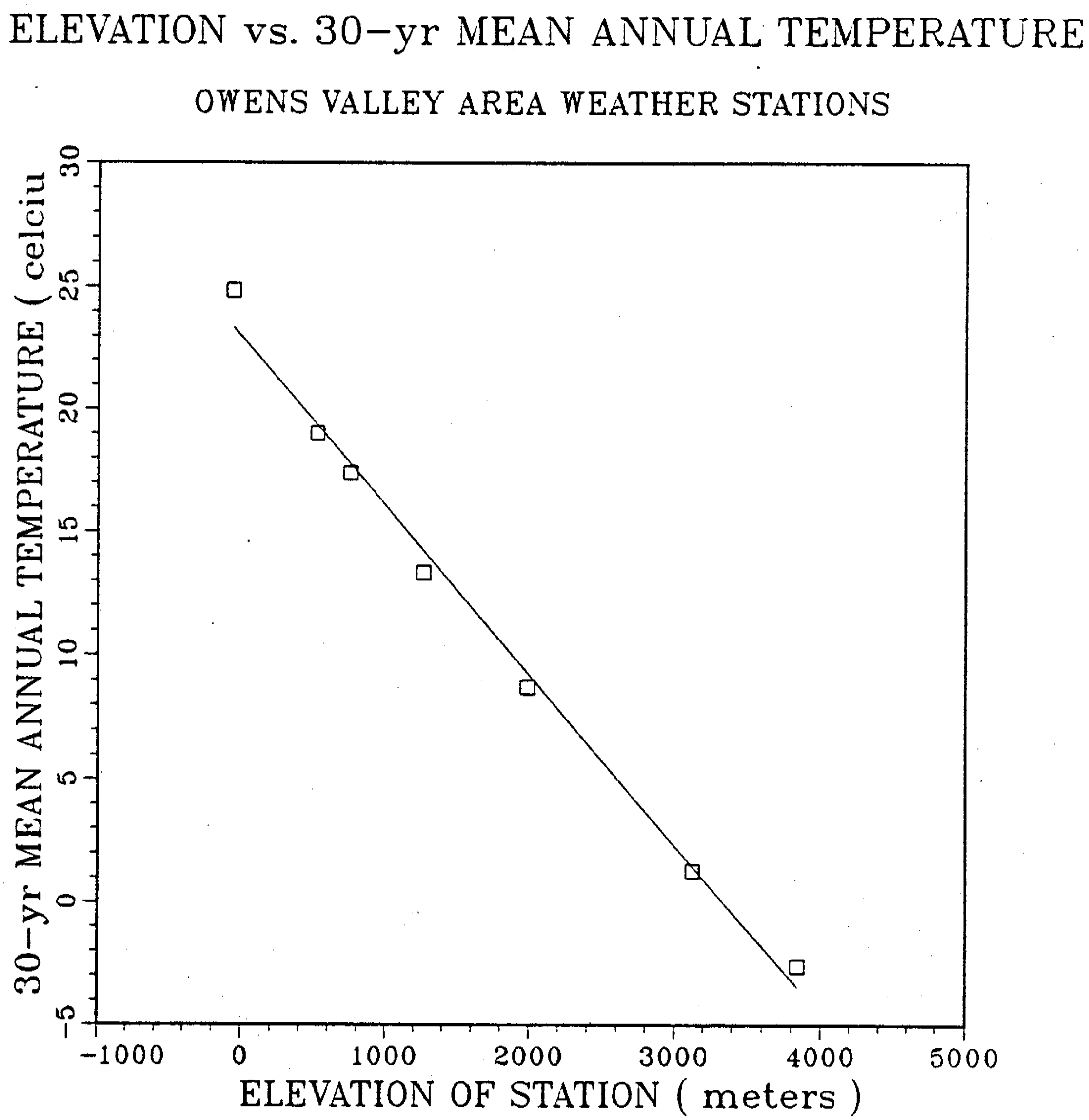

Figure 35. Linear regression of temperature as a function of elevation for Owens Valley area weather stations.

```
        FOR YOUR CHOICE:  "LINE"   Y=A+B*X
         "A"=       2.2934E+01
         "B" =     -6.8820E-03

        THE REGRESSION COEFFICIENT "R" =     0.99251

THE CALCULATED VALUES:
        X                   Y                  YCALC              % DIFF

     -5.9692E+01        2.4830E+01          2.3345E+01              5.98
      5.2154E+02        1.9000E+01          1.9345E+01             -1.82
      7.5077E+02        1.7390E+01          1.7768E+01             -2.17
      1.2640E+03        1.3330E+01          1.4236E+01             -6.79
      1.9846E+03        8.7200E+00          9.2763E+00             -6.38
      3.1231E+03        1.2800E+00          1.4414E+00            -12.61
      3.8369E+03       -2.6100E+00         -3.4713E+00            -33.00


THE NONLINEAR CORRELATION COEFFICIENT: R**2=  0.99251443
the ave. % diff=  9.82137108
```

