Goldschmidt 2000
September 3rd–8th, 2000
Oxford, UK.

Journal of Conference Abstracts
Volume 5(2), 854

Melting beneath a Continental Rift: Radiogenic Isotope and U-series Analyses from the Kenya Rift

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The extent to which the mantle lithosphere is remobilised during continental rifting and volcanism, and the mechanism whereby melt is generated are subjects of topical debate in the context of models of continental break-up and plume-lithosphere interactions. Specifically does the mantle lithosphere melt at all and if so does it melt dynamically or by batch melting? These problems have been investigated with radiogenic isotope and U-series analysis of recent basaltic lavas from the Kenya Rift.

The Kenya Rift is amongst the best documented examples of continental extension over an active mantle plume. It has been the subject of intense geological and geophysical investigations which have defined its evolution through time and provided a detailed 3-dimensional picture of the crust and mantle down to a depth of 125 km. Amounts of extension are small with β factors ranging from 1.1 to 1.6, while estimates of the volume of melt generated from the mantle range from 0.25 - 0.9 x 10^6 km^3 over the past 30 Ma. To generate such large volumes in any model of mantle melting requires the presence of mantle with elevated potential temperatures and the regional geophysical and topographical anomalies are consistent with the presence of a mantle plume.

Mafic volcanic rocks make up approximately 65% of the erupted volume and they range in composition from hy-normative basalts, alkali basalts, basanites and nephelinites. All are enriched in incompatible trace elements and are similar to mafic rocks from ocean islands. Variations in Zr/Nb and Ce/Y are consistent with derivation from a mantle source region with 2x chondritic abundances of incompatible trace elements, melt fractions ranging from 0.2 to 3% and modal garnet from 0 and 6%. However, such calculations do not preclude larger melt fractions from an enriched source.

Radiogenic isotopes are broadly similar to values in OIB and yet they appear to reflect the anisotropy of the underlying lithosphere. Specifically those erupted through late Proterozoic lithosphere have $^{143}Nd/^{144}Nd$ = 0.5130 - 0.5127, $^{87}Sr/^{86}Sr$ = 0.7030 - 0.7035 and $^{206}Pb/^{204}Pb$ = 18.3 - 19.8, defining a steep negative trend on the Nd-Sr diagram and plotting close to the NHRL on conventional Pb isotope diagrams. By contrast those samples erupted through the Tanzanian craton or its remobilised margin have $^{143}Nd/^{144}Nd$ = 0.5124 - 0.51275, $^{87}Sr/^{86}Sr$ = 0.7035 - 0.7056 and $^{206}Pb/^{204}Pb$ = 17.6 - 21.2, defining a flat-lying array on the Nd-Sr diagram and a much greater scatter and spread on Pb isotope diagrams, with many analyses plotting above the NHRL. The strong lithospheric control on the radiogenic isotopes implies a major contribution from lithospheric source regions although the balance between mantle lithosphere and plume sources is difficult to constrain. However, there is little evidence for mixing between magmas from the two lithospheric sources.

U-series analyses of recent basalts show a wide variation in ($^{238}U/^{232}Th$) from 0.46 to 1.11, ($^{230}Th/^{232}Th$) from 0.646 to 1.055 and ((^{230}Th /^{238}U) from 2.05 to 0.804. These values are broadly similar to other intra-plate basalts, showing, in general, ^{230}Th excess. There is no systematic difference between basalts erupted through contrasting basement. However, compared with MORB and OIB, the Kenya basalts have unusually low ($^{238}U/^{232}Th$) and ($^{230}Th/^{232}Th$) for their $^{87}Sr/^{86}Sr$ values. Individual volcanic centres reveal both vertical and sub-horizontal arrays on the equiline diagram although there is no clear correlation between trace element indicators of melt fraction and degree of disequilibrium

Qualitatively, the vertical arrays on the equiline diagram and the amount of disequilibrium in many of the samples imply dynamic melting beneath the rift axis. This is consistent with the results of seismic refraction studies which show that asthenospheric mantle is present as shallow as 40 km beneath the rift axis. The amount of lithospheric thinning identified by these observations is much greater than those inferred from surface extension, implying that much of the mantle lithosphere beneath the rift axis has been thermally remobilised. The lithospheric radiogenic isotopes can be reconciled with the U-series disequilibrium if the mantle lithosphere has been heated and locally incorporated into the asthenosphere, allowing the development of a dynamic melting regime. For those centres that show horizontal U-series arrays, it is possible that source regions were subject to batch melting but even in these examples the amount of disequilibrium is too great to be attributed to melting of a four-phase lherzolite.