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ASPARTIC ACID RACEMIZATION AND RADIOCARBON DATING OF AN EARLY MILLING STONE HORIZON BURIAL IN CALIFORNIA

Darcy Ike, Jeffrey L. Bada, Patricia M. Masters,
Gail Kennedy, and John C. Vogel

Concordant radiocarbon and aspartic acid racemization dates have been obtained for several Holocene aboriginal skeletons from coastal southern California sites. These results further demonstrate the reliability of racemization dating. One of the skeletons (SDM 16709), dated at 8,300 years, was a burial around which several milling stones had been placed. This well-dated burial indicates that the Southern California Milling Stone horizon is significantly older than has previously been accepted.

Within the past few years, a new chemical dating technique based on amino acid racemization has made possible the direct dating of aboriginal skeletons from southern California coastal sites. The racemization dating method is based on the fact that the amino acids utilized by living organisms for the synthesis of proteins are all of the L-configuration; over geological time, these

Darcy Ike, Archaeological Laboratory, University of California, San Diego, La Jolla, CA 92093
Jeffrey L. Bada, Scripps Institution of Oceanography and Institute of Marine Resources, University of California, San Diego, La Jolla, CA 92093
Patricia M. Masters, Scripps Institution of Oceanography, University of California, San Diego, La Jolla, CA 92093
Gail Kennedy, Department of Anthropology, University of California, Los Angeles, Los Angeles, CA 90024
John C. Vogel, Natural Isotopes Division, National Physical Research Laboratory, Pretoria 0001, South Africa

L-amino acids slowly racemize, producing the corresponding D-amino acids. Both D- and L-amino acids are found in fossil materials, and the D/L ratio increases with the age of the fossil. Each amino acid has a characteristic racemization rate, that of aspartic acid being the fastest.

Since racemization is a chemical reaction, its rate is temperature dependent. To date a fossil bone by this technique, it is necessary to evaluate two factors: the bone's D/L ratio and the average temperature to which the fossil has been exposed. The racemization of aspartic acid has been the most extensively used reaction for bone dating. The temperature history of an area can be estimated by a procedure in which the racemization rate for a particular site is calculated by determing the D/L aspartic ratio in a fossil that has previously been dated by radiocarbon or some other independent dating technique (Bada and Protsch 1973; Bada, Schroeder, and Carter 1974; Bada, Schroeder, Protsch, and Berger 1974; Bada and Deems 1975). After this "calibration" has been carried out, other fossils in the same general area can be dated on the basis of their extent of aspartic acid racemization. Ages of fossil bones derived from this "calibration" procedure agree closely with ages determined by radiocarbon or other chronological information (Bada, Schroeder, Protsch, and Berger 1974; Bada and Deems 1975; Bada and Helfman 1975).

This "calibration" procedure was the method used for dating the Del Mar Man skeletal remains, SDM 16704 (Bada, Schroeder, and Carter 1974). A radiocarbon date of 17,150 ± 1,470 years (Berger et al. 1971) on the Laguna Woman remains was used in conjunction with a D/L aspartic acid ratio of 0.25 on the same bones to calculate a k_{asp} of $1.08 \times 10^{-5}yr^{-1}$ from the equation

$$ln \left(\frac{1 + D/L}{1 - D/L} \right) - 0.14 = 2 \left(k_{asp} \right) t.$$

This k_{asp} value represents the aspartic acid racemization rate over the last 17,000 years for southern California coastal localities, and it is proportional to the average temperature along this coast over that time span. This rate constant can be used to date fossil bones that have experienced roughly equal exposure to glacial and postglacial temperatures. However, it is not suitable for dating samples of Holocene age (younger than ~11,000 years), because these bones have experienced warmer average temperatures.

During the course of investigations of the extent of aspartic acid racemization in aboriginal skeletons from southern California, several burials were identified that were estimated to have ages in the 5,000- to 8,000-year range. The k_{asp} used to calculate these racemization ages was derived from the Laguna calibration, $k_{asp} = 1.08 \times 10^{-5}yr^{-1}$. The Laguna sample, having been exposed to nearly equal amounts of glacial and postglacial temperatures, has a k_{asp} proportional to an average temperature lower than Holocene temperatures. This k_{asp} would be too slow to use for dating Holocene bones. Schroeder and Bada (1973) have shown that

$$\frac{k_{asp} \text{ (bones} < 10{,}000 \text{ years)}}{k_{asp} \text{ (bones} > 15{,}000 \text{ years)}} = 1.4$$

on the island of Mallorca in the western Mediterranean. Assuming this relationship is valid for southern California, since glacial-postglacial temperature differences are fairly similar for the two areas (Gates 1976), the Laguna k_{asp} can be adjusted to $1.5 \times 10^{-5}yr^{-1}$ for dating Holocene samples. Some of the racemization ages calculated using this adjusted k_{asp} value are listed in Table 1.

