MEETING BRIEFS

Geophysicists Peer Into Fiery Core and Icy Ocean Depths

SAN FRANCISCO—The annual fall meeting of the American Geophysical Union (AGU) drew a record 7000 attendees here in December, perhaps because its unusually late scheduling let more academics get away from classes. But there was plenty taught at the meeting, too. Participants heard how Earth's molten core might generate a magnetic field, how the deep ocean mixes, and what could have triggered the ice ages.

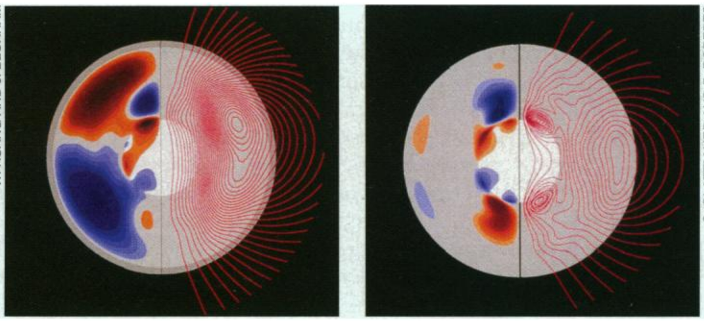
Same Earth, Different Dynamos

The planet's core is an intellectual tease. Its inner workings, cloaked in 2900 kilometers of solid rock, are discernible only in the magnetic field that guides sailors, fends off the blustery solar wind, and channels aurora to polar skies. Geophysicists have long hoped that by studying the magnetic field at the surface, they would be able to unlock the mysteries of the core. But they received a rude shock at last month's AGU meeting, when researchers running computer simulations of how that swirling ball of molten iron might produce a magnetic field reported that very different geodynamos in the core can yield the same Earth-like magnetic field at the surface.

"We have two different [models] that are very similar outside the core but very different inside the core," says geophysicist Gary Glatzmaier of Los Alamos National Laboratory, who in 1995 developed the first model with Paul Roberts of the University of California, Los Angeles. Jeremy Bloxham of Harvard University, who constructed the second model along with his Harvard University colleague Weijia Kuang, finds the discordant results "a little disturbing. Why are both models succeeding in generating an Earth-like field?" he wonders. To Glatzmaier, "It looks like now the surface magnetic field isn't going to be enough to say how the dynamo's working." Other things, like observing the [solid] inner core's rotation, are going to be more important than we thought initially."

The two groups constructed their models in a similar way. Both used essentially the same equations to calculate the flow of highly conductive iron, much as a weather forecasting model simulates atmospheric flows, and to calculate the electric currents and magnetic forces generated when that conductor flows across magnetic fields. In addition, Glatzmaier notes, there has been a fair amount of intellectual cross-fertilization as the groups have shared students and postdocs. Yet, their results are very different.

The geodynamo produced by the Harvard model "is very similar to the traditional view of how the geodynamo works," says Peter Olson of The Johns Hopkins University. It has intense contortions of magnetic field lines, where a flowing conductor produces new field lines, lying in the outermost outer core far from the solid inner core. In contrast, Glatzmaier and Roberts's simulation puts the field generation close to the inner core, which interacts with the dynamo through magnetic field lines that pierce it.


W. KUANG AND J. BLOXHAM

G. GLATZMAIER AND P. ROBERTS

Deep-rooted differences. In two computer models of the geodynamo, the magnetic fields that reach the surface (right halves) are similar and Earth-like, while the deeply buried fields of the core are different.

The most likely explanation for the differences may lie in approximations the two groups made in order to duplicate a large, complex chunk of a planet in the narrow confines of a computer model. "The problem is the viscosity of the fluid outer core—it's thought to be about that of water," says Glatzmaier. Because such a thin fluid requires more spatial detail to simulate, putting an added burden on an already demanding computational problem, modelers compromise by exaggerating the true viscosity of the core. The results are less than perfect: "Neither of us can do it exactly the way it should be done," says Glatzmaier.

Then there are the parameters chosen for properties like conductivity. Glatzmaier and Roberts tended to make them realistic whenever possible, while the Harvard group took some liberties to preserve realistic proportions rather than absolute values. "They've got to take each other's parameters and run their models with them," says Olson, which is just what the two groups will be doing. "We'll learn something that way," says Glatzmaier, "but that won't answer which one's right."

