The composition of the sub-continental mantle: evidence from magmatic rocks

C. Hawkesworth
S. Turner

Department of Earth Sciences, The Open University, Milton Keynes, MK7 6AA

The extent to which the sub-continental mantle differs from that in oceanic areas has been the subject of considerable debate. Seismic studies indicate that in many areas the continents are characterised by deep roots (Jordan, 1988), and data on mantle xenoliths confirm that at least regionally the uppermost mantle is relatively depleted in major elements (Herzberg, 1993). Re-Os isotope results have established that such depletion events are typically as old as the age of the overlying crust (Pearson *et al.*, 1994), and the most depleted material is confined to Archaean areas. However, the xenolith record is clearly restricted to those areas of suitable inclusion-rich kimberlites and alkalic basalts, and there have been a number of recent attempts to evaluate the nature of the sub-continental mantle from the much more widespread volcanic record.

Continental flood basalts (CFB) are the most striking manifestation of continental magmatism, and many CFB have isotope and trace element signatures that differ from those of oceanic basalts. A recent review of selected data sets from the Mesozoic and Tertiary CFB confirmed significant differences in their major and trace element compositions compared with basalts erupted through oceanic lithosphere (Turner and Hawkesworth, 1994). In general, those CFB suites characterised by low Nb/La, high $^{87}Sr/^{86}Sri$ and low $^{143}Nd/^{144}Ndi$, tend to exhibit relatively low TiO_2, CaO/Al_2O_3, Na_2O and/or Fe_2O_3, and relatively high SiO_2. In contrast, those which have high Nb/La, low $^{87}Sr/^{86}Sri$ and high $^{143}Nd/^{144}Ndi$ ratios, like the upper units in the Deccan, have major and trace element compositions similar to oceanic basalts. It would appear that those CFB that have distinctive isotope and trace element ratios also exhibit distinctive major

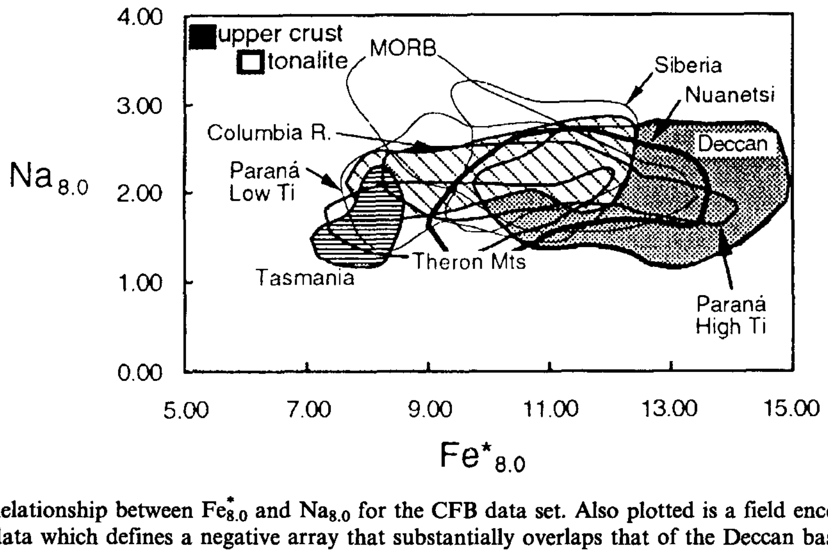

FIG. 1. Relationship between $Fe^*_{8.0}$ and $Na_{8.0}$ for the CFB data set. Also plotted is a field encompassing the MORB data which defines a negative array that substantially overlaps that of the Deccan basalts. In sharp contrast the remaining CFB define overlapping sub-horizontal arrays which extend to low $Fe^*_{8.0}$ and $Na_{8.0}$. Low pressure gabbroic fractionation will increase Na_2O and crustal rocks, represented by average upper crust and tonalite, have elevated Na_2O and low $Fe_2O_3^*$. Thus the CFB trends are not explicable by either AFC or mixing processes. Melts of depleted peridotite, on the other hand, will have lower Na and Fe for a given MgO content than those from fertile (asthenospheric) peridotite.

element contents, suggesting that major and trace elements have not been decoupled significantly during magma generation and differentiation.

When compared (at 8% MgO) with oceanic basalt trends, the displacement of many CFB to lower Na_2O, Fe_2O_3*, TiO_2 and CaO/Al_2O_3, but higher SiO_2, at similar Mg#, is not readily explicable by crustal contamination. Rather, it reflects source composition and/or the effects of the melting processes. These data have therefore been compared with the results of recent experimental studies (Falloon *et al.*, 1988; Kushiro, 1990, Takahashi and Kushiro, 1983), and melting of fertile peridotite at high temperatures and pressures, as in a plume beneath the continental lithosphere, would produce basalts with relatively low SiO_2 and high TiO_2 and Fe_2O_3. Moreover, the effects of increasing the degrees of melting at higher pressures are to shift the the melt compositions to higher $Fe^*_{8.0}$ and CaO/Al_2O_3, and lower $Na_{8.0}$ and $Si_{8.0}$, contrary to what is observed in many CFB. However, experimental melts of peridotite become increasingly TiO_2-, Na_2O- and Fe_2O_3-poor, and have low CaO/Al_2O_3, if the peridotite has been previously depleted by melt extraction. Melts of hydrated, depleted peridotite are also characterised by higher SiO_2, and lower Fe_2O_3 and CaO contents. Thus, it is argued that the source of many CFB are shallow level, melt depleted portions of sub-continental mantle. Their enriched radiogenic isotope signatures indicate that such source regions are old, and that they contain relatively high incompatible element abundances. This combination of major element depletion and trace element enrichment is a feature of many mantle xenoliths, and it is further inferred that the enrichment of incompatible elements included the introduction of small amounts of volatiles, since melt generation is likely to have taken place at the volatiles-present solidus.

Finally, such arguments on the nature of the source regions for CFB will be broadened to include continental margins, and the extent to which new continental crust is generated from similar trace element enriched source regions in the uppermost mantle. In many areas subduction-related processes appear to have been responsible for the development of incompatible element enriched portions of the sub-continental mantle. In addition, however, the degree of trace element fractionation between the bulk continental crust and depleted upper mantle is consistent with a two stage model in which new crust is generated from previously enriched source regions in the upper mantle.

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