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Seafloor spreading without magma

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Mid-ocean ridges are typically shaped by a combination of magmatic and tectonic processes. However, large sections of ultraslow-spreading ridges barely receive any magma, and are mainly composed of altered mantle units exposed at the seafloor by large-offset detachment faults. Here, we use analytical and numerical models to argue that this unique architecture may primarily reflect interactions between deformation and deep hydrothermal processes.

Amagmatic sections of ultraslow-spreading ridges form through slip on cross-cutting detachment faults that initiate sequentially, and feature unusually deep seismicity (down to ∼35 km beneath the ridge axis). These settings also show evidence for pervasive hydrothermal activity down to ∼15 km below seafloor. Such extreme characteristics challenge our understanding of mid-ocean ridge processes in several ways. First, a thick brittle lithosphere should favor moderate-offset faults not unlike those found at the East-African or Baikal Rifts, as opposed to long-lived detachments. Second, detachment faulting at slow-spreading ridges is thought to require a sizeable fraction of plate separation to be accommodated by magmatic emplacement, which is clearly not the case at ultraslow ridges. Finally, it is unclear how vigorous fluid circulation can be sustained at great depths in the absence of a magmatic heat source.

We propose that while deep hydrothermal circulation might be initiated by the heat of sporadic magma intrusions, it is likely sustained by grain-scale cracking due to thermal stresses and volume changes induced by alteration reactions. We parameterize these processes in a porous convection model and investigate the time scales on which young oceanic lithosphere can become permeable. Our models suggest that a magmatic intrusion event every 10–100 kyr is sufficient to sustain fluid circulation in low-permeability mantle units. Next, we incorporate a simplified parameterization of hydrothermal alteration into a 2-D model of ultraslow-ridge tectonics. Our simulations suggest that the growth of large-offset faults in thick lithosphere requires both significant loss of strength in the fault zones—perhaps due to the precipitation of weak phases such as talc—and moderate, yet pervasive serpentinization of the fault-bounded blocks. This suggests that active hydrothermal circulation and alteration are essential in shaping mid-ocean ridges in the absence of a robust magma supply.