For that, modelers will need some ground truth from the core itself. A good bet looks like the inner core's rate and direction of rotation, says Olson. The inner core "is like an anemometer and a weather vane at the center of the earth," he notes; it responds to the outer core's "winds." The recent discovery (*Science*, 26 July 1996, p. 428) by seismologists that the inner core is rotating eastward faster than the rest of the planet tends to support the Glatzmaier and Roberts geodynamo, which drives the model's inner core in the same direction and at roughly the same speed as observed. The inner core in the Bloxham-Kuang model has a slower relative rotation that reverses every 15,000 years or so.

Both teams agree on one point: There's a lot more work to be done. The observational support for his competitor's model "is certainly not something I'm going to worry about until the seismology settles down a bit," says Bloxham, noting that the range of reported rotation rates has broadened greatly as more seismologists get into the act. Glatzmaier agrees, remarking that "It's not clear to anybody which model solution is the closest to the Earth right now." He believes it's "quite possible that the Earth experiences each of them from time to time."

Now that would be a real tease.

Elusive Ocean Mixing Nabbed

Oceanographers know how the waters of the ocean part ways, but they have had a hard time identifying how and where those waters reunite. Near the poles, cold, salty surface waters sink into the deep sea, forming distinct deep layers that flow toward the equator. But somewhere along the way that cold, deep water mixes with warmer, fresher waters to form the relatively homogeneous seawater of lower latitudes. "We know mixing has to be going on somewhere in the ocean," says physical oceanographer James Ledwell of the Woods Hole Oceanographic Institution (WHOI), "but it's been hard to find it." Now, oceanographers think they know where at least some of the missing mixing takes place: over areas of rough bottom, which churn the overlying waters.

The clue, reported at the AGU meeting, is the discovery of a broad zone of relatively intense mixing deep in the South Atlantic over a patch of rugged sea floor. "This is the first time such high mixing has been found over a broad area near the bottom," says Ledwell, who with Kurt Polzin, John Toole, and Raymond Schmitt of WHOI conducted the latest search. "This is a step toward finding where significant mixing is going on in the ocean." And because mixing changes water density in the abyssal and middle depths of the ocean, driving currents there, "our view of what [deep] circulation looks like is going to change dramatically in the next few years," predicts physical oceanographer Eric Kunze of the University of Washington.

Oceanographers had made unsuccessful searches where some theories predicted mixing (*Science*, 8 January 1993, p. 175), but key experiments remained out of reach: detailed measurements of turbulent mixing from the surface waters all the way into the abyss. Schmitt and his WHOI colleagues had designed a promising instrument package, the probe-studded High-Resolution Profiler, which measures turbulent mixing on scales of millimeters. Dropped over the side of a ship, the profiler free-falls toward the bottom, recording temperatures and flow velocities as it goes. Approaching the sea floor, the profiler's altimeter triggers the release of ballast, and the instrument package pops back to the surface. But its ability to detect subtle mixing had to be tested and some of its sensors strengthened before it was ready to probe the greatest depths.

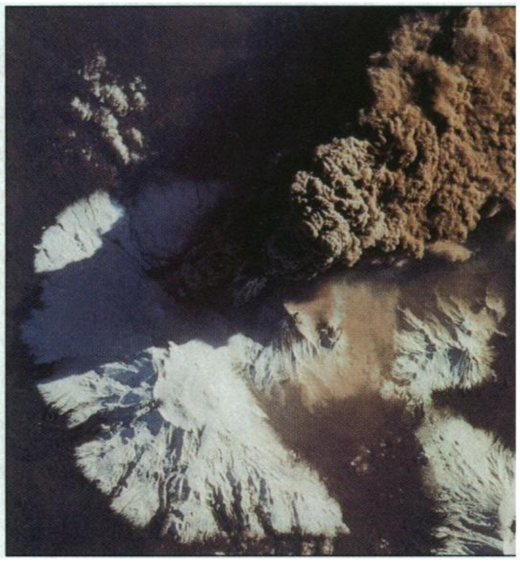
Last February, the WHOI group took the beefed-up profiler to the Brazil basin, just east of South America, in search of mixing. They knew that the cold, salty water entering this 5600-meter-deep basin from the south mixes with warmer water somewhere in the basin, because the bottom water that drains northward from the basin is warmer and fresher. To find just where and how the mixing happens, the WHOI researchers deployed the profiler at stations along a dogleg ship track from Rio de Janeiro to the mid-Atlantic ridge and back to Recife, Brazil.