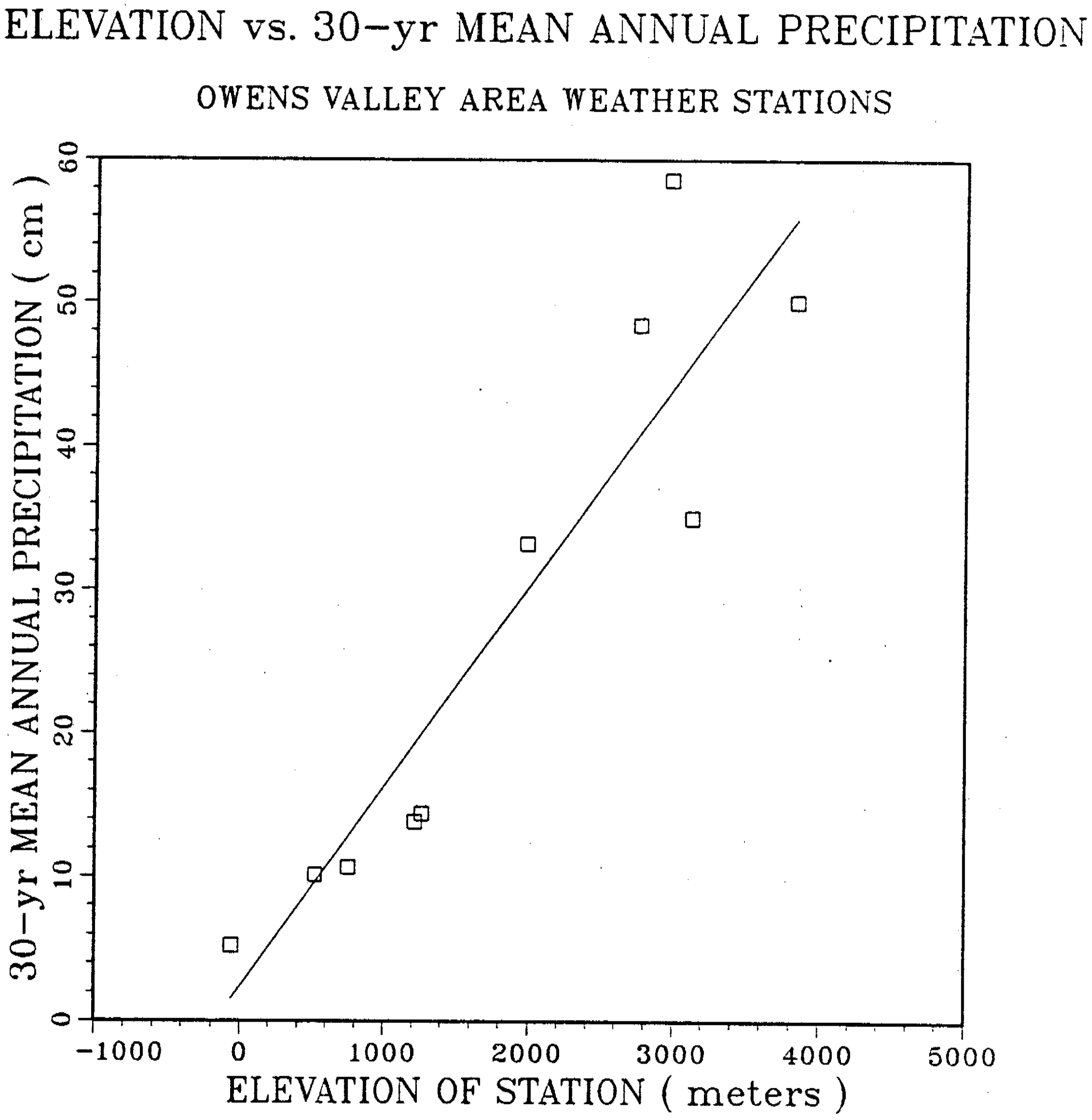

Figure 36. Linear regression of precipitation as a function of elevation for Owens Valley area weather stations.

```
        FOR YOUR CHOICE:  "LINE"    Y=A+B*X
         "A"=       2.3442E+00
         "B" =      1.3947E-02

        THE REGRESSION COEFFICIENT "R" =      0.84895

THE CALCULATED VALUES:
        X                    Y                    YCALC                % DIFF

     -5.9692E+01          5.2050E+00          1.5117E+00               70.96
      5.2154E+02          1.0128E+01          9.6180E+00                5.04
      7.5077E+02          1.0667E+01          1.2815E+01              -20.14
      1.2154E+03          1.3821E+01          1.9295E+01              -39.61
      1.2640E+03          1.4385E+01          1.9973E+01              -38.85
      1.9846E+03          3.3231E+01          3.0023E+01                9.65
      2.7600E+03          4.8436E+01          4.0837E+01               15.69
      2.9677E+03          5.8590E+01          4.3734E+01               25.36
      3.1231E+03          3.5026E+01          4.5901E+01              -31.05
      3.8369E+03          5.0077E+01          5.5857E+01              -11.54

THE NONLINEAR CORRELATION COEFFICIENT: R**2=  0.84895211
the ave. % diff= 26.78702736
```