The racemization-derived ages of southern California aboriginal skeletons have been viewed with skepticism by some, who raise the possibility that the Laguna skeleton radiocarbon age of 17,150 years used for racemization "calibration" may be incorrect or that the racemization dating technique itself is of questionable validity (Hare 1974; Von Endt et al. 1975). As can be seen from the results listed in Table 1, at two localities where both radiocarbon and racemization dates have been determined, there is close agreement between the ages derived. These com-

Table 1. Racemization Ages of Holocene Aboriginal Skeletons from Southern California Coastal Sites.

Site No.[a]	SDM no.	D/L aspartic acid	Aspartic acid age (years)[b]	C-14 age (years B.P.)
W-9, SDi 4660[c]	19241	0.154	5,700	6700 ± 150 LJ-79[d,e]
	19244	0.156	5,800	—
W-2	18402	0.15	5,400	—
W-5, SDi 4670	19229	0.155	5,800	—
W-12, SDi 4669	16709			
4-hour hydrolysis		0.142	7,900	—
24-hour hydrolysis		0.189	8,100	—
	19999	0.175	7,100	—
Ora 64[f]				
50–60 cm	—	0.170	6,800	6960 ± 140 GAK 4136[d]

[a] The W notations are the site numbers of the San Diego Museum of Man; the SDi and Ora numbers are those of the California State Archaeological Survey.
[b] Dated using $k_{asp} = 1.5 \times 10^{-5}yr^{-1}$; the derivation is explained in the text. Except as indicated, all the samples were hydrolyzed 24 hours. The $t = 0$ term for a bone sample hydrolyzed four hours is $\sim$0.05 (A. McCurdy, D. Roy, and J. L. Bada, unpublished results).
[c] Shumway et al. 1961.
[d] Radiocarbon date on shell either directly associated with the burial (W-9) or from the same stratigraphic horizon (Ora 64).
[e] Because of upwelling along the California coast, a C-14 date on marine shell may be as much as 720 ± 90 years older than the shell actually is (Berger et al. 1966). A correction has not been applied to the C-14 dates on shell carbonate listed in this table. Thus the differences between the aspartic acid ages and C-14 ages are probably smaller than they appear to be.
[f] Drover 1975.

parisons, however, could still be questioned because the radiocarbon age determinations were carried out not on the actual skeleton that was dated by racemization but rather on associated shell materials. To check the reliability of the southern California racemization dates, one of the skeletons listed in Table 1 (SDM 16709) was selected for radiocarbon dating.

The radiocarbon analysis was performed on 240 g of broken bone from the skeleton. The sample was demineralized and purified by repeated treatment with dilute (< 1%) HCl over a period of 10 days. About 3.5 g of purified collagen were recovered. The combusted sample was assayed in a carbon dioxide proportional counter (Vogel and Marais 1971) and yielded the following result: Pta 1725, San Diego Skeleton SDM 16709, 8360 ± 75 years B.P. The relative δC-13 content was −15.7%, and the age has been corrected accordingly for isotope fractionation.

The radiocarbon date agrees very closely with the date of 8,100 years deduced from aspartic acid racemization. A second analysis on SDM 16709 was performed in our laboratory using a four-hour hydrolysis instead of the standard 24-hour hydrolysis. The resulting date of 7,900 years demonstrates the intralaboratory reproducibility of the racemization procedure. The 4.3% difference between the two amino acid dates and the radiocarbon date is less than the average difference of 7% observed in previous comparisons (Bada and Helfman 1975). Two other laboratories have also analyzed fragments from 16709 with results comparable to ours (Bada et al. 1978).

The close agreement between the radiocarbon and racemization ages for SDM 16709 and for the two other skeletons listed in Table 1 (W-9 19241 and Ora 64) indicates that the Holocene k_{asp} of $1.5 \times 10^{-5}yr^{-1}$ is accurate. Since this k_{asp} was adjusted from the Laguna "calibration," using the procedure described above and elsewhere (Bada, Schroeder, Protsch, and Berger 1974), the assumption on which the adjustment was made and consequently the reliability of the Laguna k_{asp} value are supported by the concordant dates we report here. The Laguna radiocarbon age, therefore, seems to be accurate and provides a suitable "calibration" sample to use for racemization dating of Upper Pleistocene aboriginal skeletons from coastal southern California sites.

