eventually encounter the surface of a star and everywhere the sky should be about as bright as the sun. The problem was first discussed in the 18th century by de Chéseaux, of Lausanne, and the related question of infinite gravitational potential was further analyzed by Seeliger in 1895 (*Astron. Nachr. No. 3273*). One possible solution which survived as late as 1918 in Shapley's views of the galactic system and 1922 in Kapteytn's heliocentric stellar universe was the hypothesis that the world of stars is not infinite but rather a single island universe in an empty cosmos. Charlier's concept was a neat geometric solution (in nonrelativistic terms) to the problem of "how an infinite world may be built up." A hierarchical structure of the cosmos was first envisioned by the Alsatian, J. Lambert, in his somewhat fanciful "Kosmologischen Briefen" (Augsburg, 1761). An excellent historical summary (in French) on the Olbers' paradox and its sequels was published in 1966 by R. Chameaux [*Bull. Soc. Astron. Toulouse* **57**, No. 485 (1966)]. Another very interesting discussion of the paradox and its cosmological implications was presented in June 1965 by A. G. Wilson in an unpublished lecture to the Los Angeles Astronomical Society (Rand Corporation reprint P-3256) [see also (*49*)].

42. For example, statistical analyses of Abell's cluster catalog have led to the following conflicting conclusions: definite superclustering on a 50-megaparsec scale for at least a fraction (but not the totality) of the cluster population, according to Abell (*20*); some superclustering on scales of 50 to 200 megaparsecs, according to Kiang and Saslaw (*32*); no significant superclustering, according to Yü and Peebles (*43*). [However, after reading a preliminary version of this paper, Dr. Abell informed me (personal communication) that the results of Yü and Peebles "followed only by not counting those clusters in distance group 5 in the southern hemisphere, where the superclustering appears most obvious. In fact, the superclustering was so pronounced in that part of the catalog that they felt it was not representative and so discounted it."]. Similarly, analyses of the Zwicky catalogs have led to the widely diverging conclusions of Zwicky and his collaborators (*13–18*) and of Karachentsev (*22*). One additional remark should be made here; in the study of superclustering it may not be strictly equivalent to study the distribution of galaxies in general (as was done in the analysis of the Local Supercluster and of the Lick Observatory counts), on the one hand, or the distribution of large or rich clusters (as listed in the Mount Palomar surveys) on the other. It is entirely possible that superclustering of large clusters is much less pronounced and prevalent than superclustering of groups and small clusters which are automatically excluded in the Abell and Zwicky catalogs by the very definition and method of selection of "rich clusters." For example, only one cluster—and not a particularly rich one—the Virgo cluster, is known in the Local Supercluster, and if this supercluster were seen from a great distance, it would not be recognized as such from cluster counts because it would be represented by only one cluster (and perhaps none). To use again the human population analogy, it is doubtful that the obvious "superclustering" of the general population indicated by statistics of agglomerations of all sizes (that is, complete "counts") would be readily detected by an analysis restricted to the worldwide distribution of the great capital cities only (the "rich clusters"). I suspect that the apparent disagreement in the conclusion reached by various investigators arises, at least in part, from a failure to recognize that only a small fraction of the total galaxy population is concentrated in the relatively rare "rich clusters."
43. J. T. Yü and P. J. E. Peebles, *Cal. Inst. Tech. Orange Preprint Ser. No. 168* (1969); *Astrophys. J.* **158**, 103 (1969).
44. W. M. Irvine, *Ann. Phys.* **32**, 322 (1965); J. Kristian and R. K. Sachs, *Astrophys. J.* **143**, 379 (1966); R. K. Sachs and A. M. Wolfe, *ibid.* **147**, 73 (1967).
45. This concept was foreshadowed as long ago as 1928 when Jeans wrote in *Astronomy and Cosmogony* (Cambridge Univ. Press, Cambridge, p. 352) his well-known, possibly prophetic speculation: "The type of conjecture which presents itself, somewhat insistently, is that the centers of the nebulae are of the nature of 'singular points,' at which matter is poured into our universe from some other, and entirely extraneous, spatial dimension, so that to a denizen of our universe, they appear as points at which matter is being continually created."
46. M. L. Humason and H. D. Wahlquist, *Astron. J.* **60**, 254 (1955).
47. F. Hoyle and J. V. Narlikar, *Mon. Notic. Roy. Astron. Soc.* **123**, 133 (1961).
48. M. J. Rees and D. W. Sciama, *Nature* **217**, 511 (1968).
49. In recent years A. G. Wilson has given much thought to the concept of a hierarchical cosmos and has searched for signs of a possible "discretization" in "modular" structures (*51*) that might perhaps relate cosmic and atomic constants through quantized relations. Although the numerological aspects of this approach—reminiscent of Eddington's brilliant but futile *Fundamental Theory*—are admittedly highly speculative, the basic concepts and evidence of a hierarchical world structure discussed by Wilson are very much the same as those presented here. I am indebted to Dr. A. Wilson for calling my attention to his own extensive work in this area and for a preprint of his chapter *Hierarchical Structure in the Cosmos* (*52*).
50. J. R. Wertz, thesis, University of Texas, in preparation.
51. A. G. Wilson, *Proc. Nat. Acad. Sci. U.S.* **52**, 847 (1964); *Astron. J.* **70**, 150 (1965); *ibid.* **71**, 402 (1966); *ibid.* **72**, 326 (1967).
52. ———, in *Hierarchical Structures*, L. L. Whyte, A. Wilson, D. Wilson, Eds. (American Elsevier, New York, 1969), p. 113 [see also T. Page, *Science* **163**, 1228 (1969); A. G. Wilson, *ibid.* **165**, 202 (1969)].
53. J. A. Wheeler, *Annu. Rev. Astron. Astrophys.* **4**, 393 (1966).
54. E. Schatzman, *White Dwarfs* (Interscience, New York, 1958).
55. C. W. Allen, *Astrophysical Quantities* (Athlone Press, London, 1961), p. 203.
56. A. Poveda, *Bol. Tonantzintla No. 17* (1958); p. 3; *Bol. Tonantzintla No. 20* (1960), p. 3.
57. I. King, *Astrophys. J.* **134**, 272 (1961).
58. G. de Vaucouleurs, *Mon. Notic. Roy. Astron. Soc.* **113**, 134 (1953).
59. R. Minkowski, *Int. Astron. Union Symp. 15th, Santa Barbara, Calif., 1961* (1962), p. 112.
60. G. de Vaucouleurs, *Astrophys. J.* **131**, 265 (1960); *ibid.* **137**, 373 (1963).
61. K. J. Gordon, *Astron. J.*, in press.
62. S. T. Gottesman, R. D. Davies, V. C. Reddish, *Mon. Notic. Roy. Astron. Soc.* **133**, 359 (1966).
63. E. M. Burbidge, G. R. Burbidge, R. A. Fish, *Astrophys. J.* **133**, 393, 1092 (1961); *ibid.* **134**, 251 (1961).
64. J. C. Brandt and R. G. Roosen, *Astrophys. J. Lett.* **156**, L59 (1969).
65. G. R. Burbidge and E. M. Burbidge, *Astrophys. J.* **130**, 15 (1959); *ibid.* **134**, 244 (1961).
66. G. de Vaucouleurs, *ibid.* **130**, 718 (1959).
67. ———, *Astrophys. J. Suppl.* **6**, No. 56, 213 (1961).
68. T. Kiang, *Mon. Notic. Roy. Astron. Soc.* **122**, 263 (1961).
69. I am indebted to G. O. Abell, P. Couderc, T. Page, and A. G. Wilson for their helpful criticisms of a preliminary version of this paper.

