The Mush Zone

A slurpy layer lurks deep inside the planet

By RICHARD MONASTERSKY

If you were to take a supersonic elevator down toward the center of the globe, it wouldn't take long to feel the heat. Just after the start of the journey, at the meager depth of 200 kilometers, the temperature rises to 1,000°C. This is the base of Earth's lithosphere, its outermost skin.

Leaving the lithosphere, the elevator enters the mantle—the great rocky domain that makes up 84 percent of the planet's volume. If the heat doesn't do you in, the boredom certainly will. The shaft descends through thousands of kilometers of mostly featureless, solid rock. It's like enduring a cross-country bus ride that rolls past the same flat scenery for days on end.

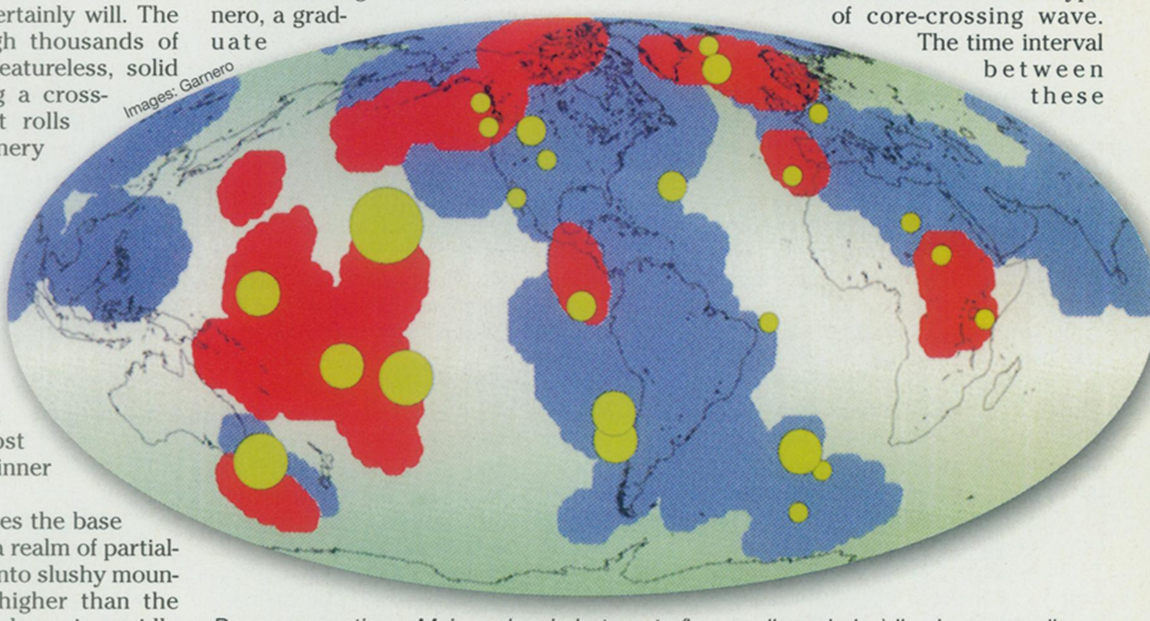
It might be tempting to doze at this point, but don't give in to the impulse. Even a brief siesta could cause you to miss the highlight of the trip—a recently discovered zone that is turning out to be one of the most important parts of the inner planet.

As the elevator reaches the base of the mantle, it enters a realm of partially molten rock molded into slushy mountain ranges 10 times higher than the Himalayas. This messy layer is rapidly churning, transporting blistering heat out of Earth's iron core and sending it rising toward the crust.

Although the mush zone lies 2,850 km down—almost halfway to the center of the planet—emerging evidence suggests that it may have direct relevance to life on the surface. The zone appears to determine where massive volcanic eruptions occur and perhaps where ocean basins form. In short, it could play an important role in shaping the very face of the planet.

"People used to think that the lower mantle was a relatively simple place and that you could probably learn more about plate tectonics by just paying attention to the top part of the mantle," says Donald V. Helmberger, a seismologist at the California Institute of Technology in Pasadena. "But the picture we're seeing is that the lower mantle is much more fascinating than people thought, and it's probably playing a bigger role in what's happening above it."

Like everyone else, when Helmberger first caught a glimpse of the mush zone, he didn't realize what he was seeing. In 1987, Edward J. Garnero, a graduate student working with Helmberger, noticed something unusual about seismic recordings from a 1969 earthquake. The quake started at a depth of more than 500 km in the upper mantle under Fiji. As in all earthquakes, the seismic waves spread out in every direction. Some shot directly toward the surface. Others rocketed down through the core and continued on through the mantle toward the opposite side of the planet, where stations in North America recorded the far-flung vibrations.



