Twin studies provide first explanations for boundary within Earth's mantle

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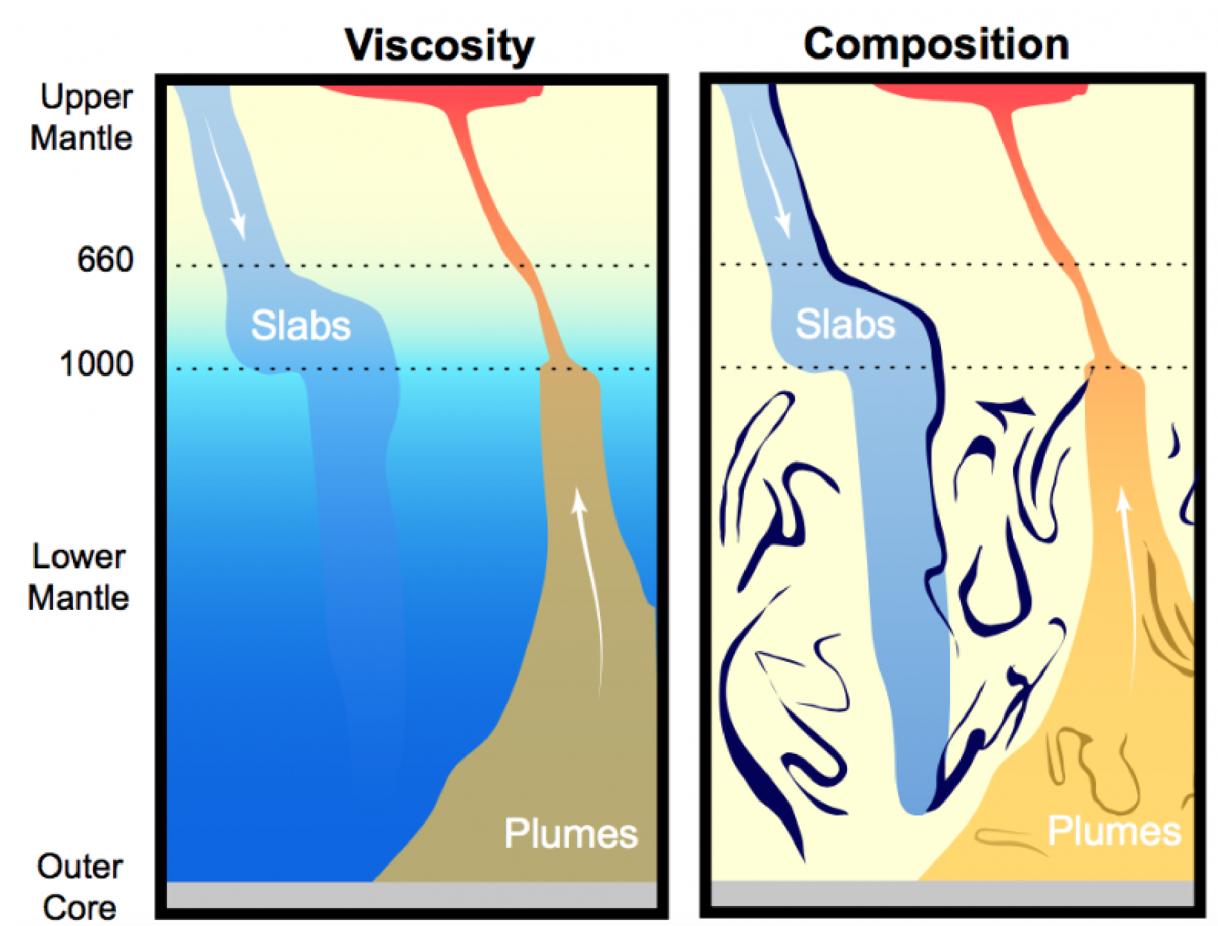

Sinking slabs of ocean crust and rising plumes of hot rock in Earth's mantle are observed to behave differently below one megameter (1,000 kilometers) depth. Two explanations for this behavior were published on Dec. 11, 2015. At left, Rudolph et al. (*Science*, 2015) propose a viscosity increase (dark blue) below the megameter boundary. At right, Ballmer et al. (*Science Advances*, 2015) propose a density increase due to accumulated ocean crust (dark squiggles) below the boundary. Credit: Nicholas Schmerr/Vedran Lekic/UMD

Earth's mantle, the large zone of slow-flowing rock that lies between the crust and the planet's core, powers every earthquake and volcanic eruption on the planet's surface. Evidence suggests that the mantle behaves differently below 1 megameter (1,000 kilometers, or 621 miles) in depth, but so far seismologists have not been able to explain why this boundary exists.

Two new studies co-authored by University of Maryland geologists provide different, though not necessarily incompatible, explanations. One study suggests that the mantle below 1 megameter is more viscous—meaning it flows more slowly—than the section above the boundary. The other study proposes that the section below the boundary is denser—meaning its molecules are more tightly packed—than the section above it, due to a shift in rock composition.

