Precisely Measuring the Past Million Years

The latest version of time scales tuned to Earth orbital variations brings 5000-year accuracy to the dating of marine sediments

In geology, measuring time is of the essence. Knowing precisely when a new species appeared or when the climate turned colder is crucial to understanding how such events occurred. A group of paleoceanographers reports that they can now measure time in marine carbonate sediment—a veritable treasure house of climate records—with an accuracy of 3000 to 5000 years as far back as 800,000 years. Their dating technique, which relies on the record of oxygen isotopes and the periodic orbital variations of Earth, may eventually be applicable to the past 15 million years as well.

Until recently, the only way of determining when an event recorded in sediment actually happened depended on radiometric dating. Carbon-14 dating worked for the past few tens of thousands of years. Another approach was to radiometrically date flip-flops of Earth's magnetic field as recorded in terrestrial lavas. The location of the same reversal recorded in a sediment would have the same age.

The problem with radiometric and paleomagnetic dates is that, between about 20,000 and 1 million years ago, only one direct radiometric and two paleomagnetic dates can be accurately located in marine sediments. Paleoceanographers had to assume that, between these bench marks, sediment had accumulated steadily, so that a centimeter of sediment represented the same amount of time no matter how far it fell from a known age. That is never true. Only the most exceptional sediments have accumulated steadily enough to provide an accuracy of even 5000 years. Elsewhere the error could be 30,000 years or more.

Since 1976, paleoceanographers have realized that magnetic reversals are not the only bench marks of known age recorded in sediments. Another recording mechanism involves a chain linking climate, glacial ice, ocean water, and the oxygen isotope composition of the microscopic skeletal remains that make up much of the ocean bottom. Down through the ocean bottom and back in time, the ratio of oxygen isotopes rises and falls in large swings and minor squiggles, reflecting the great ice ages and lesser climate fluctuations. Much of this climatic variation has been driven by the changing orientation of Earth's rotation axis and the shape of its orbit, which are collectively known as orbital variations (*Science*, 21 January 1983, p. 272). Conveniently enough for paleoceanographers, these variations are periodic and precisely calculable. The problem has been sorting out the periodic climatic signals (there are three main orbital variations) from each other and from climatic and other noise in the record.

Members of the spectral mapping (SPECMAP) group,* which is headed by John Imbrie of Brown University, report† that they have identified the orbital signals in the oxygen isotope record of the past 800,000 years, which allowed the group to create dated bench marks at more than 75 of the peaks and valleys of the isotope curve. The SPECMAP group followed the same general approach that had produced consistent time scales as long as 400,000 years. They first assumed that the rate of sedimentation in a core was constant between six control points having radiometric or paleomagnetic dates. Then, using this time scale, they compared the timing of orbital variations in two narrow frequency ranges with isotopic variations at the same frequencies, allowing for the response time of the climate.

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Neither pair of curves matched exactly, of course, so they abandoned steady sedimentation. They changed the time represented by a given section of sediment by inserting a control point at an isotopic peak or valley and assigning it an age that would improve the match. They compared the curves again, using the revised time scale. This tuning process of comparison and adjustment went on independently in five different cores for 120 iterations until, much to everyone's relief, they had a good match at both the 22,000- and 41,000-year orbital frequencies. They then averaged the fine dated isotopic curves into a single time scale. Any other researcher need only identify as many of the isotopic events as he can in his own sediment core and interpolate between them.

The SPECMAP group is confident that they have a real time scale and not a computer-finagled creation. Their main reason for confidence is not only that the peaks and valleys of the matched curves coincide, which was the object of the tuning process, but also that their amplitudes are proportional, which did not enter into the tuning. No tuning was done against the 100,000-year orbital variation, but it and the isotope curve are also in phase and highly coherent. In addition, the tuned age of 734,000 years for the Brunhes-Matuyama magnetic reversal agrees well with the radiometric age of 730,000 years. This control point had been dropped midway in the tuning process after it had helped point the time scale in the right direction.

There are two types of error involved in dating sediment with the new time scale. The errors in dating the control points of the time scale add up to a 95 percent confidence interval of ±2000 years. The error in locating the isotopic event to be dated depends on how thoroughly the sediment core has been sampled. The total dating error should range from 3000 to 5000 years, according to the group. As an example, their 734,000-year age for the Brunhes-Matuyama reversal has a claimed error of 5000 years. The best radiometric age has an error of about 11,000 years.

The SPECMAP group is using the new time scale to dissect the past workings of the monsoon-driven upwelling off Arabia, the North American ice sheet, and the deep ocean currents of the Atlantic. Imbrie believes that similar tuning may make it possible to extend this time scale as far back as 15 million years, when orbital variations appear in the isotope record (*Science*, 4 September 1981, p. 1095) and theorists can still calculate their behavior. Most researchers will probably be happy for the time being with a precise chronology of the past 800,000 years, the last half of the Pleistocene ice ages. As one comments, "Now, if we've got isotopes, we've got time."

—RICHARD A. KERR

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†Their paper will appear in *Milankovitch and Climate*, A. Berger *et al.*, Eds. (Reidel, Dordrecht, in press).