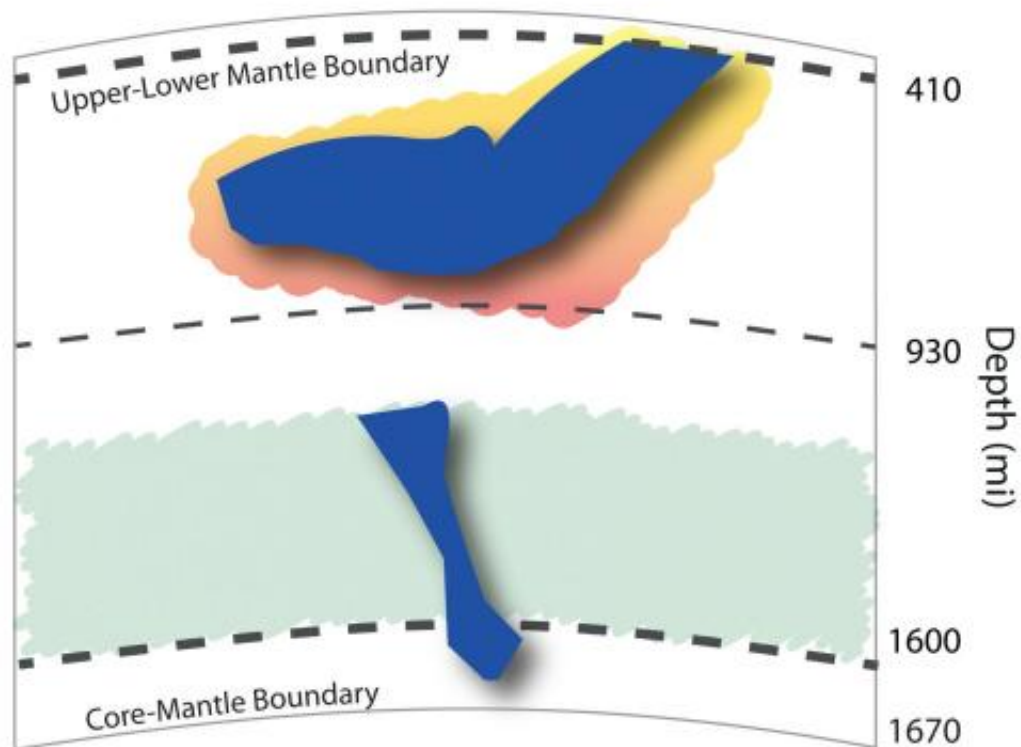


# A stiff new layer in Earth's mantle: Why the planet's conveyor belt hangs up 930 miles deep

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A simplified image of a slab from one of Earth's tectonic plates sinking through the upper mantle above, through the boundary between the upper and lower mantle 410 miles deep, then stalling and pooling at a depth of 930 miles, where University of Utah experiments suggest the existence of an extremely stiff or viscous layer in Earth. Such a layer may explain why tectonic plate slabs seem to pool at 930 miles under Indonesia and South America's Pacific coast. Below the highly viscous zone, slabs can continue to sink to the core-mantle boundary. Credit: Lowell Miyagi, University of Utah

By crushing minerals between diamonds, a University of Utah study suggests the existence of an unknown layer inside Earth: part of the lower mantle where the rock gets three times stiffer. The discovery may explain a mystery: why slabs of Earth's sinking tectonic plates sometimes stall and thicken 930 miles underground.

The findings - published today in the journal *Nature Geoscience* - also may explain some deep earthquakes, hint that Earth's interior is hotter than believed, and suggest why partly molten rock or magmas feeding midocean-ridge volcanoes such as Iceland's differ chemically from magmas supplying island volcanoes like Hawaii's.

"The Earth has many layers, like an onion," says Lowell Miyagi, an assistant professor of geology and geophysics at the University of Utah. "Most layers are defined by the minerals that are present. Essentially, we have discovered a new layer in the Earth. This layer isn't defined by the minerals present, but by the strength of these minerals."

Earth's main layers are the thin crust 4 to 50 miles deep (thinner under oceans, thicker under continents), a [mantle](#) extending 1,800 miles deep and the iron core. But there are subdivisions. The crust and some of the upper mantle form 60- to 90-mile-thick tectonic or lithospheric plates that are like the top side of conveyor belts carrying continents and seafloors.

