Shaping New Tools for Paleoceanographers

Paleoceanographers are exploring new methods for reading the geologic record and using marine ecology to improve old ones

If new tools for making observations are the life blood of the earth sciences, the young science of paleoceanography could be in for a growth spurt. At last month's Second International Conference on Paleoceanography,* many speakers presented either techniques for interpreting new aspects of the geologic record, ranging from analyses of amino acids to nitrogen isotopes, or improvements in old techniques to extract more accurate or more complete information. Many improvements involved a better understanding of the ecology of foraminifera, the microscopic protozoans whose skeletons preserve much of the record of the behavior of ocean and climate. Until recently, paleoceanographers analyzing foram microfossils knew little about how or exactly where forams live.

The ecology of forams living in or on bottom sediments is a case in point. For 25 years researchers have known that the particular mix of benthic foram species at a continental shelf site is indicative of the water depth there. By determining the changing species abundance of benthic forams down a sediment core, paleoceanographers could track changing water depths over time. More recently, distribution patterns of benthic forams have been linked to specific bodies of bottom water. The carbon and oxygen isotope compositions of the calcium carbonate skeletons of benthic forams have also been used to measure changes in deep-sea circulation as well as ice sheet volume.

But using benthic forams as a key to the past has had its problems. Although particular groupings of species could be linked to bottom water properties such as temperature or salinity, the correlation changed from region to region. Apparently, something more subtle than temperature was at work. And some species seemed to be incorporating carbon that had a different isotope composition from that of the overlying water. Shifts over time in the magnitude of this "vital effect" frustrated attempts to correct for it.

*The Second International Conference on Paleoceanography was held 6 to 13 September in Woods Hole, Massachusetts. Abstracts with program are available for $12 from the research librarian, Woods Hole Oceanographic Institution, Woods Hole, MA 02543.

Bruce Corliss of Duke University, Stephen Emerson and Daniel McCorkle of the University of Washington, and Lloyd Keigwin of the Woods Hole Oceanographic Institution (WHOI) showed at the meeting that much of the misbehavior of benthic forams might be attributed to their tendency to seek their own microhabitat within the top few centimeters of sediment. Thus, forams can reflect conditions in sediment pore water rather than bottom water, as had been assumed. Corliss found that at three sites in the North Atlantic different living forams, identified by Rose Bengal staining, preferred different depths within the top 15 centimeters of sediment.

Much of the misbehavior of benthic forams might be attributed to their tendency to seek their own microhabitat within the sediment.

Judging from shifts from place to place in preferred sediment depths, the forams respond to the availability of both food and oxygen. Some seem to require the relative abundance of food at the sediment surface, where food settles after raining down as debris from surface waters. Others seem tolerant of the dearth of food deeper in the sediment, where oxygen can become depleted by the oxidation of the very food the forams seek. Oxidation of organic matter within the sediment also affects the carbon isotope composition of pore water and thus the composition of forams within the sediment.

All in all, says Corliss, benthic forams may tell more about the biological productivity of overlying surface waters than about bottom water. McCorkle was able to show, however, that it might be possible to determine the past oxygen content of bottom waters by using the carbon isotope composition of two forams, one of which prefers the surface of the sediment and the other of which prefers deep, nearly oxygen-free pore waters.

Planktonic forams, those free-floating in surface waters, also have their little peculiarities. Paleoceanographers have studied the carbon isotope compositions of planktonic foram skeletons accumulated on the sea floor for clues to changes in productivity and to other aspects of the geochemical cycle of carbon. But the results have varied widely from lab to lab and from core to core, making it difficult if not impossible to say what carbon isotopic composition means.

Richard Fairbanks and Delia Oppo of Lamont-Doherty Geological Observatory, Palisades, New York, and William Curry of WHOI reported that they have sorted out exactly how the size of a foram affects its carbon isotope composition. Size effects had been an obvious but unsolved problem with all previous analyses, each researcher generally choosing a favorite size range to analyze, say 200 to 250 micrometers, and sticking with it. Fairbanks showed how the uptake of the foram's own respiratory carbon dioxide predominates in small, young forams and diminishes in older ones as the composition of new skeletal growth begins to reflect the composition of seawater. By analyzing a range of sizes, the group could estimate the true isotope composition of seawater as represented in the latest skeletal growth.

