Press Release

August 12, 2025

To Media Outlets

Chiba Institute of Technology
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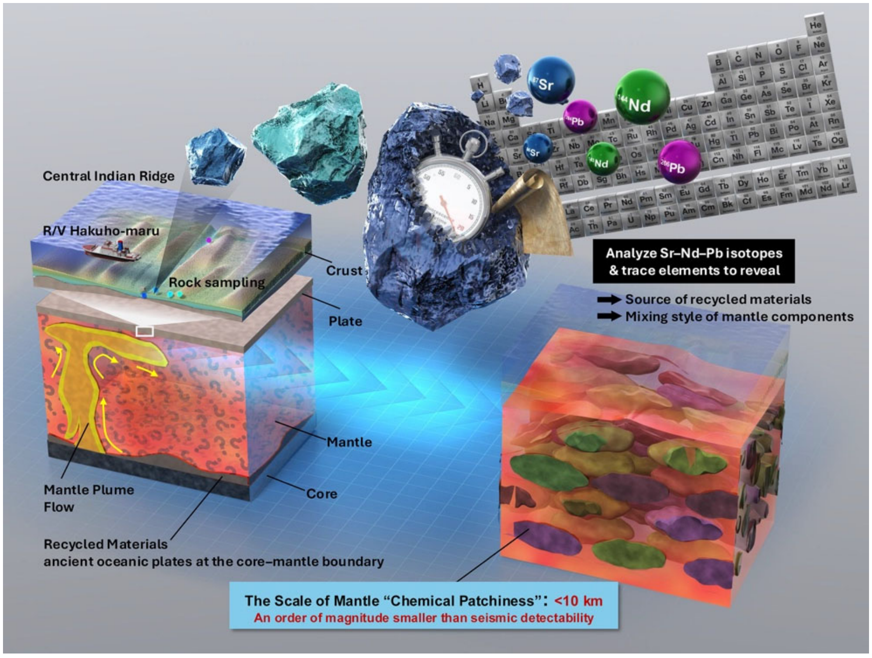
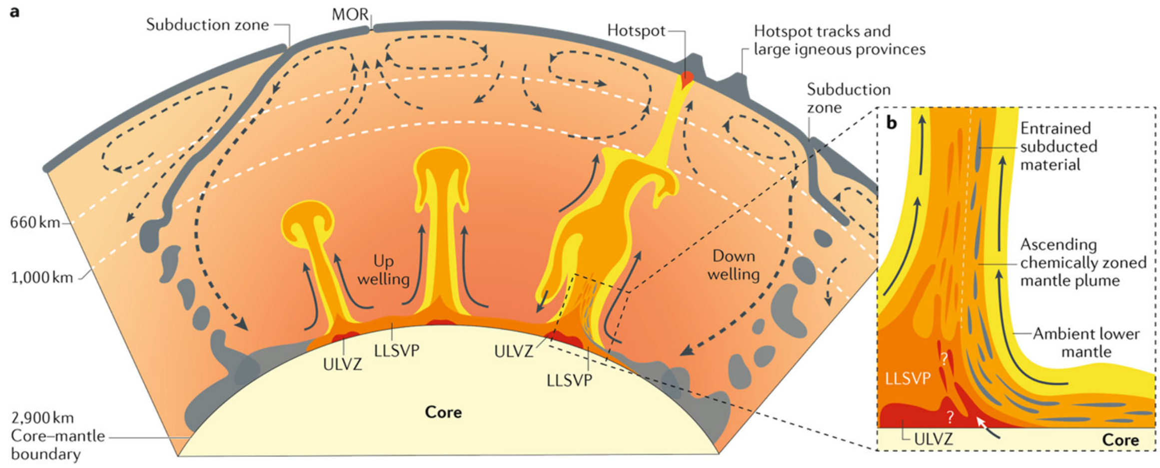
Mantle "Chemical Patchiness": First Direct Evidence of Its Spatial Scale

