Mantle source composition, melting regime and mantle flow in the NE Atlantic

Reidar G. Trønnes (rgt@hi.is), Nordic Volcanological Institute, University of Iceland

Covariations of radiogenic isotope ratios and trace elements ratios in Icelandic and NE Atlantic basalts indicate their formation by progressive melting of heterogeneous mantle sources. Alkaline basalts from the volcanic flank zones in Iceland, Jan Mayen and Vesteris Seamount are formed by low degrees of partial melting of the heterogeneous mantle and extracted mostly from the fertile source components. The enriched, alkaline melt fractions are gradually diluted by melts from increasingly depleted and refractory source components as melting progresses. Olivine tholeiites of the Icelandic rift zones and nearby ridges are formed by advanced melting of depleted sources.

The NE Atlantic tholeiites and alkaline basalt share important geochemical features that are distinct in a global perspective, including high $^{87}Sr/^{86}Sr$ for a given $^{143}Nd/^{144}Nd$, low $^{207}Pb/^{206}Pb$ and high U/Pb and Nd/Pb. The low-degree alkaline melts differ from the tholeiites by their higher concentrations of large ion lithophile elements and steep chondrite-normalized REE-patterns. The predominant fertile and refractory components have HIMU-tendencies in the form of high U/Pb and U/Th ratios and high concentrations of Nb, Ta and other HFS-elements. Both components have $^{207}Pb/^{204}Pb$ ratios below the Northern Hemisphere Reference Line and low to moderate $^{206}Pb/^{204}Pb$ ratios, indicating an origin as recycled oceanic lithosphere of Paleozoic age, probably from subducted Iapetus ocean floor.

The fertile and refractory components appear to represent upper and lower portions of recycled oceanic lithosphere, respectively. This inference is based largely on O-isotopic data consistent with hydrothermal seafloor alteration at low and high temperatures, producing low $\delta^{18}O$ values in the upper basaltic crust and low $\delta^{18}O$ in the lower oceanic lithosphere with cumulate sequences and residual mantle harzburgite. The primitive rift zone tholeiites are further characterized by positive Sr- and Eu-anomalies in chondrite-normalized REE-diagrams, indicating that their mantle sources contain significant components of plagioclase-bearing cumulates. Another feature of alkaline and tholeiitic basalts from Iceland, Jan Mayen, Vesteris Seamount and most of the NE Atlantic ridge segments is positive ΔNb-values. The common geochemical features including the Sr-, Nd-, Pb-isotopes and ΔNb-values apply to the northern Reykjanes (north of 61°N), Mohns and Knipovich ridges. The basalts along the southern part of the Mohns ridge grade compositionally into the enriched and alkaline Jan Mayen lavas. The Kolbeinsey ridge basalts, however, tend to be very refractory with low $^{87}Sr/^{86}Sr$, high $^{143}Nd/^{144}Nd$, unradiogenic Pb and negative ΔNb. Extensive depletion of material that has first flowed and melted along the Northern Rift Zone (NRZ) may explain the loss of some of the Iceland plume signatures along the Kolbeinsey ridge.

Decompressional melting occurs as the mantle source ascends vertically beneath the spreading axes. Geophysical and geochemical data also indicate the importance of lateral (subhorizontal) mantle flow along the ridges away from a deep vertical flow channel under the northwestern margin of Vatnajökull. Although seismic tomography models are barely providing sufficient resolution to identify narrow plume conduits, the Iceland plume appears to extend only to the base of the mantle transition zone. The combination of vertical, oblique and subhorizontal flow of progressively melting material produces a thermal and compositional mantle structure that may be further constrained by geophysical and geochemical data. Based on the propagation of V-shaped ridges along the spreading axes from Iceland, the lateral plume flow is inferred to reach at least 1000 km towards NE and SW. The shallow flow of suprasolidus mantle channeled along the ridges, is most likely accompanied by a flow of mostly subsolidus and more fertile mantle deflected more evenly in all directions from a deep level (200-300 km depth ?) of the Iceland plume stem.

The alkaline and transitional basalt volcanism of the Eastern Volcanic Flank Zone (EVFZ) can be explained by its location near the eastern periphery of the Iceland plume stem. The rift zone configuration leads to a shallow deflection of the plume flow mainly towards NE, W and SW, resulting in a minor supply of undepleted material towards E and SE. The Southern VFZ forms the propagating tip of the Eastern RZ. The southwesterly supply of deflected plume material is considerable, but shallow and extensive melting of refractory mantle is confined to the ERZ. Further south the melting zone is terminated at a deeper level, resulting in a higher proportion of enriched melt fractions.

The Snæfellsjökull volcanic system at the western tip of the Snæfellsnes VFZ and the Jan Mayen island are located 300 and 830 km from the Iceland plume stem, respectively. The alkaline volcanism and large volcanic productivity anomalies at these locations are inconsistent with passive ascent of a relatively shallow and depleted mantle source. Supply of material with substantial amounts of enriched components through a deeper melting zone is required. The different tectonic settings of Snæfellsjökull and Jan Mayen, however, indicate different forms of vertical mantle flow component.

The initial wet solidus intersection, probably at more than 200 km depth in the central part of the Iceland plume stem, results in efficient partitioning of H into low-degree, but mobile melt fractions. The resulting viscosity increase in the dehydrating residue may inhibit the flow of the plume stem, leading to a deep-seated partial deflection of a nearly undepleted mantle source. This deeply deflected source may rise obliquely with a major westward flow component along the transform structure of the Mid-Iceland Belt and experience its main solidus intersection under Snæfellsjökull. Deeply deflected flow spreading out in all directions may become subhorizontal at distances of 300-500 km from the plume conduit. Beneath Jan Mayen the subhorizontal flow will be deflected upwards because of plate separation along the southern part of the Mohns ridge, inducing decompressional melting of the enriched source.