Fairbanks and Curry also developed some guidelines on where in the ocean forams are most likely to pick up a useful isotope record. Fairbanks had shown by collecting forams in towed nets and stationary traps that planktonic forams live in the euphotic zone, the uppermost waters where photosynthesis occurs. Those caught in much deeper waters in the course of earlier studies, Fairbanks and Curry showed, did not live there, as had been assumed, but were merely falling to the bottom from the surface waters where they had grown.

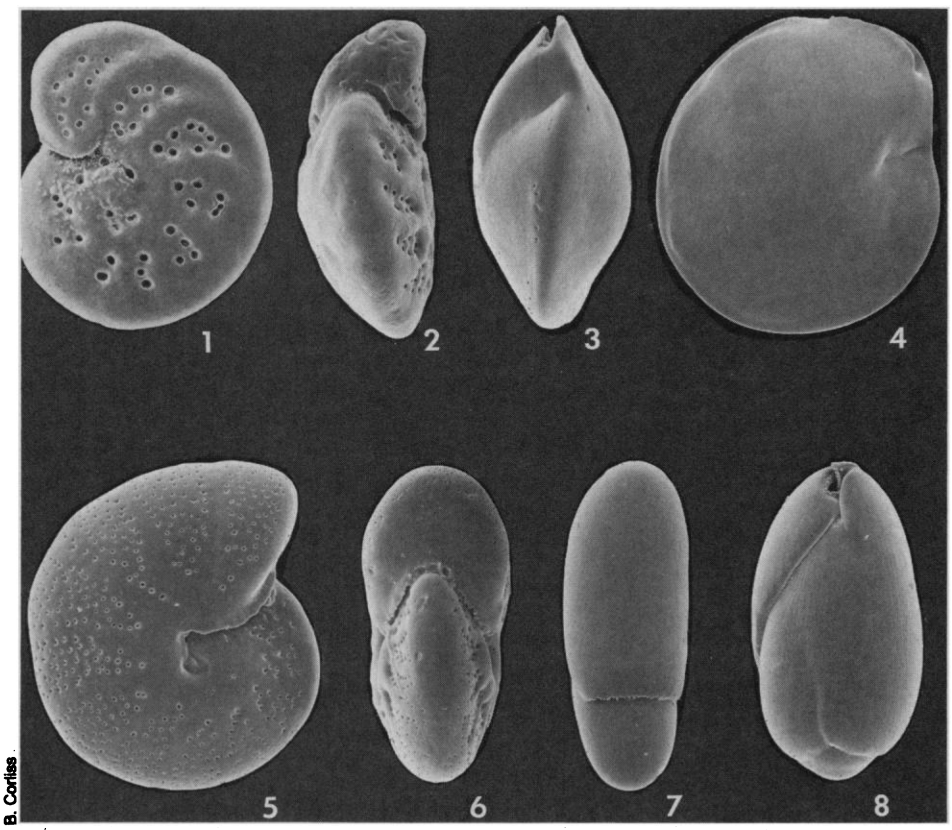
Ideally, conditions should be the same wherever planktonic forams grow so that all individuals pick up the same isotope signal. But this is often not the case in the euphotic zone, notes Fairbanks, except at places like the far western equatorial Atlantic. There, broad circulation patterns resistant to the influence of climate change create an 80-meter layer of uniformly warm water encompassing the euphotic zone. Carbon isotope analyses of a core from this area that account for the size effect are showing interpretable trends, says Fairbanks, that are absent if a single narrow range of sizes is used.

Fairbanks's guide to collecting useful oxygen isotope data draws on his global survey of seawater and living foram isotope composition as well as global data files of sea-surface temperature and salinity, properties that also influence foram composition. The map combining these three factors can tell a researcher the isotope composition of a geochemically honest foram that grows in that water today. If the composition of a particular species does not match, it can be avoided. The map also shows where the oxygen isotope signal in forams may be misleading because of the countervailing effects of seawater temperature and isotope composition. Given such an understanding of the present ocean, says Fairbanks, the oxygen isotope composition of forams could be used to reconstruct ancient seawater chemistry, temperature, or both. So far, the squiggles of the oxygen isotope record have been limited primarily to dating core samples.