The Borax Lake Site Revisited

Reanalysis of the geology and artifacts gives evidence of an early man location in California.

Clement W. Meighan and C. Vance Haynes

In 1948, Harrington published the results of his archeological studies under the title "An ancient site at Borax Lake, California" (*1*). From this location in northern California (Fig. 1) was recovered a large and diverse collection of stone implements, including a group of fluted points comparable to similar specimens from widely scattered locations where they were found in association with the bones of extinct animals such as mammoth and giant bison (*2*). Fluted points have been recognized for some time as diagnostic traces of the early Indian hunters of about 10,000 to 12,000 years ago in North America, hence the title of Harrington's report and the importance of the site as one more location where an early assemblage was found. However, for reasons discussed below, there arose an immediate and continuing controversy over the age of the site, the nature of the artifacts, and the interpretation to be drawn from the Borax Lake collection. The result was that the Borax Lake material was put to one side and treated as uncertain in meaning. We now reexamine the evidence from Borax Lake and attempt to define its importance to studies of early man in the New World. The site has more than local significance for a number of reasons.

1) The collection has remained for

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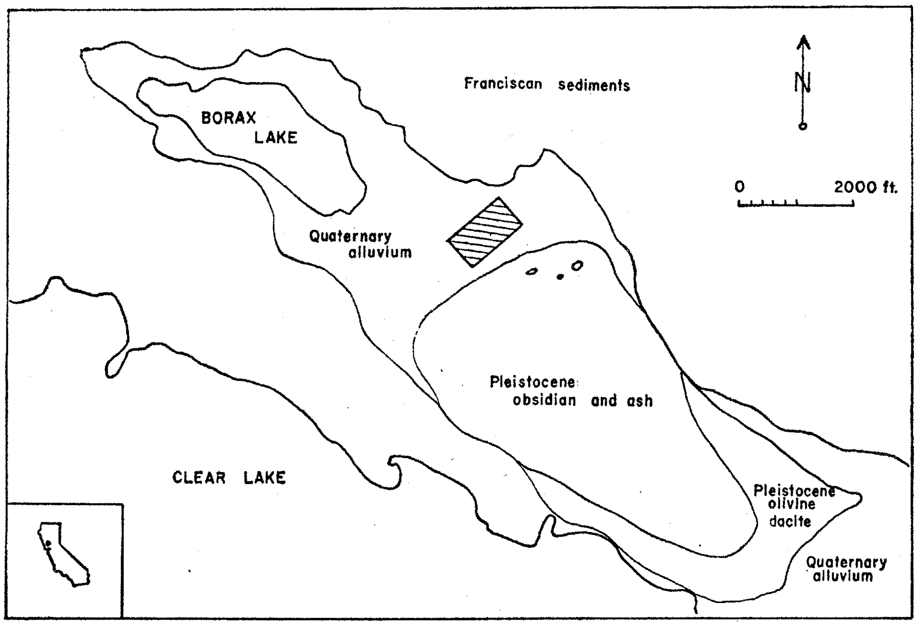


Fig. 1. Geologic map of the Borax Lake area, California. The shaded rectangle indicates the area represented in Fig. 2. [After Anderson (7, plate 2)]

20 years as a somewhat anomalous assemblage of tools which did not appear to belong together and did not fit the emerging pattern of similarities between one early man site and another. Removing some of the uncertainties about the Borax Lake material therefore eliminates some of the exceptions and contradictions that seemed to be present in the studies of early man, strengthening the general picture deduced from many other sites of considerable age.

2) The methods used to analyze the Borax Lake material are a reflection of new and developing techniques for archeological study, and the site therefore provides a good case example of the growth of knowledge and methodology in studies of early man over the past two decades.

3) Multiple lines of evidence are required for analysis of a site like Borax Lake, and the study has relevance for Pleistocene geology, classification of artifacts, and obsidian dating methods.

4) Conventional opinion regarding the settlement of the New World by the original Indians has tended to envision a path of migration through the interior of Alaska and down into the Great Basin and Plains regions of North America. This leaves the West Coast (west of the Sierra Nevada) as a marginal region which was presumably not settled by man until somewhat later, perhaps thousands of years after the original entry into the New World. Confirmation of the belief that the Borax Lake site is ancient therefore casts new light on the question of when the original settlement of the West Coast may have occurred.

Our reexamination of Borax Lake is based on new evidence and includes a restudy of the typological questions concerning the fluted points, reexcavation of the site in 1964 by C. V. Haynes and Charles Rozaire for purposes of studying the stratigraphy and geology, and the use of evidence from obsidian dating on a broad series of specimens from the site. Harrington's original interpretation of the Borax Lake finds rested on geological and typological arguments, and the dissent from his conclusions has been primarily based on doubts concerning the validity of these arguments. A concise summary of the earlier discussion has been presented by Wormington (*3*). It is unnecessary to review all the arguments, but perhaps worth while to explain why it has not been possible to find an easy resolution to the Borax Lake problems. First, the field work was done in the 1930's and 1940's, prior to the development of direct dating techniques such as the radiocarbon method. Second, the archeological deposit is badly disturbed, so that conventional artifact stratigraphy does not yield a convincing sequence of cultures at the site. Finally, the collection was a unique assemblage of artifacts at the time of Harrington's study, and there is still no published assemblage of any size which is like Borax Lake, although Heizer (*4*) identifies eight sites as being similar to Borax Lake and small samples from some of these have been published.

In the light of these considerations, Harrington's age estimates could not be proved or disproved. He concluded that the geology of the Borax Lake deposit indicated an age of "10,000 or 15,000 years ago." The same age was estimated on the basis of cultural evidence, principally the fluted projectile points. We examine these two kinds of evidence separately, beginning with the cultural evidence.

Typological Comparisons

Since the Borax Lake collection includes not only fluted points but a wide variety of other point forms as well, several typological inferences were made and debated. The most important inferences had to do with the fluted points, which were thought by Harrington to demonstrate the presence of Folsom man at Borax Lake. Furthermore, he made the suggestion that the "cruder type of Folsom, such as is found at Borax Lake, may be at least as old as the classic [Folsom point] and may be older." This statement anticipates the modern conclusion that the fluted points from Borax Lake are more in the tradition of the older Clovis points, which are also fluted but antedate Folsom points by as much as a millennium.

