North Atlantic mantle reservoirs: constraints on origins and mixing relations from double-spike Pb isotope data

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The North Atlantic has been a classic area for evaluating mixing processes between a deep mantle plume and the asthenospheric upper mantle. Sr-Pb isotopic and chemical gradients along the Reykjanes Ridge to the south of Iceland have been used to infer simple mixing between depleted MORB-source mantle south of 61.5°N and enriched Iceland plume mantle to the north. Similar isotopic ranges in lavas from the coastal ends of the active Iceland rifts have been interpreted as the result of plume-asthenosphere mixing in the melting column under Iceland (Elliott *et al.*, 1991). However, the bathymetric expression of the Iceland plume, and its primordial He signature, seem to extend to *c.* 52°N (Poreda *et al.*, 1986). The simple relationships have been questioned by several recent studies, with Thirlwall (1995) re-interpreting published Pb data to infer that the depleted component in Iceland was distinct from N. Atlantic MORB, Fitton *et al.* (1997) showing that both depleted and enriched Icelandic lavas have Nb enrichment relative to MORB; and Taylor *et al.* (1997) arguing that the Pb-Nd-Sr isotopic signature south of 61.5°N, and previously regarded as MORB asthenosphere, involved a substantial component from depleted high-^{3}He material within the Iceland plume. In contrast, on the basis of a wider comparison between Sr-Nd-Pb isotope systematics of Icelandic lavas and North Atlantic MORB, Mertz and Haase (1997) have argued that there is no clear distinction.

Pb isotopic data are critical to identifying mantle sources in the North Atlantic (Thirlwall, 1995; Mertz and Haase, 1997), in particular subtle differences in ^{207}Pb/^{204}Pb and ^{208}Pb/^{204}Pb from the Northern Hemisphere Reference Line, commonly expressed as Δ^{207}Pb and Δ^{208}Pb. Iceland and other negative-Δ^{207}Pb ocean islands were recently regarded as the products of young (200–1200 Ma) HIMU mantle (Thirlwall, 1997), based on their low Δ^{207}Pb values. However, a recent round-robin exercise to five isotope laboratories demonstrated that 2sd analytical reproducibility of Δ^{207}Pb was some 2–5 $\times$ worse than indicated by their reported reproducibility for standard samples (*c.* $\pm$3–6 instead of $\pm$1.2, H. Downes, pers. commun., Thirlwall, in prep.), at worst encompassing almost the whole variation in Δ^{207}Pb of ocean island basalts. Thus differences between Iceland and MORB Pb isotopes that rely on comparing data from several laboratories (e.g. Thirlwall, 1995; Mertz and Haase, 1997) are likely to be suspect.

In order to resolve this issue, and to use the potential of Pb isotopes for identifying mixing processes (linear arrays on several diagrams!), the ^{207}Pb-^{204}Pb double spike method for correcting for instrumental mass fractionation has been established at Royal Holloway. This provides SRM981 external reproducibility of $\pm$0.0025 (2sd, N = 32 over 10 months) on ^{206}Pb/^{204}Pb and $\pm$0.3 on Δ^{207}Pb, similar reproducibility on unknown samples, when using acid-leached hand-picked chips, and confidence of similar accuracy. So far, 16 samples have been analysed from Iceland, largely from the Reykjanes Peninsula adjacent to the Reykjanes Ridge, 18 samples from the Reykjanes Ridge, and 3 MORB remote from Iceland. Despite Pb concentrations as low as 0.08 ppm, Pb ion beams in excess of 1.5 V ^{208}Pb have been maintained for over 1 hour, leading to internal precision better than $\pm$0.002 on ^{206}Pb/^{204}Pb. Blank contributions change ^{206}Pb/^{204}Pb by up to 0.008, but have no effect on the delta-parameters. Data are summarized in the figures below.

Principal conclusions are:

(1) The three remote MORB samples analysed have low ^{206}Pb/^{204}Pb (*c.* 18.3) with Δ^{207}Pb of 0.0 to +1.2 and Δ^{208}Pb of +3.6 to +7.0; respectively above and below almost all of the Reykjanes and Iceland data shown below. The vast majority of published Atlantic and Pacific MORB data also lie above and below the Iceland/Reykjanes data fields in Δ^{207}Pb and Δ^{208}Pb respectively. While this does not confirm

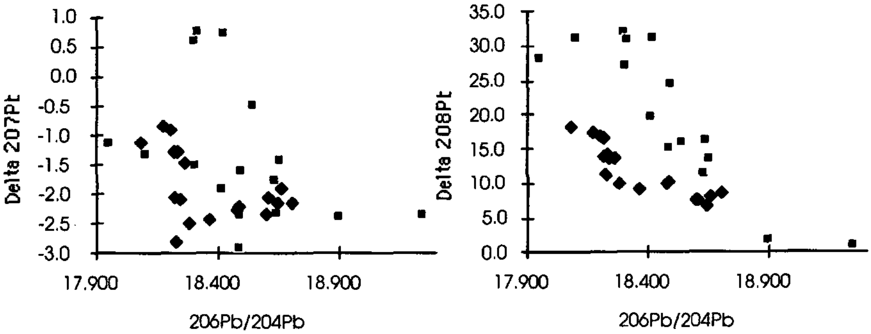

FIG. 1. Pb isotope data from the Reykjanes Ridge (diamonds), and Iceland (squares), fractionation-corrected using a double-spike procedure.

that the Iceland plume differs from all Atlantic MORB, it clearly demonstrates that significant differences exist in the North Atlantic.

(2) Icelandic and Reykjanes Ridge lavas have negative Δ^{207}Pb, with the exception of two highly depleted flows from the Reykjanes Peninsula (one flow was analysed twice). Even using the same samples, there is no evidence of the very negative Δ^{207}Pb reported by Elliot (1991). The magnitude of negative Δ^{207}Pb in Iceland is broadly consistent with HIMU mantle generated in the late Palaeozoic. Sm-Nd, U-Pb and Pb-Pb errochrons for the Reykjanes Peninsula could be consistent with *c.* 200 Ma imposition of high μ and low Sm/Nd ratios on a single mantle composition with initial slightly positive Δ^{207}Pb, but data from elsewhere in Iceland require heterogeneous mantle prior to any 200 Ma event.

(3) Depleted lavas in the Reykjanes Peninsula either have too high Δ^{208}Pb or too low Δ^{207}Pb to be generated from a normal Atlantic MORB source; those from Theistareykir (N. Iceland - the 2 samples with lowest ^{206}Pb/^{204}Pb) have more normal delta parameters and closely resemble published data from the Kolbeinsey Ridge.

(4) Reykjanes Ridge lavas show systematic changes in delta parameters south from Iceland that broadly match changes in Nd-Sr isotope ratios reported by Taylor *et al.* (1997). North of *c.* 60°N, samples show evidence for mixing between an enriched Icelandic component (^{206}Pb/^{204}Pb = 18.7) and a component with very low Δ^{207}Pb (< -2.5), low ^{87}Sr/^{86}Sr ($<$0.7026) and low Δ^{208}Pb. Between 60 and *c.* 58°, both delta parameters show a steep increase to a maximum close to the region where V-shaped ridges intersect the Reykjanes Ridge, and the highest ^{3}He/^{4}He ratios are observed. Pb ratios at this latitude are nevertheless very distinct from any Icelandic value suggesting yet a further plume component.

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