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URANIUM-SERIES AND RADIOCARBON DATES ON
TUFAS FROM SEARLES LAKE, CALIFORNIA

by

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Introduction

Though now dry, Searles Lake, near the middle of Searles Valley in southeast California, was the site of a large body of water during the relatively wet (pluvial) periods of the Pleistocene and late Pliocene. The lake was fed mostly by water draining from the steep east slope of the Sierra Nevada which is bounded by 34 peaks exceeding 4,000 m elevation. Most of that water drained into the Owens River which terminated historically in Owens Lake prior to its diversion into the Los Angeles Aqueduct early in this century. During pluvial periods, however, Owens Lake filled and overflowed to the south, filling first China Lake and then Searles Lake. When Searles Lake was nearly full, the two coalesced into one body of water having an area of about 1,000 sq km (Fig. 1). During even wetter periods, Searles Lake overflowed eastward into Panamint Valley which, during even-more-intensely pluvial periods, overflowed eastward into Death Valley, forming a chain of up to four lakes.

The number of lakes in the chain, and the resulting total surface area exposed to evaporation, was determined by the amount of water flowing into the basins and, to a lesser extent, by the relative humidity, average wind velocity, and both air and surface-water temperatures, all of which influenced the rate of evaporation. Thus, a reconstruction of the number of lakes and the size of the last lake in this chain at any time, enables us to approximate a succession of past climates of the area. For about 90 percent of the past 150,000 yrs, Searles Lake was the last lake in the chain, and moderate changes in regional climate caused fluctuations in the levels of that lake. Geologic mapping of the late Cenozoic lacustrine and interbedded alluvial deposits exposed in Searles Valley (Smith, in review), and noting the highest elevation reached by each lacustrine unit as the lakes expanded, and the lowest level reached by alluvial units as the lakes contracted, the sequence and approximate magnitudes of lake fluctuations has been established.

That sequence, however, needs to be related to the geologic time scale to be of use in a regional study or for correlation with other paleoclimatic studies. The exposed lacustrine and non-lacustrine deposits are known from correlation with subsurface records to extend back in time to about 150 ka; subsurface records document lacustrine deposition in the basin back to 3.2 Ma (Smith and others, 1983). Based on successful U-series dates on core samples of lake deposits from the middle of the valley (Bischoff and others, 1985), we applied the technique to the exposed lacustrine sediments older than 30 ka and younger than about 300 ka. This document

provides an account of the sampling methods in the field, the analytical methods in the laboratory, the results, and our interpretation of the significance of the data.

Philosophy of Approach

Physical and chemical contamination, open-system isotopic behavior, and mechanical translation are all prevalent and universal processes complicate attempts by geochronologists to obtain credible ages. In U-series methods there are internal isotopic criteria that can be used to indicate some of the forms of contamination, but these criteria can only be used to reject bad samples and never to prove the reliability of a good sample, and unfortunately they do not monitor all the possible modes of contamination. In contrast, internal criteria for contamination do not exist in radiocarbon dating. Thus, errors stated for a given date by either method are based only on the quantifiable analytical and counting considerations and do not, and cannot, reflect the "geologic" errors caused by the process of contamination. Thus, the reliability and the test for validity for any kind of radiometric date can only be demonstrated by reproducibility, and correct stratigraphic order with respect to other dates in the same deposit. Our approach, therefore, was to obtain suites of dates from coeval samples from each stratigraphic horizon.

Locations and Sample Descriptions

Geologic mapping of the Quaternary deposits in Searles Valley first identified lacustrine deposits representing periods of persistent (for >2,000 yrs) perennial lakes; these were assigned to four units designated Unit A (oldest), Unit B, Unit C, and Unit D. The interbedded non-lacustrine, shallow-water, or lacustrine deposits that represent very brief lake stands, were designated Unit AB, Unit BC, and Unit CD, with the double letters indicating the unit names of the underlying and overlying lacustrine deposits. Most of these units were further subdivided in areas of detailed mapping (e. g., AB1 to AB6, C1 to C3, or C1a to C1c, with the basal subunit being the one ending in *1* or *a*).