— New insights into the upper mantle from mid-ocean ridge lavas reveal that it is more capable of homogenizing than previously thought —



A research team led by Dr. Shiki Machida (Senior Research Scientist at the Ocean Resources Research Center for Next Generation (ORCeNG), Chiba Institute of Technology), in collaboration with Prof. Kyoko Okino (Atmosphere and Ocean Research Institute, The University of Tokyo), the Graduate School of Engineering (UTokyo), and the National Museum of Nature and Science, discovered that the spatial scale of chemical heterogeneity in the upper mantle—supplied by mantle plumes rising from the deep Earth—is less than 10 kilometers. This result is based on direct geochemical evidence from lavas erupted at the Central Indian Ridge.

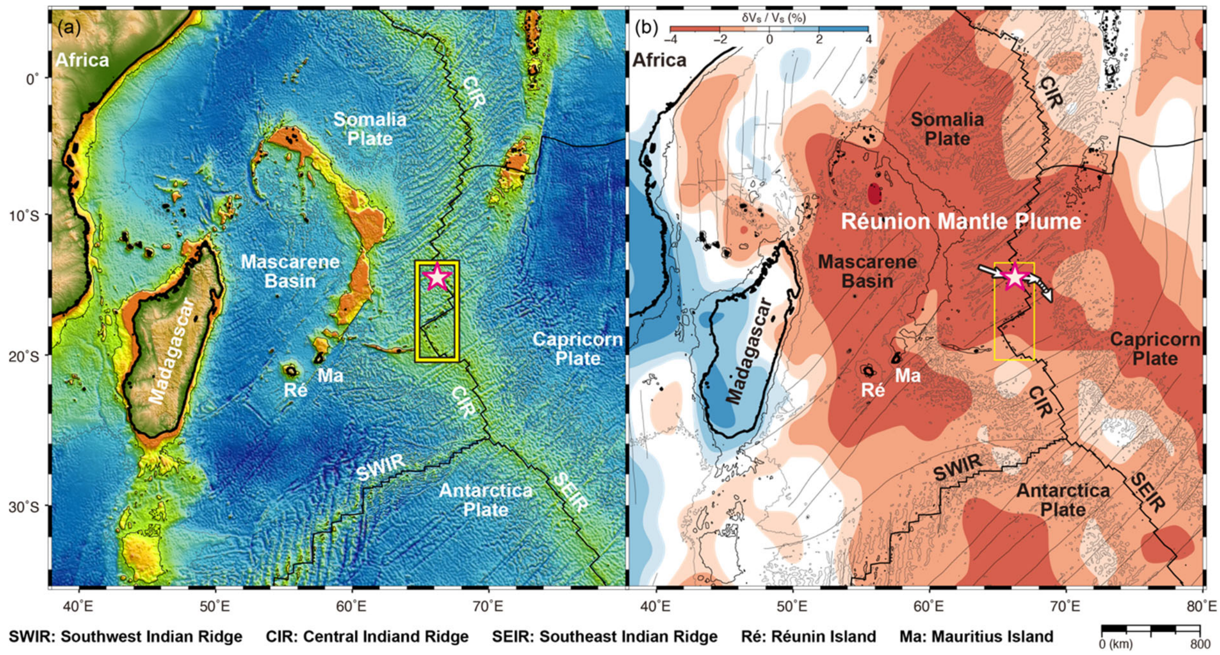
Detailed chemical analyses revealed that the source of this heterogeneity is recycled materials—rocks from ancient oceanic plates that once existed at Earth's surface, subducted into the deep mantle, and were later brought back by mantle plumes.



Schematic of Earth's internal structure. This illustration shows how heterogeneity forms in the mantle (Adapted from Koppers et al., 2021). Surface plates (gray) subduct into the Earth's interior from trenches, accumulate at the core–mantle boundary as recycled material, and mix into mantle plumes (orange and yellow).