When they analyzed the profiles, a clear pattern emerged in the Brazil basin. In the western part of the basin, over the broad, gradual slopes of the South American continental rise and the smooth, flat abyssal plain, turbulent mixing was extremely low at all depths, contrary to predictions that mixing might be pervasive. But in the eastern basin, where the flank of the mid-Atlantic ridge roughens the bottom, turbulent mixing was far higher—five to 10 times higher at middle depths and 50 to 100 times higher in the bottom 200 meters. That may be enough mixing to account for all the warming of deep, cold water in the entire basin, says Ledwell.

Bottom roughness seems to make the difference, says Polzin. He and his colleagues propose that as open-ocean tides drive water across the ridges and canyons of the ridge flank at upwards of 2 kilometers per hour, the uneven sea floor sets the water column undulating in waves analogous to the familiar waves seen on the surface of the ocean. When any of these internal waves break, the resulting "internal surf" drives the mixing of deeper and shallower waters. And because internal waves can set up oscillations in the fluid above them, they could boost mixing far above the bottom.

Whether such bottom-enhanced mixing can account for all or even most of the world ocean's missing mixing, researchers can't say. Firming up the link between mixing and bottom topography would take similar measurements at other spots that have the same combination of strong tides and a rough bottom: the Juan de Fuca ridge off the U.S.–Canadian border, the Hawaiian island chain, the Micronesia archipelago, and in the Indian Ocean in the Mozambique channel, for example.

If bottom-enhanced mixing falls short, Kunze has a favorite alternative: the intense but localized mixing driven by submarine "waterfalls" like the one Polzin and colleagues recently measured at the Romanche Fracture Zone, where deep, cold water spills through a narrow gap in the mid-Atlantic ridge, mixing with warmer water as it goes. More forays by the profiler, together with long-term mixing studies using chemical tracers, should eventually show just how the ocean puts itself back together.



JSC/NASA

A climate trigger? Eruptions like this one from the volcano Kliuchevskoi on Kamchatka in 1994 may have brought on the ice ages.

Out of Fire, Ice?—Part 2

David Rea knows as well as anyone that coincidence does not prove causation. But the tighter the coincidence between two events, the stronger the argument for a causal link. And the University of Michigan paleoceanographer says a new analysis of a sediment core from the North Pacific has strengthened the case for a link he first proposed 4 years ago: a connection between a series of volcanic eruptions that rocked the northern rim of the Pacific and the world's precipitous descent into the ice ages 2.6 million years ago.

Earth had already been cooling for tens of millions of years, perhaps because the rise of the Himalayas affected the atmosphere and weakened the natural greenhouse effect. But 2.6 million years ago, the planet suddenly slipped over the edge into a deep chill from which it has never fully recovered. In the 1970s, a few researchers suggested that a global volcanic outburst recorded in marine sediments at roughly the same time might have triggered the climate shift by lofting debris that shaded the sun, but the records were patchy and imprecise. Now, Rea and his Michigan colleague Libby M. Prueher have shown that the eruptions around the North Pacific and the sudden cooling took place within 1000 years of each other. "It looks like the climate system just needed a kick in the pants," says Michigan paleoceanographer Theodore Moore, "and this may have been it."

Rea first drew a connection between North Pacific volcanism and glaciation in 1993, when he saw cores of sediment retrieved from the far northern North Pacific. A roughly 10-fold jump in the frequency of volcanic ash layers from volcanoes up to 1000 kilometers away coincided, as best the eye could discern, with a dramatic increase 2.6 million years ago in the amount of mineral grains scoured from nearby continents by glaciation and carried to sea by rivers and icebergs. Based on a first reading of that sediment record, Rea put the two events within 50,000 to 300,000 years of each other (*Science*, 18 June 1993, p. 1725). That's keeping pretty close company in the geologic record, but the gap left plenty of room for doubts.

With more precise dating and more analysis, Prueher and Rea have greatly reduced the room for doubt. They find that the best of their cores shows the northern North Pacific switching from preglacial to glacial conditions in just under 1000 years. That's too quick to be driven by other suggested climate forcing mechanisms, says Rea, such as rising mountain ranges or the changing orientation of Earth. And the abrupt climate shift continues to match up with the volcanism.

Rea is still cautious about claiming a link. "The geologist's most serious disease is assigning cause and effect to things that occur at the same time when they may not have anything to do with each other," he notes. To avoid contracting this dreaded syndrome, he and Prueher are undertaking an even finer dissection of the cores to see if the coincidence can be tightened still more.

–Richard A. Kerr