Our strategy was to first sample bedded tufa near the base of the oldest lacustrine unit, Unit A, in a setting where the sampled material appears to have been buried by younger sediments continuously since deposition, thus reducing the chance of post-depositional alteration of the original U content and isotopic balance. The best place to satisfy these requirements was determined to be in a dry wash near the southeast end of a prominent, dark colored gravel bar exposed south-southwest of Searles Lake, and just north of an area designated on USGS maps as "The Pinnacles" (Fig. 1). The legal description of the sample area is T 26 S, R 43 E, Sec.32, SE

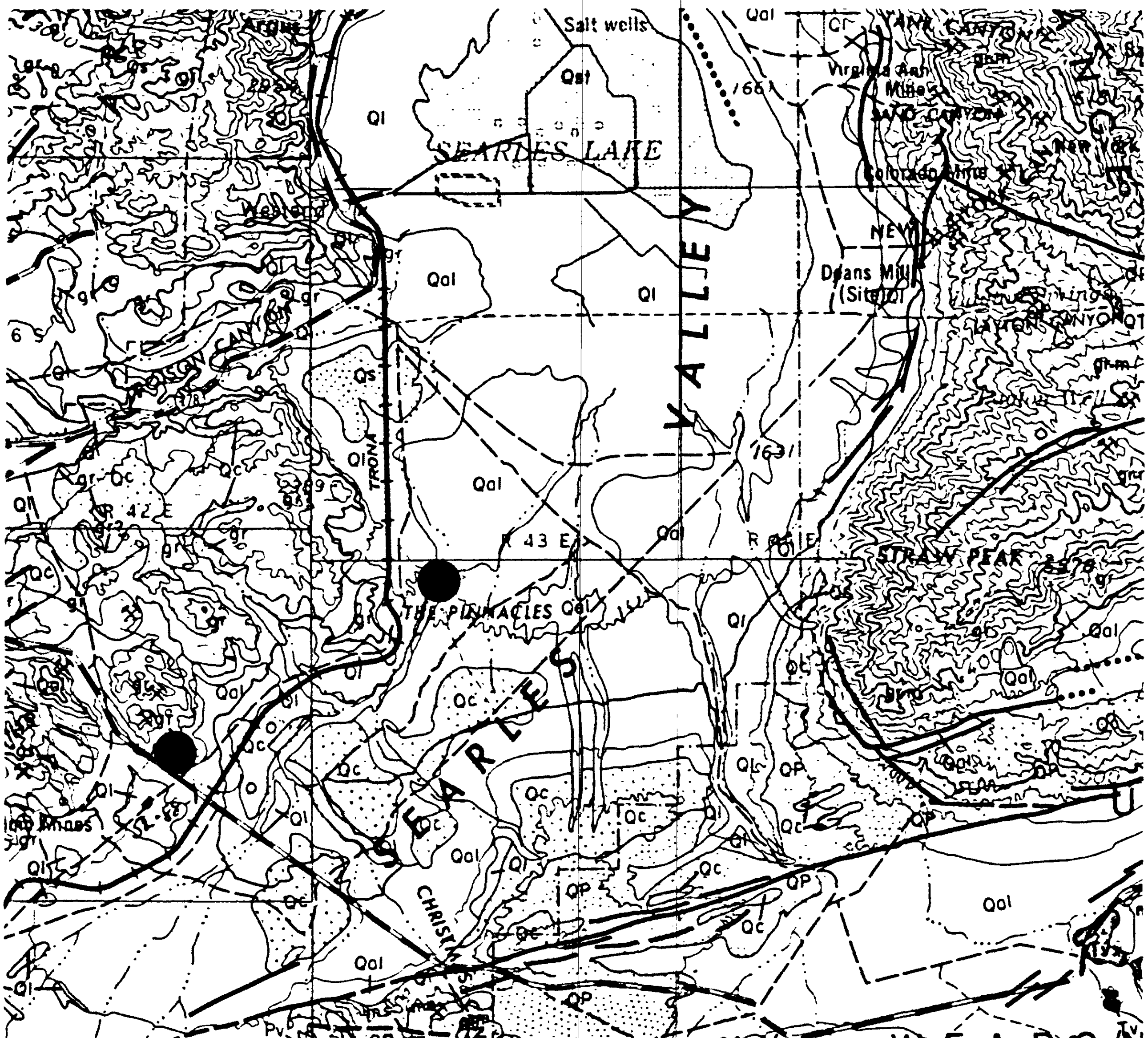

Figure 1

Locations of samples collected from Searles Valley for U-series dating (solid black circles). See text for detailed description of sample locations.

1/4 of the SE 1/4, MDBM; it is in the northwest corner (barely) of the USGS's Christmas Canyon (7 1/2') quadrangle The outcrop is on the east side of a dry wash where about 7.7 m of Unit A is exposed; the unit is here divided locally into Units A1, A2, A3, and A4. Four samples were collected at that site:

Searles 90-1: Sampled material is tufa (impure $CaCO_3$). Exposure sampled is along the east side of the wash and about 10 m downstream from prominent tufa layer that forms a 1-m-high bench across entire floor of stream bed. The sampled tufa layer is about 0.3 m thick and it forms the base of Unit A3. In this area, Unit A3 overlies Unit A1 which has a 0.3-m-thick calcareous soil developed on its paleo-surface. The soil developed during a non-lacustrine interval represented by Unit A2, a 0.5 m-thick layer of orange-gray alluvium that is exposed about 100 m downstream in this wash, along its west side.