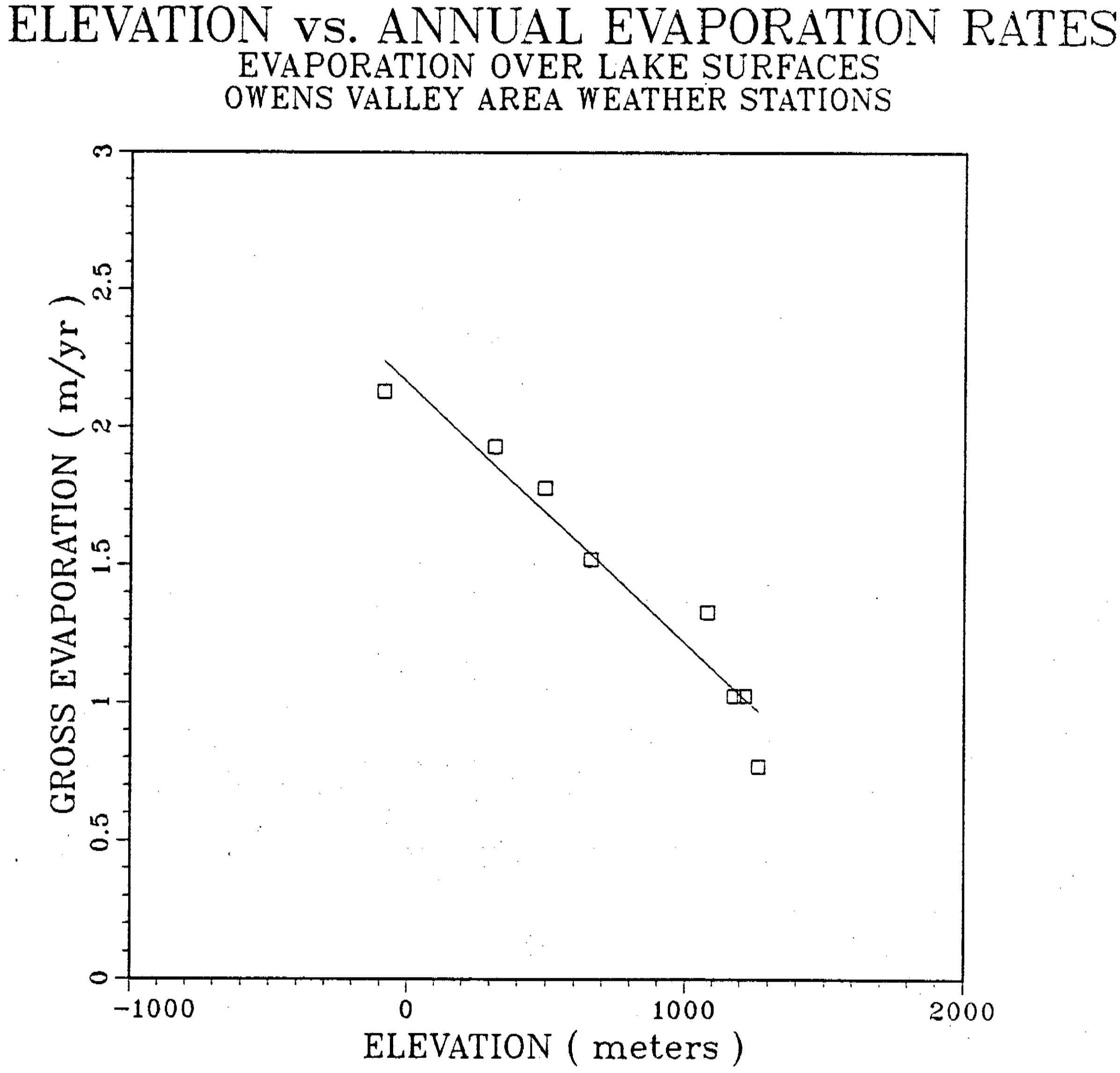

Figure 37. Linear regression of gross evaporation as a function of elevation for Owens Valley area weather stations.

```
        FOR YOUR CHOICE:  "LINE"    Y=A+B*X
         "A"=       2.1607E+00
         "B" =     -9.4398E-04

        THE REGRESSION COEFFICIENT "R" =      0.93882

THE CALCULATED VALUES:
        X                    Y                    YCALC                % DIFF

     -8.6000E+01        2.1300E+00           2.2418E+00               -5.25
      3.1700E+02        1.9300E+00           1.8614E+00                3.55
      4.9300E+02        1.7800E+00           1.6953E+00                4.76
      6.5700E+02        1.5200E+00           1.5405E+00               -1.35
      1.0810E+03        1.3300E+00           1.1402E+00               14.27
      1.1770E+03        1.0250E+00           1.0496E+00               -2.40
      1.2150E+03        1.0250E+00           1.0137E+00                1.10
      1.2640E+03        7.7000E-01           9.6747E-01              -25.64

THE NONLINEAR CORRELATION COEFFICIENT: R**2=  0.93882328
the ave. % diff=  7.29056263
```

