Magmatism and extension in the Azores

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Introduction

Ocean island basalts (OIB) provide an insight into mantle composition and melting processes. Formed by the direct partial melting of the mantle, the magmas suffer no contamination by continental crust, and their radiogenic isotope ratios and incompatible elements are widely used as tracers for mantle geodynamics. However, attempts to relate major element variations to source heterogeneity and melt regime have been less successful due to the combined effects of melt generation and extraction processes, and subsequent crystal fractionation. Melt generation is influenced by mantle temperatures and regional tectonics and the aim of this study is to assess the affect of tectonics on the chemical composition of selected OIB from the Azores.

The Azores archipelago provides an opportunity to study oceanic islands situated on young lithosphere in an area of active extension. Straddling the Mid-Atlantic Ridge (MAR), the nine islands lie on a shallow oceanic platform, indicative of the presence of a mantle plume, and analyses of MORB from the MAR in this area show them to be characterised by trace element and isotopic anomalies relative to adjacent ridge segments. The archipelago lies near to the triple junction of the Eurasian, African and North American plates, and three of the nine islands actually lie within the Terceira Rift - the present African/Eurasian plate boundary and a seismically active spreading centre. This extensional regime also affects the other islands of the archipelago which are situated in local grabens. Within the islands, however, no systematic temporal control on magmatism is seen as in other plume dominated settings, such as the Hawaiian chain.

Results

One hundred and fifty samples have been collected from four of the islands, Sao Miguel, Pico, Sao Jorge and Terceira, and analysed for major and trace elements, and isotope ratios. With the exception of Sao Miguel, the Azores are largely isotopically homogeneous both within and between the islands showing fairly uniform radiogenic isotopic ratios with $^{87}Sr/^{86}Sr$ ranging from 0.7032 to 0.7039 and $^{143}Nd/^{143}Nd$ from 0.5128 to 0.51285. This similarity between the islands implies a regionally homogeneous source composition, providing an excellent opportunity to investigate the effects of extensional tectonics without the added complexities of extensive source heterogeneity. Sao Miguel is the exception, showing a clear increase in $^{87}Sr/^{86}Sr$ to the east of the island with values approaching 0.706, while $^{143}Nd/^{143}Nd$ decreases from 0.51285 to 0.51255. Previous work (Kurz *et al.*, in press) has shown Pb and He also become more radiogenic in this direction.

Sao Miguel basalts also show considerably higher potassium than the other islands, with a broad correlation between potassium and the increase in $^{87}Sr/^{86}Sr$ across the island. The abundance of sodium in Sao Miguel lavas is also distinct, being lower than the other islands. It may be possible that the high potassium and elevated $^{87}Sr/^{86}Sr$ are related to source heterogeneity, whereas the relatively low sodium relates to a higher degree of melting. The remaining islands have broadly similar major element composition reflecting their overall isotopic homogeneity.

Although the major element compositions of basalts can be used to evaluate physical conditions, such as the pressure and temperature of the source during melting, much of the variation seen in these lavas may be due to crystal fractionation after segregation from the source region, and so the compositions require correction before inferences can be made concerning the melt regime. Two different correction techniques have been applied to the Azores data set. The first corrects all samples with greater than 6% MgO back to an assumed primary composition with a magnesium number of 0.7. The alternative method corrects compositions back to a standard MgO content. Klein and Langmuir (1987) used 8% in their analysis of global MORB variation. Once these primary compositions are established, variations in the Azores, both within individual islands and in relation to the MAR and Terceira Rift can be identified.

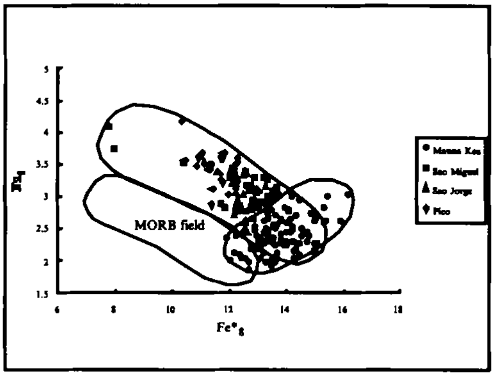

FIG. 1. Fractionation corrected analyses from Mauna Kea, Hawaii and islands of the Azores.

Total iron and silica in primary magmas are both strongly dependent on pressure (eg. Hirose and Kushiro, 1993) with high iron and low silica melts being generated at high pressures. The Azores basalts show a strong negative correlation, showing that melts are generated over a range of pressures. However there does not appear to be a strong relationship between major element composition and major tectonic features as the complete range of compositions of primary iron and silica is encompassed by magmas from Pico and Sao Jorge, both of which lie well off the Terceira Rift, and there is no indication that basalts from islands within the Rift were generated under significantly different pressure conditions. However, as volcanism on the islands away from the Terceira Rift is strongly controlled by local tectonics, most notably in the islands of Faial and Pico, it is suggested that this similarity in composition and hence depth range of melt generation indicates that melting is tectonically controlled.

Sodium behaves as a relatively incompatible element during melting and its abundance can be used as a measure of melt fraction. In the case of the Azores, primary sodium and silica define a positive correlation which implies that the lowest pressure, highest silica melts reflect smaller melt fractions than the lower silica, high pressure melts. This is the opposite of the type of melt regime modelled for other ocean islands, such as Hawaii, in which small melt fractions are generated at depth and melt fraction increases as pressure decreases.

The figure shows a comparison with Klein and Langmuir's MORB data and variation in the Azores and Hawaii similarly corrected back to 8% MgO. The Azores define a negative correlation parallel to the MORB array at higher sodium abundances, reflecting smaller melt fraction. Iron at 8% MgO varies from 10 to 14%, covering the upper range of MORB, indicating derivation from similar depths to the higher pressure MORB liquids.

By contrast, the Mauna Kea data define an array of points with a poorly defined positive slope at greater iron values than the Azores. This is consistent with a conventional plume model in which small volume melts are generated at high pressure. The negative correlation shown by the Azores data, by contrast, must reflect a more complex melting regime which, by analogy with the MORB array is in part controlled by extension. Finally, the lower sodium at 8% MgO values for the Hawaiian basalts reflect a larger degree of melting than in the Azores, despite the greater depth of melt generation in Hawaii and is presumably related to the greater plume flux beneath Hawaii.

Conclusions.

Major elements can be used to establish relative physical conditions under which melting occurred and processes in the mantle source regions of OIB, provided that the effects of crystal fractionation are corrected. The comparison of Azores basalts with MORB and Hawaii indicates three factors that can affect major element composition.

1. Lithospheric thickness.
2. Extension.
3. Plume flux.

The association of all the islands with either local or regional rifts and the similarity of major element composition throughout the Azores archipelago indicates that tectonics exert an important control on the location and amount of melting. The high sodium and low iron content of the Azores basalts relative to those for Hawaii further demonstrate that they were derived as smaller melt fractions at lower pressures. These conclusions are consistent with the location of the Azores on young oceanic lithosphere and the lower thermal and material flux of the underlying plume.

References

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