of the origin of endogenous craters.

It is not certain that either lunar-continental or Martian surfaces are saturated with large craters. If both are saturated, then, even if the flux history of the meteoroids and planetesimals that presumably bombarded these surfaces were accurately known (including now-extinct populations of primeval planetesimals), one could obtain at best only the minimum age of each surface. But the flux history is not well known. Improvements in experiments with satellites and in terrestrial photography of meteors have frequently revised substantially estimates of the present near-Earth flux of small meteoroids; neither these uncertain data nor our data on present asteroidal and cometary objects can be safely extrapolated for prediction of the flux of large primeval planetesimals in the neighborhood of Mars. Finally, internal flooding complicates the use of the lunar maria as historical impact counters (*1*).

For these reasons one must regard with considerable caution some earlier attempts (*2, 4, 9, 11*) to estimate the age of the Martian surface from crater statistics. These statistics alone justify neither a long age scale ($\sim 3 \times 10^9$ years) nor a short one ($\sim 500 \times 10^6$ years). More accurate estimates of age will require better knowledge of the early Martian meteoroid flux and of the processes that modify Martian surface topography.

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References and Notes

1. A. H. Marcus, *Icarus* **5**, 165, 177 (1966).
2. R. B. Leighton, B. C. Murray, R. P. Sharp, J. D. Allen, R. K. Sloan, *Science* **149**, 627 (1965).
3. R. B. Leighton, *Sci. Amer.* **214**(4), 54 (1966).
4. A. Binder, *Science* **152**, 1053 (1966).
5. V. A. Bronshten, *Soviet Astron.—A.J.* **10**, 1007 (1967).
6. The Jet Propulsion Laboratory's report became available while my report was being revised; the counts agree with those by Leighton *et al.*, *J.P.L. Tech. Rep. 32-884* (California Institute of Technology, Pasadena, 1967); for craters of large diameter they agree with other counts also [C. R. Chapman, J. B. Pollack, C. Sagan, *Smithsonian Astrophys. Spec. Rep. 268* (1968)].
7. Aeronautical Chart and Information Center, St. Louis, Mo., *Mariner IV Cartographic Reduction Final Report May 1967* (1967).
8. A. Marcus, in *Proc. NATO Conf. Mantles of the Earth and Terrestrial Planets* (Wiley, London, in press), p. 417.
9. W. K. Hartmann, *Icarus* **5**, 565 (1966).
10. ———, *Commun. Lunar Planetary Lab.* **6**, 39 (1967).
11. E. Anders and J. R. Arnold, *Science* **149**, 1494 (1965); J. Witting, F. Narin, C. A. Stone, *ibid.*, p. 1496; R. Baldwin, *ibid.*, p. 1498; E. J. Öpik, *ibid.* **153**, 255 (1966).
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Oxygen-Isotope Analysis of Recent Tropical Pacific Benthonic Foraminifera

Abstract. *Analysis by the oxygen-isotope method of samples of benthonic Foraminifera, collected at different depths on the continental shelf and slope off western Central America, yielded isotopic temperatures agreeing closely with the temperatures measured in the field. The validity of the oxygen-isotope method as a means of analysis of paleotemperatures is further supported.*

The $O^{18}:O^{16}$ ratios in the calcium carbonate of shells of pelagic and (to a much smaller extent) benthonic Foraminifera have been extensively used for study of the temperature variations of surface and bottom ocean water during the Pleistocene (*1*, and references). The values obtained from foraminiferal samples, separated from the top few centimeters of deep-sea cores from different oceanic areas, indicate that Foraminifera deposit their calcium carbonate in isotopic equilibrium with the ambient sea water. In order to test further this conclusion, $O^{18}:O^{16}$ analyses have been made on several specimens of Recent benthonic Foraminifera collected from water for which actual temperatures were known.

The species were taken from core samples collected (*2*) off Central America in December 1955; paired core samples were taken across the continental shelf and down the slope at depths from 20 to 3200 m, over a distance of about 80 nautical miles. Samples were taken primarily to provide information on the geographic and depth distribution of benthonic foraminiferal species in the area, and information about the physical and chemical factors affecting that distribution (*3, 4*). The samples analyzed isotopically range in depth from 47 to 885 m and include six monospecific samples and one multispecific. Five species of Foraminifera from four genera are represented; one species was