Oceanic plates collide head-on with continental plates offshore from Chile, Peru, Mexico, the Pacific Northwest, Alaska, Kamchatka, Japan and Indonesia. In those places, the leading edge of the oceanic plate bends into a slab that dives or "subducts" under the continent, triggering earthquakes and volcanism as the slabs descend into the mantle, which is like the bottom part of the [conveyor belt](#). The subduction process is

slow, with a slab averaging roughly 300 million years to descend, Miyagi estimates.

Miyagi and fellow mineral physicist Hauke Marquardt, of Germany's University of Bayreuth, identified the likely presence of a superviscous layer in the lower mantle by squeezing the mineral ferropericlasite between gem-quality diamond anvils in presses. They squeezed it to pressures like those in Earth's lower mantle. Bridgmanite and ferropericlasite are the dominant minerals in the lower mantle.

The researchers found that ferropericlasite's strength starts to increase at pressures equivalent to those 410 miles deep - the upper-lower mantle boundary - and the strength increases threefold by the time it peaks at pressure equal to a 930-mile depth.

And when they simulated how ferropericlasite behaves mixed with bridgmanite deep underground in the upper part of the lower mantle, they calculated that the viscosity or stiffness of the [mantle rock](#) at a depth of 930 miles is some 300 times greater than at the 410-mile-deep upper-lower mantle boundary.

"The result was exciting," Miyagi says. "This viscosity increase is likely to cause subducting slabs to get stuck - at least temporarily - at about 930 miles underground. In fact, previous seismic images show that many slabs appear to 'pool' around 930 miles, including under Indonesia and South America's Pacific coast. This observation has puzzled seismologists for quite some time, but in the last year, there is new consensus from seismologists that most slabs pool."

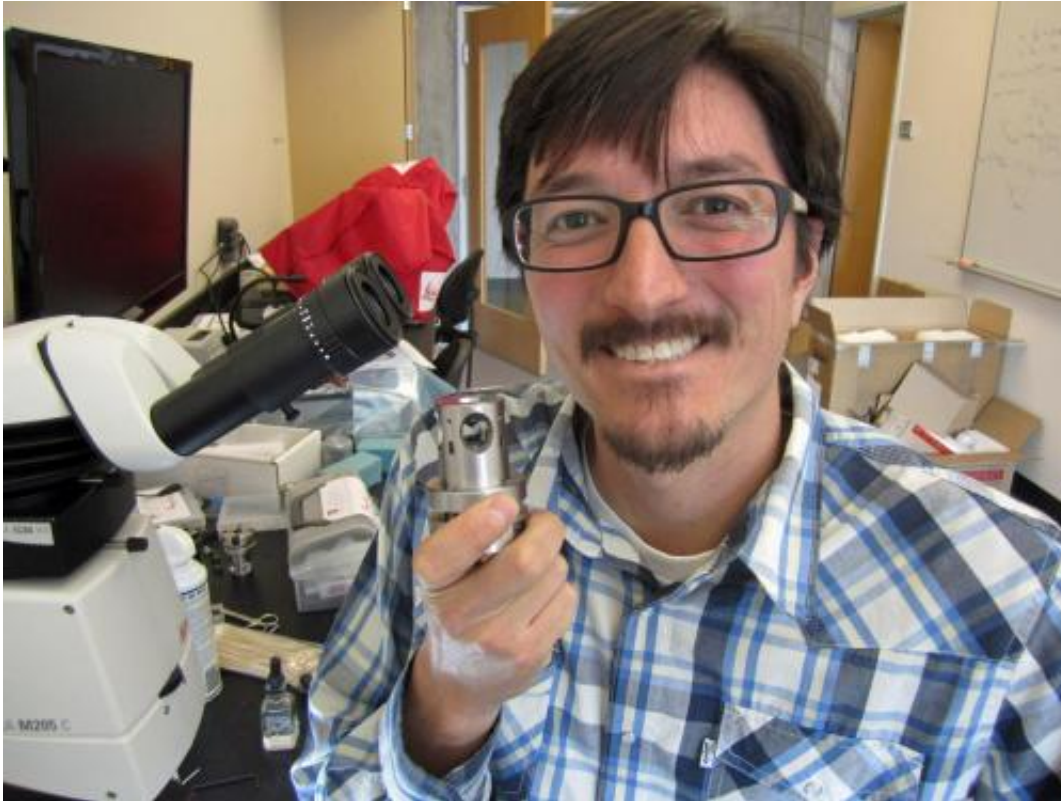
How stiff or viscous is the viscous layer of the lower mantle? On the pascal-second scale, the viscosity of water is 0.001, peanut butter is 200 and the stiff mantle layer is 1,000 billion billion (or 10 to the 21st power), Miyagi says.

