Constraints on the diversity of mantle melts using rehomogenized melt inclusions

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Abyssal peridotites have long been assumed to be examples, however modified, of the residuum of partial melting. However, the lavas we see on the surface are not in equilibrium with the full range of trace element compositions we observe in cpx from peridotite. It is clear that primary magmas undergo extensive modification by mixing and fractionation during transport through the crust. In order to interpret the composition of a magma at the surface, we must find ways to see through the effects of crustal processing and determine the compositions of melts at intermediate stages.

Melt inclusions trapped in primitive phenocrysts provide much needed information to address this apparent paradox. Ideally, each inclusion represents a 'snapshot' of the liquid trapped during the growth of the host crystal, preserving the composition of intermediate steps in the formation of a magma. Although such melts do not experience the same differentiation processes as erupted lavas, they have been affected by post-entrapment crystallization. Therefore, an experimental means was developed for re-homogenizing the inclusions and evaluating the relationship of the melt inclusion compositions to the observed range of associated lavas (Nielsen *et al.*, 1995). In addition, we have developed proceedures for evaluating the level to which the compositions represent the trapped magma (Nielsen *et al.*, in press).

Results

Our work has focused on plagioclase-hosted melt inclusions from the Gorda Ridge, the Galapagos Platform and the Endeavour Segment of the Juan de Fuca Ridge. In all areas we found that there was a correlation between the mean melt inclusion composition and the host. The major element composition of the inclusions are more primitive than the host lava suite, but can be linked to that suite by fractional crystallization. In contrast, the minor and trace element characteristics of populations of melt inclusions exhibit extreme diversity even within a single sample. N-MORB lavas contain both depleted and enriched melt inclusions, and therefore exhibit the largest compositional range. Inclusions from E-MORB lavas are relatively (but not absolutely) homogeneous and uniformly enriched.

Discussion

The different lava compositions observed cannot simply be the result of differing degrees of partial melting of the same mantle source. Major element data for melt inclusions from both N-MORB and E-MORB lavas suggest that the magmas lie on a low pressure cotectic, consistent with an origin by fractional crystallization. However, minor and trace element compositions in melt inclusions vary independently of the major element composition implying an alternative history. In spite of the considerable overlap between inclusion compositions from the E- and N-MORB host lavas, the absolute and relative ranges of inclusion compositions, the results of open system modelling and the regional tectonics suggest that the enriched and depleted lavas are derived from sources with different modal mineralogy, possibly at different depths in the upper mantle.

We can correlate data from melt inclusions with that from abyssal peridotites by calculating the composition of the equilibrium cpx for each inclusion. This calculation is dependent on the choice of partition coefficients (D). Assuming the intermediate D values of Johnson *et al.* (1990), we obtained values for calculated cpx that overlap those of observed abyssal peridotite for Ti, Zr and the *HREE*, and cover much of the range exhibited by the entire global dataset of abyssal peridotite cpx. Equally important, the range of calculated values extends to peridotites containing less than 3 % cpx, essentially the assumed point at which partial melting consumes all cpx (cpx-out), leaving a harzburgite restite. For the *LREE*, K, and Ba however, the calculated values are more enriched than most (but not all) observed abyssal peridotite cpx.

If fractional melting proceeds to the point of cpx-out, we must ask ourselves what the effect would be on the cpx-melt partition coefficients. On the basis of recent phase equilibria studies (Longhi and Bertka, 1996) we can infer that as we approach cpx-out, the equilibrium cpx may become progressively lower in Ca. Our understanding of the controls of cpx-melt partitioning indicates that this would have a dramatic effect on the partition coefficients for Ti, *REE* and HFSE. We also know that the effect of decreasing Ca in cpx is greater for the *REE* and HFSE than for Ti. This would have the effect of increasing the DTi/DZr ratio, and during progressive melting, deflecting the trend of liquids toward a rapid decrease in Zr relative to Ti, just as we observe in the melt inclusions. In addition, using those lower D's extends the range of calculated cpx for many of the most depleted inclusions into the assumed range for a harzburgite source. This progressive drop in D does not explain the relative enrichment of some inclusions with respect to LIL and *LREE* elements. However, relatively high Cl in some of the most depleted inclusions suggests that such enrichment may be related to components added by a fluid.

Conclusions

There is evidence for three distinct endmember magmas in melt inclusion data: (1) partial melts of depleted mantle – based on their range in Zr and *HREE* concentrations, the most depleted component in the array of N-MORB parent magmas can be produced by variable degrees of near-fractional melting up to or perhaps even past the point where cpx is consumed. (2) partial melts of enriched mantle and veins – based on their buffered *HREE* concentrations and the absence of depleted inclusions, we conclude that E-MORBs are the result of variable % partial melting within the spinel stability field by a process of open system melting assuming a depleted lherzolite source veined with clinopyroxenite. This component is present even in areas where the dominant magmatism is N-MORB. (3) a 'fluid' phase rich in *LREE*, Ba, Sr, K, Cl – One mechanism that would explain the relatively high concentrations of Cl, K, Ba and *LREE* in some of the ultra-depleted inclusions is the presence of a fluid enriched in those components. Such a component would be necessarily low in Zr (and probably Ti) in order to maintain the Ti/Zr levels. This largely excludes the possibility that the LIL-rich component is an enriched basaltic magma as proposed by Elthon (1992), but is consistent with the concept of re-fertilization.

References

Elthon, D. (1992) *J. Geophys. Res.*, **97**, 9015–25.

Johnson, K.T.M., Dick, H.B. and Shimizu, N. (1990) *J. Geophys. Res.*, **95**, 2661–78.

Longhi. J. and Bertka, C.M. (1996) *Amer. Mineral.*, **81**, 685–95.

Nielsen, R.L., Crum, J., Bourgeois, R., Hascall, K., Forsythe, L.M., Fisk, M.R. and Christie, D.M. (1995) *Contrib. Mineral. Petrol.*, **122**, 34–50.

Nielsen, R.L., Michael, P.J. and Sours-Page, R.E. (in press) *Geochim. Cosmochim. Acta.*