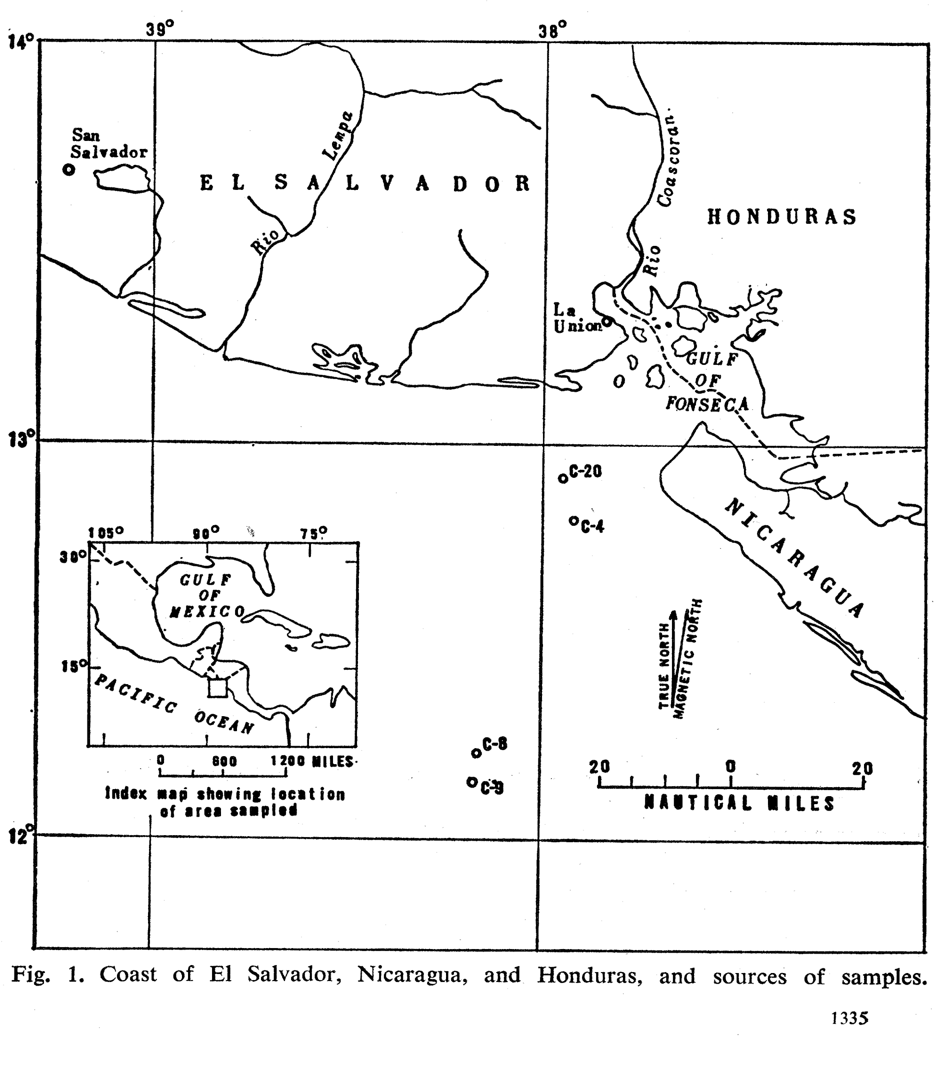

Fig. 1. Coast of El Salvador, Nicaragua, and Honduras, and sources of samples.

Table 1. Comparison of temperatures that were measured in the field with isotopic temperatures obtained by mass-spectrometric analysis; δO^{18} data relate to the Chicago standard PDB-1.

Species	Core (No.)	Water depth (m)	Temp. (°C)	δO^{18} (‰)	Isotopic temp. (°C)
Hanzawaia concentrica	C-20	47	15–23	− 0.79	20.0
H. concentrica	C-4	50	15–23	− 0.45	18.5
Angulogerina carinata	C-8	450	7–9	+ 1.72	8.8
Bolivina subadvena	C-9	885	5–5.5	+ 2.50	5.9
Uvigerina peregrina	C-9	885	5–5.5	+ 2.43	6.1
U. excellens	C-9	885	5–5.5	+ 2.69	5.2
Mixed benthonic species	C-9	885	5–5.5	+ 2.43	6.1

analyzed from two core stations of different depths.

The area sampled is off the Gulf of Fonseca, between El Salvador and Nicaragua (Fig. 1). The coast is drained by several large rivers and is entirely volcanic; this fact excludes reworking of fossil Foraminifera, apart from the possibility of subsea deposits in the Recent ocean sediments. Despite river water emptying into the gulf, salinity at depths below 20 m is typical of normal sea water, ranging from 34.29 to 34.83 parts per thousand (*3*, *4*). Detailed statistical analysis of 18 species of the genus *Bolivina* (*3*) indicates a high degree of morphologic correlation between living and dead faunas at any given station, so that large-scale downslope movement is unlikely.

Many benthonic species found off Central America, particularly on the shelf and on the upper parts of the continental slope, do not occur farther north (*4–6*). The planktonic faunas are characteristic of the Equatorial West Central Fauna (*7*). Planktonic species present are *Globigerina bulloides* d'Orbigny, *G. quinqueloba* Natland, *Globoquadrina dutertrei* (d'Orbigny), *Globigerinoides ruber* (d'Orbigny), *G. sacculifer* (Brady), *Globigerinella aequilateralis* (Brady), and *Orbulina universa* d'Orbigny.

