Volcanism at the Slowest Spreading Ocean Ridges

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The strong outer shell of Earth, the lithosphere, is broken into rigid plates that move away from each other at mid-ocean ridges and collide at subduction zones. Although we have unmistakable proof of this motion, it is still unclear how this global process of plate tectonics functions. One popular idea is that plate motion is lubricated, both at the base of the plates and at the margins between plates, by fluids – either water or magma. What happens, then, at the slowest spreading ridges, where very little molten magma appears to make it to the surface? How much magma is actually present beneath the surface, and how is it distributed?

Answering these questions requires a combination of data collection and numerical modeling. I was fortunate to receive a grant from DOEI to develop a general modeling toolkit to address the generation and propagation of magma at mid-ocean ridges. The results of this study, which have been submitted to the journal, *Geophysical Research Letters*, show that magma is probably present at depth but cannot traverse the thick, cold lithosphere of the slowest spreading ridges. Plate lubrication appears possible, even though little volcanism is visible at the surface of the ocean ridge.

The slowest spreading ridges on Earth tend to be in rather inaccessible locations, such as underneath the Arctic ice or in the harsh environment of the “Furious Fifties” in the waters south of Africa. In spite of the difficulties, WHOI mounted several expeditions to the southwest Indian ridge in the early 2000s. These expeditions, headed by geologist, Henry Dick, revealed a new type of seafloor spreading, now qualified as “ultraslow,” in which much of the ridge axis is covered not by oceanic crust but by mantle rock. Instead of being distributed along the axis, volcanism is concentrated in very large seamounts – underwater volcanoes.

What does this paucity of volcanism mean? At mid-ocean ridges, mantle melts as it rises to fill the gap between spreading plates. The magma then collects to form the oceanic crust. However, if the spreading is relatively slow, the hot mantle should cool down as it rises and melting should stop. Are ultraslow ridges so cold that no magma is being produced? Together with WHOI geophysicist, Mark Behn, we reexamined estimates of how much magma is produced. In fact, enough magma should be produced at ultraslow ridges to create 3-kilometer-thick crust continuously along the axis. But this crust is not observed geophysically. We realized that, at ultraslow ridges, the magma is produced entirely at depths greater than 25 kilometers. Therefore, it seems that magma has trouble traversing the thick, cold lithosphere and is, instead, trapped along the way.

Magma produced underneath a mid-ocean ridge is lighter than the mantle from which it is extracted. Furthermore, it is somewhat corrosive. Therefore, it is expected that magma will follow porous channels, migrating rapidly up toward the surface until it reaches the cold lithosphere. There, it either forces the opening of a crack and continues to move upward or travels instead along the base of the lithosphere, searching for the point where the lithosphere is thinnest. At the slowest ridges, the lithosphere is so thick that cracks are unlikely to form. Therefore, it should be possible to test whether the magma, impeded by thick lithosphere, spreads out and pools at the points where the lithosphere is thinnest. Will ascending magma manage to find these locations and collect to form a seamount?

DOEI funding enabled me and collaborator Mark Behn to test this hypothesis using a model in which we analyzed seamounts at an ultraslow ridge. Our model indicates the movement of magma in three dimensions underneath a ridge. We found that the seamounts are, in fact, located at portions of the ridge where the lithosphere is thinnest.

This work not only sheds new light on magma movement beneath the slowest spreading ridges, but also can be applied to many other places. The 3D modeling capacity developed for this project has enabled MIT/WHOI Joint Program Student Trish Gregg to estimate the thermal state of many mid-ocean ridges all over the globe. By comparing it to the gravity field of these ridges, she inferred different modes of magma transport in the crust at fast and slow ridges. This work was published in July in the scientific journal *Nature*. Finally, the initial work conducted with this DOEI support was key to obtaining a grant from the National Science Foundation to relate magma movement to the geochemistry at ultraslow and other mid-ocean ridges.

– Laurent Montesi