One complication in the Borax Lake collection is the occurrence of numerous points which have concave bases but no fluting. Harrington stated that these unfluted points "may or may not be contemporaneous" with the others, but he clouded the issue by referring to them as "Folsomoid," a term which implies relationship. Also, in certain of these tabulations he apparently deals with these points as if they were equivalent to the fluted points. Points of the kind Harrington calls Folsomoid are present in abundance in other California sites of no great antiquity, most notably in the Middle Central California sites. Since Harrington was unable to show any clear separation in time between his "Folsom" and "Folsomoid" points, he was vulnerable to the following criticism: the Folsomoid points are known to be late in time, therefore the fluted points are probably not "real" Folsom points and there is no reason to accept Borax Lake as a site of early man.

Similar kinds of typological problems arose with respect to many other classes of artifacts in the Borax Lake collection. Throughout his report Harrington mentions trait similarities (chiefly of point types) between Borax Lake and numerous other California archeological assemblages, including Pinto Basin, Lake Mohave, and Early Central California. The principal shortcoming of Harrington's report is its suggestion that these different types of points imply visits to the site by different bands of people, and that these diverse cultural groups all camped around Borax Lake within a very short period. "The most plausible explanation of the fact that the artifact complex shows little if any change from bottom to top," the report states, ". . . is that the whole artifact-bearing deposit at Borax Lake was laid down within a relatively short time—perhaps within a few centuries."

Hence, because of his preoccupation with Folsom and the early man problem, Harrington saw the site as entirely ancient, and as influenced or visited by a series of ancient cultures in a short period. This interpretation arose largely from the disturbed nature of the deposit and the impossibility of showing a neat stratigraphic change from one artifact type to another.

Several other kinds of typological comparisons have been made in an effort to relate the artifacts from the Borax Lake site to similar finds in other California locations (*4–6*). It is clear, however, that the typological or comparative method used in seeking to understand the Borax Lake collection has been only partly successful. Fortunately, the obsidian hydration method provides another source of evidence for sequencing the artifacts from Borax Lake and permits resolution of many of the uncertainties.

Geological Stratigraphy of the Borax Lake Site

Borax Lake is adjacent to Clear Lake in the California Coast Range, and is surrounded by bedrock of Franciscan sediments except to the southeast, where an obsidian and dacite plug of late Quaternary age separates the Borax Lake Valley from Clear Lake (*7*). Borax Lake itself (Fig. 1) is bordered by late Quaternary alluvium, a part of which consists of alluvial fan deposits containing the archeological artifacts. The geomorphic history of the area has been discussed by Hodges (*8*), who suggests that, at some time during the Pleistocene, Clear Lake may have stood 300 feet (90 meters) higher than its present level.

During the initial archeological excavations, Ernst Antevs stated in a letter that he concurred with Carl Sauer in the belief that the artifacts occurred in an alluvial fan (*9*). This origin of the sediments was questioned by Treganza (*10*). In the hope of resolving this question and of finding better evidence for dating the occupation, 20 backhoe trenches were excavated in 1964 across the walnut orchard containing the site (Fig. 2). An average trench depth of 10 feet exceeded that of the original excavations. This fact, plus the greater area covered, has provided a better picture of the stratigraphy than was previously available (Fig. 3; Table 1 gives a general description of the sediments).

The poor sorting and clayey nature of units D and E (subunits E_1 and E_2) of Table 1 and Figs. 2 and 3 suggest transportation either as mudflows or over distances too short to allow sorting such as might be expected in a landslide. The fact that there is some layering approximately parallel to the surface indicates that a mudflow origin is the most plausible hypothesis, and this is consistent with the alluvial-fan shape of the deposit, because mudflows are typical of some alluvial fans. Today, intermittent discharge from the canyon at the head of the fan is generally insufficient to add new material to it. The last significant outwash of debris reportedly occurred during a period of intense winter rains from 1903 to 1909. Active erosion of the fan today is confined to minor slope washing; no significant channels are apparent. It appears, therefore, that the fan has experienced neither net aggradation

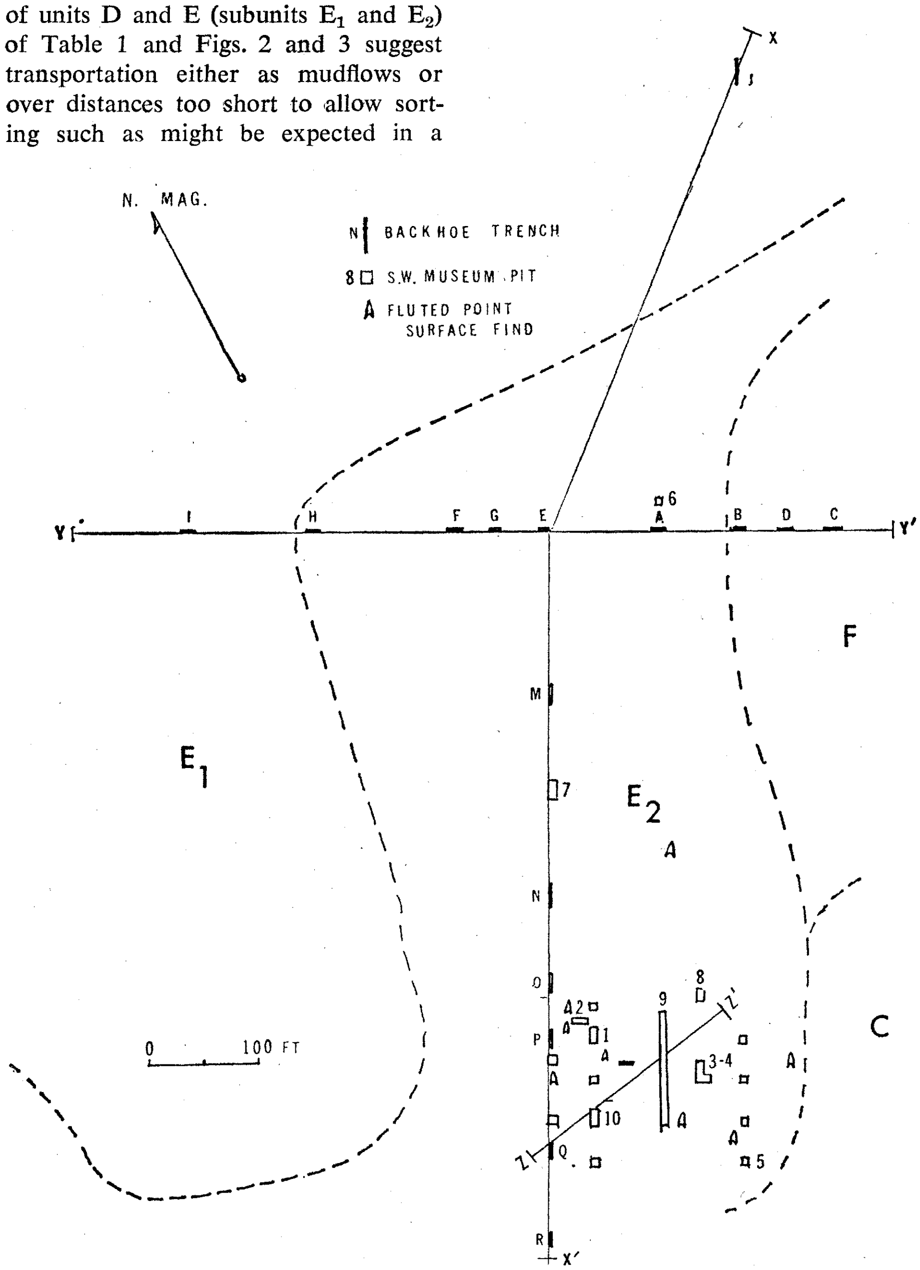


Fig. 2. Geologic map of the Borax Lake site, Lake County, California. Rectangles 1–8 and 10, Southwest Museum pits; 9, Southwest Museum trench; *N. Mag*, north magnetic pole.

