Oceans apart: New research suggests that ocean-crust formation is a dynamic process

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Rock samples from the East Pacific Rise were obtained by the Isis ROV during the RRS James Cook cruise in 2008. Photo: Johan Lissenberg, Christopher MacLeod and the JC21 Scientific Party

Three-fifths of Earth's crust lies underwater, spread out along the seafloor. More than four cubic miles of ocean crust forms each year, constantly regenerating like new skin across the globe. This ocean crust arises along mid-ocean ridges — underwater mountain ranges that ripple along the ocean floor like jagged scars.

These ridges line the boundaries of tectonic plates, which slowly shift around the planet. As plates pull apart, magma from the underlying mantle erupts at the surface, eventually solidifying as new crust. In time, this newly formed crust moves with the migrating plate away from the ocean ridge, leaving room for newer crust to take its place. The speed of crust formation varies from ridge to ridge: Some fast-spreading ridges produce up to six inches of new crust per year, while slower-spreading ridges creep along at just two inches per year.

While the general process of ocean-crust formation — also known as seafloor spreading — is well understood, it's not clear what happens within the volatile deep-sea environment that produces new crust. Matthew Rioux, a research scientist in MIT's Department of Earth, Atmospheric and Planetary Sciences (EAPS), describes the environment at a mid-ocean ridge as an indecipherable "mush zone": part liquid magma, part crystallized rock. Understanding how this zone behaves may give scientists a better idea of how fast oceanic crust forms.

Now, in a paper published in the current issue of Nature Geoscience, Rioux and his colleagues have found that ocean crust formation may be a much slower and more dynamic process than previously thought.

Rioux worked with Sam Bowring, a professor of geology at MIT, and postdoc Noah McLean — along with researchers at the University of Hawaii, Cardiff University in the U.K. and the Woods Hole Oceanographic Institution — to analyze crustal fragments from the East Pacific Rise, a mid-ocean ridge 1,200 miles off the west coast of South America that's one of the fastest-spreading ridges in the world. Scientists have thought that magmas that form new crust at fast-spreading ridges rise up from the depths, quickly crystallize and then push away from the ridge to form new ocean floor.

To test this theory, Rioux and his colleagues analyzed crustal fragments recovered from outcrops at two locations in the East Pacific Rise and determined the age of different parts of each rock. They reasoned that if existing theories were correct and fast-spreading ridges produce new crust quickly, every part of a rock should be of a similar age — having crystallized more or less simultaneously.

However, the team found quite the opposite. Within each rock, the researchers looked for trace amounts of zircon, a mineral often used to determine a rock's age. When zircon crystallizes, it takes in uranium, which slowly decays to lead. Measuring the ratio of uranium to lead gives scientists a precise estimate of the rock's age.

To isolate zircon, the team ground rock to a powder, then separated out zircon based on its density and magnetic properties. The researchers then dated each microscopic grain of zircon, and found a surprising result: Two of four rock samples contained zircon with a wide range of ages, meaning different parts of the rock crystallized, or turned into new crust, at different times.

Rioux says there may be several explanations for the findings. For example, the "mush zone" at a mid-ocean ridge may be "recharged" by new magma spewing out from the mantle — as new crust starts to solidify, magma reheats it, turning parts of it back into liquid that hardens again later on. Another explanation may be that magma "intrudes" into a long-crystallized rock. Existing zircons in the rock, resistant to melting, would remain as new magma solidified to form younger zircons.

Such scenarios would not be unexpected at slower-spreading ridges, where new crust has more time to interact with liquid hot magmas. In contrast, fast-spreading ridges pull crust away quickly, and magmas theoretically would not have much time to remelt a rock. The results, Rioux says, suggest that ocean-crust formation takes much longer at fast-spreading ridges than scientists had expected.

Jonathan Snow, an assistant professor of earth and atmospheric sciences at the University of Houston, says in light of their results, the researchers' dating techniques may be applied in the future to investigate other mid-ocean ridges in the world.

"They reached the very surprising result that magma cooling was a much more protracted affair than had been predicted," Snow says. "It's a good 'first time out' for a new generation of radiometric techniques applied to the ocean floor."

"It's a step forward in our understanding of how these ridges work," Rioux says. "Dating of the oceanic crust will allow us to better understand how much variation there is between different mid-ocean ridges, how those variations relate to tectonic setting, and ultimately what the data tell us about the magmatic processes during formation of a very large fraction of the Earth's crust."

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