Deep connections: Major volcanic hot spots (large yellow circles) lie above peculiar parts of the lowermost mantle (red), where seismic waves slow markedly.

Most of the waves traveling through the core followed relatively direct paths, but a small fraction got temporarily sidetracked. At the core-mantle boundary, they took a funny bounce—called a critical reflection—that sent them rippling along the base of the mantle for a short stretch. Eventually, they passed through the core and then to the other side of the globe.

While studying seismograms recorded in North America, Garnero grew interested in these odd, little-studied waves with the funny bounce. He noticed that they had straggled into various North American stations well after a more direct type of core-crossing wave. The time interval between these two sets ran several seconds longer than seemed reasonable, given what seismologists knew about the inner Earth.

Garnero took his finding to Helmberger, who confirmed that the gap was unusual. Apparently, something was not quite right with the standard model of Earth's interior. Some part of the planet was either speeding up the first set of waves or delaying the second set, the two researchers concluded. Then, as happens often in science, both of them got back to more immediate projects. Garnero stored the observation in a file and forgot about it.

Five years later, however, the problem waves resurfaced. Stephen P. Grand, a

Science Service, Inc. is collaborating with JSTOR to digitize, preserve, and extend access to *Science News*. www.jstor.org

visiting seismologist from the University of Texas at Austin, happened upon another example of them while sifting through the microfiche files in the subbasement of the Caltech seismology building. Grand has a photographic memory for seismograms and a reputation for painstaking work. Instead of relying on neat, abridged catalogues compiled by other people, he likes to wade through original seismic recordings, poring over the wiggly, messy tracings.

It was this encyclopedic knowledge of seismograms that tipped Grand off. While studying records from some deep South American earthquakes, he found an odd set of vibrations arriving at stations far later than they should have. These delayed waves turned out to be another example of what Garnero and Helmberger had puzzled over. Grand convinced Garnero to follow up on the tardy vibrations to see what was causing the traffic jam inside the planet.

"[Grand] really was the catalyst," says Garnero. "Without him, it probably still would be in my desk along with several other files of things that I thought were interesting but didn't get around to."

Garnero first tried working within the confines of the system. He knew that the mantle contains some regions considered fast or slow—where seismic waves speed up or slow down by a few percent. Geophysicists attribute the changes mostly to slight differences in mantle temperature, with slow regions corresponding to warmer rocks (SN: 7/19/97, p. 46).

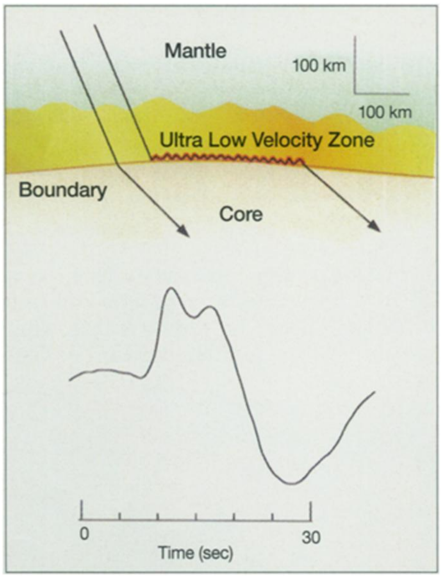
To explain the retarded waves, Garnero calculated what would happen if the vibrations lost 5 percent of their speed while passing through a thick layer at the base of the mantle. The suggestion seemed extreme. In seismology, a 5 percent drop in speed represents a drastic change—the biggest ever observed in the 2,100-kilometer-thick lower mantle.

The 5 percent scenario worked well in explaining the first few earthquakes, but it started to break down as Garnero looked into more quakes. Finally, Helmberger suggested a way around the problem. If 5 percent did not fit, try an inconceivable number like 10 percent, Helmberger offered. "He was really instrumental in pushing me to open up my preconceived notions of what the Earth is," says Garnero, now at the University of California, Berkeley.

However unpalatable, the 10 percent solution provided the best match for the observations. The most reasonable explanation, concluded Garnero and Helmberger, was that certain regions of the lowermost mantle had a veneer of rock where seismic waves practically crawled along. The scientists named this region the Ultra Low Velocity Zone (ULVZ).

At just 5 to 40 km thick, the ULVZ forms an uneven layer that seems to resemble giant mountain ranges. Patchy in distribution, the zone has been spotted only under certain portions of the globe, such as Iceland, the southwest Pacific, Central America, southern Africa, Tasmania, and southern Alaska.

