Using glass inclusions to investigate a heterogeneous mantle: An example from N- and EMORB-like lavas from Baffin Island

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The study of glass inclusions in early-crystallized phenocrysts in basalts offers a means for investigating primitive melt compositions.(e.g. Sobolev and Shimizu, 1993; Nielsen *et al.* 1995). Glass inclusions may sample melt compositions not available as erupted magmas, most of which probably represent mixtures of a range of melts (largely homogenized in magma chambers and conduits). In particular, where mixing of melts derived from sources of different composition has occurred, glass inclusions can potentially provide information on endmember compositions unavailable from the study of erupted lavas alone.

Results and discussion

We have analysed olivine-hosted (Fo_{84}–Fo_{92}) glass inclusions from a suite of picritic rocks from Baffin Island, Canada, erupted during the opening of the Davis Strait at ~ 58 Ma (Francis, 1985). Major element compositions of ~200 glass inclusions were measured by electron microprobe and *REE* abundances were measured in a subset of these inclusions by ion microprobe. Our results are also compared to major element and *REE* data for matrix glasses from the same samples reported by Robillard *et al.* (1992). The Baffin Island picrites occur as two stratigraphically interbedded, but geochemically distinct, lava types: (i) NMORB-like lavas, that have matrix glasses with depleted *LREE* ($[La/Sm]_N$ ~ 0.6–0.7) and low K_2O/TiO_2 (< 0.08); and (ii) EMORB-like lavas that have matrix glasses with enriched *LREE* ($[La/Sm]_N$ ~ 1.1–1.2) and higher K_2O/TiO_2 (> 0.08) (Robillard *et al.*, 1992). Sr and Nd isotopic analysis of these matrix glasses were also performed as part of this study and show that E- and NMORB–like samples are also isotopically distinct: NMORB-like glasses have $^{87}Sr/^{86}Sr$ < 0.7030 and $^{143}Nd/^{144}Nd$ > 0.51300; and EMORB-like glasses have $^{87}Sr/^{86}Sr$ > 0.7030 and $^{143}Nd/^{144}Nd$ < 0.51300. Sr and Nd isotopic compositions are negatively correlated and form an array between depleted values similar to high-latitude North Atlantic MORB and enriched compositions similar to those observed in plume-related rocks from the North Atlantic (e.g. Iceland, Jan Mayen fracture zone, Vesteris seamount; Mertz and Haase, 1997). Indices of incompatible element enrichment (e.g. K_2O/TiO_2, $[La/Sm]_N$) for matrix glasses also form correlated arrays with Sr and Nd isotopic composition (Fig. 1). These new isotopic data are consistent with the suggestion of Robillard *et al.* (1992), made on the basis of trace element modelling and limited Sr isotope data, that the Baffin Island picrites represent mixtures of melts derived from (1) a depleted mantle source, similar to that from which typical MORB are derived; and (2) an incompatible-element enriched, high-$^{87}Sr/^{86}Sr$, source.

Compared to the host lavas, compositions of glass inclusions are considerably more varied, even after correction for olivine fractionation. This suggests that the observed range in glass inclusion composition reflects the preservation of a diversity in liquid composition that was present during olivine growth, but that is not present among erupted lavas. The simplest explanation of this is that erupted magmas were formed by mixing/blending of a compositionally diverse range of phenocryst-bearing magmas at depth and that the liquid fractions of these mixed magmas were then homogenized (either in conduits and/or magma chambers) prior to eruption.

The K_2O (and, to a lesser extent, TiO_2 and Na_2O) contents of glass inclusions in NMORB and EMORB-like lavas are different. Inclusions from

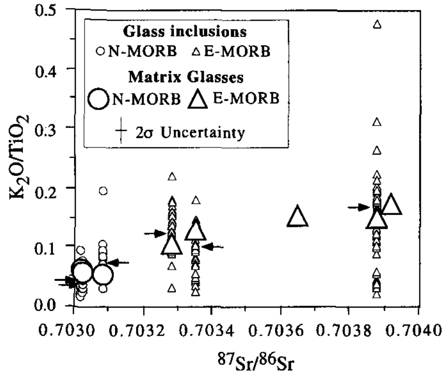

FIG. 1. $^{87}Sr/^{86}Sr$ *vs* K_2O/TiO_2 for matrix glasses and glass inclusions (glass inclusion compositions are plotted against the $^{87}Sr/^{86}Sr$ of the host sample). Arrows represent average glass inclusion composition. K_2O/TiO_2 ratios of glass inclusions have similar minimum values for all samples (~0.02) but range up to significantly higher values in EMORB.