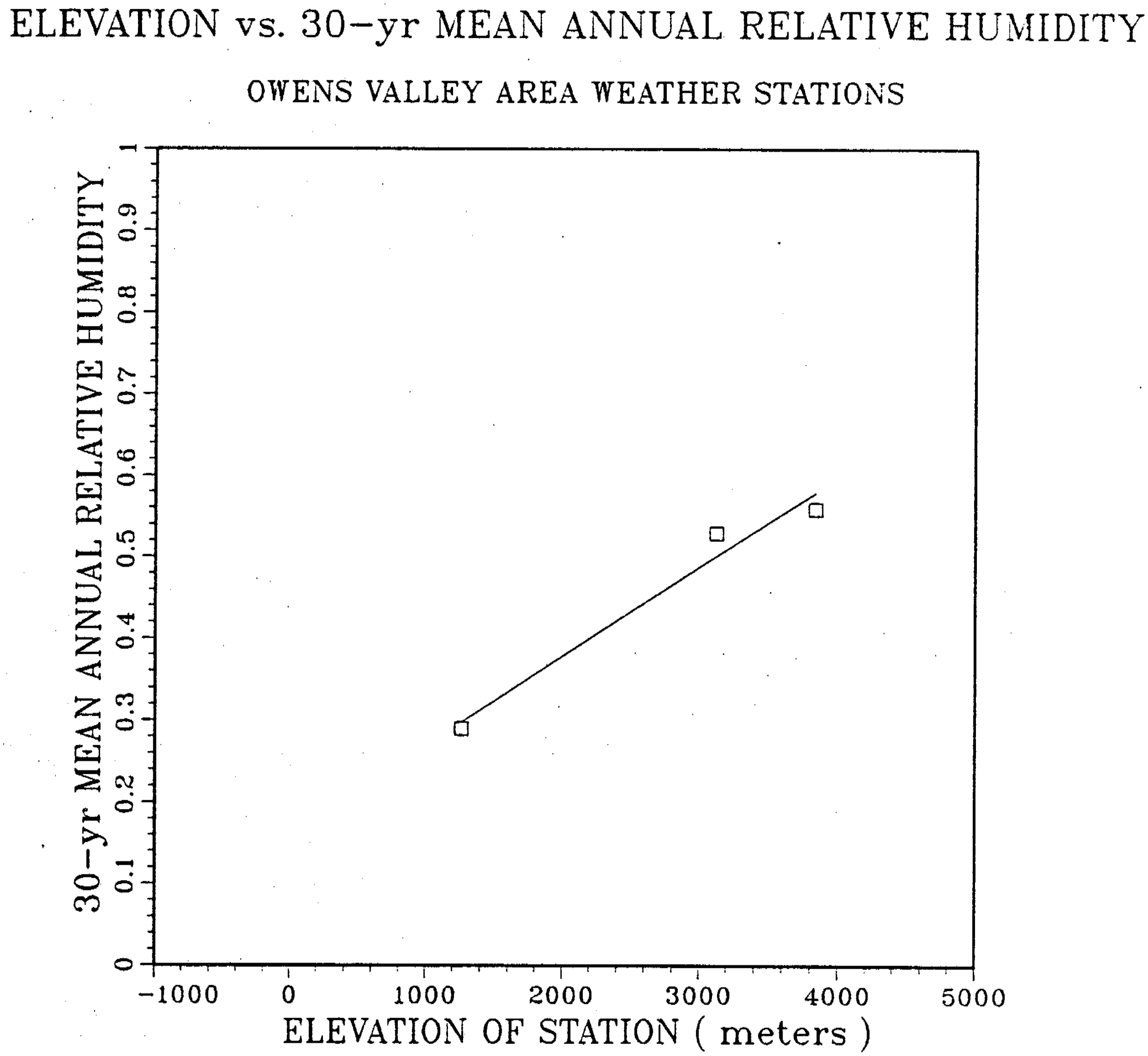

Figure 38. Linear regression of relative humidity as a function of elevation for Owens Valley area weather stations.

```
        FOR YOUR CHOICE:  "LINE"   Y=A+B*X
         "A"=       1.6001E-01
         "B" =      1.0907E-04

        THE REGRESSION COEFFICIENT "R" =     0.97026

THE CALCULATED VALUES:
        X                   Y                     YCALC                 % DIFF

      1.2640E+03        2.9000E-01           2.9787E-01              -2.71
      3.1231E+03        5.2900E-01           5.0064E-01               5.36
      3.8369E+03        5.5800E-01           5.7849E-01              -3.67


THE NONLINEAR CORRELATION COEFFICIENT: R**2=  0.97026372
the ave. % diff=  3.91607213
```

# Appendix J

## Bathymetric Data for Lakes in the Paleo-Ownes River System

```
********************************************************************************
*                                                                              *
*   This file contains routing data for the Owens River Lake System            *
*   Data for Owens and Searles are from Smith( 1979 )                          *
*   Data for China Lake from Jannik (1989)                                     *
*   Data for Panamint is from Smith, R.S.U. (      )                           *
*   Data from Death Valley is from Jannik (1989)                               *
*                                                                              *
********************************************************************************

CUMULATIVE        CUMULATIVE        LAKE     ADDED    CUMULATIVE        K
DEPTH             AREA              AREA     VOLUME   LAKE VOL.         AREA/VOLUME
  ( m )           (x10^9 m^2)       (x10^9   (x10^9   (x10^9
                                    m^2)      m^3)     m^3)
_______________________________________________________________________________

0.0               0.0               0.0      0.0      0.0               0
2.4               0.20              0.20     0.16     0.16              1.25
14.0              0.29              0.29     2.99     3.15              0.092
64.0              0.694             0.694    26.87    30.02             0.023

