Seismic Journey to the Center of the Earth

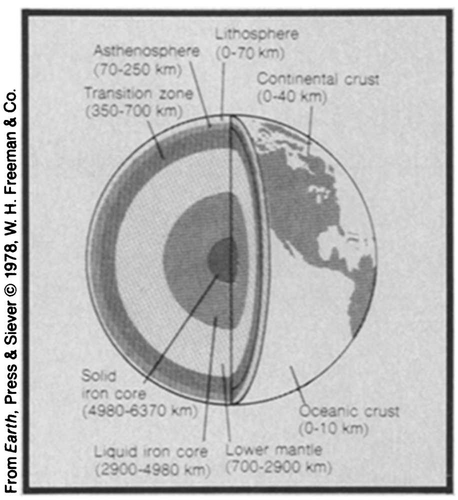
Seismologists are detecting 'continents' and other structures in and near the earth's core that may provide clues to the flow patterns of the inner earth and the creation of the geomagnetic field.

By STEFI WEISBURD

Geoscientists like to think of the earth as a giant machine, a complex assembly of circulating fluids and rocks powered by the hot heart of the planet. The swirlings of liquid iron in the outer core create the geomagnetic field (SN: 10/5/85, p. 218) and pass heat to the mantle. And the cyclic flow of mantle rocks fires up volcanoes at the surface and drives the motions of the plates that generate earthquakes, create oceans and build mountains.

Charting the flow patterns and structure of the inner earth is central to understanding the workings of the earth machine. In the last few years, geophysicists have made remarkable progress in learning how to use seismic waves generated by earthquakes to construct three-dimensional maps of the mantle with a technique similar to the computer-assisted tomography, or CAT scans, used in medicine (SN: 4/30/83, p. 280).

Now scientists are using seismic energy to probe beyond the mantle, into the deepest reaches of the earth. In the past few months, two research groups have produced the first tomographic maps of the earth's core. These maps and other new seismic studies show that the core and its outer boundary are structured into large, irregular regions of differing temperatures and/or compositions. The researchers have different ideas about the location of these regions as well as their origin. But with additional data and study these discrepancies are likely to be worked out. And as the seismic work is fine-tuned, scientists interested in many different aspects of the earth machine will be drawn to this new window on the planet's center.



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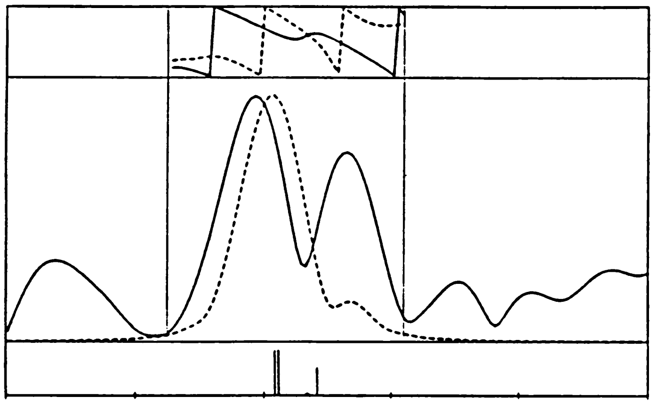
Scientists, using acoustic waves generated by earthquakes to probe the earth's interior, are now developing a picture of the inner core.

Instrumental in the development of the new maps are earthquakes, which release different kinds of seismic waves that spread throughout the world. The speed at which these waves travel depends on the temperature and composition of the earth; if, for example, a wave enters a region that is colder than what it had previously encountered, it will speed up. By monitoring the time it takes a wave to arrive at a detection station, scientists can calculate the wave's velocity. Then, by charting the paths and velocities of hundreds of thousands of waves, seismologists can construct a three-dimensional picture showing how the seismic velocity, and hence the properties of the inner earth, vary over the globe.

Once they developed a good sense of the seismic structure of the mantle, researchers could begin to do tomographic studies with the kinds of waves that can penetrate into the regions of the core. Using 19 years' worth of earthquake data, Andrea Morelli and Adam M. Dziewonski at Harvard University produced an image of the core that contains velocity anomalies of up to 1.5 percent – regions in which seismic signals traveled up to 1.5 percent faster or slower than the average speed – in the top 300 kilometers of the solid inner core.

The researchers do not yet know how to interpret these anomalies, which might be caused by differences in core temperature or composition or both. But in any case Dziewonski thinks it likely that the anomalies are related to the growth of the inner core, which scientists suspect occurs as the liquid outer core cools and solidifies.

