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Probing the Mantle: The Isotope Story from Carbonatites

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Although much of the isotopic information about mantle relationships has been obtained from mafic silicate rocks, especially those in oceanic settings, carbonatites provide a second variety of probe with several specific advantages over data from silicate rocks. Carbonatites can be found on all continents, where they provide information extending back in time to at least 2.7 Ga (not possible in oceanic settings), and they contain exceptionally high abundances of Sr and Nd, making them especially useful for monitoring the secular evolution of the sub-continental mantle.

Earlier work has defined Nd, Sr and Pb isotope data in young (<300 Ma) carbonatites around the world situated in rifts or hot spots. A group that we call "Reference Carbonatites" encompasses data from 8 sites located in Magnet Cove, Arkansas; Oka, Quebec; Fuerteventura, Canary Islands; Santiago, Cape Verde Islands; Kaiserstuhl, Germany; Chilwa Lake, Malawi; Koga, Pakistan and Westland, New Zealand. In an E(Nd) - $^{206}Pb/^{204}Pb$ diagram the data define an impressive linear trend with nearly constant E(Nd) values and mantle HIMU as an end member in model mantle space as defined by HIMU, EM1 and DMM [1]. All data closely fit an end-on view of the mantle plane in Nd-Sr-Pb space. The other end member for the carbonatite pattern is best represented by the very uniform isotope data from mafic rocks at Pitcairn Island in the southern Pacific Ocean [2]. An $^{87}Sr/^{86}Sr$ - $^{206}Pb/^{204}Pb$ diagram yields a quite similar pattern. Those observations seem especially significant since the Pitcairn data plot well within the range of isotope values proposed for FOZO [3]. The carbonatite data suggest that mantle with isotope ratios similar to the Pitcairn values is present around the world.

A second suite of eleven young carbonatites in the East African Rift yield a distinctly different isotope pattern that largely requires the two model mantle end members, EM1 and HIMU. The fit of the data to the model mantle plane in Nd-Sr-Pb space is again good. The African rift *per se* does not seem to account for the differences in the isotope patterns of the two groups of carbonatites given that one of the Reference Carbonatites, Kaiserstuhl, is also associated with a major rift. The different pattern shown by the East African carbonatites may be related to a major thermal anomaly in which lower velocity mantle material can be traced to the core-mantle boundary [4]. If true, the EM1 component in the African Rift samples likely originates in the deep mantle; not necessarily in the sub-continental lithosphere, as sometimes claimed in the literature. A world-encircling FOZO source provides an alternate interpretation to the Sr and Nd isotopic evolution patterns described for Canadian Shield carbonatites spanning a range of ages between 0.1 (the Oka pluton of our Reference group) and 2.6 Ga [5,6]. These remarkably uniform evolution patterns having "depleted mantle" signatures, were originally attributed to a major differentiation event in the mantle that produced depleted sub-continental lithosphere and continental crust ca. 2.8 billion years ago [5,6]. The present carbonatite data, suggest that the source could equally well be the FOZO mantle, indicating that it has existed for billions of years as an approximately closed system.

From these observations we conclude: (1) Present data yield two distinct carbonatite populations; (2) The apparent EM1 component in the Reference Carbonatite population does not originate in the upper mantle lithosphere; (3) A FOZO-like source is widely distributed in the sub- lithospheric mantle and may have existed there for at least ca. 3 billion years as an approximately closed system.

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