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INFLUENCE OF TECTONISM ON THE COMPOSITION OF ACID AND BASALTIC LAVA

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Abstract

The Neovolcanic zones in Iceland are of threefold origin: the Mid-Atlantic rift-zone, the Snæfellsnes "leaky-transform fault", and South-Iceland transgressive volcanic zone or propagating rift segment. Basalt compositions range from alkali basalts through transitional basalts to tholeiites along the off-rift zones towards the centre of Iceland. Diminishing proportion of garnet-pyroxenite melts towards the centre of the mantle plume is the preferred explanation. The origin of silicic magmas reflects their tectonic settings and appears to be controlled by the crustal geothermal gradient.

Basaltic lavas

Mantle heterogeneity beneath oceanic islands can be inferred from basaltic bulk lava samples or glass inclusions. Lava samples represent the integrated magma formation processes (melting, mixing, contamination and fractionation) whereas glass inclusions record melts less affected by higher-level processes. Nevertheless, more precise analyses of compositional parameters can be obtained on bulk samples that permits thorough assessment of mantle heterogeneity from the final basalt composition at surface. This is especially true for well characterized sample suites from oceanic islands showing important compositional variability in their basalts. Here, we present new major-, trace element and Sr-Nd-Hf-Pb isotope results on post-glacial basalts from the Neovolcanic belt of Iceland: the Snæfellsnes Volcanic Zone (SNVZ), the South Iceland Volcanic Zone (SIVZ) and the Mid-Iceland Volcanic Zone (MIVZ). The results reveal systematic lateral variations. Along the strike of the off-rift zones (SNVZ and SIVZ), regular decrease is observed for alkalinity, La/Yb, Sm/Yb, HFSE/Y, $^{87}Sr/^{86}Sr$ and $^{206\text{-}207\text{-}208}Pb/^{204}Pb$ towards the centre of Iceland, where olivine-tholeïtes with depleted trace element compositions, low $^{87}Sr/^{86}Sr$ and $^{206\text{-}207\text{-}208}Pb/^{204}Pb$ (and high $^{143}Nd/^{144}Nd$ and $^{176}Hf/^{177}Hf$) are produced. These latter have similar composition as most mafic lavas along the rift zones that cut through the island from SW to NE. A clear compositional difference is thus observed for basalts erupting at the spreading axis compared to those from the non-rifting flank zones.

The systematic decrease of residual garnet signature (high La/Yb, Sm/Yb, HFSE/Y) and Sr and Pb isotope ratios (and the increase of Nd and Hf isotope ratios) in the off-rift lavas towards the assumed centre of the plume at Iceland's centre, is consistent with the occurrence of fertile garnet pyroxenites in the mantle source. Basalts from the periphery of the flank zones are probably generated by less total melting and thus sample the more enriched and fusible component(s) of the mantle beneath Iceland. Melts of this fertile mantle thus dominate the bulk melt composition at the periphery, and are progressively diluted towards the centre. In the Mid-Iceland Volcanic Zone, basalt compositions are dominated by melts derived principally from the more refractory component(s) of the mantle. The lateral variations of the basalt compositions and the proposed diminishing role of fertile pyroxenites towards the centre of the island is readily explained by increased total melting towards the hotter core of the Iceland mantle plume. Finally, the first-order observation of strong correlations between geochemical parameters and geographical location of the basaltic craters strongly suggests that mantle heterogeneity dominates the highly-incompatible trace element and radiogenic isotope ratios relative to other magma processes, such as crustal contamination and fractional crystallization forming the final basalt composition.

In-situ analysis of major- and trace elements in Holocene tephra produced during subglacial eruptions confirm the spatial variability of the basalt compositions as recorded in the lava samples . Furthermore, cross-correlations of the compositional variability permits to identify the very centre of the Iceland hot-spot, namely the most active Icelandic volcano, Grímsvötn. Moreover, eruption frequency of the principal tephra-forming volcanoes can be determined for the last 6 kyears, where robust age models for soil accumulation can be obtained from well-dated silicic key-layers.

