PROTRACTED PLUME–LITHOSPHERE INTERACTIONS IN THE ETHIOPIAN PROVINCE: TWO MANTLE PLUMES?

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The timing and duration of magmatic events in continental basaltic provinces, combined with temporal and spatial variations in basalt composition place important constraints on melt generation models associated with mantle plumes. This study presents comparative geochronological, geochemical and isotopic data for two different areas of the complete Tertiary volcanic succession in the Ethiopian Province. The Southern Rift region presently lies at the periphery of the topographic expression of the Afar plume, and at the southern-most terminus of the Ethiopian Rift system whereas the Northern Highlands are closer to the centre of the plume and to the region of maximum extension in Afar, the Red Sea and the Gulf of Aden.

The succession in S Ethiopia displays a protracted and episodic history of magmatism predating and synchronous with extension in the Ethiopian Rift itself. Whole-rock laser $^{40}Ar/^{39}Ar$ ages confirm previous K–Ar ages of 35–45 Ma for pre-rift transitional tholeiites which have a stratigraphic thickness of 0.5 km. These events were followed by the 0.5 km thick syn-rift alkaline basalts erupted between 19 and 11 Ma, synchronous with extension in the Ethiopian Rift. Basalts from these stratigraphic subdivisions have distinct trace element and isotopic characteristics, the pre-rift transitional tholeiites having Zr/Nb ratios of 7.0–14.4 whereas the syn-rift lavas have values of 4.0–4.6. Incompatible elements become more enriched with time, suggesting that later magmas are the products of smaller degrees of melting. However, Sr, Nd and Pb isotope ratios also change with time, the high Zr/Nb, pre-rift lavas have higher $^{87}Sr/^{86}Sr$ and $^{206}Pb/^{204}Pb$ ratios and lower $^{143}Nd/^{144}Nd$ ratios than the syn-rift basalts, implying temporal changes in magma source regions.

The basaltic succession in the Northern Highlands shows a more restricted range in both eruptive history and chemical composition $^{40}Ar/^{39}Ar$ ages range from 31 Ma to 24 Ma, with further alkalic magmatism at ~10 Ma, and the available evidence points to a closer relationship between the onset of magmatism and regional extension (25–30 Ma) than in Southern Ethiopia. The temporal geochemical variations in the north are similar to those of the south, with lavas displaying decreasing Zr/Nb ratios with time (16–17 to 6–10). The Sr and Pb isotope ranges are comparable with those in the pre-rift S basalts, but Nd isotope ratios extend to higher values, implying more depleted source compositions. Thus the geochemical data for the Northern Highlands are consistent with decreasing degrees of melting in the convecting asthenosphere with time. However, unlike Southern Ethiopia, the isotopic composition of the later phase of magmatism at 10 Ma does not display enriched lithospheric characteristics.

In the Southern Rift, these trace element and isotopic changes are interpreted as a transition from melting of a convecting mantle source (45–40 Ma), to melting of enriched regions of the lithospheric mantle. In geodynamic terms, this can only be explained if the early plume-related melting event is linked to contemporaneous Eocene rifting events in SE Sudan. The later alkalic phase can be accounted for conductive heating of the lithosphere by the underlying mantle plume. In N Ethiopia plume melting was initiated by extension in the Red Sea but the implied northward progression of the initiation of plume melts from S (45 Ma) to N (31 Ma) is the opposite of that predicted by the track produced by a stationary hotspot under a northerly directed plate. However, if a northerly migration rate of ~2 cm/y is assumed for the African plate over the last 50 Ma, then S Ethiopia would have been positioned approximately over the Kenyan mantle plume at 45 Ma. With continued northward migration, melting of the Afar mantle plume would have ensued in Central and N Ethiopia in response to Red Sea rifting. Melting of two discrete plumes may therefore explain some subtle trace element and isotopic differences between plume-generated melts in the S compared with the N, but more palaeogeographic constraints are required to substantiate this model.