Table 1. Stratigraphy of the Borax Lake Site, California.

Unit	Description
F	Clay—dark gray to black (10 YR* 2/1, moist), firm sandy clay with moderate, medium angular structure breaking to very fine angular in upper 8 inches (20 centimeters). Numerous root molds; *p*H, 7.0. Maximum observed thickness, 3 feet.
E_2	Silt and gravel—grayish brown (10 YR 5/2, dry), soft, sandy, clayey, pebbly silt or silty, angular, pebble gravel with weak, medium angular structure. Contains dispersed charcoal fragments and obsidian debitage. Upper contact is transitional over 4 inches. Maximum observed thickness, 5 feet.
E_1	Clay and gravel—yellowish brown (10 YR 6/4, dry), compact, sandy, silty, pebbly clay or clayey, angular, pebble gravel with widely dispersed obsidian flakes and artifacts. Becomes more compact and iron-stained with depth. Upper contact is transitional over about 4 inches. Maximum observed thickness, 6 feet.
D	Gravel—dark brown (7.5 YR 4/4, dry), hard, silty, sandy, clayey, fine-to-medium, subangular, pebble gravel with iron and manganese stains and interbedded lenses of silt and sand. Upper contact is gradational over about 2 inches and is apparently erosional. Oxides may be in part pedogenic. Maximum observed thickness, 5 feet.
C	Clay—pale olive (5 Y† 6/4, moist), tough, sticky clay with orange mottlings at the top in some places and pale, bluish-green mottlings in deeper portions. Interbedded with unit D. Sharp-to-gradational upper contact. Maximum thickness not observed.

* YR, yellow-red. † Y, yellow.

nor net degradation during historic times.

The stratification of units D and E indicates that in the past there were at least two periods of general aggradation of the fan. Unit D, representing the earlier period, is interfingered with the clay of unit C, which is undoubtedly of lacustrine origin. The more sorted sand lenses in unit D and the more rounded nature of some of the pebbles may be due to the action of littoral water, but it is clear that the early period of aggradation coincided with a higher stand of the lake than has occurred since.

The greater firmness of the top of unit D and the concentration of secondary iron and manganese oxide there and in the higher parts of unit C suggest that these features are products of weathering. The partial conformation of this zone to a buried topography supports this interpretation, which indicates that deposition of unit D was followed by a period of stability. That this in turn was followed by a period of erosion is indicated by the fact that the irregular contact at the base of unit E truncates both the paleosol and units C and D.

From the report of the original excavations it is apparent that the first occupation of the site postdates the paleosol and possibly the erosional interval as well, because all of the excavated artifacts occurred well within unit E or within pockets of displaced unit E carried into unit D by the activity of rodents.

Unit E is similar to unit D except for the fact that it is less compact, is lighter in color, and has more angular-shaped coarse particles. It is divided into subunits E_1 and E_2 on the basis of color, compaction, and subtle lithological differences. These subunits probably represent two episodes of aggradation under depositional environments similar to that of unit D except for the fact that the lake level must have been considerably lower, because no lacustrine facies of unit E were encountered in any of the trenches.

From the artifact assemblages in unit E and from the range of obsidian hydration thicknesses, it appears that unit E represents a span of at least 4000 years. During this period, net aggradation took place presumably at a faster rate than has occurred since.

Unit F is a local deposit occurring adjacent to the east side of the alluvial fan in a low area. It is in part pedogenic and resembles a wet-meadow soil. In trench K in this area (not shown in Fig. 2) the water table was found to be at least 20 feet higher than in trench R, closest to the lake shore, and at least 5 feet higher than in trench F, near the center of the fan. This indicates either that a local source of recharge is maintaining the high water table or that the less permeable clay of unit C is maintaining a perched water table. In either case, unit F is obviously a younger deposit than unit E and postdates the original human occupation of the fan.

Accurate radiocarbon dating of unit E is not possible because charcoal is so dispersed that it cannot be precisely related to either culture or stratigraphy. A series of obsidian hydration readings, taken on chips found from 1 to 7 feet below the surface, also shows internal disturbance. Unit E is thoroughly disturbed by rodent activity; this explains the near-absence of cultural stratigraphy and obscures the natural stratigraphy in many places. Therefore, our only recourse for estimating the geologic age of the deposit is by geologic correlation. The nearest late Quaternary sequence containing a record of lacustrine and alluvial deposits separated by paleosols is that of Morrison (*11*) for pluvial Lake Lahontan. The Borax Lake paleosol may be reasonably correlated with the Harmon School soil of the Lake Lahontan area. If this correlation is valid, lacustrine unit C and its alluvial-facies equivalent, unit D, are equivalent in age to the lower Sehoo Formation, and unit E is equivalent in age to the upper Sehoo Formation. On the basis of the radiocarbon chronology of the Lake Lahontan area and its correlation to the Wisconsin chronology (*11*), it appears that the Harmon School soil is of Twocreekan age, or approximately 12,000 years old. Such an age for the Borax Lake paleosol is consistent both with the results of obsidian dating and with our general opinion that the Borax Lake fluted points are typologically similar to Clovis points, which elsewhere are dated between 11,000 and 12,000 years ago (*2*).

If this correlation of the Borax Lake paleosol and the Harmon School soil is in error, it probably errs in suggesting too young an age for the former, because both the results of the obsidian dating and the cultural assemblages are consistent with a Valderan age for the fluted points. The other most likely correlation of the Borax Lake paleosol would be with the Churchill soil of the Lake Lohontan area, which is believed to be approximately 27,000 years old (*11*). This interpretation suggests that the erosional contact between units D and E represents a hiatus of at least 15,000 years, and such a hiatus seems unlikely because this period is one of maximum pluvial deposition elsewhere.

On the other hand, past high stands at Clear Lake have not been solely dependent upon climate (*8*), and we suggest the possibility that Borax Lake may have been at one time an arm of Clear Lake that became isolated upon emplacement of the obsidian and dacite intrusions between Clear Lake Park and Borax Lake. Because no volcanic ash has been recognized in the deposits at the Borax Lake site and because the artifacts are probably made of Borax Lake obsidian instead of Konocti obsidian (*7*), it appears that the intrusives are probably more than 12,000 years old and late Pleistocene, instead of Holocene as suggested by Anderson (*7*).

