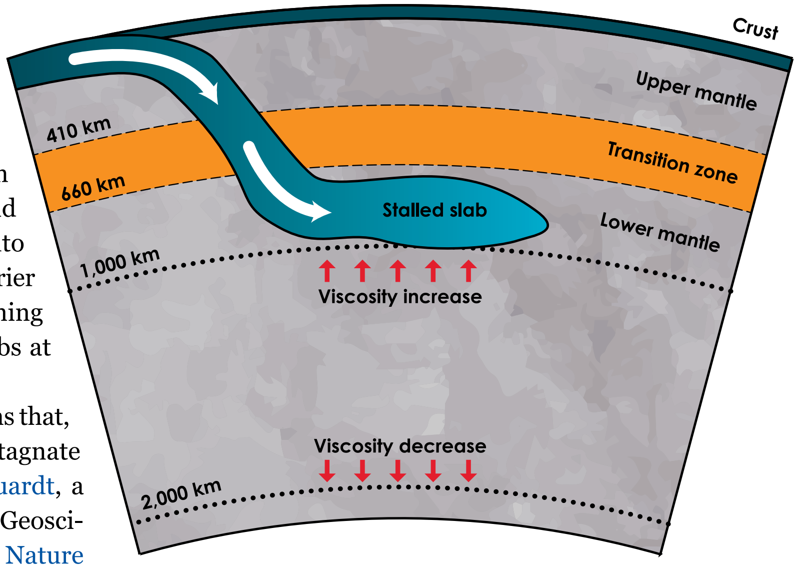
Stalled slabs sometimes stopped by mineral strengthening



In some subduction zones, the downgoing slabs get stuck at depths of about 1,000 kilometers, held up by some unseen barrier that might be related to high-pressure-induced strengthening of minerals in the rocks surrounding the subducting slabs.

Credit: K. Cantner, AGI

Subduction of tectonic plates into the mantle functions as an eons-long recycling system for Earth's crust and lithosphere. But in some subduction zones, the downgoing slabs seem to get stuck at depths of about 1,000 kilometers, held up by some unseen barrier on their journey deeper into the lower mantle. Now, scientists propose that this barrier might be related to high-pressure-induced strengthening of minerals in the rocks surrounding subducting slabs at these depths.

"Seismologists are finding more and more indications that, in some regions of Earth's mantle, subducting slabs stagnate around 1,000 kilometers depth," says Hauke Marquardt, a mineral physicist at the German Research Centre for Geosciences in Potsdam and co-author of the new study in Nature Geoscience. "From a mineral physics perspective," he says, "it's not obvious why slabs should stagnate there" because unlike higher up in the mantle, there are no known structural or compositional changes at that depth that should cause significant changes in the viscosity, or stiffness, of the rock.

To test an alternative hypothesis — that the extreme pressures that slabs experience at 1,000 kilometers depth could be slowing them down — Marquardt and his co-author, Lowell Miyagi of the University of Utah, squeezed samples of ferropericlase in a diamond anvil cell at pressures up to 960,000 atmospheres. Ferropericlase is the second-most abundant mineral in the lower mantle.

They found that at pressures above roughly 240,000 atmospheres — equivalent to those near the boundary between the upper and lower mantle 660 kilometers below the surface — the strength of ferropericlase starts increasing. At pressures equivalent to those 1,000 kilometers down, the mineral's volume is decreased by roughly 20 percent while its strength is increased threefold. When the researchers then simulated how this squeezed ferropericlase should behave when mixed with bridgmanite — the most common mineral in the mantle — they calculated that the viscosity of the mantle rock at a depth of 1,000 kilometers should be about 200 times greater than it is at the 660-kilometer-deep upper-lower mantle boundary. "This isn't a compositional change at this depth," Marquardt says; rather, it involves the physical properties of the minerals themselves changing.

This approach to studying slab stagnation 1,000 kilometers down has not been tried before because of the technical difficulties involved, says Patrick Cordier, a mineral physicist at Lille University in Villeneuve d'Ascq, France, who was not involved in the new study. Cordier wrote an accompanying commentary about the new study in the same issue of Nature Geoscience.

"Only a few teams in the world have the capability to create these very high pressures and do this analysis. This simulation represents pressure in the mantle very well," Cordier says. And pressure, rather than temperature, is likely the most important variable, he says.

Still, studying the influence of temperature may offer clues as to why some subducting slabs stagnate about 1,000 kilometers down — such as those diving beneath the coasts of Indonesia and South America — while those at the Cascadia Subduction Zone and the Japan Trench, for example, keep sinking down into the lower mantle at a steady rate, Cordier says. Experiments in the new study were conducted at room temperature.

"Now that we know that the slabs stagnate because the minerals in [the mantle] are getting stronger under pressure, we can consider what factors would overcome that strengthening in some zones," Cordier says. "Perhaps it is temperature, or maybe something like the grain size of the minerals in the slab."

Marquardt and Miyagi plan to continue their work by studying more samples of bridgmanite, which is notoriously unstable at the low pressures at Earth's surface. They also plan to develop more sophisticated models to test how other variables, such as dip angles or subduction speeds, might affect slab descent. "We don't know yet why some slabs stagnate but not others," Marquardt says. "So far, it hasn't been correlated with a particular [type of] tectonic setting."

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