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Marine Fossils at Rancho La Brea

Abstract. *Marine assemblages of foraminifera, ostracods, mollusks, and echinoids were recovered from deposits stratigraphically beneath the classic vertebrate assemblages from the tar pits at Rancho La Brea. The marine fossils indicate deposition in quiet, shallow water and suggest that accumulation of the type Rancholabrean material began during Wisconsin time.*

The Rancho La Brea tar pits in Los Angeles, California, famed for their rich yield of Late Pleistocene vertebrates, form the type locality of the Rancholabrean mammalian provincial age (*1*). The absolute age range represented by the locality is uncertain, although radiocarbon dates on material from the pits range from 4450 ± 200 for recent Indian artifacts to over 40,000 years B.P. for the tar itself (*2–4*). The time at which these deposits began to accumulate has not been determined. Newly discovered marine Pleistocene invertebrate fossils from strata (unit D, Fig. 1) that are stratigraphically beneath the classic vertebrate-bearing beds (unit E, Fig. 1) suggest that the type Rancholabrean fauna was deposited no earlier than the Wisconsin age.

The marine fossils were recovered from a building site excavation (for the Mutual Benefit building) across Wilshire Boulevard from Hancock Park, on the corner of Wilshire Boulevard and Ogden Drive. Various bore holes in the Hancock Park region have also penetrated the marine sand of unit D, which has yielded shell debris from depths between about 50 and 75 feet (16 and 22 m) below the surface (*5*). Borings at the edge of a tar pit have encountered marine shells at depths between 45 and 50 feet (14 and 16 m) (*6*). The fossiliferous stratum is thus rather widespread in the region of the La Brea deposits. The fossils reported here come from a fine, tar-impregnated quartzose sand near 117 feet above sea level (Fig. 1).

The 22 molluscan species are all represented by living populations in the eastern Pacific. Their living habits suggest that the association inhabited shallow, quiet water on a soft-sediment substrate. There are no species characteristic of intertidal conditions or of rocky substrates. Several of the bivalve specimens are articulated. These species could probably have lived in association in a sandy bottom community in the shallow inner sublittoral zone of a relatively protected marine embayment. The environmental preferences that are recorded for living populations of the other fossils, which include 21 species of foraminifera and 14 species of ostracods, are consistent with this interpretation, except for a few moderately deep-water foraminiferans. These latter specimens appear to be reworked from older Lower Pleistocene or Pliocene sediments which contain the deeper forms in abundance in the Los Angeles Basin.

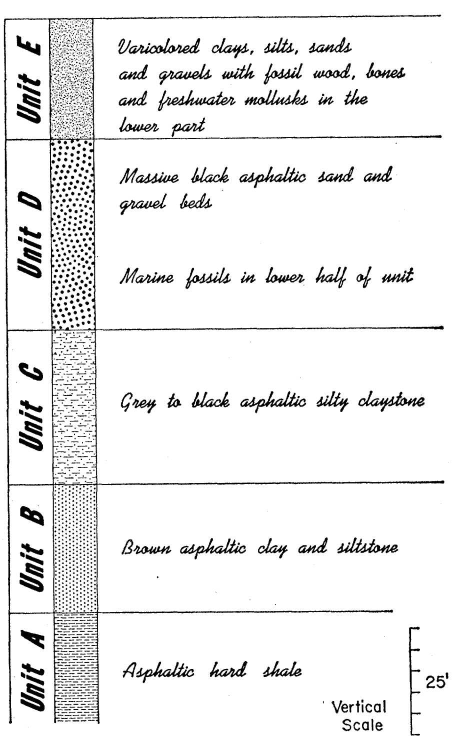

Fig. 1. General stratigraphic column near the southwest corner of Rancho La Brea (*5*). Rock units are generally recognizable throughout the Rancho La Brea region, but their thicknesses vary.

The bivalve species *Crassinella branneri* (Arnold), which is represented in the collection by a single relatively large valve, is a member of a southern faunal association that occurs commonly in late Pleistocene fossil assemblages from southern California (*7, 8*). Many of the species in this southern element live today only south of Cedros Island, Baja California. A small form of *C. branneri*, however, may live as far north as San Diego (*8*). Nevertheless, the presence of *C. branneri* suggests that the assemblage from the Mutual Benefit excavation belongs to the upper Pleistocene biozone that is characterized by the southern element.

Radiometric dates are available for marine fossil associations from several southern California localities that belong to this biozone. Ratios of helium to uranium and ^{230}Th to ^{238}U for the Palos Verdes Sand suggest an age between 110,000 and 140,000 years B.P. or possibly slightly younger (*9*). Age estimates based on thorium-uranium dating have been reported from a terrace at Cayucos, California (*10*), as 130,000 ± 30,000 to 140,000 ± 30,000 B.P. and from San Nicolas Island (*11*) as 120,000 ± 20,000 B.P. Even considering the uncertainties of methods of age estimation, an age of about 100,000 years or more is suggested for the biozone.