Searles 90-2: Sampled material is tufa. Exposure sampled is about 10 m to the north of, but from the same stratigraphic horizon, as sample 90-1.

Searles 90-3: Sample is carbonate-cemented beach sand. Exposure sampled is about 12 m south of the Searles 90-1 locality, and about 0.3 m above the base of Unit A1.

Searles 90-4: Sample is pod-like tufa. Exposure sampled is about 160 m due south of Searles 90-1 sample site, and according to the geologic map, on upper surface of Unit A4. Our field notes, however, describe a thin layer of gravel resting on the sampled tufa. At the time, we interpreted this to mean that the sample represented a short gap in gravel deposition during the period between Units A3 and A4, but we later realized it could have been the gravel facies of Unit B which crops out extensively 300 m northwest of this locality.

Searles 90-5: The fifth sampled locality is the highest-fossil shoreline in the southwest part of Searles Valley, about 8.8 km southwest of the site responsible for samples Searles 90-1 to 90-4 (Fig. 1). It is reached using the U.S. Navy road that links the southeast corner of the Naval Weapons Center (near Ridgecrest) with the Navy's Randsburg Wash facility, and the outcrop is reached where the road starts its descent into Searles Valley (heading southeast) and crosses the 2260-ft contour. The legal description of this site is T 27 S, R 42 E, Sec. 22, SW 1/4 of the NW 1/4; it is on the USGS's Spangler Hills East (7.5') quadrangle. The tabular outcrop of tufa is about 30 m northeast of the road. The sample is lithoid tufa that rests on bedrock and pre-lake alluvium. It is not buried by younger lacustrine sediments, and its morphology is superficially similar to the type of tufa normally associated with Unit A. In hand specimen, however, the tufa is highly porous,

composed of 1-10 mm diameter spheres and sphere fragments suggestive of bubbles trapped by growing shoreline algae. The $CaCO_3$ presumably crystallized in the thin aqueous walls of the bubbles as algae extracted CO_2 in the local environment. The walls of the spheres are about 1mm thick. The tufa has a fresh crystalline appearance when the surface is broken away, appearing qualitatively younger than the tufas exposed in the 90-1 to 90-4 collection site. Searles Lake rose to this (spillway) level approximately 16,000 yrs B.P. (during deposition of Unit B) and again at about 12,000 yrs B.P. (during deposition of Unit C).

Procedures

Large kilogram-sized samples were taken from each outcrop to allow later subdivision and replicate analyses of each. In addition, two samples (90-1 and 90-2) are from the same stratigraphic horizon but separated from each other on strike by about 10 m. 16 separate sub-samples of these five were processed for U-series analyses. One of each was selected for radiocarbon analysis. The U-series samples were lightly ground, dissolved in HNO_3, and U and Th isotopes were isolated by ion-exchange chromatography using procedures described in Bischoff et al (1988), and analyzed by alpha spectrometry. Radiocarbon analyses were carried out at the Menlo Park Radiocarbon Laboratory of the U.S Geological Survey. The CO_2 was liberated by standard acid-treatment and was analyzed by gas-proportional counting for a minimum of 2500 minutes (Robinson and Trimble, 1981).

Results and Discussion

U-series

Analyses of all 5 samples indicate rather uniform U-series isotopic compositions optimum for dating (Table 1). Uranium contents are unusually high and range from 12 to 63 ppm, facilitating ease of analysis and yielding very high analytical accuracy and counting precision. The uranium ratios ($^{234}U/^{238}U$)) are remarkably homogeneous, ranging from 1.16 to 1.30. The index of detrital contamination is given by the thorium ratio ($^{230}Th/^{232}Th$). Ratios less than about 20 generally indicate the presence of excessive extraneous Th harbored by detrital clays (Bischoff and Fitzpatrick, 1991) that are mechanically inseparable from the authigenic carbonate. Thorium ratios for the Searles samples are all high and extremely favorable, ranging from 19 to >1000. Thus, all the internal isotopic criteria are favorable and give no evidence of detrital contamination nor open-system behavior.

Replicate dates within each hand specimen agree fairly well, and are in correct stratigraphic order. The isolated sample of the shoreline tufa located at the elevation of the spill point (90-5) yielded

three identical dates of 17±1 ka bp. This corresponds in time to the maximum glacial conditions of the Wisconsin when Searles was receiving maximum input from the Owens River and was full to its spill point. The remaining four samples collected from three different beds within Unit A exposed in the wash near the Pinnacles yield the following dates in descending stratigraphic order: sample 90-4 from above Unit A3 yields two U-series dates at 27±1 and one at 23±1 ka bp. Results from the tufa sampled at the two localities from the base of unit A3 (90-1 and 90-2) are somewhat puzzling. Replicate analyses of 90-1 yields 84±3, 87±4, and 94±4 ka bp. while replicates of 90-2 yield 62±4, 63±3, 67±2, and 67±3 kyrs. Both sets individually display good internal agreement, yet the two sets differ by about 23 ka bp. The stratigraphically oldest sample, 90-3, located immediately above the base of Unit A1 yields replicate dates of 160±8, 162±9, and 176±12 ka bp.

