Reports

Earthquake Dating: An Application of Carbon-14 Atom Counting

Abstract. *Milligram-sized specimens of detrital charcoal from soil layers associated with prehistoric earthquakes on the Wasatch fault in Utah have been dated by direct atom counting of carbon-14 with a tandem Van de Graaff accelerator. The measured ratios of carbon-14 to carbon-12 correspond to ages of 7800, 8800, and 9000 years with uncertainties of ± 600 years.*

In the absence of written records that go back more than 150 years, the frequency of major earthquakes in the seismically active regions of the western United States can only be deduced from geologic evidence. Scarps along the Wasatch fault near Salt Lake City, Utah, exhibit cumulative surface displacements as large as 10 m in alluvial deposits that postdate the recession of Lake Bonneville 12,000 years ago, although no damaging earthquakes have occurred since the area was settled. Trenching studies in this area by Swan *et al.* (*1*) exposed ancient surface soil layers in which discontinuities reveal a sequence of significant surface faulting events. Radiocarbon dates of detrital charcoal from these deposits would be a record of earthquake recurrence intervals, vital data for contemporary earthquake hazard assessment. However, many of the samples collected so far, flecks of charcoal presumably from forest fires, have been too small for conventional beta-decay counting.

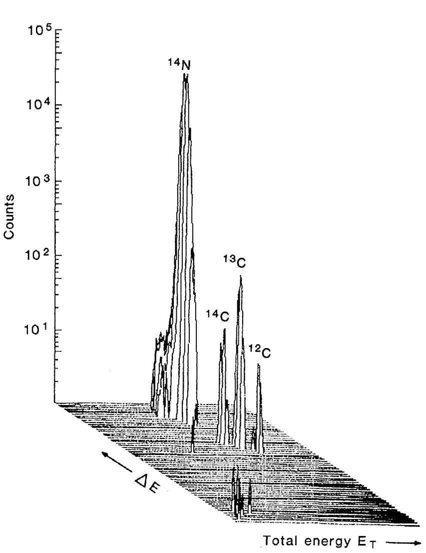

Fig. 1. Particle identification spectrum.

Recently, a technique has been developed for measuring the relative amounts of specific isotopes in small samples. It is basically high-energy mass spectrometry, in which the beam analyzing and particle identification tools of accelerator-based nuclear spectroscopy are used to count single atoms of selected isotopes (*2–4*).

The measurements reported here were made with the tandem Van de Graaff accelerator facility at ETH, Zurich (*5*). Sputter source targets were prepared by dissolving approximately 4 mg of each sample in 50 mg of iron melted under vacuum. Similar calibration targets were prepared from four charcoal specimens with known ages determined by beta counting at the University of Bern and the U.S. Geological Survey. An electrostatic analyzer selected 22-MeV 3^+ ions from the accelerated beam. After precise collimation by a double set of slits defining both beam position and direction, the monoenergetic ions were sorted in a magnetic spectrometer. The abundant isotopes were counted by collecting their currents in Faraday cups. A two-stage (dE/dx - E) gas-filled ionization counter detected and identified atoms at the mass-14 port (Fig. 1).

The data were taken in a series of counts alternating between calibration samples and samples of unknown age. Each consisted of a sequence of 20 computer-controlled 3-minute cycles, the injection magnet between the ion source and the accelerator being set for 15 seconds at mass 12 and at mass 13 and then 150 seconds at mass 14. (With this slow switching sequence the $^{12}C^-$ beam had to be limited to 200 nA to maintain stable accelerating voltage.) The $^{13}C/^{12}C$ ratio was a monitor of system stability. Each sample was counted a minimum of three times during the 72 hours of continuous accelerator operation. Repeated measurements agreed within the statistical accuracy of the ^{14}C counts, approximately 10 percent.

Figure 2 shows the results. The four calibration points fall on a straight line with slope corresponding to a half-life of 5568 years, the value used in decay dating. Each of the four geological specimens produced a sufficient carbon beam for an age determination. As suspected by the geologists, one sample was modern material. Three specimens were ancient, having $^{14}C/^{12}C$ ratios corresponding to ages of 7800, 8800, and 9000 years with counting statistical uncertainties of ±600 years. These ages are consistent with the geologic evidence that this material was deposited after the recession of Lake Bonneville about 12,000 years ago. A larger charcoal sample from a nearby site had an age, determined by beta counting, of approximately 5600 years. Strata at the two locations could not be correlated, but the similarity of the ages of samples from the two sites was expected.