It is important to note that the D/L aspartic acid ratios determined for the Holocene skeletons in no case exceed 0.2, which is considerably less than the D/L ratios of $\sim$0.5 determined for skeletons such as Del Mar Man (Bada, Schroeder, and Carter 1974; Bada and Helfman 1975) and the Scripps Cliff horse (Masters and Bada 1978). These horse bones, identified as the extinct Pleistocene *Equus occidentalis*, were found exposed in the face of a sea cliff north of the SIO pier after a landslide. Charcoal from strata above the bones has been dated to 21,500 ± 700 years (W-142) and 38,000 ± 3,000 years (LJ 3530). The horse remains must therefore be older than 30,000 years. The D/L aspartic acid ratio was 0.54, comparable to the Del Mar Man ratios of 0.52 and 0.53 (Bada, Schroeder, and Carter 1974; Bada and Helfman 1975). By use of the Laguna k_{asp}, an age of 50,000 years was determined.

If variations in environmental parameters (soil pH, humidity, "leaching") could produce anomalously high D/L ratios, as has been suggested elsewhere (Hare 1974; Von Endt et al. 1975), this effect should have been detectable in some of the Holocene skeletons. They came from several different locations, where these parameters would be expected to vary, but the D/L ratios are all 0.2 or lower. These results have therefore provided additional evidence of the accuracy of racemization-based ages and further suggest that the 40,000 to 50,000-year dates obtained for several southern California paleo-Indian skeletons are reliable (Bada, Schroeder, and Carter 1974; Bada and Helfman 1975).

After the dating of SDM 16709, we reviewed the original field notes of M. Rogers (n.d.), on file at the San Diego Museum of Man, to ascertain the provenience of the skeleton. About 1936, at Site W-12 (SDi 4669), Rogers discovered skeleton SDM 16709 eroding out of the midden exposed on the cliff face. The burial was excavated by George F. Carter, and four whole "killed" sandstone milling stones, several fragments, and one mano were recovered from "around and over" the interment. Photographs of the in situ burial taken at the time of excavation are shown in Figures 1 and 2.

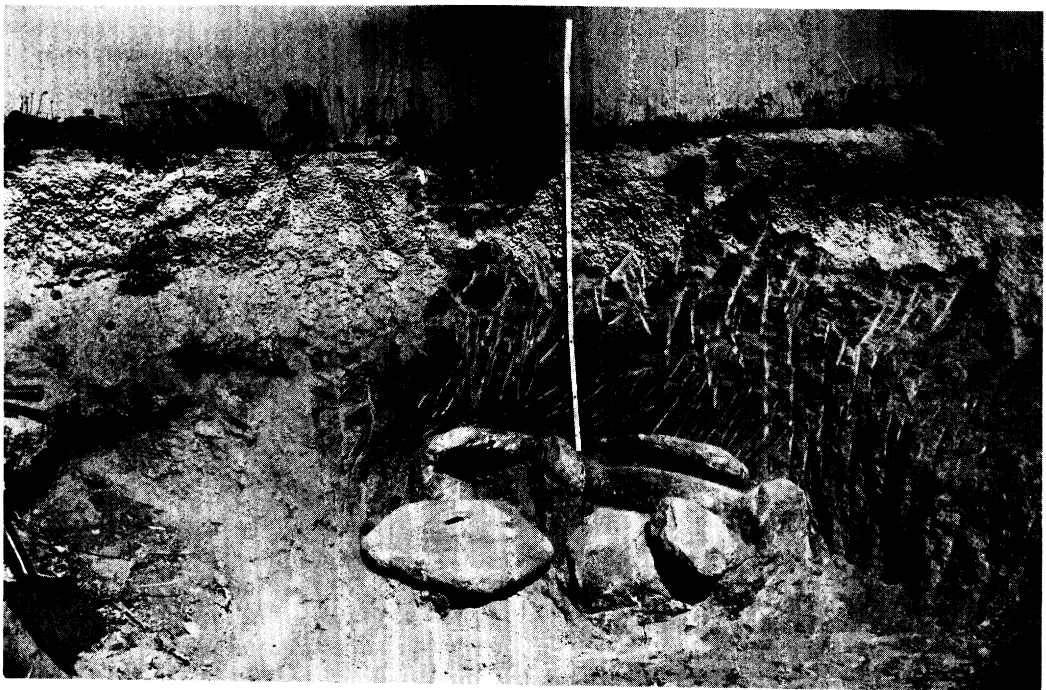

Figure 1. Photograph taken at the time of excavation (1936) of burial SDM 16709, showing milling stones around and over the interment. The depth from the surface to the top of the first milling stone is 92 cm. All milling stones over interment are face down. Note hole punched through (killed) milling stone at lower left. In his field notes, M. Rogers (n.d.) speculated that two milling stones from the burial were lost by erosion. Depth to the bottom of the interment is 130 cm. (Photograph courtesy of the San Diego Museum of Man, with printing assistance from the National Geographic Society.)

Figure 2. Photograph showing the in situ skeleton with one milling stone still in place. (Photograph courtesy of the San Diego Museum of Man, with printing assistance from the National Geographic Society.)