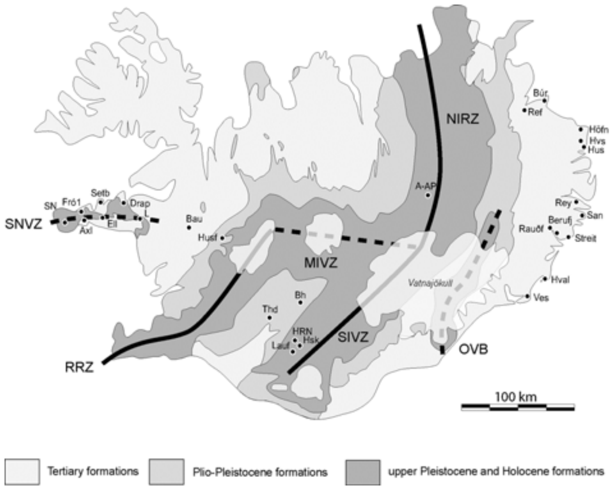

Figure 1 Map of Iceland showing sample locations. The Neovolcanic zones are the Snæfellsnes Volcanic Zone (SNVZ), Reykjanes Rift Zone (RRZ), Mid-Iceland Volcanic Zone (MIVZ), North-Iceland Rift Zone (NIRZ), South-Iceland Volcanic Zone (SIVZ) and the Öræfi Volcanic Belt (OVB). White areas correspond to the main glaciers.

Acid lavas

Pleistocene and Holocene peralkaline rhyolites from Torfajökull (South Iceland Volcanic Zone) and Ljósufjöll central volcanoes and trachytes from Snæfellsjökull (Snæfellsnes Volcanic Zone) allow the assessment of the mechanism for silicic magma genesis as a function of tectonic settings and variable crustal geothermal gradient. The low □18O (2.4‰) and low Sr concentration (12.2 ppm) measured in Torfajökull rhyolites are best explained by partial melting of hydrated metabasaltic crust followed by major fractionation of feldspar. In contrast, very high 87Sr/86Sr (0.70473) and low Ba (8.7 ppm) and Sr (1.2 ppm) concentrations measured in Ljósufjöll silicic lavas are best explained by fractional crystallisation and subsequent 87Rb decay. Snæfellsjökull trachytes are also principally generated by fractional crystallisation, with only small crustal contamination. The fact that silicic magmas within, or close to, the rift zone are principally generated by crustal melting whereas those from off-rift zones are better explained by fractional crystallisation clearly illustrates the controlling influence of the thermal state of the crust on silicic magma genesis in Iceland.

The origin of the Quaternary silicic rocks in Iceland thus appears to be linked to the thermal state of the crust, which in turn depends on the regional tectonic settings. This simple model can be tested on rocks from the Miocene to present, both to suggest an internally consistent model for silicic magma formation in Iceland and to constrain the link between tectonic settings and silicic magma petrogenesis. New major and trace element compositions together with O-, Sr- and Nd-isotope ratios have been obtained on silicic rocks from 19 volcanic systems ranging in age from 13 Ma to present (see sample location in Fig.1). This allows tracing spatial and temporal evolution of both magma generation and the corresponding sources. Low $\delta^{18}O$ (<5 ‰ SMOW) in most silicic rocks results from partial melting of hydrothermally altered metabasaltic crust, whereas low Ba and Sr concentrations (down to 9 and 1 ppm, respectively), in addition to Th concentrations higher than 9 ppm in the silicic rocks, indicate important role of fractional crystallisation during the final stage of magma formation. Trace element ratios, such as Th/U, Th/Zr and Th/La, record important role of accessory minerals during final differentiation. The $^{143}Nd/^{144}Nd$ proves to be an excellent marker of the silicic-magma source: high $^{143}Nd/^{144}Nd$ (0.51303 to 0.51296) characterizes a "rift-zone source", from which the silicic magmas are generated by crustal anatexis, whereas low $^{143}Nd/^{144}Nd$ (0.51290 to 0.51297) is typical of an "off-rift source", where rhyolites formed by fractional crystallisation of mantle-derived basaltic magma in a cooler environment far from the rift-zone.

