Causes of melt generation in the sub-continental mantle

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Within-plate magmatism is caused by the emplacement of mantle plumes, and by lithospheric extension in response to regional tectonic forces. However, the causes of magmatism in specific areas, and the extent to which present models can account for variable eruption rates and melt generation in both the mantle lithosphere, and the underlying asthenosphere, are not well established. This contribution considers the causes of melt generation in two areas for which there is now a large quantity of high quality geochemical data, the Tertiary to Recent magmatism in the Western US, and the Paraná continental flood basalts (CFB).

Most CFB provinces are characterised by large volumes, and may be linked to the presence of a mantle hot-spot. Nonetheless, different CFB suites have different major, trace element and radiogenic isotope compositions, and there is some evidence that such features vary with average eruption rate. Thus, uncontaminated basalts in the Deccan CFB have minor, trace element and radiogenic isotope ratios similar to oceanic basalts associated with the same hot spot, on the island of Reunion. In contrast, almost all the Paraná CFB have isotope and trace element ratios not commonly observed in oceanic basalts, and only a few late dykes preserve any evidence for even a contribution from magmas similar to those erupted on Tristan da Cunha. In some areas there is evidence for open system fractional crystallisation, but in general the distinctive minor and trace element ratios of the basaltic rocks are widely attributed to old, enriched source regions in the sub-continental mantle. In addition, whereas most of the Deccan lavas appear to have been erupted within 1-2 m.y., those in the Paraná were erupted over a 10 m.y. period (Turner *et al.*, 1994).

In the Western US there are striking differences in the chemical changes with time within individual provinces (Fig. 1), and these appear to be accompanied by differences in eruption rates

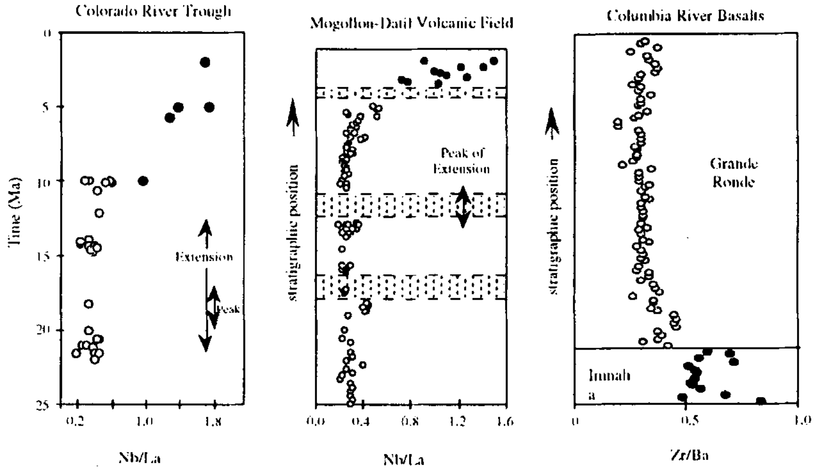

FIG. 1. Variations of a HFS/LIL element ratio, Nb/La or Zr/Ba, with stratigraphic position in the basaltic lavas of the central Colorado River Trough, the Mogollon-Datil Volcanic Field, and the Columbia River CFB (Bradshaw *et al.*, 1993; Davis *et al.*, 1993; Hooper and Hawkesworth, 1993). Open circles are those samples which are inferred to have been derived from the continental mantle lithosphere, and the filled circles are those samples which have relatively smooth mantle normalised trace element patterns, and which may therefore have been derived from the underlying asthenosphere.

and the amounts of extension. In the Columbia River CFB large volumes of magma were erupted in a period of limited regional extension, and the composition of the magmas evolved with time from basalts similar to OIB to those with a significant contribution from the continental lithosphere (Hooper and Hawkesworth, 1993). In contrast, in the Basin and Range the rates of eruption are very much less, extension was typically 100%, and the composition of the bulk of the magmas is high-K calc alkaline basalts to rhyolites. They have enriched isotope ratios and high LIL/HFSE ratios attributed to source regions in the continental mantle lithosphere, and it is only the last few metres of post-extensional basalt that have isotope and trace element ratios similar to oceanic basalts (Bradshaw *et al.*, 1993, and Fig. 1). Thus, magmatism in the Basin and Range appears to have been characterised by a change from source regions in the mantle lithosphere to those in underlying asthenosphere with time (Fitton *et al.*, 1991), and this may be a feature of extension driven magmatism.

Overall, there are a number of unresolved issues regarding magma generation rates and the roles of mantle plumes and tectonics. For example, high rates of magma generation are expected for plume related CFB (e.g. the Deccan), but the Paranç, which is dominated by a lithospheric geochemical signature, appears to have a comparatively low rate. In the Western US, the Columbia River CFB are widely attributed to a mantle hotspot, but the role of mantle plumes in the Basin and Range is more controversial. Specifically, the average elevation in the northern and southern Basin and Range is anomalous in as much as extension leads to subsidence rather than uplift, for normal thicknesses of continental crust. Although a mantle plume might dynamically support such elevations (Parsons *et al.*, 1994), Bradshaw *et al.* (1993) have argued that the low melt generation rates, and the small volumes of magma from asthenospheric sources, are more consistent with mantle potential temperatures only slightly higher than normal.

Rates of melt generation will reflect the temperature-pressure path of a rock relative to its solidus over time. In the asthenosphere, melt generation depends on the excess temperature and the minimum depth to which a plume can rise, i.e. the overlying lithospheric thickness. Assuming that the undisturbed lithospheric lid is thin enough to allow some melting then the rate of magma generation will reflect the rate of upwelling. If lithospheric extension occurs then the hot mantle can upwell to shallower depths and the rate of magma generation will have a tectonic control (i.e. rate of extension), as the material passively flows below the thinned lithosphere.

Generation of melt within the continental lithosphere is controlled by the same factors as the asthenosphere, but locally may be determined by a different solidus as a result of relative enrichment in volatiles. If this is the case, it is necessary to consider the thermal contribution from an underlying plume or hotspot. Conductive heating will occur and can lead to melting of the lithosphere in the absence of melting in the asthenosphere, provided that the lithosphere is more than about 70 km in thickness. Preliminary calculations show that the timescales of heating and melt generation are controlled by the thickness of the lithosphere and the position of the more readily fusible zone. The shortest timescales will occur for lithosphere enriched in volatiles at its base. The temperature anomaly of the plume will not affect the timescale of heating but will determine how much melt (i.e. degree of melting) can be generated, and also the relative contributions of lithospheric and asthenospheric melt.

Those CFB (e.g. Deccan) considered to have been erupted rapidly (1-2 m.y.) are attributable to melting in an upwelling plume. However, others such as the Paranç, which were erupted over a duration of ~ 10 m.y., and these timescales are consistent with conductive heating and melting of the mantle lithosphere, as Brazil migrated over the Tristan plume. Model calculations will be presented to investigate the extent to which the elevated topography and magma generated in the Basin and Range may be explained by a simple model of convective thinning and subsequent heating of the mantle lithosphere without invoking a mantle plume.

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