Genesis of the Iceland melt anomaly by plate tectonic processes

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ABSTRACT

Iceland is the best studied, large-volume, active volcanic region in the world. It features the largest subaerial exposure of any hotspot at a spreading ridge, and it is conventionally attributed to a thermal plume in the mantle. However, whereas the apparently large melt productivity and low-wavespeed mantle seismic anomaly are consistent with this attribution, at any more detailed level, the observations are poorly predicted by the plume hypothesis. There is no time-progressive volcanic track, the melt anomaly having been persistently centered on the Mid-Atlantic Ridge. Spatial variations in crustal structure are inconsistent with the southeastward migration that is required of a plume fixed with respect to other Indo-Atlantic hotspots. The mantle seismic anomaly weakens with depth and does not extend into the lower mantle. Estimates of excess temperature using a broad range of methods are inconsistent with a mantle potential temperature anomaly greater than a few tens of K. Much of the lava erupted in Iceland has geochemistry little different from normal mid-ocean ridge basalt, and the detailed spatial geochemical pattern bears little resemblance to what is predicted for a plume beneath central Iceland. We propose an alternative model in an attempt to explain the observations at Iceland with fewer difficulties. Our model involves only shallow plate tectonic processes and attributes the large melt volume to the remelting of subducted oceanic crust trapped in the Caledonian suture in the form of eclogite or mantle peridotite fertilized by resorbed eclogite. Delaminated continental mantle lithosphere may also be involved. Such a source can produce several times more melt than pure peridotite without the need for high temperatures. The longevity of anomalous volcanism at the Mid-Atlantic Ridge at the latitude of Iceland is attributed to its location on a Caledonian structure that runs transversely across the north Atlantic. Many aspects of the geochemistry of Icelandic lavas fit this model, which also provides an explanation for the high maximum helium isotope ratios observed there. The “depleted plume component” may be derived from abyssal olivine gabbro cumulates and the “enriched plume component” from recycled enriched material that forms part of the crustal section of subducted slabs. Such a model for the Iceland melting anomaly raises new questions concerning how much thermal energy can be generated by isentropic upwelling of eclogite at a ridge, the location of the homogenizing reservoirs required, and the mechanism by which fertile material is incorporated into the asthenosphere beneath new oceans. Most fundamentally, if validated, such a model can explain the generic observations associated with hotspots as shallow processes associated with plate tectonics, and thus raises the question of whether thermal plumes are required in general in the Earth.