New Ocean Eddies Found off California

Conventional wisdom had it that the California Current is a "broad, shallow, sluggish, and not very exciting flow," as one physical oceanographer puts it. It seemed unlikely that such a current could churn out the energetic swirls and spinning rings of water that the Gulf Stream throws off in the Atlantic.

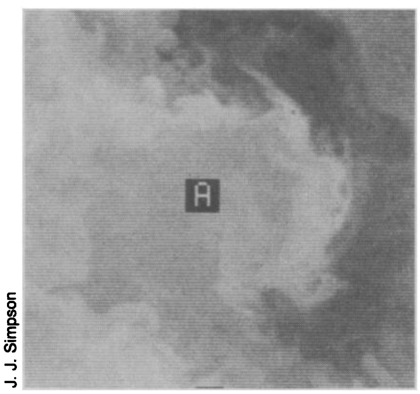
So much for conventional wisdom. Physical oceanographers have recently realized that large eddies commonly dot the waters from Vancouver to Baja California. A group of researchers reported at the ocean sciences meeting in San Antonio* that, with the help of satellite surveillance, they have now made the first detailed study of a California Current eddy. Oceanographers are only beginning to study these eddies, but these new features are already enlivening the study of this "not very exciting" region of the ocean.

James Simpson and Charles Koblinsky of Scripps Institution of Oceanography and Thomas Dickey of the University of Southern California reported that the eddy that they got a close look at bears a family resemblance to Gulf Stream rings, but it has a number of unusual characteristics. It first appeared in satellite infrared images in October 1980 about 500 kilometers off Point Conception, California. That is well out into the California Current system. By January 1981, the Scripps group mounted a research cruise during which they lowered instruments into the eddy. But in February the eddy disintegrated for no apparent reason and was never seen again. During the surveillance, it was either stationary or drifted southward at about 1 kilometer per day. Gulf Stream rings, in contrast, typically move at 3 to 5 kilometers per day and persist for 2 to 3 years if they do not blunder into the Gulf Stream first.

The California Current eddy looked different, too. At the time of the cruise, it had a diameter of about 150 kilometers. Vertically, it was something of a split-level eddy, which sets it apart from Gulf Stream rings. Beneath a 75-meter-thick layer of surface water, the Scripps group found a core of relatively cold water that extended to a depth of about 250 meters. Below that, the eddy core was warmer than the surrounding water down to about 1400 meters.

The entire cylinder of anomalous water was rotating clockwise, its currents reaching a maximum speed of 30 centimeters per second (about 1 kilometer per hour) at a distance of 25 kilometers from its center. Gulf Stream rings are larger and more energetic, having currents of 150 centimeters per second at a radius of about 55 kilometers.

There are few clues yet as to how such an eddy forms or why it decays.



J. J. Simpson

Warm-core eddy (A) in infrared

The salinity and temperature characteristics of the Point Conception eddy match those of California Undercurrent water, Simpson notes, so whatever formed it happened below a depth of 200 meters. There are also curious variations in eddy behavior that seem to be related to geography. The eddies in the vicinity of Point Conception frequently decay and disappear from view each February or March. Those near Point Eugenia, halfway down Baja California, wax and wane with the seasons but do not disappear, Simpson says. And Koblinsky notes that an eddy is often associated with the submarine Mendocino Escarpment off northern California.

If Gulf Stream rings are any example, the California Current eddies should have some significant effects. They may affect the movement near the coast of everything from pollutants to fish eggs. Simpson notes that the eddies "are extremely strong sources of heat compared to the surrounding water." With three to six eddies lined up from Baja California to Vancouver, as appears to be typical, their combined effect might influence sea surface temperature and thus climate, Simpson says.

*A joint meeting of the American Geophysical Union's Oceanography Section and the American Society of Limnology and Oceanography, 16 to 19 February 1982. Abstracts are in *Eos*, vol. 63, No. 3, 19 January 1982.

Chemical Analysis Traces the Sea's Past

First, paleontologists separated the skeletal remains of microscopic marine animals by species in order to trace the changing temperature and salinity of their ancient habitats. Then, chemists measured their stable isotope chemistry in order to follow the waxing and waning of the great ice sheets. Now, geochemists are finding in the same microfossils a record of the shifting chemical composition of the ocean. Researchers are in turn using this record, in the form of trace element compositions, to detect changes in related geological and geophysical processes, such as the flow of a deep-sea current.

As reported at last month's ocean sciences meeting in San Antonio, Edward Boyle of the Massachusetts Institute of Technology (MIT) and Lloyd Keigwin from Woods Hole Oceanographic Institution have found that microfossil cadmium content can reflect changes in the flow of some deep-sea currents. Cadmium and ocean currents may seem an unlikely pair, but they are linked by a convenient series of circumstances. The cadmium content of the skeletons of foraminifera, which are marine protozoans, depends on the cadmium content of the seawater in which the forams lived. The concentration of cadmium in seawater is strongly influenced by biological activity; it is reduced in surface waters, where plants and animals take up cadmium, and enhanced in deep waters, where their decay releases cadmium.