Taken together, the studies provide the first detailed look at why large-scale geologic features within the mantle behave differently on either side of the megameter divide. The papers were published on December 11, 2015, in the journals *Science* and *Science Advances*.

"The existence of the megameter boundary has been suspected and inferred for a while," said Vedran Lekic, an assistant professor of geology at UMD and co-author of the *Science* paper that addresses mantle viscosity. "These papers are the first published attempts at a detailed explanation and it's possible that both explanations are correct."

Although the mantle is mostly solid, it flows very slowly in the context of geologic time. Two main sources of evidence suggest the existence of the megameter boundary and thus inspired the current studies.

First, many huge slabs of ocean crust that have been dragged down, or subducted, into the mantle can still be seen in the deep Earth. These slabs slowly sink downward toward the bottom of the mantle. A large number of these slabs have stalled out and appear to float just above the megameter boundary, indicating a notable change in physical properties below the boundary.

Second, large plumes of hot rock rise from the deepest reaches of the mantle, and the outlines of these structures can be seen in the deep Earth as well. As the rock in these mantle plumes flows upward, many of the plumes are deflected sideways as they pass the megameter boundary. This, too, indicates a fundamental difference in physical properties on either side of the boundary.

"Learning about the anatomy of the mantle tells us more about how the deep interior of Earth works and what mechanisms are behind mantle convection," said Nicholas Schmerr, an assistant professor of geology at UMD and co-author of the *Science Advances* paper that addresses mantle density and composition. "Mantle convection is the heat engine that drives plate tectonics at the surface and ultimately leads to things like volcanoes and earthquakes that affect people living on the surface."

The physics of the deep Earth are complicated, so establishing the mantle's basic physical properties, such as density and viscosity, is an important step. Density refers to the packing of molecules within any substance (gas, liquid or solid), while viscosity is commonly described as the thickness of a fluid or semi-solid. Sometimes density and viscosity correlate with each other, while sometimes they are at odds. For example, honey is both more viscous and dense than water. Oil, on the other hand, is more viscous than water but less dense.

In their study, Schmerr, lead author Maxim Ballmer (Tokyo Institute of Technology and the University of Hawaii at Manoa) and two colleagues used a computer model of a simplified Earth. Each run of the model began with a slightly different chemical composition—and thus a different range of densities—in the mantle at various depths. The researchers then used the model to investigate how slabs of ocean crust would behave as they travel down toward the lower mantle.

In the real world, slabs are observed to behave in one of three ways: The slabs either stall at around 600 kilometers, stall out at the megameter boundary, or continue sinking all the way to the lower mantle. Of the many scenarios for mantle chemical composition the researchers tested, one most closely resembled the real world and included the possibility that slabs can stall at the megameter boundary. This scenario included an increased amount of dense, silicon-rich basalt rock in the lower mantle, below the megameter boundary.

Lekic, lead author Max Rudolph (Portland State University) and another colleague took a different approach, starting instead with whole-Earth satellite measurements. The team then subtracted surface features—such as mountain ranges and valleys—to better see slight differences in Earth's basic shape caused by local differences in gravity. (Imagine a slightly misshapen basketball with its outer cover removed.)

The team mapped these slight differences in Earth's idealized shape onto known shapes and locations of mantle plumes and integrated the data into a model that helped them relate the idealized shape to differences in viscosity between the layers of the mantle. Their results pointed to less viscous, more free-flowing mantle rock above the megameter boundary, transitioning to highly viscous rock below the boundary. Their results help to explain why mantle plumes are frequently deflected sideways as they extend upward beyond the megameter boundary.

"While explaining one mystery—the behavior of rising plumes and sinking slabs—our results lead to a new conundrum," Lekic said. "What causes the rocks below the megameter boundary to become more resistant to flow? There are no obvious candidates for what is causing this change, so there is a potential for learning something fundamentally new about the materials that make up Earth."

Lekic and Schmerr plan to collaborate to see if the results of both studies are consistent with one another—in effect, whether the lower mantle is both dense and viscous, like honey, when compared with the mantle above the megameter boundary.

"This work can tell us a lot about where Earth has been and where it is going, in terms of heat and tectonics," Schmerr said. "When we look around our solar system, we see lots of planets at various stages of evolution. But Earth is unique, so learning what is going on deep inside its mantle is very important."

The research paper, "Viscosity jump in Earth's mid-mantle," Maxwell Rudolph, Vedran Lekic and Carolina Lithgow-Bertelloni, was published on December 11, 2015 in the journal *Science*.

The research paper, "Compositional mantle layering revealed by slab stagnation at ~1000-km depth," Maxim Ballmer, Nicholas Schmerr, Takashi Nakagawa and Jeroen Ritsema, was published on December 11, 2015 in the journal *Science Advances*.

More information: "Viscosity jump in Earth's mid-mantle," by M.L. Rudolph et al. *Science*, www.sciencemag.org/lookup/doi/ … 1126/science.aad1929

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