The experiments of Schmalz (*12*) on the rates of patination of flint suggest the likelihood that, under certain geochemical conditions, obsidian could become hydrated at an anomalous rate. Sulfataras in the area of Borax Lake were reportedly active in historic time (*7*). These are clearly recognizable today as three conspicuous white barren areas approximately 400 yards (360 meters) southeast of the site (Fig. 2). At present there is no sign of activity, but a pungent smell is perceptible when one walks over these inactive sulfataras.

Within the fan sediments themselves there is no evidence of anomalous geochemical activity such as rock alteration, stains, salts, or unusual odors. For this reason, and for reasons mentioned below in discussion of the obsidian hydration results, we do not believe that the past sulfataric activity has affected the obsidian hydration of the artifacts from the Borax Lake archeological deposit.

Obsidian Dating of Borax Lake Artifacts

Clark (*13*) made the first series of obsidian determinations for Borax Lake in the course of his study of obsidian dating in California. He published 27 obsidian hydration readings on specimens from Borax Lake. The original microscope slides from which these readings were taken were donated to the obsidian hydration laboratory at the University of California, Los Angeles, and the hydration thicknesses were reread for purposes of this study. An additional series of readings was made on specimens collected by Haynes in the course of his field work. All the original readings were suggestive of considerable age, but since all the specimens were chipping waste rather than finished artifacts, they provided no information about the relative ages of specific kinds of artifacts. Hence the series of hydration readings was augmented through the courtesy of the Southwest Museum, Los Angeles, which permitted us to use the specimens classified and described in Harrington's original excavation report (*1*). These readings provided not only indications of age but also a sequence for the artifact types. A preliminary report based on 49 obsidian readings was published (*14*); the present discussion is based on 80 hydration readings from the Borax Lake site itself plus several additional test specimens from nearby sites. The specimens used for hydration dating are represented in Fig. 4.

The determination of absolute age for obsidian specimens from California is still a process of considerable uncertainty. There are various reasons for this, some of which are discussed below, but the principal problem is that there is no extensive series of radiocarbon dates that can be linked to a comparably extensive series of obsidian hydration readings. Use of obsidian dating to estimate the chronological age of the Borax Lake finds is therefore tentative and may be subject to considerable revision; the attempt is made nonetheless, since the hydration readings provide the best body of evidence currently available for dating the site.

The broadest study of obsidian dat-

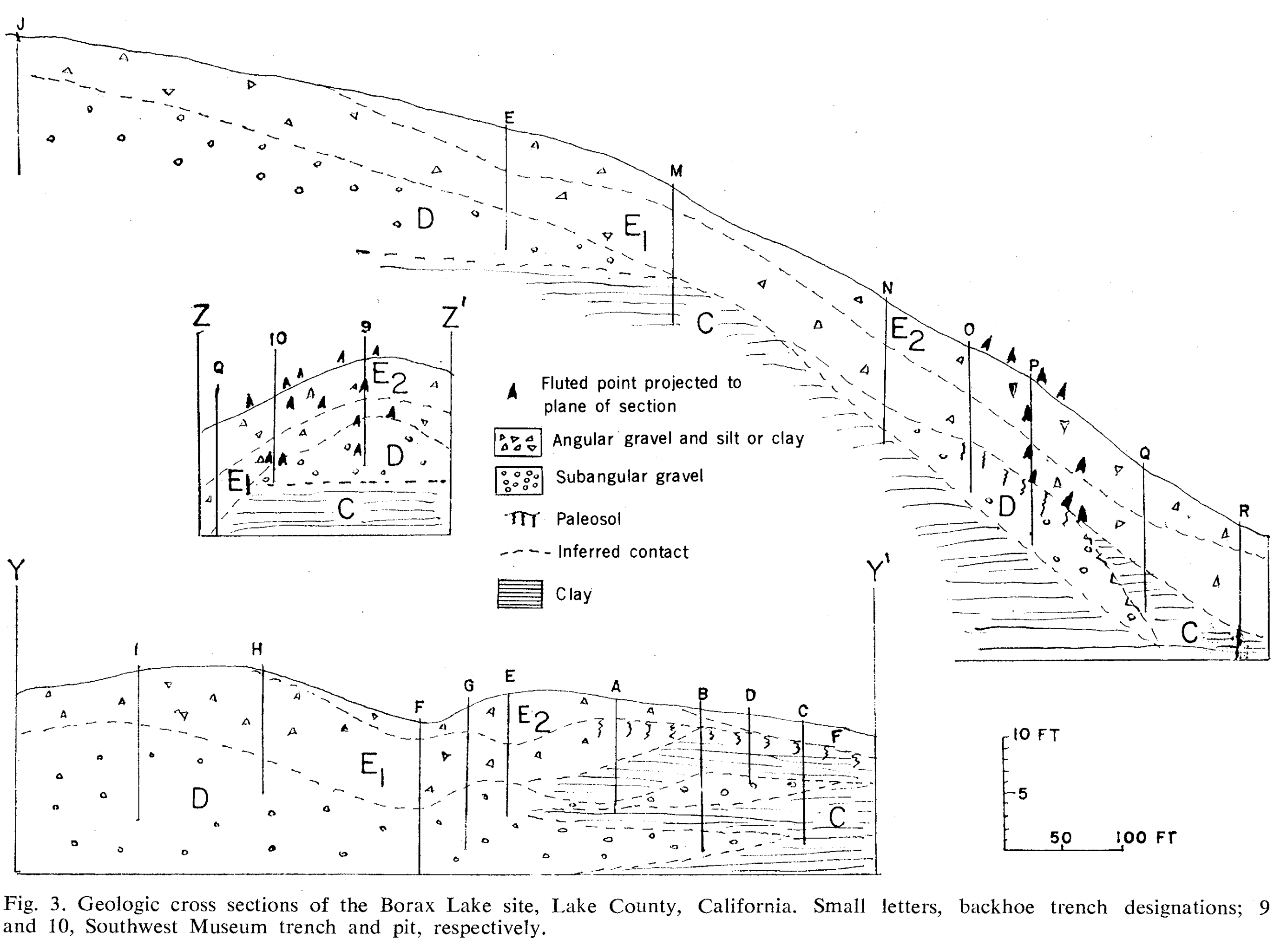
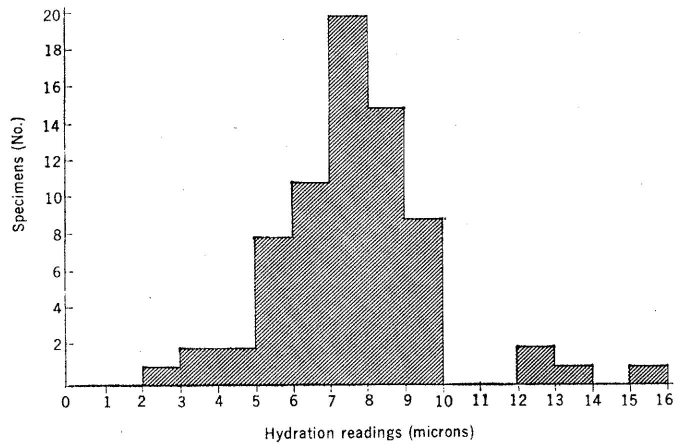


Fig. 3. Geologic cross sections of the Borax Lake site, Lake County, California. Small letters, backhoe trench designations; 9 and 10, Southwest Museum trench and pit, respectively.



