

Possible chemical leftovers from early Earth sit near the core

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Let's take a journey into the depths of the Earth, down through the crust and mantle nearly to the core. We'll use seismic waves to show the way, since they echo through the planet following an earthquake and reveal its internal structure like radar waves.

Down near the core, there are [zones](#) where seismic waves slow to a

crawl. New research from the University of Utah finds that these enigmatic and descriptively-named ultra-low velocity zones are surprisingly layered. Modeling suggests that it's possible some of these zones are leftovers from the processes that shaped the early Earth—remnants of incomplete mixing like clumps of flour in the bottom of a bowl of batter.

"Of all of the features we know about in the deep mantle, ultra-low velocity zones represent what are probably the most extreme," says Michael S. Thorne, associate professor in the Department of Geology and Geophysics. "Indeed, these are some of the most extreme features found anywhere in the planet."

The study is published in *Nature Geoscience* and is funded by the National Science Foundation.

Into the mantle

Let's review how the interior of the Earth is structured. We live on the crust, a thin layer of solid rock. Between the crust and the iron-nickel core at the center of the planet is the mantle. It's not an ocean of lava—instead it's more like solid rock, but hot and with an ability to move that drives plate tectonics at the surface.

How can we have any idea what's going on in the mantle and the core? Seismic waves. As they ripple through the Earth after an earthquake, scientists on the surface can measure how and when the waves arrive at monitoring stations around the world. From those measurements, they can back-calculate how the waves were reflected and deflected by structures within the Earth, including layers of different densities. That's how we know where the boundaries are between the crust, mantle and core—and partially how we know what they're made of.

Ultra-low velocity zones sit at the bottom of the mantle, atop the liquid metal outer core. In these areas, seismic waves slow by as much as half, and density goes up by a third.

Scientists initially thought that these zones were areas where the mantle was partially melted, and might be the source of magma for so-called "hot spot" volcanic regions like Iceland.

"But most of the things we call ultra-low velocity zones don't appear to be located beneath hot spot volcanoes," Thorne says, "so that cannot be the whole story."

So Thorne, postdoctoral scholar Surya Pachhai and colleagues from the Australian National University, Arizona State University and the University of Calgary set out to explore an alternate hypothesis: that the ultra-low velocity zones may be regions made of different rocks than the rest of the mantle—and that their composition may hearken back to the early Earth.

Perhaps, Thorne says, ultra-low velocity zones could be collections of iron oxide, which we see as rust at the surface but which can behave as a metal in the deep mantle. If that's the case, pockets of iron oxide just outside the core might influence the Earth's magnetic field which is generated just below.

"The physical properties of ultra-low velocity zones are linked to their origin," Pachhai says, "which in turn provides important information about the thermal and chemical status, evolution and dynamics of Earth's lowermost mantle—an essential part of mantle convection that drives plate tectonics."

Reverse-engineering seismic waves

To get a clear picture, the researchers studied ultra-low velocity zones beneath the Coral Sea, between Australia and New Zealand. It's an ideal location because of an abundance of earthquakes in the area, which provide a high-resolution seismic picture of the core-mantle boundary. The hope was that high-resolution observations could reveal more about how ultra-low velocity zones are put together.

But getting a seismic image of something through nearly 1800 miles of crust and mantle isn't easy. It's also not always conclusive—a thick layer of low-velocity material might reflect seismic waves the same way as a thin layer of even lower-velocity material.

So the team used a reverse-engineering approach.

"We can create a model of the Earth that includes ultra-low wave speed reductions," Pachhai says, "and then run a computer simulation that tells us what the seismic waveforms would look like if that is what the Earth actually looked like. Our next step is to compare those predicted recordings with the recordings that we actually have."

Over hundreds of thousands of model runs, the method, called "Bayesian inversion," yields a mathematically robust model of the interior with a good understanding of the uncertainties and trade-offs of different assumptions in the model.

One particular question the researchers wanted to answer is whether there are internal structures, such as layers, within ultra-low velocity zones. The answer, according to the models, is that layers are highly likely. This is a big deal, because it shows the way to understanding how these zones came to be.

"To our knowledge this is the first study using such a Bayesian approach at this level of detail to investigate ultra-low velocity zones," Pachhai

says, "and it is also the first study to demonstrate strong layering within an ultra-low velocity zone."

Looking back at the origins of the planet

What does it mean that there are likely layers?

More than four billion years ago, while dense iron was sinking to the core of the early Earth and lighter minerals were floating up into the mantle, a planetary object about the size of Mars may have slammed into the infant planet. The collision may have thrown debris into Earth's orbit that could have later formed the Moon. It also raised the temperature of the Earth significantly—as you might expect from two planets smashing into each other.

"As a result, a large body of molten material, known as a magma ocean, formed," Pachhai says. The "ocean" would have consisted of rock, gases and crystals suspended in the magma.

The ocean would have sorted itself out as it cooled, with dense materials sinking and layering on to the bottom of the mantle.

Over the following billions of years, as the mantle churned and convected, the dense layer would have been pushed into small patches, showing up as the layered ultra-low velocity zones we see today.

"So the primary and most surprising finding is that the ultra-low velocity zones are not homogenous but contain strong heterogeneities (structural and compositional variations) within them," Pachhai says. "This finding changes our view on the origin and dynamics of ultra-low velocity zones. We found that this type of ultra-low velocity zone can be explained by chemical heterogeneities created at the very beginning of the Earth's history and that they are still not well mixed after 4.5 billion years of

mantle convection."

Not the final word

The study provides some evidence of the origins of some ultra-low velocity zones, although there's also evidence to suggest different origins for others, such as melting of ocean crust that's sinking back into the mantle. But if at least some ultra-low [velocity](#) zones are leftovers from the early Earth, they preserve some of the history of the planet that otherwise has been lost.

"Therefore, our discovery provides a tool to understand the initial thermal and chemical status of Earth's [mantle](#)," Pachhai says, "and their long-term evolution."

More information: Internal structure of ultralow-velocity zones consistent with origin from a basal magma ocean, *Nature Geoscience* (2021). [DOI: 10.1038/s41561-021-00871-5](https://doi.org/10.1038/s41561-021-00871-5)

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