At MIT, Kenneth C. Creager and Thomas H. Jordan, working with a slightly different kind of data set, have also produced seismic tomographic images of the inner earth. But Creager and Jordan believe their data fit is best when velocity anomalies are put somewhere near the boundary between the outer core and the lower mantle, and



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Earthquakes make the planet vibrate like a bell. Because the earth is asymmetric, the vibrations are "split" into other frequencies. Here researchers have tried to predict one split vibrational mode by taking into account the asymmetries caused by the earth's rotation and elliptical shape. The theoretical line (dashed) clearly does not replicate the actual data (solid line). The fit between the data and the theory is much better when other aspherical structures are added to the earth model. One team of researchers thinks these structures are at the core-mantle boundary and in the inner core, while another group places them in the lower mantle and outer core.

not in the inner core as Dziewonski and Morelli suggest.

Moreover, Jordan thinks that what they have mapped are "continents" on the core-mantle boundary. "What we've seen is something really incredible," he says. According to Jordan, the anomalies are analogous to continents on the surface of the earth, because they can't be accounted for by temperature variations alone but must reflect some compositional change as well. These features "represent the scum or slag that sits up on the outer core boundary, just as continents sit on the outer surface of the earth," he says.

And while these anomalies are probably far less rigid than continents, their shape and distribution, like those of continents, are likely to be controlled by the dynamics and flow of material at the very active core-mantle boundary.

At this stage, the researchers are not sure if the anomalies lie in the mantle or in the core or if they involve the topography of the boundary itself. They also don't see any obvious relation between the distribution of core "continents" and those on the surface, but they do think that the two are somehow dynamically linked.

The core-mantle features may provide important information for scientists trying to model both the movement of material in the mantle and in the core as well as the coupling between the two flow regions, says Jordan. "There are some unusual correlations between the behavior of the magnetic field machine and the plate tectonic machine, and it might be that this boundary layer will help describe some of those correlations," he adds.

In Creager and Jordan's map, high-velocity regions tend to be concentrated near the poles and low-velocity areas near the equator. According to Jordan, that's the same kind of pattern that other researchers have obtained with another kind of seismic study looking at the "free oscillations" of the earth. Teams at the University of California at San Diego (UCSD) and, independently, at Harvard University have examined how the shape of the earth and the distribution of material inside affect the low-frequency vibrations that are set up when an earthquake rattles the planet.

A large earthquake will make the entire planet vibrate in the same way that hitting a bell will make the bell ring. If the shape of the ringing body, whether planet or bell, has a lot of symmetry to it, the resulting tone will be very pure. But if the shape is distorted or the mass is unevenly distributed, new tones or frequencies will be produced, creating a fuzzier sound.

This phenomenon is called "spectral splitting" – individual frequencies in the spectrum are split into other frequencies. Scientists have found that the spectrum for a perfectly spherical earth is split by the planet's equatorial bulge from the earth's rotation, the uneven distribution of continents and oceans and structures in the mantle. But these aspherical factors cannot entirely account for all of the splitting that is observed.

"In order to explain the splitting we see, we all agree that there has to be a large-scale deviation from spherical structure that is seated very deep in the earth," says Freeman Gilbert of UCSD. The model that Gilbert, Michael Ritzwoller and Guy Masters at UCSD have developed to fit their data places part of the aspherical structure in the lower mantle and part of it in the outer core.

The Harvard group, on the other hand, thinks the splitting is caused by structures at the core-mantle boundary and in the inner core. In particular, Domenico Giardini, Xiang-Dong Li and John H. Woodhouse at Harvard believe their data are best explained if the inner core is more elliptical by about 20 kilometers than what would be predicted by virtue of rotation alone.

"Nobody has enough data at the present time to really nail down the final answer," says Gilbert. This is because most of these seismic studies of the core are still new; they are being presented for the first time at meetings this summer and none has yet appeared in a journal. In the coming months, all of the researchers involved will be thinking about how to justify their proposed locations for these structures on physical grounds. They will have to explain, for example, how the regions of different temperature or composition have withstood the vigorous mixing of the outer core for such a long time, or how the earth's gravitation forces could support large deviations from a spherical shape of the inner core.

These seismic studies are sure to attract other kinds of earth scientists, hungry for information about such problems as how the geomagnetic field is created or why the earth is still so active and hot when other planets have long since died. The recent core studies are a spark in the engine of scientific thinking about the great earth machine. □