Magnetospheric Workings: AMPTE Draws a Blank

Geophysicists poring over some recent results from the Active Magnetospheric Particle Tracer Explorers (AMPTE) are wondering what went wrong. Like dye dropped in a rushing river, the lithium and barium that they had released in and around Earth's magnetosphere was supposed to let them trace the path taken by solar wind particles as they moved toward Earth, perhaps to take up residence in the radiation belts. But six times tracers were released and six times they were never seen again. As researchers heard at last month's American Geophysical Union meeting in Baltimore, something was obviously wrong with the models of magnetospheric behavior developed during the past 20 years that the experimenters used as a guide. How fundamental or intractable the problem may be is unclear, but, as one researcher observed, "it is fair to say that it's a little unsettling."

Tracing anything through the magnetosphere presents a considerable challenge. Formed by the 400-kilometer-per-second solar wind blowing on Earth's magnetic field and pulling part of it into a long tail, the magnetosphere is more than 200,000 kilometers across and filled with magnetic and electrical weather more poorly understood and more difficult to predict than the kind on Earth. Once the solar wind's charged particles such as protons manage to penetrate the barrier presented by the outer magnetosphere, this weather carries them toward Earth and accelerates them until they may be a thousand or a million times more energetic than when they entered.

How all this happens has been studied for almost three decades through satellites that measure natural magnetospheric particles and fields. Stamatios Krimigis of the Johns Hopkins Applied Physics Laboratory in Laurel, Maryland, and Gerhard Haerendel of the Max-Planck Institute for Extraterrestrial Physics in Garching, West Germany, thought they could take a more active role. A satellite could release lithium or barium, rare elements in the magnetosphere, either upwind of Earth outside the magnetosphere or in the magnetotail itself while a second satellite waited closer to Earth near the radiation belts. When, how, and in what quantities the tracers arrived at the second satellite would help reveal the mechanisms responsible for their transport and acceleration. Such tracer experiments became a central component of the AMPTE program, which also includes passive observations and the creation of "artificial comets."

The first two tracer releases occurred last September upwind of Earth outside the magnetosphere. Once ionized, the lithium spiraled toward its target. Twenty-one percent hit the bull's-eye—the central leading face of the magnetosphere—the first time and 69 percent the second, according to model predictions of their paths in the solar wind. According to other models, some would simply blow by, but some would presumably enter the magnetosphere and be detected near Earth. None were.

The initial presumption was that although the vacillating solar wind had not blown the tracer off target, when the tracer struck it found the magnetosphere tightly closed. Constrained by operational circumstances, the experimenters had to release the first tracer when the magnetic field carried by the solar wind paralleled the northward field of Earth. By generally accepted theory, that condition bars entry by charged particles.

The failure to detect any tracer during the first two experiments seemed merely bad luck, until the four magnetotail releases this spring. Again no tracer appeared where predicted although no entry barrier need have been overcome. The amounts predicted to appear at the detecting satellite ran 2 to 30 times higher than the maximum amounts that could have been hidden in background readings.

"In some ways," says Krimigis, "these results are bringing us to a hard question: Are all the things we've done for 20 years wrong? Or, are there more mundane answers?" Everyone agrees that the models were not accurate enough and are probably too simple, but few see an impending revolution in the field. Data are sparse enough and opinions diverse enough that someone's model may soon fit the negative observations. But perhaps only more tracer experiments can resolve the mystery.

Were North Pacific Waters Sinking 18,000 Years Ago?

Today the deep waters of the North Pacific Ocean are at the end of the line, a pool of oxygen-depleted, sluggishly moving water that has been wending its way through the depths of the world ocean for thousands of years since it was last at the surface. But a marine micropaleontologist has found evidence that as recently as 18,000 years ago, at the height of the most recent ice age, water at the surface of the North Pacific was sinking directly into the depths as now happens only in the North Atlantic and near Antarctica. Climate change may thus have made the North Pacific a source of new deep water for the global ocean circulation rather than the terminus from which deep water must finally find its way to the surface again.

Nicholas Shackleton of the University of Cambridge, England, reported that the isotopic composition of fossil bottom-dwelling microorganisms called forams indicate that cold, oxygenated water had covered the bottom of parts of the North Pacific at depths of 1 to 3 kilometers. The ratio of two stable isotopes of carbon—carbon-13 and carbon-12—suggested that bottom-water oxygen had been higher than now. The ratio decreases as organic debris falls into deep water and is oxidized, consuming oxygen and generating carbon dioxide that forams incorporate into their tests. The longer water has been in the deep sea out of touch with the surface, the greater this "aging" will be. The ratio of foram oxygen-18 to oxygen-16, which increases with decreasing water temperature, suggests that bottom water was much colder, even at shallow depths, than it is now.

If these preliminary results hold up, it would appear that 18,000 years ago cold surface water became dense enough to sink to great depth and possibly create a new loop in the plumbing of the sea. It does not do that now, according to Bruce Warren of the Woods Hole Oceanographic Institution, because the North Pacific is too cool to lose much of its freshwater input to evaporation but not so cold as to sink. That allows a stable layer of fresher, lighter surface water to form. The North Pacific is cool because westerly winds that help shape the subpolar surface circulation there stay farther to the south than they do in the Atlantic, forming a larger, more isolated gyre.

