

What goes down, must come up: Geoscientists offer new model for degassing of Earth's mantle

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A new analysis of the processes that constantly stir the Earth's deep mantle is helping to explain how the mantle holds onto a portion of ancient noble gases that were trapped during the Earth's formation.

The research, which appears this week in the journal *Nature*, takes aim at a question that has vexed geoscientists for years: how to reconcile leading theories about the convection of Earth's [mantle](#) with observations of ancient noble gases in [volcanic rocks](#). Researchers at Rice University

and Harvard University developed a new model to explain how noble gases -- elements like helium, neon and argon -- are lost from the Earth's interior during mantle convection.

"Most existing models find that convection should have left the mantle extensively depleted in ancient noble gases, unless part or all of the lower mantle has been somehow isolated," said study co-author Helge Gonnermann, assistant professor of Earth science at Rice. "We set out to see if there was a mechanism that could both preserve ancient noble gases in the lower mantle and still be consistent with the existing framework for whole mantle convection."

On human timescales, the Earth's surface seems to change very little. But geoscientists know the planet's topmost layer, or lithosphere, is actually a series of interlocking tectonic plates that are in constant motion. When plates collide, mountain ranges form, and when they pull apart, as happens deep beneath the oceans, new crust forms by partial melting of the uppermost mantle. Plates also slide one beneath another in a process known as subduction, and seismologists discovered about 15 years ago that some subducted plates plunge deep into the Earth. In some cases, they even sink across the mantle transition zone, a layer about 660 kilometers deep that divides the Earth's upper and lower mantle.

"This was a real problem because the prevailing view in geoscience was that only the [upper mantle](#) was involved in this plate tectonic recycling process," Gonnermann said. "One reason people believed this was because there appear to be relatively high concentrations of ancient noble gases in ocean island basalts, volcanic rocks found at volcanic island chains, such as Hawaii."

One of these ancient noble gases is helium-3, an isotope of [helium](#) that isn't created by any process inside the Earth. Consequently, scientists know that virtually all the helium-3 found on Earth is left over from the

planet's formation. Helium-3 tends to get released from the mantle when it rises to form new crust. As the mantle cycles, from mantle to ocean crust and back to mantle again, geochemists expect to see less and less helium-3. While this is what's observed in most basalt rocks formed from lavas erupting at mid-ocean ridges, there are exceptions, particularly in basalt rocks from Hawaii and other volcanic ocean island chains.

Ocean island chains are thought to form when mantle plumes rise from the lowermost mantle to the Earth's surface, where the mantle undergoes partial melting to produce basalt magma.

"The presence of ancient noble gases in these basalts implies that they have remained locked inside the lower mantle since the Earth formed about 4.5 billion years ago," Gonnermann said. "In contrast, most of these ancient noble gases appear to have leaked out of the upper mantle, because the plate tectonic recycling process allows noble gases to escape with the basalt magma as it continuously forms new ocean crust at mid-ocean ridges."

In the new study, Gonnermann and longtime collaborator Sujoy Mukhopadhyay, a Harvard geochemist, developed a model that could reconcile convection involving the lower mantle with the helium-3 measurements found in ocean island basalts.

The model suggests that both the upper and lower mantle are involved in convection, but it affects them in different ways. Whereas the upper mantle has been extensively degassed through repeated tectonic cycling, the lower mantle has been recycling approximately once during the past 4.5 billion years.

Continuous mixing of subducted plates into the lower mantle has been diluting the concentrations of ancient noble gases there. Instead of

extracting ancient noble gases at their original concentrations, progressively smaller amounts are extracted at any given rate of tectonic cycling. Consequently, about 40 percent of the ancient helium-3 can still be present in the lower mantle, even though it may have undergone one complete tectonic cycling over the past 4.5 billion years.

"Contrary to the conventional view that tectonic cycling of the lower mantle should result in extensive mixing between the lower and upper mantle, thereby erasing any differences in helium-3, we find that much of the tectonic cycling of the lower mantle essentially bypasses the upper mantle," Mukhopadhyay said. "What goes down must come up: Slabs that subduct and mix into the lower mantle are balanced by mantle plumes, rich in helium-3, which rise from the lower mantle to the Earth's surface without mixing significantly as they traverse the upper mantle."

Source: Rice University ([news](#) : [web](#))

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