When Garnero and Helmberger began reporting findings from their 10 percent model in 1995, they generated considerable skepticism among other scientists. Eventually, though, "Garnero had enough observations that were sufficiently robust that they were absolutely unequivocal," says Quentin Williams, a geophysicist at



Some seismic waves pass cleanly into the core, whereas other waves are slowed down as they skim the lowermost mantle. The lag shows up between two peaks on this seismogram (bottom).

the University of California, Santa Cruz.

Williams and Garnero teamed up to investigate what was causing the slowdown inside the ULVZ. An experimental physicist by training, Williams specializes in studying the planet's interior by squeezing and heating materials in a diamond-tipped vise. From these experiments, he knew that it would be very difficult to reduce seismic wave speeds in solid mantle minerals by 10 percent. The only realistic explanation, however improbable, was that the ULVZ rocks were partially molten, he and Garnero reported in the Sept. 13, 1996 SCIENCE.

Geophysicists had always assumed that the mantle was solid, but Williams and Garnero proposed that, in places, the bottom of the mantle was semiliquid—a material resembling fluid-filled Swiss cheese or perhaps a melting snow cone. This conclusion, if correct, could have profound implications for understanding Earth, the scientists maintained. "Melting in the deep mantle would basically change all the rules for how the deep mantle behaves," says Williams.

Williams predicted that seismologists would find further evidence of partial melting by studying shear (S) waves—seismic waves that vibrate minerals from side to side as they pass through the planet. The original ULVZ discovery had involved research on compressional waves, which cause vibrations backward and forward along the direction of motion. S waves are far more sensitive to small amounts of fluid in the rock, so if the ULVZ were partially molten, it would slow S waves by 30 percent or more, predicted Williams.

Recently, Justin Revenaugh at UC-Santa Cruz has obtained indirect evidence of the drastically slowed S wave speeds in the ULVZ. In a different study, John E. Vidale at the University of California, Los Angeles has found corroborating evidence of partially molten rock in the ULVZ under Fiji.

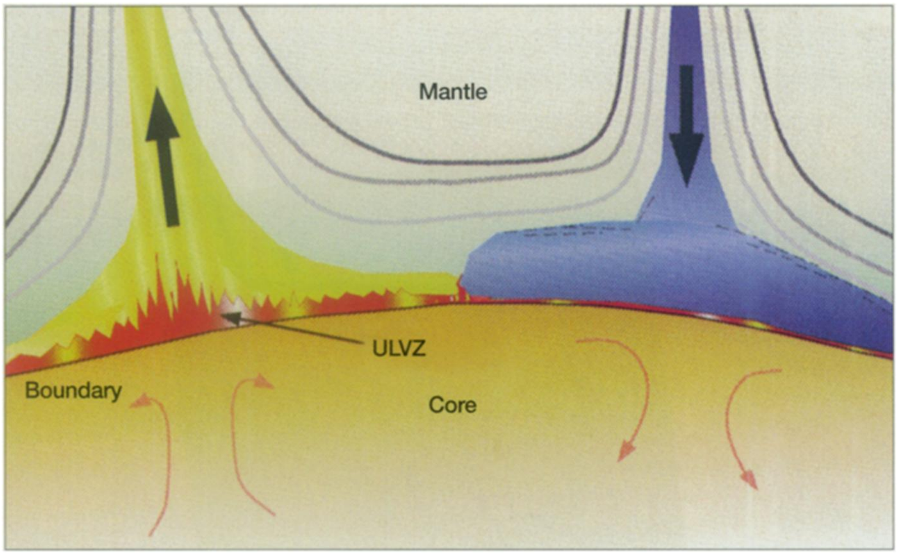
To put the ULVZ studies into perspective, Williams compares them to studying the human body. "It would be almost like discovering a new organ or a new part that we didn't know was there before—like discovering the pancreas. This may be a gland for the planet. It's something that is small, but it's likely very important."

The gland analogy may be an especially apt one. In the human body, glands release far-reaching hormones; the ULVZ appears to release something—heat—that travels far and has profound effects throughout the planet.

If the ULVZ is partially molten, it may provide a window through which heat can escape from the core, says Williams. In places without a ULVZ, where the lowermost mantle is solid, heat travels relatively slowly up from the core into the mantle. Partially molten rock, however, can transport heat perhaps a hundred times faster out of the core, he says. The flood of energy leaving the core should cause the solid mantle rock above the ULVZ to start rising, creating a plume of superheated rock creeping toward the surface.