NMORB samples have low K_2O contents (0.04–0.08 wt.%), and, although both EMORB and NMORB samples have glass inclusions with K_2O concentrations lower than the lowest values measured in matrix glasses, EMORB-like samples also contain glass inclusions with K_2O contents that extend up to values (> 0.5 wt.%) considerably higher than the highest K_2O contents of matrix glasses (0.22 wt.%). This variation is also evident in the K_2O/TiO_2 ratio (Fig. 1): most glass inclusions from NMORB samples have K_2O/TiO_2 ratios less than 0.10, but glass inclusions from EMORB-like samples have K_2O/TiO_2 ratios that range from ~ 0.02 (similar to the lowest values in NMORB glass inclusions) up to ~ 0.50. Variations in *LREE* contents of glass inclusions parallel those in K_2O/TiO_2, with depleted *LREE* in NMORB-hosted inclusions (typically $[La/Sm]_N$ = 0.2–0.5) and large variations in *LREE* depletion/enrichment in EMORB hosted inclusions ($[La/Sm]_N$ = 0.2–1.7). The *LREE* enrichment in glass inclusions correlates strongly with the K_2O/TiO_2 ratio.

Although the variations in K_2O/TiO_2 in glass inclusions are much larger than those observed in matrix glasses, the average K_2O/TiO_2 for glass inclusions in each sample correlates with the Sr (and Nd) isotopic composition of that sample (see arrows in Fig. 1). Further, the range of K_2O/TiO_2 ratios in glass inclusions from each sample also correlates with the Sr and Nd isotopic composition of the host matrix glass (i.e. samples with the highest $^{87}Sr/^{86}Sr$ and lowest $^{143}Nd/^{144}Nd$ ratios show the largest range of glass inclusion K_2O/TiO_2 ratios). Sobolev and Shimizu, (1993) suggested that in MORB it may be possible to explain large variations in incompatible element enrichment in glass inclusions by 'critical' melting of a single mantle column, this process cannot explain the observed correlations between the isotopic composition of matrix glasses and: (1) the average K_2O/TiO_2 of the glass inclusions contained within the same samples; and (2) the range of K_2O/TiO_2 ratios present in glass inclusions from the same sample.

We suggest that these observations are most simply explained by a model similar to that proposed by Robillard *et al.* (1992) to explain matrix glass compositions, where NMORB-like lavas from Baffin Island represent melts derived from an incompatible element depleted source, similar in isotopic composition to the source of other depleted North Atlantic MORB. EMORB-like lavas represent homogenized mixtures of melts derived from this depleted source and melts derived from an incompatible element enriched source (or perhaps from a range of variably enriched sources or from mixtures of depleted and enriched sources). Glass inclusions from EMORB-like samples are more varied in their degree of incompatible element enrichment because they represent mixtures of melts from the depleted and enriched sources (or again, perhaps melts of variably enriched or depleted sources or of mixtures of depleted and enriched sources) prior to homogenization and eruption of the host lavas. If the glass inclusions with the lowest and highest K_2O/TiO_2 ratios represent the most enriched and depleted endmembers that contributed to these lavas, and if individual inclusions lie on the K_2O/TiO_2 *vs* $^{87}Sr/^{86}Sr$ and K_2O/TiO_2 *vs* $^{143}Nd/^{144}Nd$ trends defined by the matrix glasses (Fig. 1), then the K_2O/TiO_2 ratios of ~0.02 and ~0.48 of these inclusions would correspond to $^{87}Sr/^{86}Sr$ ratios of 0.7025 and 0.7060 and to $^{143}Nd/^{144}Nd$ ratios of 0.5132 and 0.5124. The high $^{87}Sr/^{86}Sr$, low $^{143}Nd/^{144}Nd$ endmember is significantly more enriched than plume-related samples from the North Atlantic (Mertz and Haase, 1997), but is similar to isotopically enriched magma compositions found in some other oceanic islands (Hofmann, 1997).

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