Geophysical Research Abstracts
Vol. 20, EGU2018-11227-1, 2018
EGU General Assembly 2018

Rapid propagation of small-scale mantle upwelling instabilities along the Reykjanes Ridge

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The Reykjanes Ridge is a type-setting for examining how crustal structure may reflect the dynamics of small-scale mantle upwelling. This ridge displays prominent changes in axial segmentation and flanking V-shaped crustal ridges overlying a strong regional gradient in mantle melting. Here we focus on geophysical observations indicating that these crustal features can be explained by upper mantle small-scale upwelling instabilities propelled along-axis by regional gradients in mantle properties.

The typical pattern of crustal accretion at slow spreading ridges involves crustal segmentation at a scale of 50-100 km, even where there is little or no offset of the axis. The segment boundaries are often formed by non-transform discontinuities (NTDs) associated with thin crust and are thought to delimit individual cells of small-scale mantle upwelling centered beneath each segment. The NTDs can migrate slowly and erratically even when plate spreading is stable, forming troughs that are not parallel to spreading flowlines. The migrations are most likely due to small and random variations in mantle properties affecting the dynamics of the small-scale upwelling instabilities. In contrast, the North Atlantic basin flanking the Reykjanes Ridge displays a prominent and long-lived residual depth anomaly centered beneath Iceland and extending southward to the Charlie-Gibbs Fracture Zone. This indicates a corresponding large mantle melting anomaly causing the increasing crustal thicknesses toward Iceland.

Following continental breakup, the Reykjanes Ridge originated as a $\sim$1000 km long and linear spreading center overlying the pre-existing gradient in mantle melting. The ridge was unsegmented but displayed subtle evidence of flanking V-shaped crustal ridges. We interpret these early-formed V-shaped ridges as due to small-scale upwelling instabilities rapidly propagating along the linear ridge propelled by the strong and systematic regional gradient in mantle properties. Near magnetic anomaly 17 ($\sim$37 Ma) the direction of spreading abruptly changed by about 30° and the ridge became segmented and offset by transform faults. This change in segmentation was likely a mechanical effect of the new opening direction on the upper rigid lithosphere. Immediately thereafter the spreading segments migrated laterally to remove the offsets and re-establish their original linear configuration, even though they now had to spread obliquely to do this. We interpret the reassembly of the ridge as due to the persistence of the deeper, low viscosity wet melting regime that remained linear following the abrupt change in opening direction. As the segmentation was progressively eliminated from north to south, prominent V-shaped crustal ridges formed, which we interpret as reflecting the continued rapid along-axis propagation of small-scale upwelling instabilities propelled by the regional mantle melting gradient. Thus, the tectonic evolution of the North Atlantic is shaped by axially propagating small-scale upwelling instabilities that control the segmentation and crustal accretion patterns of the entire basin.