Seismolgists get handle on heat flow deep in Earth

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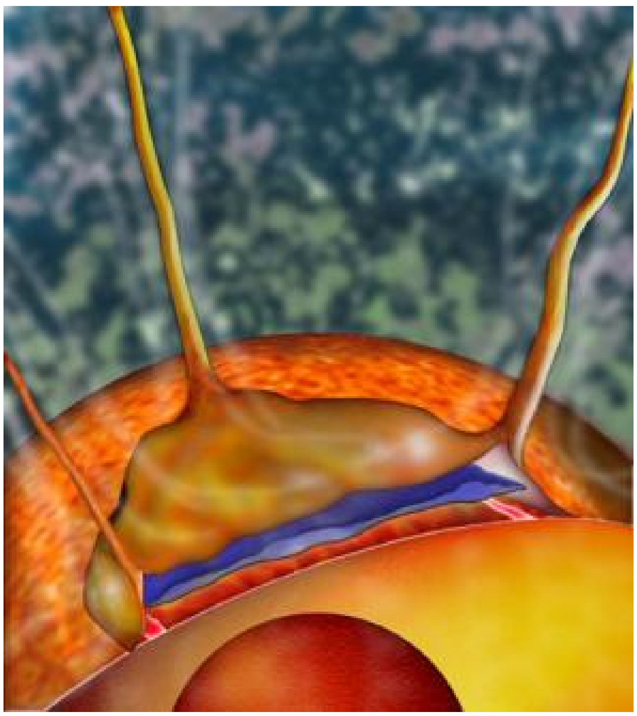

Seismologists detected a lens-shaped structure (blue) within a large pile of chemically distinct material at the boundary between the liquid outer core and the solid mantle, half-way to the center of the Earth. The tubes rising from the edges of the pile represent plumes of hot mantle material rising toward the surface. The core-mantle boundary is the curved orange surface, and the small red ball is the solid inner core. (Image by Edward Garnero)

Earth's interior is not a benign world that only stores the geologic history of our planet. Geologists now see the normally assumed placid inner

Earth as a dynamic environment filled with exotic materials and substances roiling under intense heat and pressures. It is an environment that continues to evolve in interesting ways and one that has an impact on what happens at its surface.

The latest evidence of this dynamic inner Earth is revealed in a recent series of measurements that peered deep within Earth, halfway to its center. The new experiments have yielded important results that help determine temperature halfway to the center of Earth. It also has implications for the age of Earth's solid inner core and how its magnetic field may be generated.

"We have found unexpected rock layering in Earth's deepest mantle," said Edward Garnero of ASU's School of Earth and Space Exploration and one of the researchers on the team. "The implications of the layering are far reaching, with intimate connections to the rock chemistry, temperature and convective flow, all of which have been previously inaccessible."

"Understanding of Earth's core-mantle boundary environment puts us in the position of answering a host of important questions, such as how much heat from the molten outer core cooks the overlying mantle," Garnero explained. "While this might seem distant and esoteric, it actually relates to the vigor of convective mantle flow that ultimately jostles Earth's surface with volcanic and earthquake processes."

Garnero, and his fellow researchers (Thorne Lay of the University of California, Santa Cruz; John Hernlund of the Institut de Physique du Globe de Paris; and Michael Thorne of the University of Alaska, Fairbanks) report their findings in the Nov. 24, 2006 issue of *Science* magazine.

In "A post-perovskite lens and D" heat flux beneath the central Pacific," the researchers discuss measurements that have led them to determine temperatures at different levels deep within Earth. The researchers, for the first time, have been able to measure the flow of heat emanating from Earth's core into the base of its mantle, which can help determine the age of the core and help understand how Earth's magnetic field is generated.

Earth is made up of several layers. The crust, which includes the surface of Earth, extends only 40 km (25 mi) deep. Below the crust is the mantle area that extends to about 2900 km (1800 mi) into Earth, the D" layer is the deepest 200 to 300 km of the mantle. The outer core is beneath that and extends to 5150 km (3200 mi) and the inner core to about 6400 km (4000 mi). The researchers probed the D" layer, which lies at the bottom of the mantle.