Atom counting offers the field geologist two advantages over the standard beta counting technique. First is the ability to analyze very small samples, a few milligrams compared to the grams required by commercial radiocarbon laboratories. If a fleck of charcoal can be seen, it can be counted. Second is the potential for prompt results. Decay counting takes weeks or, for small samples, months; the atom counting facilities being developed throughout the world will be able to date samples within days. Results can be available while a trench is still open. Preliminary judgments can be tested and revised while additional samples are still easily available.

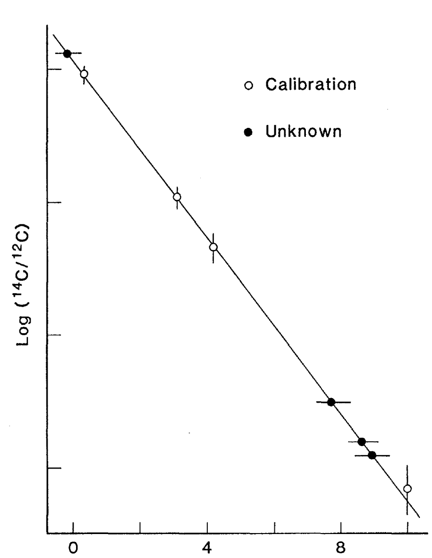

Fig. 2. Results: (○) calibration points fit with a half-life of 5568 years; (●) data from samples of unknown age.

This technique has been improved significantly during the last year. Measurements with 1 percent statistical accuracy in a 10-minute counting time have been reported by the ETH group (*6*). The limit to dating accuracy will probably be our understanding of sample contamination with "old" and "new" carbon.

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References and Notes

1. F. Swan III, D. Schwartz, Lloyd Cluff, *Bull. Seismol. Soc. Am.* **70** (No. 5) (1980).
2. R. A. Muller, *Science* **196**, 489 (1977).
3. D. Nelson, R. Korteling, W. R. Stott, *ibid.* **198**, 507 (1977).
4. C. L. Bennett, R. P. Beukens, M. R. Clover, H. E. Gove, R. B. Liebert, A. E. Litherland, K. H. Purser, W. E. Sondheim, *ibid.*, p. 508.
5. M. Suter, R. Balzer, G. Bonani, W. Woefli, J. Beer, H. Oeschger, B. Stauffer, *IEEE Trans. Nucl. Sci.* **NS-28**, 1475 (1981).
6. M. Suter, R. Balzer, G. Bonani, W. Woefli, J. Beer, H. Oeschger, B. Stauffer, in *Proceedings of the Symposium on Accelerator Mass Spectrometry* (Argonne National Laboratory, Argonne, Ill., May 1981).
7. Excellent collaboration with J. Beer, H. Oeschger, and B. Stauffer is gratefully acknowledged. This work was supported in part by the Swiss National Science Foundation, the U.S. Geological Survey Earthquake Hazards Reduction Program, and Chevron Oil Field Research Company.

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East Pacific Rise Near 13°N: Geology of New Hydrothermal Fields

Abstract. *Abundant massive sulfide deposits are present at the crest of the East Pacific Rise near 13° North, where the opening rate is about 12 centimeters per year. Large manganese and helium-3 anomalies in seawater samples, evidence of intense present-day activity of hydrothermal springs, indicate that sulfides are still being produced along this segment of the rise. Massive sulfides also occur on adjacent off-axis seamounts.*

The most detailed studies of the East Pacific Rise have been concentrated on a segment of the rise crest near 21°N (*1, 2*), where the opening rate is 6.2 cm/year (*3*). The first find of polymetallic sulfide deposits on the East Pacific Rise was made there (*4*). A later investigation led to the discovery of active, sulfide-producing hydrothermal vents and associated fauna (*2*). We report results of exploratory work in May and June 1981 with the R.V. *Charcot* on a segment of the East Pacific Rise which is about 1000 km to the south of the 21°N area and where the spreading rate is about twice as fast. The cruise, "Clipperton," was designed to prepare the way for a submersible operation in 1982. The main area selected for detailed investigation (zone A) lies about halfway between the two fracture zones, Orozco and Clipperton, where high ^{3}He and manganese (*5, 6*) anomalies in deep water were previously found (Fig. 1).

