The Iceland plume in space and time: A Sr-Nd-Pb-Hf study of the North Atlantic rifted margin

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The North Atlantic Igneous Province (NAIP) offers an unusual, if not unique, opportunity to investigate the composition, evolution and melting dynamics of a mantle plume. Unlike most plumes which remain trapped beneath a lithospheric cap, the interaction between the Iceland plume and the Mid-Atlantic Ridge have allowed the plume to decompress and melt at shallow levels. This is an important aspect since, crucial to existing models are (a) whether we can distinguish the various components in the plume and (b) whether we can distinguish a depleted component that is sourced in a shallow layer, or from another (deeper?) depleted source.

In an effort to constrain the nature of the Iceland plume in time and space, we have undertaken a geochemical (major and trace elements) and isotopic (Sr-Nd-Pb-Hf) study of basalts from the North Atlantic Igneous Province. Included are samples ranging from some of the oldest stages of plume magmatism (i.e. ~60Ma, ODP Legs 152 and 163) to virtually zero-age rocks from the Iceland neovolcanic zone. Their spatial distribution is shown in Fig. 1. In this study, we will be considering only Iceland and the southern sites (i.e. ODP Legs 49, 81, 152, 163, and the Reykjanes Ridge). The northern localities (i.e. ODP Legs 38 and 104) will be discussed at a later date.

Results

Our New Pb-Nd-Hf results are presented in Figs 2 and 3. Thirlwall (1995) showed that Icelandic basalts and picrites have higher $^{208}Pb/^{204}Pb$ *vs* $^{207}Pb/^{204}Pb$ than North Atlantic MORB. Our new data for Iceland lie within the field defined previously by Thirlwall (1995), and support the interpretation that the depleted Iceland end-member is different from MORB. Basalts from the present day Reykjanes Ridge and from Leg 49, Site 407 (~35–40 Ma) form trends parallel to Iceland and MORB, lying in the gap between the two fields. In contrast, the other localities show roughly horizontal trends in Fig. 2, which would suggest mixing between Iceland and the MORB source in the genesis of these rocks. In fact, basalts from Leg 81 (Rockall) lie totally within the MORB field. Note that some of the oldest lavas from the North Atlantic (i.e. Legs 152 and Legs 163 on the

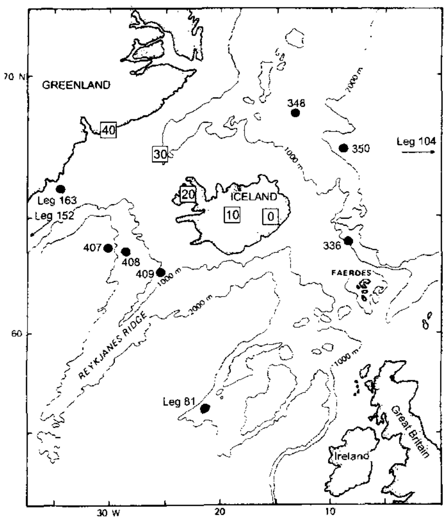

FIG. 1. Map of the N. Atlantic, showing sample locations. The estimated position of the Iceland plume at different times (in Ma) from Lawver and Müller (1994).

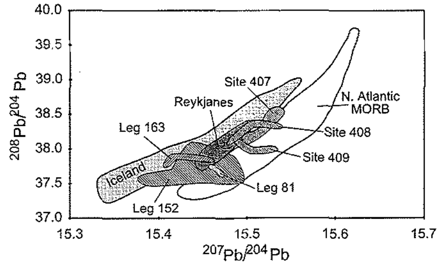

FIG. 2. $^{207}Pb/^{204}Pb$ *vs* $^{208}Pb./^{204}Pb$. Reykjanes Ridge data from Welke *et al.* (1968) and Taylor *et al.* (1997). Iceland and MORB fields from Hards *et al.* (1995)

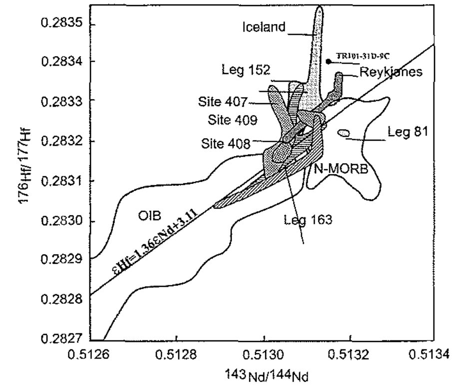

FIG. 3. $^{143}Nd/^{144}Nd$ *vs* $^{176}Hf/^{177}Hf$. Fields for OIB and MORB after Nowell *et al.* (in press).

east Greenland margin) are variably contaminated by continental crust (Fitton *et al.*, in press; Saunders *et al.*, in press), extending to very low Pb isotope ratios (i.e. $^{206}Pb/^{204}Pb$ = 13.684, $^{207}Pb/^{204}Pb$ = 14.439, $^{208}Pb/^{204}Pb$ = 33.649); these contaminated lavas have been excluded from our analysis. It is also interesting to note from Fig. 2 that older basalts (i.e. Legs 81, 152, and 163) have less radiogenic Pb isotope compositions than younger ones (Sites 407, 408 and 409 and the Reykjanes).

In contrast, all of the basalts in this study except for those from Rockall (Leg 81), lie within the Iceland array in Nb/Y *vs* Zr/Y as defined by Fitton *et al.* (1997), suggesting no involvement of MORB in their genesis.

To address this apparent conflict, we have analysed 70 samples for Hf isotopes (40 by TIMS and 30 by ICP-MS). Figure 3 shows that samples from Iceland, Leg 49 (Sites 407, 408 and 409), Legs 152, 163 and the Reykjanes define fields that are oblique to the main ocean island basalt (OIB) array, and which extend toward a component with higher $^{176}Hf/^{177}Hf$ than N-MORB. Although a few samples overlap the field of N-MORB, most do not.

These new data are consistent with previous studies which indicate that depleted MORB mantle does not represent the depleted component within the Iceland Plume (Hards *et al.*, 1995; Taylor *et al.*, 1997; Nowell *et al.* in press). Furthermore, it demonstrates that the high $^{176}Hf/^{177}Hf$ depleted component is a long-lived and intrinsic feature of the Iceland plume. Furthermore, this depleted component must represent the residue of an ancient melting event in which garnet was a restite phase. Since long term isolation of this component from the convecting upper mantle is necessary to achieve these high $^{176}Hf/^{177}Hf$ ratios, a plausible candidate is recycled oceanic lithosphere with a composition similar to abyssal peridotite.

Conclusions

Our new Hf-Nd-Pb data are consistent with the existence of 3 components in the genesis of basalts from the North Atlantic: (1) enriched Iceland plume, (2) depleted Iceland plume, and (3) MORB. However, the MORB component is relatively minor. These components have been available since inception of the plume.

Pb isotope data show considerable variation among the different localities. Since the drill sites from Legs 163 and 49 effectively form a time line from ~60Ma to 2Ma (Site 409), the data indicate that the plume composition has changed through time. In particular, the older plume (>40 Ma) was dominated by a less radiogenic Pb isotope signature. This distinction is not apparent in Hf-Nd space, as all of the data converge on the same general area of the diagram.

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