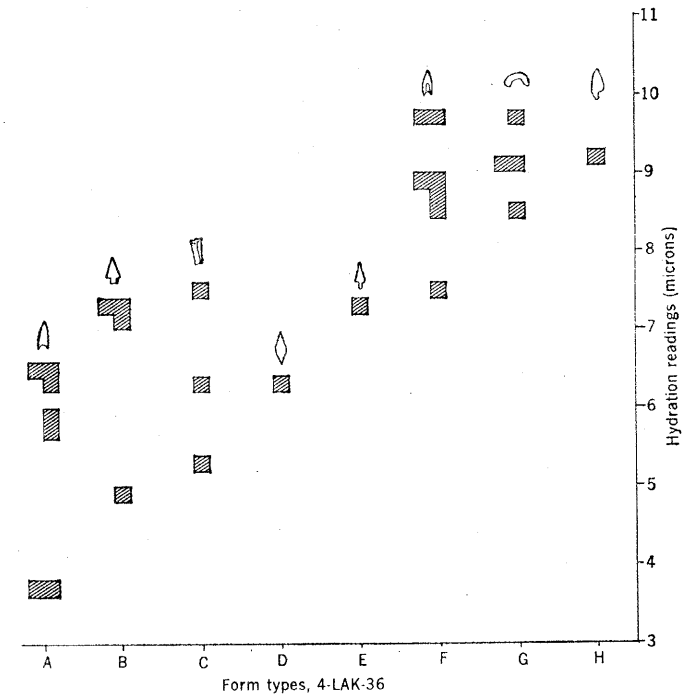


Fig. 4 (above). Distribution of obsidian hydration readings, Borax Lake site. Fig. 5 (right). Obsidian hydration readings for different artifact types, Borax Lake site. Form types: *A*, concave based point without fluting; *B*, Borax Lake wide-stemmed point; *C*, single-flake blades; *D*, bipointed point; *E*, stemmed point; *F*, fluted points; *G*, crescents; *H*, single-shoulder point.

ing in California is that of Clark (*13*), who attempts to date a considerable number of California sites through correlation of radiocarbon and obsidian dates to determine the hydration rate. His 27 hydration readings for Borax Lake yielded age estimates between 3000 and 8900 years; in general, Borax Lake yielded the highest hydration thicknesses of any of Clark's California sites. Clark discounts the apparent age, however, because "the hydration thicknesses . . . are probably due to thermal actions around the Clear Lake area rather than primarily from considerable age of the site." This is the so-called "hot springs effect" discussed below; we consider it unlikely that such an effect is present in the readings of hydration thickness which form the basis of our tentative conclusions.

The hydration rate suggested by Clark on the basis of empirical fitting of radiocarbon dates to associated obsidian hydration measurements is indicated in Table 2 along with other possible hydration rates. Friedman and Smith (*15*) propose a different formula, and Friedman (*16*) has recently used a rate of 5 microns, squared, per 1000 years (for Mono County obsidian in Central California). Meighan and Haynes (*14*) used a simple linear rate of approximately 1 micron per 750 to 1000 years to make a gross estimate of age, but do not state in detail the basis for their use of this rate. Discussion of the problems involved in establishing the rate is beyond the scope of this article, but application of the different rates to the Borax Lake hydration readings yields the results shown in Table 2.

It can be seen that, in spite of wide differences in results, all the rates indicate that the Borax Lake site is old, was abandoned by 2600 years ago, and has a maximum age in excess of 10,000 years. However one views the validity of the obsidian dating method, unless the method is totally discarded it is clear that Borax Lake is, at least in part, an occupation site of early man. The suggestion that Borax Lake is no more than a Middle Central California site dating back to perhaps 2000 B.C. is clearly erroneous. The average age of the site appears to be over 6000 years, hence older than Early Central California.

Agreement that the site is old still leaves considerable latitude for argument about how old. Application of the Friedman rate gives results that seem unacceptable for both the maximum age and the span of occupation of the site; for the average age of the site it gives a value that seems a possibility but is not close to that given by the other rates. The Clark rate is the one most carefully worked out on the basis of empirical evidence, and it should probably be used until there is additional evidence to modify it. However, when we have hydration bands thicker than 8 or 9 microns, both the Clark and the Friedman rates seem to indicate a greater age than archeologists would find acceptable for specimens of the type found at Borax Lake. These problems cannot be resolved here, and we must therefore simply point out that all of the conceivable hydration rates proposed for California indicate that the Borax Lake has artifacts of considerable antiquity.

Aside from its use in suggesting the calendrical age of the Borax Lake specimens, obsidian dating is used in the sequencing of artifacts—an application of equal importance. If our understanding of the hydration process is correct, we can say that, regardless of the absolute age of the specimens, the older artifact types will have greater hydration thickness than specimens more recently made. This conclusion is particulary reliable in the case of collections from a single site, because the artifacts will be derived from few obsidian sources, and all will have been subject to the same conditions since they were buried. The local conditions, whatever they are, should affect all artifacts in the site equally, so determination of the relative ages can be made with some confidence. The validity of obsidian dating for sequencing artifacts has been firmly demonstrated by the work of Michels (*17*), who made more than 500 obsidian determinations on a site in Mono County, California, and was able to work out the sequence of point types from his hydration data.

Application of the hydration method to the obsidian from Borax Lake should, therefore, throw light on two critical questions: (i) Are the fluted points from the site older than the bulk of the artifacts? (ii) Is it possible to sort out of the Borax Lake collection those artifact types which are contemporaneous, thus obtaining the basis for an objective determination of the different cultural complexes present? The results of a test made in an effort to answer these questions are shown in Fig. 5, which gives hydration readings for a sample of 32 specimens which can be identified as to artifact type. The sample is small, but the results are consistent. We conclude that the fluted points are indeed older than the other artifacts from Borax Lake, and we suggest below a sequence of cultural assemblages in the total Borax Lake collection.

The principal problems in utilizing obsidian dating for the Borax Lake collection are as follows.

1) Uncertainties in the rate of hydration formation. Although there is general agreement on the results of obsidian hydration readings back to 5000 or 6000 years ago, there is considerable divergence in the interpretation of readings for materials older than this, as discussed above (Table 2).

2) The "hot springs effect" mentioned above, in which abnormal formation of hydration bands can be caused by exposure of the obsidian to high temperatures during its time of burial in the archeological site. This effect has been observed in at least one archeological site (*18*) but does not appear significant at Borax Lake.

