The heterogeneous Icelandic plume: constraints from Pb isotopes and trace element ratios

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Although the volcanic rocks of Iceland have been the subject of numerous geochemical investigations, none has included both Pb isotopes and precisely determined trace-element ratios. This combination, when used together with existing petrological and geochemical data, has the potential to provide strong constraints on the composition and origin of the Iceland plume, the manner in which it interacted with surrounding mantle, and the way in which it melted.

We report here measurements on well documented (Hémond *et al.* 1988, 1993) mafic volcanic rocks from all parts of the island. Compositions range from picrite to alkali basalt and include the most common olivine and quartz tholeiites. Extended trace-element patterns show a wide range, from strong depletion of incompatible elements ($(La/Sm)_N$=0.5) in the picrites, to moderate enrichment ($(La/Sm)_N$=2.7) in the alkali basalts. $^{206}Pb/^{204}Pb$ ratios vary from 18.0 in picrites to 19.2 in alkali basalts. These ratios correlate with both $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$, and with Ce/Pb which is as low as 10.7 in picrites and as high as 46.8 in alkali basalts. In addition, Ce/Pb correlates both with Sm/Hf and with the size of positive Sr and Ba anomalies which are large and conspicuous in the picrites. In contrast with the strong correlation beween chemical composition and rock type, there is no systematic relationship between isotopic or trace-element ratios and the geographic position of the samples. Correlations are also observed between Ce/Pb, Sr/Nd, Sm/Hf and $\delta^{18}O$ which ranges from +3‰ in the alkali basalts to +6‰ in the picrites.

Even though some of the trace-element characteristics can be attributed to extreme fractionation during melting (Elliott *et al.*, 1991), most of the variations that we report here cannot. The mantle-like $\delta^{18}O$ of the picrites argue against an hydrothermal origin for the positive Sr and Ba anomalies and rules out an important role for interaction of magmas with the present Icelandic crust. Correlations between isotopic compositions and ratios such as Sr/Nd, Sm/Hf and Ce/Pb lead to the identification of two end-member compositions, one enriched, the other depleted. We believe that both components came from the plume, with no significant contribution from ambient depleted mantle.

The enriched component, which was tapped to form the alkali basalts, has no marked trace-element anomalies, low $\delta^{18}O$ and relatively enriched isotopic compositions (high $^{87}Sr/^{86}Sr$ and $^{206}Pb/^{204}Pb$ and low $^{143}Nd/^{144}Nd$). Its composition is like that of many other oceanic-island basalts, and clearly was part of the plume: it could result of melting of ancient hydrothermally altered MORB recycled in the mantle and stored over a long period before melting.

The nature of the trace element and isotopic trend from alkali basalts to picrites shows clearly that the depleted endmember, the dominant source of the picrites, was distinct from the source of MORB and must also have come from the plume. This component had some highly unusual characteristics: the combination of positive Sr and Ba anomalies and negative Hf and Zr anomalies, low Ce/Pb ratios, mantle $\delta^{18}O$ and unradiogenic isotopes identifies it as distinct from ambient depleted mantle. These features, in particular the positive Sr anomalies, are not easily explained by deep-mantle processes and more likely had their origin at shallow levels where plagioclase is stable.

We suggest therefore that the source of Iceland plume consists of heterogeneous material representing a cross section through old oceanic lithosphere. The geochemical signature of the more alkaline lavas arises from preferential melting of the trace-element-enriched upper basaltic part of the lithosphere while that of the picritic liquids is dominated by the lower cumulate portion. The Sr anomalies are inherited from plagioclase-rich cumulates at the base of the crust. Olivine and quartz tholeiites, whose compositions fall between these two endmembers, result either from mixing of magmas from these two endmembers, or from melting of material with intermediate compositions. Iceland

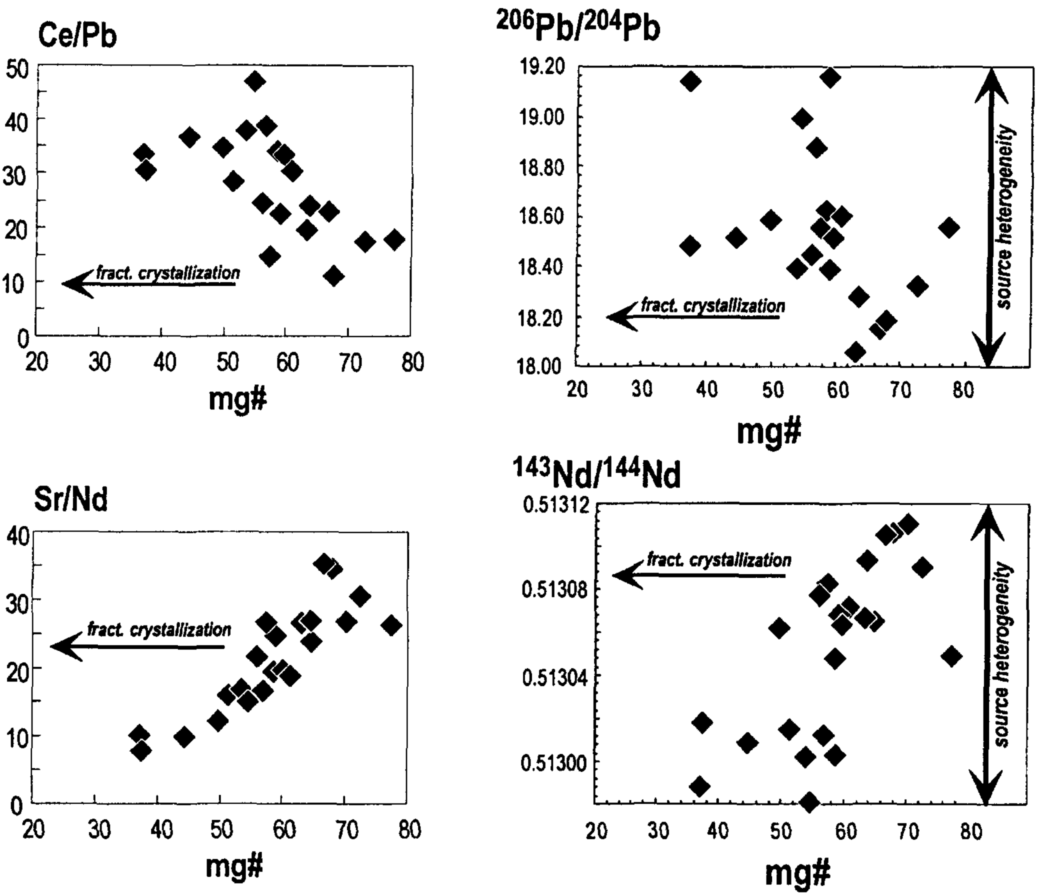

FIG. 1.

would therefore be the first clear example of differential melting of the various parts of a recycled oceanic crust within the mantle.

Both the Reykjanes Ridge Southwest of Iceland and the Kolbeinsey ridge to the North have isotopic compositions intermediate between that of North Atlantic depleted mantle and that of the Iceland plume. This provides evidence that the mantle is contaminated by the Icelandic plume on both sides of the island, and not only to the South.

References

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