******************   OWENS OVERFLOW   ****************************************

68.0              0.721             0.027    0.036    0.036             0.75
72.0              0.849             0.155    0.660    0.696             .223

******************   CHINA OVERFLOW   ****************************************

97.0              1.094             0.245    2.04     2.04              .120
129.0             1.149             0.300    8.71     10.75             .028
160.0             1.199             0.350    10.07    20.82             .017
192.0             1.291             0.442    12.64    33.46             .013
219.0             1.382             0.533    13.14    46.60             .011

250.0             1.564             0.715    19.27    65.87             .011
   *****   China coalesces with Searles   *****
272.0             1.688             0.994    18.71    85.28             .012

******************   SEARLES OVERFLOW   **************************************

290.0             1.806             0.118    0.71     0.71              .166
310.0             1.863             0.175    2.91     3.62              .048
321.0             1.877             0.189    2.00     5.62              .034
351.0             1.930             0.242    6.45     12.07             .020
382.0             1.977             0.289    8.22     20.29             .014
412.0             2.017             0.329    9.26     29.55             .011
443.0             2.057             0.369    10.81    40.36             .009
478.0             2.116             0.428    13.93    54.29             .008
498.0             2.176             0.488    9.15     63.44             .008
513.0             2.212             0.524    7.59     71.03             .007
533.0             2.256             0.568    10.92    81.95             .007
559.0             2.326             0.638    15.67    97.62             .007
574.0             2.415             0.727    10.23    107.85            .007

*****************   PANAMINT OVERFLOW    *************************************

613.0             2.465             0.050    0.65     0.65
786.0             2.998             0.583    46.35    47.0
```