3) The abrasion effect, in which all or part of the hydration band has been removed by wind or water abrasion. This effect is clearly present in some Borax Lake specimens, and (as would be expected) is most marked on the older artifacts. Several specimens show no hydration at all; these create no problem of interpretation since they do not enter into the results. More important are specimens which show that some, but not all, of the hydration rim has been removed. Some chips and flakes show greater hydration on one surface than on the other; such pieces either have had part of the hydration rim removed or represent rechipping of an older object. Again, these do not affect the age estimates, since the older reading can be used to determine the age of first working. A few specimens are more problematical, however. A chipped crescent from Borax Lake (S.W. Museum, No. 18 F 2248) has no hydration band on one surface and has 1.6 microns of hydration on the other side. Since no reworking of the piece can be seen, it must be concluded that some external effect has taken all of the hydration rim off one surface and an unknown amount of it from the other side. Another specimen (a projectile point) shows a surface hydration of 2.9 microns, but a crack in the same specimen (protected from surface abrasion) has a hydration rim 8.1 microns thick. These specimens, which have apparently lost part, but not all, of their original hydration bands, show that some hydration readings could be misleading. Since any abrasion effect will reduce the thickness of the hydration layer, if not detected it will result in age estimates that are too young. Such an effect cannot increase the apparent age of the artifact, and therefore it does not alter our conclusions about the age of the Borax Lake site.

4) A final problem is the question of reuse—the situation in which the Indians picked up an artifact from an older site and introduced it into a more recent context. Clark (*13*) believes this to be the explanation for occasional items that appear too old for their associated context. Since we have no caches or grave lots from Borax Lake, we cannot check on this situation for our collection of obsidian artifacts.

The anomalous readings from Borax Lake total 13; these are for specimens with no hydration band or with two or more different hydration bands. Of the 13 specimens, seven contribute nothing to the readings because they lack hydration bands. For four specimens which have two hydration bands, the thicker band was used in computing averages. Two specimens have been eliminated: the crescent referred to above (see 3) and a Borax Lake point with a hydration rim of 2.6 microns. The latter specimen shows no visual evidence of abrasion, but the value seems inconsistent with the readings for four other specimens of the same type. If this reading is authentic it indicates persistence of the wide-stem Borax Lake point until quite recent times.

Table 2. Age estimates from obsidian hydration readings of Borax Lake specimens.

Archeological period	Width of hydration band (microns)	Clark rate*	Friedman rate†	Linear rate‡
Most recent§	3.8	2,600	2,880	3,130
Oldest	15.6	16,800	48,600	12,950
Average ($n = 66$)	7.9	6,820	12,500	6,550
Span of occupation	3.8–15.6	16,800 yr	ca. 46,000 yr	9,820 yr

* See *13*. † See *16*. ‡ This rate is based on the assumption of linearity and uses only the data from site SJo-68, an Early Horizon site in the Sacramento Valley, as presented by Clark (*13*). There are 13 obsidian hydration readings and three radiocarbon dates from the site. While this is about as large a single sample as is available for California, it is still inadequate and there are considerable uncertainties about the individual readings. The estimated rate of 830 years per micron is not considered to have any great validity, and it is included here primarily to show the effects of a linear rate on age interpretations. Note that the Clark rate is approximately linear after the first 2500 years. § One anomalous reading of 2.6 microns is omitted. This is considered to be a recent intrusive specimen.

Conclusions

Neither the geological nor the typological evidence is inconsistent with a date of up to 12,000 years ago for the original occupation of the Borax Lake site. Obsidian dating also suggests the reasonableness of such an age, although problems in the obsidian dating make the age determinations estimates rather than certainties.

The overall pattern of evidence suggests an interpretation of the Borax Lake site which is closely consistent with the general pattern of early man sites in the West. Borax Lake, in its original occupation, is probably to be seen as a lakeside hunting camp comparable to Lake Mohave and to similar dry lake sites of the Great Basin and Southern California. It was so interpreted by Harrington and by some recent writers (*19*). The difference is that, in the desert areas, the desiccation was so severe that the sites were abandoned in ancient times. The Borax Lake environment, being closer to the Pacific Coast, experienced less harsh changes, so the site area could be occupied by successive hunters and gatherers down to relatively recent times. However, for the past 2000 years at least, the drier Borax Lake basin has been less attractive for aboriginal settlements than the nearby Clear Lake, which is still full of water.

The diagnostic artifacts of the early period at Borax Lake include the fluted points and the crescents. Most of the stone artifacts were of obsidian, although fluted points of jasper and chalcedony also occur.

The pairing of fluted points with crescents does not occur in Folsom or Clovis cultures. Further, the association has not yet been demonstrated stratigraphically, and the only direct evidence for such an association is the obsidian dating from Borax Lake. However, the possibility of such an association has been suggested for at least three localities other than Borax Lake.

1) Lake Mohave, California. Warren (*20*) has found fragments of fluted points in the Lake Mohave collections. This is a culture which also contains crescents. However, since the finds are all surface material and are from several different sites, the association of crescents with fluted points in the same assemblage is yet to be firmly documented.

2) Long Valley Lake, Nevada. A similar relationship is noted by Tadlock (*21*) in his summary article on crescents. His article also shows that crescents tend to be most common in cultures of considerable age (over 7000 years).

3) Tulare Lake, California. Roehr and Wilwand (*22*) also present a surface assemblage from Tulare Lake which contains both crescents and fluted points. This material is reported to be associated with the 194-foot level of Tulare Lake, but, again, the artifacts are surface finds and we cannot be sure that the crescents and fluted points are of the same age. In a more detailed discussion of the Tulare Lake situation, Riddell and Olsen (*23*) also speculate that fluted points and crescents may be of the same age at this location.

All of these observations are in agreement with the evidence of obsidian dating at Borax Lake, which indicates that the crescents and fluted points occur together and are very early. Since, as Tadlock (*21*) points out, crescents occur mainly in the Great Basin and Southern California (they are rare west of the Sierra Nevada), a valid association of crescents with Clovis-related points would argue for a western variant of the Clovis tradition which, unlike known Clovis sites, includes crescents as one of the significant components of the artifact assemblage. This western variant may differ in age, as well as in cultural content, from the Clovis tradition defined for the Plains and the Southwest. At Borax Lake, the fluted points and crescents appear to be on a time level with the Folsom culture, perhaps extending down to slightly more recent times.

The second assemblage of artifacts at the Borax Lake site probably follows a break in the occupation and has an apparent age of 6000 to 8000 years. This period represents the major part of the occupation of the site and includes the largest part of the artifact collection, including wide-stem Borax Lake points, some coarse single-flake blades, and probably the manos and metates. The latter suggestion is conjecture, since there are no hydration readings for the grinding implements, but this is a logical association based on other known assemblages of the West.

The third period at Borax Lake is typified by the concave-based points without fluting, by stemmed points, and by some continuance of manos and metates as grinding implements. This horizon is related to the Middle Central California complex and has an age of about 3000 to 5000 years. Out of this terminal occupation at Borax Lake developed (in other locations) the Mendocino complex described by Meighan (*5, 24*). This sequence puts the fluted points in the earliest period at Borax Lake and the concave-based points *without* fluting in the latest period; in our small sample there is no overlap in the obsidian hydration readings on the two kinds of points.