The sand of unit D may have accumulated somewhat over 100,000 years ago along the quiet margin of a marine embayment which extended into the Los Angeles Basin. The sea eventually withdrew and the sands were succeeded by freshwater clays and fluvial and alluvial sediments of varying textures that comprise unit E. Unit E includes the present alluvial fan that descends from the "Hollywood Hills" section of the Santa Monica Mountains and the terrestrial sediments that contain the famous tar pits of Rancho La Brea (*12*). Radiocarbon age estimates of the vertebrates (*2–4*), taken together with compositional studies of the assemblages recovered from separate pits (*13*), suggest that there was a fairly long period, and in some pits intermittent periods, of accumulation, and that the pits were not all active at the same time. The radiocarbon dates associated with Rancholabrean fossils suggest accumulation at least as late as 12,650 ± 160 years B.P. (*3*). Shells have been found previously in one pit but they were associated with Indian artifacts (*14*), one of which has been dated by radiocarbon methods as 4450 ± 200 years B.P. (*2*). These shells clearly represent an occurrence entirely distinct from the fossils at the Mutual Benefit site.

The high sea level that accompanied the late Pleistocene marine biozone appears to represent the Sangamonian Interglacial. Therefore, the vertebrate-bearing beds associated with the subsequent lowered sea level may be entirely of Wisconsin age or younger.

JAMES W. VALENTINE
JERE H. LIPPS
Department of Geology and Institute of Ecology, University of California, Davis 95616

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Lunar Atmosphere as a Source of Argon-40 and Other Lunar Surface Elements

Abstract. *The lunar atmosphere is the likely source of excess argon-40 in lunar surface material; about 8.5 percent of the argon-40 released into the lunar atmosphere will be implanted in the surface material by photoionization and subsequent interaction with fields in the solar wind. The atmosphere is also likely to be the source of other unexpected surface elements or of solar wind elements that impact from non-solar wind directions.*

Analysis of the lunar samples from Apollo 11 indicates anomalous compositions for several elements. In particular, the isotope ^{40}Ar is overabundant as compared with ^{36}Ar in the fine-grain samples, the ratio being much greater than that expected in the solar wind composition (*1*) and several times greater than could be accounted for by in situ decay of ^{40}K (*2*). Heymann *et al.* (*3*) have shown that the ^{40}Ar is surface correlated and have suggested a lunar source: the ^{40}Ar, produced in the moon by potassium decay, subsequently diffuses into the lunar atmosphere and is then driven back into the surface, perhaps by collisions with the solar wind ions (*4*).

We show here that the source of ^{40}Ar, and perhaps other surface-correlated elements, is very likely the lunar atmosphere; the atmospheric argon is ionized and swept into the moon by solar wind fields. However, in the lunar rest frame, the ion is accelerated primarily by the interplanetary electric field, and the resulting flux is not in the direction of the solar wind flow, as has usually been thought, but rather is nearly perpendicular to that flow (*5*). In addition, we show that the energy of the lunar ion will be sufficient for implantation and that the process is reasonably efficient.

Table 1. Orbit parameters for ^{40}Ar starting at one scale height above the lunar surface (calculated for the noon-midnight meridian plane).

λ_1 (deg)	λ_2 (deg)	α (deg)	$\mathcal{E}_{\mathrm{impact}}$ (ev)
−90	−90.0	92.2	215
−60	−59.1	61.4	246
−30	−27.3	30.3	422
−10.4	0	5.5	1390
− 9.3	6.5	0	2085

The idea that the magnetic field moving with the solar wind can cause lunar ions to impinge upon the surface is not new; Michel (*6*) has discussed the deposition of ions on the surface due to the solar wind interaction, and recently a representative cycloidal trajectory and impact energy has been calculated (*7*). These considerations were recalled by T. Gold at the Apollo 11 Lunar Science Conference, Houston (1970).

The source of ^{40}Ar in the lunar atmosphere would be the decay of potassium in the moon to ^{40}Ar, which either diffuses steadily into the lunar atmosphere or which, in the past, has been driven out by some heating of the surface. Once out of the moon, the neutral argon is gravitationally bound and forms part of the equilibrium atmosphere whose density decreases approximately exponentially with a scale height given by

$$h = kT/mg \qquad (1)$$

where k is the Boltzmann constant, T and m are the species temperature and mass, and g is the lunar gravitational constant. The ^{40}Ar scale height is about 50 km on the sunlit hemisphere, and about one-third of the argon is at heights greater than h. Previous reviews of the source and loss mechanisms in the lunar atmosphere include discussions of ^{40}Ar in the lunar atmosphere due to decay of ^{40}K in the moon (*8*) and calculations of atmospheric lifetimes against ionization of $\sim 10^7$ seconds (0.3 year) as compared with 10^8 years of gravitational escape (*6*).

Whether an ion, once formed, escapes or is accreted will be determined primarily by electric fields at the lunar surface and in the interplanetary medium (*5*). The interaction of lunar ions with the solar wind is best treated in a frame of reference that is at rest with respect to the moon. In this system there is an interplanetary electric field given by

$$\mathbf{E}_{sw} = -\mathbf{V}_{sw} \times \mathbf{B}_{sw} \qquad (2)$$

where $\mathbf{V}_{sw}$, $\mathbf{B}_{sw}$, and $\mathbf{E}_{sw}$ are, respectively, the solar wind velocity, magnetic field, and electric field. In addition, the lunar surface electric field will moderate incoming ion energies; this surface potential could have a significant effect