The best known early cultural tradition in southern California is Wallace's Milling Stone horizon (Wallace 1955), which occurs along the coastal strip from San Luis Obispo County into Baja California. Milling stones that have been ritually killed by having a hole punched through the basin or by being broken are reported in association with burials at several Milling Stone horizon sites. Significant among these are the Browne site (VEn 150) in Ventura County (Greenwood 1969), the Tank site (LAn 1) in Los Angeles County (Treganza and Malamud 1950), and the Glen Annie site (SBa 142) in Santa Barbara County (Owen 1964), where radiocarbon dates on shell were obtained that range from 6,380 ± 120 to 7,270 ± 120 years. Similar dates, ranging from 5,460 ± 100 to 7,370 ± 100 years, were obtained in San Diego County on shell from the Scripps Estates site, W-9 (Shumway et al. 1961). Two sites that lack the killed milling stones specifically but demonstrate an ∿6,000-year time span for the Milling Stone horizon, are Diablo Canyon (SLO-2) in San Luis Obispo County (Greenwood 1972) and LAn-2 in Los Angeles County (Johnson 1966). Greenwood (1972) reports a radiocarbon date on shell from the 200-cm level of Site 6 at Diablo Canyon of 8,410 ± 190; at least one milling stone and five manos were recovered from below 200 cm. At site LAn-2, Johnson (1966) reports that charcoal from firepits yielded five radiocarbon dates ranging from 2,440 ± 200 to 2,700 ± 150; these appear to be the youngest dates belonging to the Milling Stone horizon. Most Milling Stone horizon sites, however, have been dated between 7500 and 3000 B.P., which has been the more generally accepted time range of the culture.

The four milling stones recovered with burial SDM 16709 were killed by punching a hole through the basin. They are unifacial and have well-developed basins averaging 44 cm long, 28 cm wide, and 9 cm deep. The mano is of a granitic material, is bifacial, and exhibits only moderate convexity on both grinding faces. It does not appear functionally to fit any of the associated milling stones. Since these artifacts were in direct association with excellent datable material (skeleton SDM 16709), we are able to confirm the antiquity that Greenwood has suggested for the northern end of the distribution of the Milling Stone cultures, as well as to establish the southern variant as being considerably older than had previously been accepted.

The burial represents the fragmented but nearly complete skeleton of an adult male, 25 to 35 years of age on the basis of cranial suture closure, since the pubic symphyses are not present. The skull is dolichocephalic (cephalic index = 74.8) and robustly built. Large bony exostoses are present in the auditory canals. These extend from the lateral margin of the external auditory meatus across the tympanic bone (the ectotympanic) and onto the squamosal portion of the temporal. Such auditory exostoses have been reported in other individuals from La Jolla (S. Rogers 1964) and from elsewhere in California (Hrdlicka 1935). All teeth are present except the RP^3, which appears to have been lost post mortem. Evidence of heavy dental attrition is present, with partial or complete exposure of the dentine on the molars. Such tooth wear is consistent with the use of milling stones.

The SDM 16709 burial demonstrates that seed grinding (and/or plant processing) was a known cultural practice in southern California at least 8,300 years ago. As far as we can ascertain, the SDM 16709 milling stone burial is the oldest found so far in southern California. The fact that the milling stones were interred with the burial suggests that they were valuable components of the culture. During the summer of 1976, some of the remaining portions of W-12 (SDi 4669) were excavated, and the analysis of these recovered materials will provide further important information about the lifestyle of these early southern California coastal inhabitants.

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THE ARCHAEOLOGY OF VACANT LOTS IN TUCSON, ARIZONA

Richard Wilk and Michael B. Schiffer

An archaeological survey of 17 vacant lots in Tucson, Arizona, was carried out as a student exercise. The survey disclosed evidence for a recurrent set of activities: travel from place to place, refuse disposal, storage, automobile-related uses, adult and children's play, camping, and various removal processes. Hypotheses about several formation processes, especially trampling, are provided. It is argued that vacant lots are a distinctive kind of activity area involving public use of private space, present in all cities, whose archaeological study may shed light on past urban systems.

In the spring of 1978 the authors taught a course at the University of Arizona on the method and theory of archaeological fieldwork. Students were presented with a series of practical problems requiring observation and interpretation of material culture in Tucson. One exercise, an archaeological survey of a vacant lot, produced results that may be of general interest. In this paper we summarize the students' hypotheses about the patterns of use and the formation processes that created the archaeological record in Tucson's vacant lots. We include our ideas about the broader implications of these findings.

The vacant lot project served to introduce students to a variety of cultural and noncultural for-

Richard Wilk and Michael B. Schiffer, Department of Anthropology, University of Arizona, Tucson, AZ 85721