The 400-km-long segment of the East Pacific Rise between the Orozco (15°N) and Clipperton (10°N) fracture zones has a narrow horstlike crest; it is apparently linear for long distances and has a low, along-strike relief, the depth at the rise axis varying between about 2700 and 2500 m (Fig. 1). The relatively flat zero-age bathymetric pattern may reflect a correspondingly consistent crustal thickness. A single-channel seismic reflection profile, made while navigating according to the real-time Seabeam plot precisely along the topographic axis of the rise between 12°52′N and 12°N, shows an intermittent reflection at a nearly unvarying depth corresponding to a 0.6-second double travel time below the sea floor. It is not known whether the reflector is real or is a side echo from sea-floor relief parallel to the rise axis.

Zone A, lying between 12°38′N and 12°54′N and between 103°49′W and 104°01′W, covers about 600 km^2 (Fig. 1). The rise crest strikes north 345° and its axial zone is about 1500 m wide. Along much of its length, it incorporates a double ridge system with a steep-sided central graben less than 40 m deep and a maximum depth below sea level of 2465 m. The western side of the axial zone is characterized by narrow, linear, steplike ridges with steep inward-facing scarps, which are the hallmark of the "normal" tectonics associated with accretion at the rise crest. On the eastern side this structural grain, where it exists, stops 3 km out from the axis; beyond this the morphology is determined by the presence of two seamounts, both about 2 km from the rise axis and about 250 m above the surrounding sea floor (Figs. 1 and 2A). The northern seamount has a broader, flatter top and gentler upper slopes. The seamounts may have been created by off-axis volcanism in approximately their present location or may have been the sites of renewed eruptive activity of smaller volcanoes originally closer to the axis. A third seamount, rising about 1000 m above the surrounding floor, was discovered outside the main study area, about 18 km west of the axial zone near 12°34′N and 104°02′W. We named this the Clipperton seamount.

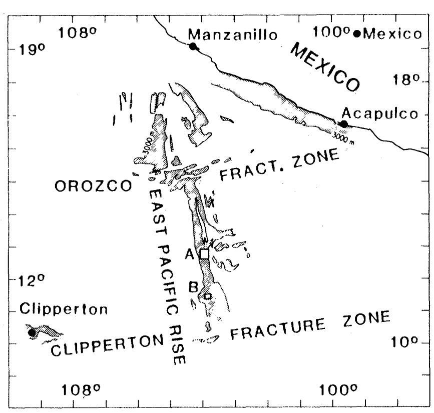

Fig. 1. Locations of the principal study area near 12°50′N (zone A) and the secondary study area near 11°30′N (zone B). Shading indicates depths less than 3000 m. [Courtesy of J. Mammerickx]

Color photographs of the sea floor in the zone A axial area, taken with a deep-tow system over a total distance of about 35 km, show that the flanking scarps of the graben are commonly associated with talus piles that may produce local relief as great as 20 m. They also show numerous, en echelon, open fissures in the very lightly sedimented central graben. The fissures are oriented parallel to the regional strike of the rise crest and are between a few tens of centimeters and about 4 m wide. Some fissures are present on the bordering ridges where interconnecting pockets of sediment occur and the fissures also strike parallel to the rise axis. The photographs show the presence of the three main categories of lava flows previously recognized on the East Pacific Rise (*1, 7*). Lobate sheet flows are the most abundant and occur in the central graben and on the lateral highs (Fig. 2B). Unbroken flat sheet flows, apparently less than 1 m thick, are found in isolated patches, but their associated debris occurs everywhere, particularly in the central graben. The passage from lobate to flat sheet flows is generally transitional so that clear boundaries cannot be easily drawn. Pillow flows are prominent on the slopes of the twin ridges bordering the central graben, particularly where the sediment cover is greatest. The pillows often sit on, or are in lateral contact with, lobate flows from which they cannot be readily distinguished and appear to be derived. It has been suggested (*8*) that sheet flows rep-