As the significance of isotopic records becomes clearer, researchers are pursuing new chemical records. The most highly developed so far is that of cadmium in foram microfossils, as pioneered by Edward Boyle of the Massachusetts Institute of Technology. Cadmium in forams provides a measure of seawater phosphate, an essential plant nutrient, because cadmium behaves geochemically in seawater much like phosphate, and forams incorporate cadmium in their skeletons in proportion to its concentration in the surrounding seawater. Conveniently enough, different water masses have different phosphate concentrations, so foram cadmium can be used to trace past changes in ocean circulation as well as to track changes in seawater chemistry.

Boyle had earlier reported that the flow of phosphate-poor North Atlantic Deep Water, which forms by sinking from the surface north of Iceland, weakens during glacial periods. At the meeting, he revised that picture on the basis of new benthic foram analyses from sites shallower than 2100 meters. Apparently, the water that flowed along the bottom at deeper sites simply rose to shallower levels during glacial periods. Perhaps, said Boyle, glacial cooling led to less evaporation from the ocean and thus less concentration of salts, which would make the deep water less dense.

Boyle also found that there was little or no difference between glacial and interglacial periods in the total phosphate content of the whole ocean. That eliminates at least one explanation for how the climate system can amplify weak signals from Milankovitch orbital variations. Carbon dioxide and its greenhouse effect may be involved, but one explanation that calls for the ocean to release carbon dioxide to the atmosphere depends on a decrease of total oceanic phosphate. Less phosphate would mean less fixation of carbon dioxide through photosynthesis and release of the excess to the atmosphere. But Boyle's cadmium studies do not allow that kind of change in phosphate.



Which forams live in the sea and which in the mud? *If the calcium carbonate skeletons of forams (here magnified 60 to 130 times) are to be used to learn about changes in the ocean over geologic time, researchers must know exactly where they live. The two species in the top row (side and edge views) live on the surface of bottom sediments, where they probably do indeed record bottom water conditions. The three species in the bottom row (5 and 6—side and edge views—7, and 8) live within the sediment in three different depth ranges and probably record instead sediment pore water conditions.* [*Copyright © by Macmillan Journals Ltd., 1985*].

Margaret Delaney of the University of California at Santa Cruz and Boyle pointed out that there are now a number of paleoceanographic indicators, both chemical and isotopic, whose behavior is linked to one another through common geochemical cycles. These indicators, taken together, more tightly constrain the possible changes in ocean chemistry than if considered separately. Measured from microfossils, the indicators are the water depth at which sediment calcium carbonate begins to dissolve, a measure of seawater carbonate; the stable carbon isotope composition, which reflects the fraction of carbon as organic matter supplied by rivers or buried in sediment; the strontium isotope composition; the ratio of lithium to calcium; and the ratio of strontium to calcium. The first three indicators have changed during the past 65 million years, although not dramatically, and the last two have remained unchanged.

Individually, the behavior of an indicator can be accounted for easily enough by simple changes in the supply, from rivers or deep-sea hot springs, for example, or the disposal to the sediments of the elements concerned. But Delaney found that that did not work for a combination of indicators. The best that she has been able to do so far is achieve some consistency in the direction of the major changes and in some of their magnitudes, but their timing before 15 million years ago remains a problem. "The simple models can't do it all," she says.

In an effort to further constrain the increasingly complex models of ocean behavior, researchers at the conference proposed a variety of possible new paleoceanographic indicators. Water temperature might be monitored through analysis of the slow conversion of left-handed to right-handed amino acids. Bottom currents might be traced by following the trail of distinctive minerals in sediments. Radioactive carbon-14 might provide a measure of how rapidly the ocean airs out its deep waters. Nuclear magnetic resonance imaging should map the fine organic layers of laminated sediments. Stable nitrogen isotopes may reveal the role of blue-green algae in the ocean. The list goes on. If even a small proportion of such efforts bear fruit, the harvest should be plentiful. ■ Richard A. Kerr