The boundary between the Earth's core and mantle lies halfway to the center of Earth, to a depth of 2900 km. The seismologists were able to probe the structure of this region by studying its effects on seismic waves generated by large earthquakes.

"What we have found are various layers deep within Earth under the central Pacific Ocean, near the edge of what appears to be a pile of hot, chemically distinct material," Garnero said. "In this 'thermochemical pile' the layering is consistent with a new high pressure phase of a compound called perovskite, a material that exists specifically under high pressures that cause new arrangements of atoms to be formed."

Using seismic waves generated by earthquakes in the Tonga-Fiji region of the southwest Pacific Ocean, the seismologists were able to probe the structure of the D" region inside Earth by studying the patterns of waves reflecting from any distinct objects in the deep Earth. They detected the waves with a new array of highly sensitive instruments deployed by the EarthScope project (a National Science Foundation initiative), located throughout the Western U.S.

What they detected was a novel material alternating between two distinct forms, Garnero said. The material they detected is called post-perovskite, a modified version of perovskite. Separate laboratory mineral physics tests set the temperatures and pressures that would be required to change perovskite material to post-perovskite material.

Temperature measurements in Earth were obtained by relating seismic observations to the mineral transformations of perovskite/post-perovskite material, which occurs under extremely high pressures and temperatures that the researchers say prevail near the core-mantle boundary.

"Perovskite refers to a specific arrangement of the silicon-iron-oxygen-magnesium atoms," Garnero said. "Post-perovskite happens at the highest pressures in the deep mantle of Earth, so if we can pinpoint a depth where that occurs it will allow us to determine the temperature (as determined in laboratory tests) required to make this phase transition from perovskite to post-perovskite."

"We not only found a boundary marking an entrance into this material, but an additional boundary showing an exit from the material back to its original structure as well," Garnero added. "It is like a lens or a cloud that is hovering in the lower most mantle above Earth's core."

Because the research team was able to determine the temperature at two different depths, one right above the other, it gave them a temperature gradient, "which tells us the amount of heat flowing from the core into the base of the mantle," said UC Santa Cruz's Thorne Lay, lead author of the Science paper.

"Heat flow is the Holy Grail because it tells us how much energy powers the geodynamo, and it tells us how much the mantle is being heated from below," Lay added. The geodynamo is the convective motion in Earth's fluid outer core that generates the magnetic field we observe at Earth's surface.

As heat flows from the outer core into the mantle, it drives important processes in the mantle and the core. The mantle is a thick layer of silicate rock and surrounds a dense, predominantly iron core.

The high heat flow found within Earth supports the idea that mantle convection, the slow turnover of mantle material that moves Earth's tectonic plates at its surface, is strongly controlled by this intense degree of heating at the mantle's base by the upwelling of hotter material from near the core mantle boundary.

"The implication from this study is that the flow of heat from the core to the mantle suggests that the inner core of Earth is not as old as the Earth itself," Garnero said.

"The core must have been pretty hot in the past for this much heat to still be coming out, and the inner core, which is slowly solidifying from the inside out as it cools, may be only 1 billion years old," Lay added.

The age of Earth itself is generally regarded as 4.6 billion years old.

The researchers suspect that an upwelling of hot mantle material may be taking place near the edges of the lens of the post-perovskite material. They detected the lens in the lowermost mantle southeast of Hawaii, an area where previous studies have suggested there is a root of a hot upwelling plume from near the core mantle boundary that is ultimately responsible for volcanism that created and continues to create the chain of the Hawaiian Islands.

Garnero said overall this new finding adds an important missing piece to the puzzle of what is going on deep in Earth's interior, adding to the larger picture emerging of a dynamic interior that affects what happens at the surface.

"These glimpses into Earth are revealing key pieces of Earth as a system," Garnero added. "They beckon for a larger understanding of larger scale cycles of our planet."

Source: Arizona State University