There is nothing in the Borax Lake site that is truly late in the archeological sequence. Hydration readings on known late sites in the Clear Lake area show hydration thicknesses of less than 2.5 microns; no reading for unaltered hydration from Borax Lake is that small, and the average reading is much higher.

This tentative reconstruction of the Borax Lake site's history is fragmentary; it does not place in time many of the artifact classes at Borax Lake because we do not yet have hydration evidence sufficient for establishing such chronology. However, the outlined sequence is consistent with the general pattern of western prehistory, and it seems to make sense out of a collection which has been a center of controversy for 20 years. If our conclusions are accepted as a working hypothesis, it becomes possible to relate the early archeology of the northern Coast Ranges of California to early developments in Southern California and the Great Basin. It suggests that there may be a far-western variant of Folsom or Clovis culture, present in the regions north and west of classic fluted point sites, which is approximately contemporaneous with Folsom culture but has crescents as well as fluted points as its diagnostic artifacts. Finally, settlement of the northern Coast Ranges of California by ancient man is pushed considerably further back in time, and Meighan's suggestion (*25*) that the region was not entered by man until after 8000 B.C. is open to reexamination.

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24. In his 1955 paper, Meighan (*5*) described the Mendocino complex on the basis of excavations some 50 miles (80 kilometers) north of the Borax Lake site. The Mendocino complex was identified as being similar to Borax Lake in some of its artifacts and was interpreted as probably derivative from a Borax Lake cultural ancestor. On the basis of the data presented here, it is possible to reevaluate the relationships between Borax Lake and the Mendocino complex and to suggest a better age estimate for the latter. The Mendocino complex lacks the older remains of the Borax Lake collection, having no

fluted points, crescents, Borax Lake points (with one possible exception), or "long stem points." On the other hand, the Mendocino complex shares 8 of its 12 point types with Borax Lake, although the Mendocino specimens are smaller, on the average, than Borax Lake points of the same type. The Mendocino complex shares six point types with the Middle Central California complex; all but one of these is also shared with the Borax Lake site. Finally, while the Mendocino complex has metates as grinding stones, it has a much more prominent assemblage of mortars than Borax Lake has. When the Borax Lake age estimates are used as a guide, it appears that the Mendocino complex would have to be more recent than the wide-stem Borax Lake points—that is, less than 7000 years. The smaller point size and the use of mortars in the Mendocino complex suggest a Middle Central California affinity, although not a strong one. If a rough age of 1000 B.C. is accepted for Middle Central California, this places the Mendocino complex between 1000 and about 5000 B.C., there being some feeling that the true age is likely to be closer to the more recent end of that time span. This is not very precise dating, but it is a substantial revision toward greater age than the "guess" date of A.D. 500 to 1000 previously published.
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26. This work is in part supported by National Science Foundation grants GP-5548 to P. E. Damon and GA-1288 to C. V. Haynes. The cooperation and assistance in the field of Charles Rozaire, Freddie Curtis, Robert and Melva Orlins, Richard Muers, and George and Mary McLeod are gratefully acknowledged. A special word of gratitude is due Willard Hodges of the Lake County Realty Company for permission to excavate trenches in the company's walnut orchard and to Edward Fitts for a masterful job of backhoe excavation. Microscope slides and illustrations were prepared at the University of California, Los Angeles, by Leonard Foote and Paul Aiello. The costs of laboratory work were paid by a Faculty Research Grant from UCLA to C. W. Meighan. The Southwest Museum, through Director Carl Dentzel and Curator Bruce Bryan, permitted access to the original Borax Lake collection and generously allowed us to cut small pieces from many important specimens for purposes of obsidian dating. This cooperation made possible the first objective sequencing of Borax Lake artifact types.

Reproductive Physiology of Marsupials

Unique features of marsupial reproduction suggest two evolutions of viviparity in therian mammals.

G. B. Sharman

The marsupial mother bears her young after a shorter gestation period than that usually occurring in other mammals of comparable size, and the young are born in a generally embryonic condition. Although the pouch, or marsupium, from which the marsupial order takes its name, is not a universal feature of the group, the young are always firmly attached to the teats for a period after birth which roughly corresponds to the latter part of intrauterine gestation in eutherian or true mammals. It was once believed that the eutherian mammals were descended from marsupials, but this view is no longer held. However, it has more recently been suggested that marsupials are descended from ancestors with a true allantoic placenta, such as that occurring in all eutherians and few marsupials, or that the marsupial type of reproduction is derived from the fully viviparous reproduction of eutherians (*1*). It is at least equally probable that marsupials and eutherians are derived from common oviparous ancestors and that viviparity evolved independently in each group. Accordingly, I examined the physiology of marsupial reproduction and compared analogous processes in marsupials and eutherians.

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Chromosomal Sex Determination

Diploid chromosome numbers of marsupials vary from 10 in the female and 11 in the male to about 32. Chromosome numbers are known for about 60 species, or about 26 percent of extant marsupials, and in all but four of these sex is determined by XX female chromosomes and XY male chromosomes. In the American superfamily Didelphoidea (opossums), two species, *Caluromys derbianus* and *Marmosa mexicana* have 14 chromosomes. The two X chromosomes are less than half the size of the smallest autosomes, and the Y chromosome is minute, much smaller than the X, and less than 1 micrometer in length (*2*). All of the Australian superfamily Dasyuroidea (marsupial "mice" and "cats," for example) thus far studied also have 12 autosomes, a small X chromosome and a minute Y chromosome (*3*). *Burramys parvus* (superfamily Phalangeroidea), an Australian marsupial known until 1966 only as a Pleistocene fossil, and related animals grouped by Kirsch as Burramyidae have similar karyotypes to the dasyuroids and are always distinguishable on sex chromosome morphology from the remaining phalangeroids (*4*). The occurrence of similar karyotypes in *Caluromys*, which Reig (*5*) regarded as being one of three surviving genera of the otherwise extinct subfamily Microbiotheriinae, in the dasyuroids, and in the most generalized of the phalangeroids suggests that the small X and minute Y chromosome of these animals may represent the ancestral marsupial condition.

Sixteen species of marsupials have 22 chromosomes, and in most of these, and in those with various other chromosome numbers, the sex chromosomes are larger than those of the 14 chromosome didelphoids, the dasyuroids and the burramyids. The X chromosome is about the same size as the smallest autosome, and the Y is the smallest chromosome of the set. The X and Y chromosomes are thought to associate by chiasmata at meiosis. In both mitosis and meiosis they show a cycle of condensation different from that of the autosomes, and, although they separate first at the anaphase of meiosis, they lag on the spindle and reach the poles after the other chromosomes. Failure of prophase pairing during meiosis and loss during mitosis occur, and it is suggested that the sex chromosomes are at some disadvantage during division as compared to the autosomes (*6*).

Intersexual marsupials with sex chromosome aberrations are apparently produced from union of gametes with unbalanced sex chromosome complements. The incidence of intersexuality