Presumably, climate during the ice age differed from present conditions in such a way as to make surface water dense enough to sink. Instead of simply modulating the size of present-day deep currents, as previously shown, glacial conditions may have allowed this young deep water to move out of the North Pacific to form new circulation patterns.

References

1. B. Warren, *J. Mar. Res.* **43**, 327 (1983); A. L. Gordon, *Nature (London)* **305**, 385 (1983).

Antarctic Meteorites: Are They a Breed Apart?

A few years of hunting in Antarctica has produced about as many meteorites as had been collected around the world in 200 years. Michael Lipschutz of Purdue University believes that, aside from providing a larger volume of rocks, the Antarctic bonanza furnishes a view of meteorites from sources that may no longer provide extraterrestrial samples to Earth.

Lipschutz presented several lines of argument that the meteorites found in Antarctica after concentration by the flowing ice can differ from non-Antarctic meteorites. For example, all three known meteorites from the moon were found in Antarctica. The only ureilite meteorite that is not shocked by a powerful impact is in the Antarctic collection. The ratio of the abundant group H to group L ordinary chondrites is about 1:1 outside but 3:1 inside Antarctica. And the type III iron meteorite common in non-Antarctic collections is represented by only 2 of 21 samples from Antarctica. Lipschutz also found that eight of 13 trace elements analyzed are present in significantly different proportions in Antarctic H5 chondrites.

Lipschutz favors an explanation involving a shift in the source of meteorites during the past few hundred thousand years, perhaps from one asteroid or part of the asteroid belt to another. Having spent 100,000 to 700,000 years in the ice, Antarctic meteorites represent rocks arriving at Earth long before those falling today. Other researchers point out some potential problems. Even Antarctic meteorites can suffer significant weathering affecting their chemical composition. Proportions of different types can vary with meteorite breakup, especially when sample numbers are small. And a relatively rapid change in source seems suspect because meteorite supply is seen as the sum total of many collisions between asteroids and long travel times to Earth.

Suture Between North America and Africa Found

Researchers using the oil exploration technique of seismic reflection profiling have pinpointed the buried boundary between the North American continent and a scrap of the African continent now known as Florida and south Georgia. Since the advent of plate tectonics 20 years ago, geologists and geophysicists had suspected that an errant bit of Africa had been left behind after the two continents collided and then pulled apart about 180 million years ago. This direct probing of a continent-continent suture using reflection seismology should help decipher how the continents attained their present shapes through the billiards-like jostling of continents.

Jill Arnow, John McBride, Douglas Nelson, and their colleagues at Cornell University reported that two separate seismic reflection surveys by the Consortium for Continental Reflection Profiling (COCORP) had apparently detected the suture running roughly east-west across south Georgia. Roughly parallel survey lines, along which artificial seismic waves were reflected off crustal features buried beneath a blanket of sediments, began in Florida where rocks recovered from bore holes resemble African rocks. The survey lines ran to the north into both eastern and western central Georgia, where the deeper underlying rock is certifiably North American. Across the middle of the two lines runs the Brunswick Magnetic Anomaly, a narrow low in the magnetic field attributed in the past by some to the suture. Others noted that the anomaly might also result from a sediment-filled rift opened when Africa pulled away.

The COCORP lines found what appears to be the suture directly beneath the magnetic low and roughly where shallow bore hole samples suggested it would be found. In the seismic profiles, the suture appears as a 68-kilometer-wide zone of reflections beginning at a depth of about 5 kilometers, inclined toward the south at least 15° to 25°, and penetrating to a depth of 35 kilometers. There the zone ends at the Moho, the seismically reflective layer traditionally considered the boundary between the chemically distinct crust and mantle.

The Cornell group has several reasons for thinking that this feature is the suture. Among others, the feature coincides with the Brunswick Magnetic Anomaly. It is the only reflection feature penetrating the crust anywhere between the two areas of identified continental crust. And it appears to have no connection with the rift basin in the crust rifted open to the south.

Although the identification of the reflective zone as the suture seems reasonably secure, a problem common in reflection seismology remains to be tackled—exactly what is reflecting the seismic signal? Sediment completely blankets the suture so that no reflectors can be identified by field studies. Individual reflections may represent intrusions of molten rock, bits of sediment or crust of the ocean that was swallowed up between the two continents, or fault rock deformed during the collision.

One particularly strong, horizontal reflection looks familiar from oil and gas exploration. In shallow sediments, such a reflection comes from the boundary of a gas pocket. But the COCORP "bright spot" is 15 kilometers down, far below the reach of drilling and perhaps too deep for petroleum to persist. It could be fluid trapped during the collision or still-molten rock.

Another mystery is the Moho, which was found at the same depth on both sides of the suture. That seems an unlikely coincidence unless it formed after the collision, implying that some physical transformation or faulting creates it rather than a preexisting difference in chemical composition.

—RICHARD A. KERR