## Slab subduction triggers earthquakes and volcanoes

For the new study, Miyagi's funding came from the U.S. National Science Foundation and Marquardt's from the German Science Foundation.

"Plate motions at the surface cause earthquakes and volcanic eruptions," Miyagi says. "The reason plates move on the surface is that slabs are heavy, and they pull the plates along as they subduct into Earth's interior. So anything that affects the way a slab subducts is, up the line, going to affect earthquakes and volcanism."

He says the stalling and buckling of sinking slabs is due to a stiff layer in the mantle may explain some deep earthquakes higher up in the mantle; most quakes are much shallower and in the crust. "Anything that would cause resistance to a slab could potentially cause it to buckle or break higher in the slab, causing a deep earthquake."



University of Utah geophysicist Lowell Miyagi holds a press that houses a diamond anvil, in which minerals can be squeezed at pressures akin to those deep within the Earth. Miyagi and a colleague in Germany squeezed mineral crystals in a diamond anvil under pressures like those deep underground. Their findings suggest the existence of a previously unknown layer of extremely stiff or viscous rock 930 miles underground in the top part of Earth's lower mantle. Such a layer would explain why seismic images have shown slabs from Earth's sinking tectonic plates sometimes stalling and thickening or pooling at that depth. Credit: Lee J. Siegel, University of Utah

Miyagi says the stiff upper part of the lower mantle also may explain different magmas seen at two different kinds of seafloor volcanoes.

Recycled crust and mantle from old slabs eventually emerges as new seafloor during eruptions of volcanic vents along midocean ridges - the rising end of the conveyor belt. The magma in this new plate material

has the chemical signature of more recent, shallower, well-mixed magma that had been subducted and erupted through the conveyor belt several times. But in island volcanoes like Hawaii, created by a deep hotspot of partly molten rock, the magma is older, from deeper sources and less well-mixed.

Miyagi says the viscous layer in the lower mantle may be what separates the sources of the two different magmas that supply the two different kinds of volcanoes.

Another implication of the stiff layer is that "if you decrease the ability of the rock in the mantle to mix, it's also harder for heat to get out of the Earth, which could mean Earth's interior is hotter than we think," Miyagi says.

He says scientists believe the average temperature and pressure 410 miles deep at the upper-lower mantle boundary is 2,800 degrees Fahrenheit and 235,000 times the atmospheric pressure on Earth's surface. He calculates that at the viscous layer's stiffest area, 930 miles deep, the temperature averages 3,900 degrees Fahrenheit and pressure is 640,000 times the air pressure at Earth's surface.

## **Studying Earth's interior by squeezing crystals**

Such conditions prevent geophysicists from visiting Earth's mantle, so "we know a lot more about the surface of Mars than we do Earth's interior," Miyagi says. "We can't get down there, so we have to do experiments to see how these minerals behave under a wide range of conditions, and use that to simulate the behavior of the Earth."

To do that, "you take two gem quality diamonds and trap a sample between the tips," he says. "The sample is about the diameter of a human hair. Because the diamond tips are so small, you generate very high

pressure just by turning the screws on the press by hand with Allen wrenches."

Using diamond anvils, the researchers squeezed thousands of crystals of ferropericlase at pressures up to 960,000 atmospheres. They used ferropericlase with 10 percent and 20 percent iron to duplicate the range found in the mantle.

To observe and measure the spacing of atoms in ferropericlase crystals as they were squeezed in diamond anvils, the geophysicists bombarded the crystals with X-rays from an accelerator at Lawrence Berkeley National Laboratory in California, revealing the strength of the mineral at various pressures and allowing the simulations showing how the rock becomes 300 times more viscous at the 930-mile depth than at 410 miles.

The finding was a surprise because researchers previously believed that viscosity varied only a little bit at temperatures and pressures in the planet's interior.

The study's simulations also determined that just below the 930-mile-deep zone of highest viscosity, slabs sink more easily again as the [lower mantle](#) becomes less stiff, which happens because atoms can move more easily within ferropericlase crystals.

Descending slabs have been seen as deep as the core-mantle boundary 1,800 miles underground. As the bottom of the conveyor-belt-like mantle slowly moves, the slabs mix with the surrounding rock before the mixture erupts anew millions of years later and thousands of miles away at midocean ridges.

**More information:** Slab stagnation in the shallow lower mantle linked to an increase in mantle viscosity, *Nature Geoscience*, [DOI](#):

[10.1038/ngeo2393](https://doi.org/10.1038/ngeo2393)

Provided by University of Utah

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