The Inner Earth Is Coming Out

Geophysicists are on the cutting edge of the planet's deepest frontier

By STEFI WEISBURD

For earth scientists, the inside of our planet is about to come into focus. Advances in seismology and mineralogy in the last few years have been providing new insights into the properties of the core and lower mantle in unprecedented detail (SN:1/3/87,p.9; 2/14/87, p.106).

Now, scientists trying to understand the inner earth may be helped as well by possible advances in two other geologic disciplines: the gravitational study of waves oscillating in the fluid outer-core and research on the earth's magnetic field, which is generated by the swirling motion of the outer-core fluids.

While scientists are still debating the validity of some of the new geomagnetic and gravitational data, a few researchers have recently published NATURE papers in which they begin to interpret the new findings. These papers, although admittedly speculative, provide a taste of where future investigations may lead, as scientists from a range of disciplines work together to unveil the workings of the inner earth.

Einstein once described the origin of the earth's magnetic field as one of the three most important unsolved problems in physics. Today, the detailed fluid motion of the outer core that gives rise to this field remains a mystery. But in recent years scientists have come one step closer to a solution by making the first reliable pictures of the large-scale field as it appears at the outer edge of the core, below the interfering effects of the crust and mantle.

Some of this work has been done by Harvard University's Jeremy Bloxham, who has culled historical records of magnetic field measurements from 1715 through 1980. Using new mathematical methods of analyzing these measurements taken at the earth's surface, he and colleague David Gubbins have produced a series of maps of the field at the core – the first magnetic models at the core-mantle boundary that are based on data going back farther than a few decades, according to Bloxham.

"We are for the first time really beginning to a get a picture of what the field looks like," he says, "and from that we have stuck our necks out and speculated" on why the field looks the way it does. And in two papers in the Feb. 5 NATURE, he and Gubbins, who is currently visiting the Australian National University in Canberra, do just that.

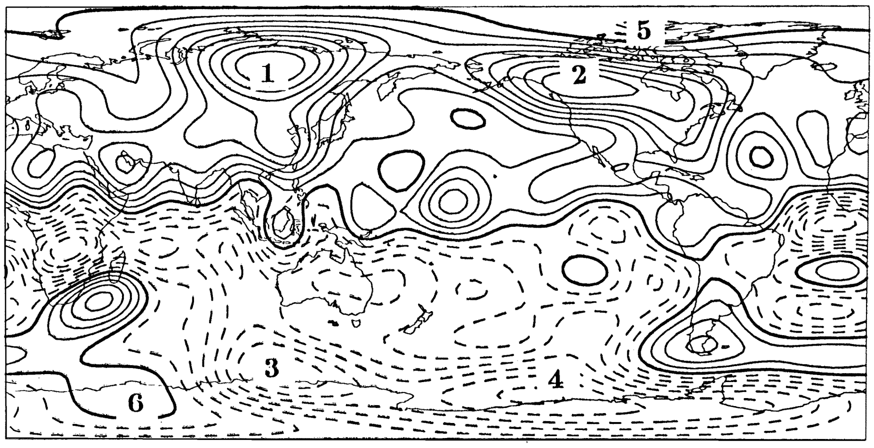
In one paper, the researchers point out that there are some features in their maps that, unexpectedly, remain in the same place over the entire 265-year time period. These include the polar regions, through which there is essentially no magnetic flux, and four lobes – placed symmetrically on either side of the equator at 60° latitude and at 120°W and 120°E longitude – in which magnetic field lines are highly concentrated.

That the four lobes have stayed in place for nearly 300 years is surprising, says Bloxham. Traditionally, scientists have envisioned the entire field as drifting westward across the face of the planet at about 0.2° per year because the core rotates more slowly than do the mantle and crust. If the four lobes had been drifting at 0.2° per year, they would have moved by over 50° longitude since 1715.

"We can be quite certain that westward drift is not happening everywhere at the core surface," says Bloxham. "Since the lobes are staying put, this indicates that something is keeping them there."

Gubbins and Bloxham believe that the four lobes and other stationary features are part of the main field of the core. The symmetric pattern of this observed field is consistent with one class of theoretical models that treat the core as if it were an electromagnetic dynamo (SN: 10/5/85, p.220). Using one particular dynamo model, in which the earth's rotation organizes the core fluids into north-south-trending convective rolls or columns, the researchers suggest that the concentrated field lines appear where core fluids are sinking down these columns, away from the overlying mantle and toward the equator. And in the adjacent columns where the fluids are upwelling toward the core-mantle boundary, the magnetic flux is low.

He and Gubbins think the mantle, which convects much more slowly than the core, is anchoring the convective rolls, and hence the lobes, in place. They found that the high magnetic flux zones correspond to areas in the lower mantle that seismologists have recently found to be cold and sinking. This sinking mantle material, the researchers propose, induces a similar downwelling in the underlying core. Likewise, where the lower mantle is hot and rising, core fluids follow the upwelling motion toward the surface.



Gubbins and Bloxham/NATURE

Contour map of the magnetic field as it appeared at the core-mantle boundary in 1980. Solid lines indicate where magnetic flux is going into the core; broken lines mark where flux is coming out. Two pairs of stationary lobes (1,3 and 2,4) are 120° apart in longitude. For symmetry, a third pair of lobes would be expected near 0° longitude. Bloxham thinks strong fluid motions in that region are wiping out the slower influence of the mantle, which anchors the lobes in other places. The patches labeled 5 and 6 mark areas near the poles that contain little magnetic flux.