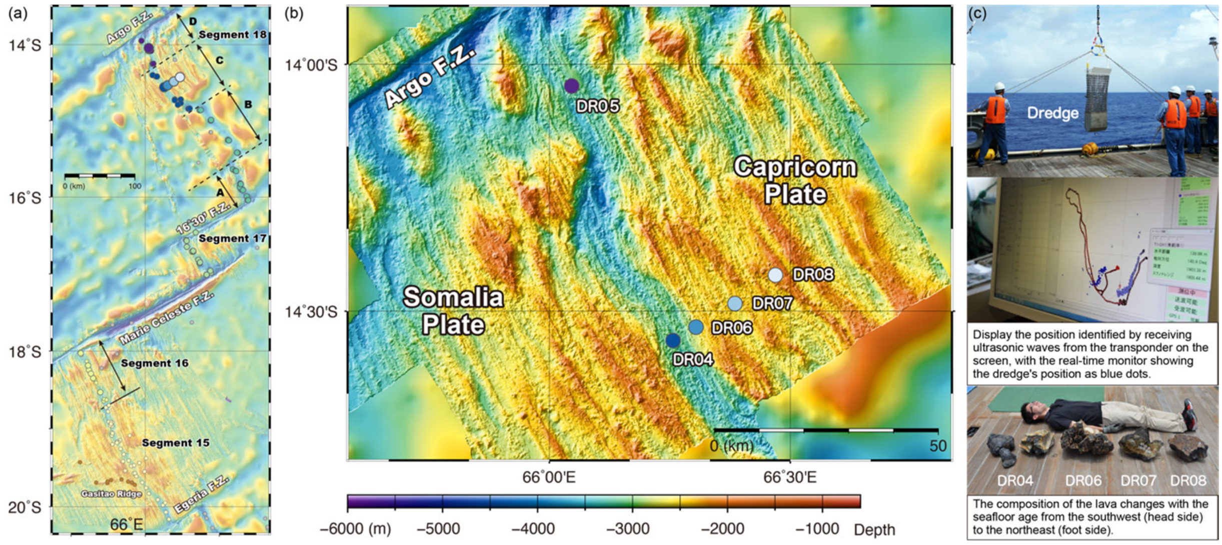
By analyzing lava compositions in relation to seafloor spreading and plate movement, the team quantitatively constrained the spatial scale of heterogeneity in the upper mantle. The estimate of <10 km is more than ten times smaller than the typical ~100 km scale previously inferred from seismic data.

To explore the initial structure of mantle heterogeneity, the research team conducted a research cruise (KH-15-5) on the R/V Hakuho-maru in 2015. Lava samples were dredged from five locations along and across segments 18C and 18D of the Central Indian Ridge (14–15°S, 66–67°E), an area where seismic observations indicate that the Réunion mantle plume flows laterally beneath the ridge.



Ridge-hotspot interactions in the Central Indian Ridge and Réunion hotspot regions. (a) Seafloor topography. (b) Seismic tomography at a depth of 120 km from the seafloor (modified from Barruol et al., 2019), showing lowvelocity anomalies (red) interpreted as hotter mantle material. The Réunion plume rises beneath the Mascarene Basin and flows laterally, intersecting the ridge. The pink star marks the study area. The white arrows illustrate direction of the plume flow beneath the study area.

