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The Role of Deep Melting Under the Cameroon Line in the Fractionation of Helium and Incompatible Lithophile Elements

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Helium ($^4He/^3He$) and Pb (^{206}, $^{208}Pb/^{204}Pb$) isotopes show a positive linear correlation in Cameroon line basalts. Lead isotopic data show large variations in $^{206}Pb/^{204}Pb$ relative to the MORB Pb reference line and indicate a recent (~125 Ma) fractionation event (Halliday et al. 1990). The combined trace element and isotopic evidence show that this event produced an enrichment of both U/Pb and U/He. A second trace element fractionation, superimposed upon the first, which is uncorrelated with the isotopic compositions is most likely related to the latest stage of partial melting leading to eruption. Isotopic (Nd, Hf) and trace element evidence indicate that these features are not the result of mixing processes. Instead, the data are explained by a partial melting model where melts are formed by a plume impinging on Gondwana lithosphere at ~125 Ma and are subsequently trapped and stored in the asthenosphere beneath the Cameroon line. Remelting of the trapped material immediately prior to eruption produces a second fractionation of U(and Th)/Pb (and possibly U/He) that is uncorrelated with Pb isotopic compositions. The least complex model to fit the data requires that He behaves more compatibly than U and Th during partial melting, i.e., D(He)>D(U) and D(Pb)>D(U), to produce an array of positively correlated $^4He/^3He$ and $^{206}Pb/^{204}Pb$ isotopic compositions. The array of Pb and He isotopic compositions derive from stored melts produced by variable degree of partial melting (or melt percolation), and hence variable U/Pb, Th/Pb and U/He. The decreased incompatibility of He may result from high-pressure partial melting (~150 km depth) corresponding to a decrease in ionic porosity of silicate melts (Chamorro-Pérez et al. 1998). The electronic configuration and similar sizes of He and U^{4+} dissolved in crystals suggest that He may be at least as compatible as U and Th. Melting beneath thick continental lithospheres may lead to the generation of trace element and noble gas enriched source regions characterized by correlated Pb and He isotopic compositions. Alternatively, a decrease in incompatibility of helium could manifest simply as a result of the absence of CO_2 fluid/vapor phases during melting. In this case, the condition D(He)<D(U) would only be realized at shallow depths where CO_2 saturates as a gas phase in silicate melts.

Potential regions of deep melting such as at the core-mantle boundary (Williams and Garnero 1996), the 410km discontinuity (Revenaugh and Sipkin 1994), or the source region of komatiites in the early Earth (Herzberg 1995) may have produced depleted reservoirs possessing low U/He and Th/He ratios. Thus, present day manifestation of high $^3He/^4He$ ratios in OIB may in some cases reflect tapping of these previously depleted regions rather than derivation from completely undegassed reservoirs.

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