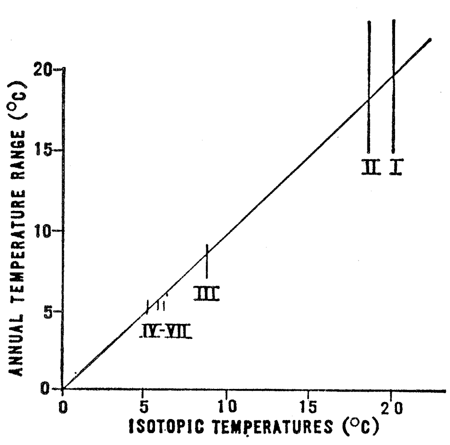

Fig. 2. Isotopic temperatures versus observed annual temperature range, the 45-deg line showing absolute coïncidence. *I*, *Hanzawaia concentrica*, core 20; *II*, *H. concentrica*, core 4; *III*, *Angulogerina carinata*; *IV*, *Bolivina subadvena*; *V*, *Uvigerina peregrina*; *VI*, *U. excellens*; *VII*, mixed benthonic species.

The ranges of water temperature for El Salvador are taken from hydrographic casts made by the EASTROPIC expedition in December 1955 and the SHUTTLE expedition in June 1952. The range of shelf temperatures is much greater off Central America than off California, correlating with the previously mentioned faunal changes (*3*, *4*); ranges for the analyzed samples appear in Table 1.

The more abundant benthonic species have been analyzed isotopically. Complete synonymies are given by Smith (*4*). *Hanzawaia concentrica* (Cushman) (Fig. 2, *I* and *II*) (*4*, pl. 6, fig. 2) apparently does not occur north of Baja California. It is characteristic of the continental shelf; the rare specimens on the slope are small; the depth ranges from 37 to 1600 m. *Angulogerina carinata* Cushman (Fig. 2, *III*) (*4*, pl. 3, figs. 1 and 2) occurs off El Salvador between 435 and 1700 m; it has been reported off California (*5*, *8*). *Bolivina subadvena* Cushman (Fig. 2, *IV*) (*3*, pl. 30, figs. 13–16) from off El Salvador has been discussed quantitatively (*3*). It is widely distributed geographically; off El Salvador its depth ranges from 140 to 1700 m. *Uvigerina peregrina* Cushman (Fig. 2, *V*) (*4*, pl. 2, figs. 15 and 16) is widely distributed geographically; its depth distribution off El Salvador is from 800 to 1700 m. *Uvigerina excellens* Todd (Fig. 2, *VI*) (*4*, pl. 2, fig. 13) appears to be restricted to the more southern latitudes; the depth range off El Salvador is from 435 to 885 m.

The samples selected for isotopic analysis were crushed, washed in distilled water in an ultrasonic cleaner, dried at 90°C, pulverized in an agate mortar, heated at 475°C in a stream of helium for removal of organic material, and reacted with 100-percent H_3PO_4 at 25°C. The CO_2 gas thus obtained was analyzed with a high-precision Nier-Urey-type mass spectrometer. In the calculation of the isotopic temperatures, a correction of −0.20 per mille was applied to the samples from cores C-8 and C-9 to account for the oxygen-isotope composition of eastern Pacific deeper waters (*9*).

The results (Table 1 and Fig. 2) indicate close agreement between the temperatures observed in the field and those calculated from the isotopic ratios. Thus it appears that the benthonic Foraminifera analyzed deposit their calcium carbonate in isotopic equilibrium with the ambient sea water. It is interesting that the sample composed of mixed benthonic specimens yielded results similar to those from monospecific samples from the same depth.

We conclude that oxygen-isotope analysis of Foraminifera, benthonic as well as pelagic, can yield accurate temperature values when appropriate corrections for the isotopic composition of the ambient water are made.

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References and Notes

1. C. Emiliani, *J. Geol.* **74**, 109 (1966).
2. During the Scripps Institution of Oceanography EASTROPIC expedition.
3. P. B. Smith, *U.S. Geol. Surv. Profess. Paper 429–A* (1963), pp. A1–A39.
4. ———, *U.S. Geol. Surv. Profess. Paper 429–B*, (1964), pp. B1–B55.
5. M. L. Natland, *Calif. Univ. Scripps Inst. Oceanog. Tech. Ser. Bull.* 3(10), 225 (1933).
6. O. L. Bandy, *J. Paleontol.* **27**, 161 (1953); W. R. Walton, *ibid.* **29**, 952 (1955).
7. J. Bradshaw, *Cushman Found. Foraminiferal Res. Contrib.* **10**(68), 25 (1959).
8. T. Uchio, *Cushman Found. Foraminiferal Res. Spec. Publ.* **5**, 1 (1960).
9. S. Epstein and T. Mayeda, *Geochim. Cosmochim. Acta* **4**(5), 213 (1953).
10. Publication authorized by the director, U.S. Geological Survey. Contribution 919 from the Institute of Marine Sciences.

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