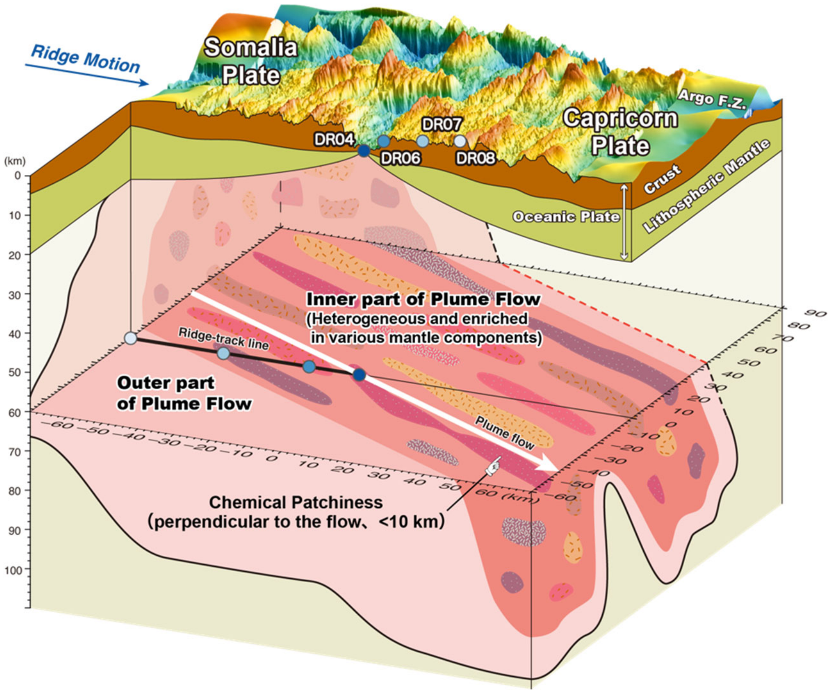
Sampling included dredging perpendicular to the ridge—a method rarely used in past studies. Transponders enabled high-precision tracking of the dredge position, allowing accurate correlation between sample location, seafloor age, and lava chemistry. This method captured a two-dimensional spatial picture of mantle heterogeneity, not just along the ridge.



Sampling sites and dredging operations. (a) Past sampling along the ridge axis. (b) This study's sampling “across” the ridge axis. (c) Dredging with acoustic transponders for real-time monitoring.

Lava compositions were then visualized in three-dimensional isotope space, revealing previously undetected geochemical patterns. These findings pointed to previously unrecognized mantle components.

Numerical mixing models revealed that each site exhibited distinct mixing styles, implying that the recycled materials within the plume-induced mantle are distributed heterogeneously over spatial scales of less than 10 km.



Fine-scale mantle heterogeneity beneath the Central Indian Ridge. 3D seafloor view looking from the southeast, which is based on the topographic map in the previous figure. The mantle top, below the oceanic plate, is cut away to show the lateral flow of plume material. Ridge migration along the “ridge-track line” (black line) and volcanic activity occurred from DR08 (1.43 million years ago) to DR04 (present), with lava chemistry varying across sites due to mantle patchiness.

This study suggested that even at just after the plume was supplied, the upper-mantle already exhibited fine-scale patchiness. This finding challenges earlier assumptions that mantle heterogeneity started at much larger scales, requiring long periods to homogenize. Instead, the fine structure implies a mantle that can homogenize more rapidly than previously thought.

Future Outlook:

This study provides the first direct geochemical determination of the spatial scale of mantle heterogeneity. This work lays the foundation for future numerical modeling studies of mantle convection and mixing.

Earth’s mantle behaves like a vast recycling system, where old oceanic crust sinks into the deep interior and is eventually returned to the surface via mantle plumes. As this cycle continues, small-scale heterogeneities form and gradually homogenize, creating planetary-scale “metabolism.” Understanding the scale and rate of this process has major implications for volcanic activity, geodynamics, and the Earth’s evolution.

Researcher's Comment:

"Peering into the Earth's mantle is like trying to read a message written in invisible ink. We cannot see it directly, so we rely on clues—like lava—to tell its story. Analyzing those clues, plotting data in 3D, and unraveling the mixing of hidden materials was slow, meticulous work. But when the patterns finally made sense, it felt as if the mantle had whispered its secret to us. I hope this discovery marks a small but meaningful shift in how we understand our planet's inner life."

Papers:

Shiki Machida, Kyoko Okino, Kana Ashida, Shigekazu Yoneda, and Yasuhiro Kato, “Analyses across a mid-ocean ridge give the scale of plume-fed heterogeneity,” *Lithos*: July 7, 2025, doi: 10.1016/j.lithos.2025.108175.

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