Other researchers caution that Gubbins's and Bloxham's interpretations, and also, to some extent, their models of the field at the edge of the core, are not yet widely accepted by the geomagnetic community. "Their ideas have some merit and could be correct, but they are extremely speculative and by no means proven," comments geomagnetist Coerte V. Voorhies at NASA Goddard Space Flight Center in Greenbelt, Md. Voorhies notes that while, in the NATURE papers, Gubbins and Bloxham are using static features to qualitatively study deep flows in the core, the approach of most other researchers is to quantitatively investigate flow at the top of the core based on changes in the magnetic field.

Peter Olson, a geodynamist at Johns Hopkins University in Baltimore, says he is most intrigued by Gubbins's and Bloxham's maps showing magnetic features in the Southern Hemisphere that appear to be terrestrial analogues to sunspots. Sunspot pairs, which are thought to be the sites where the sun's magnetic field erupts from and reenters the sun, intensify as they move from midlatitudes to the west and toward the equator. In contrast, says Olson, "core-spot" pairs appear to move westward and poleward; they appear at midlatitudes under the Indian Ocean, intensifying as they drift under South Africa and into the southern Atlantic Ocean.

The core-spot movement toward the poles, he says, shows that "the old notion of westward drift as an explanation of secular variation [changes in the magnetic field over time] is on the way out and may be replaced with something more like the sunspot descriptions used for the solar field." The concept of westward drift assumes that the field as a whole rotates westward with the core; with core spots, most of the westward drift is due to *localized* disturbances that have a more complex motion, moving not only westward with the core but poleward too.

Because sunspots have been successfully modeled by a dynamo theory for the sun, Olson suspects that this theory may bear fruit for the earth as well. Olson also notes Gubbins's suggestion that an observed decrease in the total strength of the earth's main dipole field over the last several centuries may be due to the intensifying core spots, which produce a magnetic field in a sense opposite to that of the main dipole.

While the behavior of the earth's magnetic field offers one set of clues about the flow of core fluids, gravity measurements promise another. Last year, Paul Melchior and B. Ducarme of the Observetoire Royal de Belgique in Brussels published the results of their studies on changes in the local gravity field as measured by a superconducting gravimeter, which is at least 100 times more sensitive than a conventional gravity meter. Melchior and Ducarme reported that following two large, deep earthquakes in 1983 and 1984, they detected slow waves in the local gravity field that had periods of 13 to 15 hours.

Geophysicist Keith Aldridge and graduate student L. Ian Lumb, both at York University in Toronto, think these fluctuations in the gravity field were caused by "inertial waves," or oscillations of the outer-core fluids, which redistributed the mass in the core and hence changed the reading on the Belgium gravimeter. If their interpretation is correct, scientists say the finding could provide an important tool for learning about the properties of the outer core.

In a paper appearing in the Jan. 29 NATURE, they compare the observed periods with those predicted by a simple theoretical model of inertial waves set up in a rotating, fluid sphere. To understand this model and the origin of the inertial waves, imagine a ring of fluid centered about the earth's axis of rotation. This ring is kept in place by two opposing forces: the centripetal force due to the earth's rotation and a counteracting pressure gradient force. If some disturbance, such as an earthquake, perturbs the ring, moving it away from its stable position, the centripetal and pressure forces will play against one another to return the ring to its original position. The result is that the ring will oscillate around its stable position, until frictional forces dissipate all of the oscillation energy.

Of course, the real core is more complex than this simple model. But the close agreement between the observed and predicted periods of oscillation led Aldridge and Lamb to conclude that "... the data of Melchior and Ducarme can be interpreted as the discovery of predominately inertial waves in the earth's fluid outer core."

Not all other researchers agree. Some doubt that the magnitude of such inertial waves would be great enough to be picked up by the gravimeter. Nevertheless, if the signals Melchior and Ducarme measured do turn out to be real and if Aldridge's interpretation of them is correct, scientists say the implications would be enormous.

"It would be a very significant piece of work," says Edward R. Benton at the University of Colorado in Boulder, "because it would enable us to do spectroscopy on the earth's core; it would provide a way of probing the structure of the core that is different from either seismology or magnetic field studies."

In particular, the periods of inertial waves are sensitive to such things as the strength of the magnetic field, the shape of the boundary between the inner and outer core and the density stratification of the outer core, according to Olson. And Aldridge notes that with inertial waves, scientists may be able to determine the distribution of velocities among the moving fluid.

The promise of inertial-wave studies, as well as the progress being made in geomagnetism, paleomagnetism, high-pressure physics and seismology, mean that for the first time scientists in these different fields are saying they have something of interest to communicate to one another about the inner earth.

Benton and others think the time is ripe for a multidisciplinary effort to study the inner earth. At the 19th general assembly of the International Union of Geodesy and Geophysics, scheduled to meet in Vancouver in August, they hope to get approval for the Study of the Earth's Deep Interior, an eight-year, international program that would bring scientists from different fields together for a series of workshops and conferences.

The prospect for such cooperative ventures demonstrates how far the study of the inner earth has come since the inner core was discovered 50 years ago. "It looks like things are heating up," Voorhies says. "I think we're all going to be learning a heck of a lot in the next 10 years — things we just had no idea of before." □