In general, therefore, the U-series dates seem to be of good quality and represent the true ages of the sampled beds. Troubling, however, is the apparent discrepancy between samples 90-1 and 90-2 which, in the field, appeared to have come from the same bed. Exposure of this bed between the sampled sites was virtually 100 percent, and at both sites the sampled bed was underlain by the calcareous soil horizon described earlier. Furthermore, it appears that the sampled horizons have been buried by at least 5 m of sediment most of the time since deposition of Unit A ceased. This sediment cover would appear to have protected the bed from repeated immersion in a succession of different waters that could have added or dissolved its initial uranium, although it is clear that whenever lakes covered this part of the valley floor they were immersed in groundwaters. Incision of the dry wash to its present depth appears to have been a Holocene--possibly, late Holocene event--as none of the sediments deposited during those lake expansions are seen (or were preserved?) within the incised area. Thus, we are perplexed about the apparent discrepancy, and offer no obvious explanation.

Radiocarbon

The quality of dates obtained from radiocarbon analysis of carbonates depends on the initial activity of the dissolved inorganic carbonate, and the degree to which the sample has been open to exchange with younger carbon. In the present case, the radiocarbon results on the tufas are in correct stratigraphic order and might be initially taken for correct were it not for the U-series dates and geological considerations. Samples 90-1, 90-2, and 90-3, are beyond the limit of radiocarbon dating of about 40kyrs, according to the U-series dates and stratigraphy, yet yield apparent radiocarbon dates of only 25 to 32 kyrs. Carbonates have been shown to be susceptible to contamination by exchange with young carbon from the atmosphere and ground water (Fontes, 1992; Chappell, et al, 1972; Robinson, 1991), and this must be the explanation for these results . Likewise, samples 90-4 and 90-5 yield dates of ca. 18 and 11 kyrs , systematically younger than

the corresponding U-series dates of ca. 25 and 17 kyrs, respectively, suggesting that such contamination has also affected the younger samples. This discrepancy is much greater than a correction for past variations in the rate of ^{14}C generation in the atmosphere can provide. The samples analyzed for this report are especially susceptible to ^{14}C contamination as they are relatively porous tufas that were exposed at the surface (Olsson, et al, 1968). Therefore, it appears to confirm the earlier experience that porous tufa, exposed at the surface to both precipitation and to younger lake waters, is so easily contaminated with younger carbonate that radiocarbon dates represent, at best, a minimum age.

Table 1

Uranium-series analysis of tufa deposits from Searles Lake, California

Sample	lab no.	U ppm	$^{234}U/^{238}U$	$^{230}Th/^{232}$	Date ka bp
90-1	90-51	40±1	1.24±0.02	40±3	87±4
90-1	90-57	44±1	1.30±0.02	35±2	85±3
90-1	90-63	46±1	1.25±0.03	36±2	84±5
90-2	90-47	35±1	1.23±0.04	46±6	62±4
90-2	90-53	34±1	1.21±0.02	45±5	63±3
90-2	90-56	28±0.5	1.23±0.02	44±4	67±2
90-2	90-61	32±1	1.22±0.03	45±4	67±3
90-3	90-54	19±0.3	1.18±0.02	27±2	160±8
90-3	90-59	19±0.3	1.12±0.02	28±2	162±9
90-3	90-62	12±0.3	1.21±0.03	22±1	176±12
90-4	90-55	63±2	1.18±0.02	63±6	23±1
90-4	90-60	26±0.5	1.20±0.03	32±2	27±1
90-4	90-116	25±0.5	1.18±0.01	24±3	26±1
90-5	90-48	24±0.4	1.18±0.02	33±4	17±1
90-5	90-58	29±0.5	1.16±0.02	>1000	17±1
90-5	90-64	34±0.8	1.20±0.02	>1000	17±1

Table 2

Radiocarbon dates for tufa deposits from Searles Lake, California

Sample No.	USGS ^{14}C No.	$\delta^{13}C$	Date ka bp
90-1	2841	2.0	25.4±0.14
90-2	2842	1.7	29.1±0.24
90-3	2843	1.6	32.3±0.29
90-4	2844	4.4	18.1±0.17
90-5	2845	1.4	10.9±0.04

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