Boyle took advantage of this redistribution of cadmium in his search for a record of the flow of North Atlantic Deep Water (NADW). NADW originates as cadmium-poor surface water in far northern latitudes of the North Atlantic, sinks to a depth of about 2500 meters, and then flows south toward Antarctica, sandwiched between two water masses with high

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cadmium concentrations. Boyle chose to study a sediment core taken at 42°N 32°W, where NADW brushes against the shallower Mid-Atlantic Ridge. He reasoned that the skeletal cadmium of bottom-living forams, whose remains form the sediment, would reflect changes in the flow of NADW—the higher its flow, the less cadmium forams would pick up through mixing of NADW with the surrounding high-cadmium waters.

As it turned out, the ratio of cadmium to calcium in the forams' calcium carbonate skeletons rose and fell twice over the past 150,000 years. These cycles were roughly in step with glacial cycles, as determined by Keigwin's oxygen isotope analysis of the same core; when glacial ice grew, the flow of NADW shrank by as much as one-half (possibly in absolute terms, but at least in relation to the flow from the south of surrounding water). That fits the expected pattern; most researchers believe that the encroachment of sea ice on NADW's source area would decrease its flow. Some researchers have suggested, on the basis of isotopic or paleontological studies, that NADW flow may actually cease during glacial periods. But the cadmium-calcium ratio recorded no such cessation at this site. Analysis of more sites is in order, Boyle notes, as are more detailed comparisons with other kinds of deep-sea current indicators.

Other trace elements in microfossils may be useful indicators of the ocean's changing composition. At the San Antonio meeting, Phillip Froelich of Florida State University proposed that the ratio of germanium to silica in the skeletons of siliceous microfossils may record changes in the rate of continental weathering and hot spring activity at the mid-ocean ridges. The latter is directly related to the rate of formation of new ocean crust and to plate motion. In other work, David Graham and Michael Bender of the University of Rhode Island have found significant dips in the ratio of strontium to calcium, one 4 million to 8 million years ago and another about 50 million years ago. These may be related to changes in hot spring activity or in sea level. Margaret Delaney of MIT is working on an 80-million-year record of the lithium-calcium ratio, which may reflect mainly changes in hot spring activity.

African Lakes as Alternative Oceans

Central Ethiopia may seem to be an odd place to study the ocean, but two chemical oceanographers believe that it is just the place to learn more about how the ocean works. They are trying to get around the problem of having only a single example of seawater—the world ocean—to study. John Edmond and Karen Von Damm of MIT reported at the San Antonio meeting that a string of Ethiopian lakes appear to behave like the ocean in many ways, but this alternative ocean has a more easily deciphered system for ridding itself of some salts.

The Galla Lakes, which lie along the Ethiopian Rift south of Addis Ababa, serve as an alternative ocean because, like the ocean, they are closed systems. Water and dissolved salts flow into them, but only water leaves by evaporation. As water flows through this system toward the closed lakes of Abiata and Shala, evaporation concentrates the salts until the salinity of the lake water is about two-thirds that of seawater. But the dissolved salts never become concentrated enough to combine among themselves and precipitate new minerals. If they did, they would create an oceanographer's nightmare, obscuring any processes that might be more ocean-like.

Instead of precipitating, some of the major cations, such as magnesium, potassium, and sodium, are combining with clays to form new minerals, Von Damm and Edmond say. The lake water chemistry is consistent with such a process, and likely mineral products have been reported in the sediments of one of the lakes. Oceanographers have been searching in the ocean for evidence of such a process, called reverse weathering, for 15 years with only limited success. No one has found such new minerals in open ocean sediments, and interpretation of the single study that supports the existence of oceanic reverse weathering is controversial.

Von Damm and Edmond detected reverse weathering in the Galla Lakes by analyzing lake water rather than by looking for new minerals in the sediments. By sampling all parts of the lake system and the rivers that drain into it, they found a preferential removal of some cations relative to chloride as the salts become concentrated by evaporation. Calcium obviously becomes too concentrated to remain in solution; it precipitates as calcium carbonate. But something is removing magnesium, potassium, sodium, and fluorine before they can be precipitated.

Instead of combining with other dissolved substances, these ions apparently become part of the mineral structure of clays by displacing hydrogen ions. This is the reverse of the chemical reaction responsible for the corrosive weathering of continental rocks. On the continents, rain made slightly acidic by its dissolved carbon dioxide degrades the minerals of the rock. They take up acid and water, lose cations and silica, and take on the less organized crystal structures of clays. Once rivers carry these clays to the ocean, the theory of reverse weathering says, the high concentrations of cations there would push the reaction in the opposite direction. This would tend to limit the buildup of salts carried in river water, avoiding the high concentrations that could turn the sea into a biological wasteland.

The prominence of reverse weathering in the Galla Lakes might be attributed to their *p*H, Von Damm and Edmond say. The Galla Lakes are distinctly basic, greater than *p*H 9, which would favor reverse weathering reactions. The ocean, however, is nearly neutral at a *p*H of about 7.7. If the *p*H is crucial to determining how a body of water removes added cations, they say, the reason for the differing behavior of the real ocean and their alternative ocean may be the presence of mid-ocean ridge hot springs. According to Edmond's interpretation, enough acid debouches from the world's submarine hot springs to keep the ocean's *p*H below the point at which reverse weathering might become important.

The Galla Lakes study will not settle the reverse weathering controversy. Oceanographers still lack confidence in estimates of both the magnitude of reverse weathering in ocean sediments and the global flux of acid and dissolved salts from hot springs. But at least they may not have to use so much imagination to see what the sea would be like under other circumstances.

Richard A. Kerr