The spatial and temporal distribution of samples having a “rift zone” Nd-isotope signature allows inferences to be drawn about the past tectonic regime. At Snæfellsnes Peninsula, silicic magmas younger than 5.5 Ma have an “off-rift” Nd-isotope signature, whereas those older than 6.8 Ma have typical “rift zone” characteristics. This suggests that before 6.8 Ma silicic rocks were generated in a rift-zone by crustal melting caused by high geothermal gradient. But later than 5.5 Ma they were produced in a flank zone environment by fractional crystallisation alone, probably due to decreasing geothermal gradient, of basalts derived from a mantle source with lower $^{143}Nd/^{144}Nd$. This is in agreement with an eastwards rift-jump, from Snæfellsnes towards the present Reykjanes Rift Zone , between 7 and 5.5 Ma. In the South Iceland Volcanic Zone (SIVZ), the intermediate Nd-signature observed in silicic rocks from the Torfajökull central volcano reflects the transitional character of the basalts erupted at this propagating rift segment. Therefore, the abundant evolved rocks at this major silicic complex result from partial melting of the transitional alkaline basaltic crust (<3 Ma) generated in this propagating rift segment, suggesting rapid crustal recycling there.

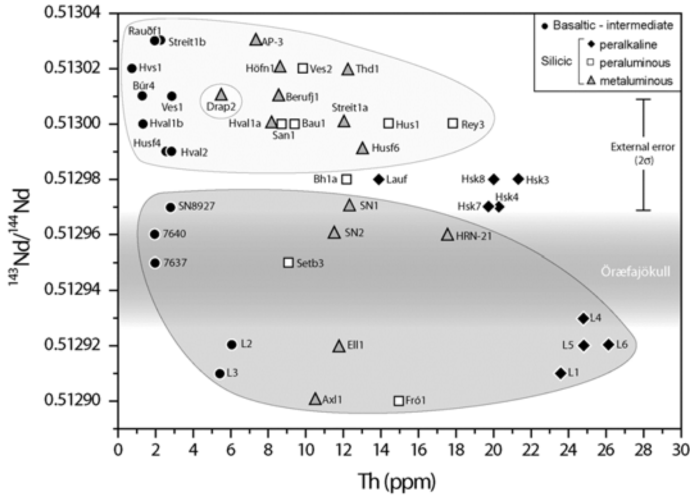

Figure 2. The isotope ratio $^{143}Nd/^{144}Nd$ vs. Th concentration in lavas from Iceland. The light and dark grey fields represent the ““rift-zone” and “off-rift” values, respectively (see text for further discussion). Note that all samples from the Snæfellsnes Peninsula (SNVZ) plot in the “off-rift” field with the exception of Drap 2. All other samples from this study plot in the “rift-zone” field with the exception of the samples from the SIVZ that fall in between. The DRAP 2 is a 6.8 Ma dacite that formed in a former rift-zone that was active from 15-6 Ma, hence its higher $^{143}Nd/^{144}Nd$ compared to other volcanics from the SNVZ . For comparison, range of $^{143}Nd/^{144}Nd$ from Öræfajökull volcanic system is also shown (Prestvik et al., 2001). The error bar (2σ) corresponds to the external error of our standard over the duration of this project.

Improved understanding of silicic magmatism in Iceland can, therefore, be used for deciphering past geodynamic settings characterized by rift- and off-rift zones resulting from interaction of a mantle plume and divergent plate boundaries.

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