Revenaugh, Williams, and Garnero described evidence supporting this idea in December 1997 at a meeting of the American Geophysical Union in San Francisco. They compared the mapped location of the ULVZ with the known position of mantle hot spots. As the name suggests, hot spots are anomalously warm regions at the top of the mantle; they melt the base of the lithosphere and create volcanoes such as Hawaii and Iceland. As a lithospheric plate passes over a hot spot, like a conveyor belt passing over a lit candle, the heat raises a chain of volcanoes.

The researchers report finding strong evidence linking the ULVZ to the position of hot spots. So far, geophysicists have searched almost half the bottom of the mantle; their mapped locations of the ULVZ underlie a total of 12 percent of the globe. Although relatively limited, the doc-



The Ultra Low Velocity Zone, shown in red, may generate plumes of rock that rise through the mantle.

umented ULVZ shows up beneath a third of all hot spots, including the most prodigious ones, says Williams. There is only a 1 percent chance that this pattern would occur randomly, the researchers estimate.

Some other scientists, however, remain cool to the hot spot–ULVZ connection at this point. "So far, it is more tantalizing than compelling," comments Vidale. He says that researchers will need to survey the rest of the globe to see just how pervasive the ULVZ is.

If the link between hot spots and the ULVZ holds, it offers insight into aspects of Earth's evolution. When plumes rise from the mantle and start burning through the lithosphere, they may have the power to fracture continents. Indeed, some geophysicists suggest that a plume severed Africa from South America 130 million years ago, creating the South Atlantic Ocean. It may be, says Williams, that the distribution of the ULVZ has helped determine the position of the ocean basins and continents on the modern globe.

"What we're seeing at the surface may effectively be a manifestation of something that's occurring 2,850 km below our feet," he says.

Geophysicists like to refer to the continents as the scum of the planet. These rocky rafts represent an amalgam of the buoyant materials that bobbed to the surface throughout Earth's evolution. Following that nomenclature, then, the ULVZ may be the dregs of the mantle—in other words, the densest rocks in the planet.

Since the discovery of a partially molten layer at the base of the mantle, researchers have wondered just what kind of materials make up the ULVZ. At this point, they have little evidence to go on, says Williams. It could be that when portions of the deep mantle start to melt, the fluids are actually denser than the surrounding rock and sink to the bottom. Or the ULVZ may contain iron-rich minerals, created when mantle minerals react with the molten iron of the outer core. In recent years, high-pressure experiments have taught scientists that these reactions are possible.

If the lowermost mantle contains pockets of iron-rich rock, these electrically conductive patches should have noticeable effects on Earth's geomagnetic field. The field draws its power from the swirling currents of molten iron in the outer core, but the lowermost mantle may exert some control over the behavior of the field, says seismologist Thorne Lay of UC-Santa Cruz.

One sign of this comes from patterns of geomagnetic reversals, when Earth's north and south magnetic poles swap positions. During these chaotic episodes—which happen once or a few times every million years—the positions of the poles migrate over Earth's surface in two distinct corridors running through the Americas and the western Pacific. These corridors tend to avoid places where scientists have detected the ULVZ, which suggests that the deep mantle may play a role in how reversals happen, says Lay.

With so many new discoveries of the deep mantle appearing in research journals during the last few years, scientists are struggling to put all the observations into a coherent picture. For some, the current state of affairs brings on a sense of déjà vu—back to the days just before the birth of plate tectonics, when research on the lithosphere was blossoming. The giddiness is almost palpable at scientific meetings, where scientists flock to crowded halls to watch new images of the deep planet flash up on screen.

"The field is poised," says Lay, "for a bunch of different observations to come together into some enhanced understanding of how the deep mantle works." □

NEW ADDRESS?

Whenever you write to us about your subscription, please enclose a SCIENCE NEWS address label to ensure prompt service.

Change of address: Please let us know about your change of address 4 to 6 weeks before you move.

To: SCIENCE NEWS
Subscription Office
231 W. Center St.
P.O. Box 1925
Marion, Ohio 43305

To subscribe, mail this form to the address shown above.

Subscription rates:

□ 1 year $49.50 □ 2 years $88.00
□ Payment enclosed □ Bill me later
(foreign postage $6.00 additional per year.)

NEW ADDRESS:

name (please print)
address
city state zip code

Attach **OLD** label or print **OLD** address

name (please print)
address
city state zip code

AO78

We invite you to visit our Web site at:

SCIENCE NEWS ONLINE

http://www.sciencenews.org

- Highlights from current and past issues
- MathTrek, Food for Thought, and other features not in the magazine
- Full text of selected articles from SCIENCE NEWS
- Complete book listings
- Ability to search and contact SCIENCE NEWS ONLINE
- Bibliographic references for SCIENCE NEWS articles