Major element modelling of changes in lithospheric source with time for the Paraná CFB

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Introduction

Most discussions of the source regions of basalts involve isotopes and trace elements, both of which are strongly affected by crustal interaction, making it harder to see back through to processes in the upper mantle. Major element modelling has been applied to oceanic basalts (Klein and Langmuir, 1987: Kinzler and Grove, 1992) where MORB analyses were first extrapolated back to 8wt% MgO (to eliminate shallow level fractionation trends) and then compared with experimental data. In this way depth and degree of melting can be inferred using certain key major elements. Turner and Hawkesworth (1994) adapted this approach for the generation of CFB magmas, concluding that many CFB derive from depleted peridotite which they placed in the sub-continental lithosphere. Detailed studies of the Paraná basalts reveal chemical changes with time which suggest that different lithospheric source regions in terms of depth, fertility and degree of fluid enrichment were successively sampled during the evolution of this magmatic province.

Background geology

The Paraná CFB is a voluminous ($\sim$790,000km^3) basalt province in southern Brazil which was erupted over a $\sim$10My period during the final stages of Gondwana break-up. Intracontinental rifting and close proximity to the Tristan da Cunha hotspot combined to initiate this intense volcanic activity, resulting in the Paraná and Etendeka CFB now asymmetrically distributed on either side of the present South Atlantic. The Paraná basalts can be divided geographically into low- and high-Ti groups found in the south and north of the basin respectively. This division was originally attributed to variable degrees of melting in the lithosphere (Fodor, 1987), but is now thought to be caused by source heterogeneities (Hawkesworth *et al.*, 1988). More detailed chemical stratigraphy of the basalts was compiled by Peate *et al.* (1992) using boreholes to gain a 3-D picture, in which five major basalt types are recognized.

The chemically defined magma types appear to occur in mapable units that overlap to the north-west, and since rifting proceeded northwards parallel to the Paraná Basin this was postulated to be the cause of magmatism. However new $^{40}Ar/^{39}Ar$ ages (Stewart *et al.*, 1994) have established that the oldest basalts (138Ma) are in the extreme north-west, and that they young successively towards the south-east corner of the basin (127Ma). This southward migration indicates that initial magmatism was not closely related to rifting in the South Atlantic, but the rate of migration is thought to be too rapid for the movement of a hotspot trace. Therefore while a plume is invoked in the initial stages of lithospheric melting, extension along the east-west Ponta Grossa weakness provided a potential mechanism for tapping the magma. Later extension associated with the opening of the South Atlantic could have accelerated melting in the south-east of the basin, adjacent to the continental margin. The 10My period of eruption is also longer than popularly held for CFB, and so the Paraná does not qualify as a sudden, catastrophic event.

Discussion

Certain major elements were identified by Klein and Langmuir (1987) as showing coherent trends for parameters such as pressure of melt generation and degree of partial melting. For example Fe_8 (Fe_2O_3 abundance corrected back to 8wt% MgO) shows a positive correlation with pressure, while Na_8 shows a negative correlation with degree of melting. Turner and Hawkesworth (1994) used experimental data to contrast fertile and depleted peridotite as source materials, which is best illustrated by Ti_8 and Ca/Al_8. Ambiguities exist where certain elements are affected simultaneously by a number of factors, such as the combined effects on Fe_8 of pressure, degree of melting and source fertility. However by selecting pairs of

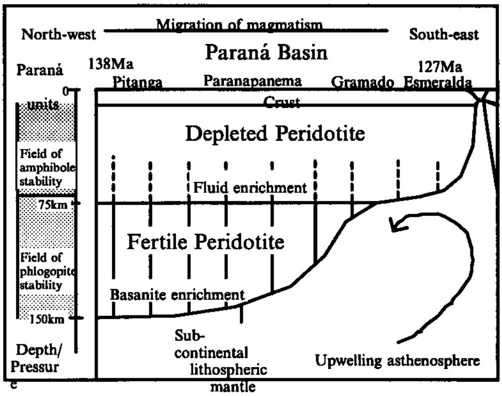

Figure 1. Schematic cross-section through the lithospheric mantle beneath the Paraná Basin. Depleted peridotite is underlain by relatively fertile peridotite at depths > ~80km. Basanite enrichment gives way upwards to enrichment by more mobile fluids. Progressively shallower lithospheric sources were tapped as magmatism migrated from NW-SE (left to right), culminating in asthenosphere-dominated melts once rifting occurred.

elements which demonstrate particular conditions it is possible to interpret the data in terms of source conditions during melting.

The four major magma types within the Paraná have been considered and each appears to reflect unique source conditions. In rough order of age (oldest first) these are Pitanga (high-Ti), Paranpanema (intermediate-Ti), Gramado (low-Ti) and Esmeralda (low-Ti). There is a marked change in CaO/Al_2O_3 from the Pitanga and Paranapanema to the Gramado, suggesting that the latter was derived from a more depleted source. This is accompanied by progressively lower Fe_8 values, indicating a decrease in the inferred pressure of melt generation through these three units (see also Kinzler and Grove (1992)). It is argued that the Paraná CFB sampled a stratified sub-continental lithosphere which is more fertile at depth (Fig. 1). The youngest unit, Esmeralda, has the closest chemical affinity with MORB and has been interpreted as a largely asthenospheric melt resulting from late stage rifting and opening of the South Atlantic. In terms of major elements Esmeralda is slightly displaced from the MORB array of Klein and Langmuir (1987) which might be due to mixing with Gramado-type lithospheric melts, or generation at unusually high temperatures above a mantle plume.

Preliminary results on new samples from Uruguay suggest a strong affinity in terms of incompatible elements with the Gramado magma type of the Paraná Basin. Using major element modelling they show low Ca/Al_8 ratios, implying a depleted source similar to that postulated for Gramado, although higher Fe_8 indicates a greater pressure of magma generation in Uruguay. Since ages of the Uruguay samples are as yet undetermined, it is not known whether they represent a southward continuation of Paraná activity, or are part of a younger phase of alkalic volcanism at 80Ma.

In summary, major elements indicate that the lithosphere was more depleted at shallow levels, and that melting took place at progressively shallower depths finally giving way to asthenosphere-dominated melts. Having established a framework of major element compositions it is interesting to turn to incompatible elements and isotope ratios in order to look at source enrichment processes. Pitanga shows a very similar trace element signature to basanite (Frey *et al.*, 1978), consistent with addition of a small degree melt to the lithosphere. Gramado shows a contrasting pattern of relatively high abundances of LILE elements such as Rb and K, which can result from infiltration of a hydrous fluid. This appears logical in that water-rich fluids, being more mobile, migrate to higher levels in the lithosphere. Nd isotope ratios also distinguish between these two groups, with the deeper Pitanga source being apparently younger than that for Gramado, which supports the general age stratification shown by mantle xenoliths from the Kimberly region of South Africa (Waters and Erlank, 1988).

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