**Reykjanes Ridge Evolution by plate kinematics, propagating small-scale mantle convection, and a regional thermo-chemical mantle anomaly**

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# Abstract

The Reykjanes Ridge is the part of the Mid-Atlantic Ridge between the Bight transform fault and Iceland. It has a distinct evolution from the rest of the Mid-Atlantic Ridge, originating as one arm of a RRR triple junction that separated Greenland, North America and Eurasia. The Reykjanes Ridge initiated as a linear spreading center between Greenland and Eurasia following breakup around anomaly 24 (~55 Ma). It spread stably in this linear configuration until about anomaly 17 (~34 Ma) when Labrador Sea spreading ceased joining Greenland to North America, resulting in an abrupt ~30° change in opening direction across the Reykjanes Ridge, and converting the triple junction into a single ridge offset at the Bight transform fault. In response, the Reykjanes Ridge reconfigured to an orthogonal stair-step configuration with short spreading segments offset by transform faults oriented in the new opening direction. Without further changes in opening direction, the ridge then promptly began to systematically and progressively eliminate the just-formed stair-step boundary from north to south to reestablish its original linear axis, even though it now had to spread obliquely to do this. Thicker crust and prominent V-shaped crustal ridges and troughs formed diachronously as the ridge became linear and oblique. The re-establishment a linear ridge is now nearly complete to the Bight transform fault.

The tectonic reconfigurations of the Reykjanes Ridge took place over a regional mantle melting anomaly, most pronounced at Iceland and extending southward to the Charlie Gibbs transform fault. The anomaly is manifest in the axial depth profile of the Reykjanes Ridge, forming a 3000 m depth valley near the Bight transform fault progressively shallowing northward to an axial high reaching sea level at the Reykjanes peninsula on Iceland. A similar large basement depth anomaly is evident on both ridge flanks to the initiation of spreading, indicating that it has been a long-lived aspect of the mantle beneath the Reykjanes Ridge.

Here we hypothesize that the evolution of the Reykjanes Ridge reflects normal plate boundary processes, typical of slow spreading ridges, but enhanced and directed by a pronounced regional gradient in mantle properties. Gravity studies indicate a moderate regional asthenospheric temperature anomaly (~75°C). Axial lavas display elevated water contents increasing toward Iceland. These effects should both increase mantle melting and decrease mantle viscosity toward Iceland, promoting small-scale mantle convection. Small-scale mantle upwelling instabilities are thought to be significant at slow spreading ridges, giving rise to the prominent crustal segmentation and bulls-eye mantle Bouguer gravity lows characteristic of these ridges. The upwelling cells are temporally episodic, producing ridge flank crustal thickness variations across individual ridge segments. Where ridge offsets are small the instabilities may propagate, probably due to small and random mantle heterogeneities, forming broad V-shaped non-transform discontinuities. At the Reykjanes Ridge its linear geometry and the strong gradient in mantle properties away from Iceland rapidly propel mantle upwelling instabilities along axis, forming the ridge flank narrow V-shaped crustal ridges. These rapidly propagating cells likely maintained the linearity of the axis, as well as prevented the development of spatially stable segmentation. In effect, the V-shaped crustal ridges and troughs are the expression of segmentation when the axial upwelling instabilities propagate rapidly along a linear axis. When the Greenland-North America ridge failed, the abrupt change in opening direction was accommodated mechanically in the lithosphere by breaking of new plate boundary segments orthogonal to the new opening direction. However, this abrupt segmentation of the surficial strong lithospheric plate boundary was decoupled from the deeper low viscosity voluminous asthenospheric melting regime, which persisted in its linear geometry. The offset between the new lithospheric plate boundary segments and the deeper linear melting regime induced migration of the plate boundary segments to re-establish their original configuration over the linear melting regime. During the time when the plate boundary was offset, the propagating upwelling instabilities likely continued along the deep linear melting regime, but crustal accretion was controlled by the segmented lithospheric plate boundary, so that V-shaped ridges could not form and instead a more typical-looking segmented crust developed. As the segment offsets diachronously merged to a linear axis from north to south, V-shaped crustal ridges were again formed along the now linear but oblique axis.

The cause of the regional North Atlantic melting anomaly is not explicitly addressed by our data. Seismic tomographic images suggest that a broad thermo-chemical anomaly may extend into the lower mantle and may have slowly upwelled to its present position. Other studies suggest the anomaly is limited to the upper mantle and formed by ancient subduction. In either case the mantle thermo-chemical anomaly probably passively existed long before North Atlantic rifting beneath the thick continental lithosphere and below its solidus depth. On continental rifting and lithospheric thinning, this mantle would have been advected above its solidus where melting would have induced vigorous small-scale mantle convection. Due to the gradient in properties of the thermo-chemical anomaly away from what becomes Iceland, the upwelling cells would have propagated along the developing rift and succeeding spreading axis helping configure its original linear geometry at breakup and preference for a linear axis even favoring oblique spreading to achieve this. Our conceptual model suggests that broad thermo-chemical mantle anomalies may passively exist beneath thick continental lithosphere and induce voluminous volcanism on rifting through small-scale mantle convection, thus explaining the coincidence of anomalous volcanism and rifting without need for the simultaneous arrival of a coextensive mantle plume. On transition to spreading, gradients within the mantle thermo-chemical anomaly may induce propagation of the small-scale convective cells along a linear axis, leading to diachronous ridge flank crustal thickness variations without mantle plume flow.