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Is Primitive Mantle a Proterozoic Feature of the Earth?

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The concept of fertile pyrolitic "primitive mantle" is now entrenched in geochemistry and a general consensus exists on its major and trace element composition. This acceptance reflects the apparent success of primitive mantle as a source in melt-residue relationships between Phanerozoic picritic magmas and refractory harzburgite mantle xenoliths. Serious major element mass-balance problems arise, however, when this equation is applied to Archean high-Mg magmas and any observed harzburgite composition, especially the Si-rich harzburgite xenoliths in the kimberlites of some Archean cratons. Archean high-Mg magmas are too low in Al and high in Si (Figure 1) to have left such harzburgite residues, following extraction from a source with the composition of primitive mantle. Moreover the Fe-rich compositions of some Precambrian alkaline ferropicrites suggest that Archean mantle sources were also richer in Fe than the accepted composition of primitive mantle (Francis et al., 1999).

The proposed compositions of primitive mantle are strongly tied to the compositions of ultramafic xenoliths carried from the mantle by recent alkaline basalts. A recent compilation of Re-Os isotopic data, however, shows that such xenolith suites, the world over, consistently yield Proterozoic Os model ages (Meisel et al., 2000). Furthermore, the most fertile ultramafic xenoliths in these suites, those that constrain the presently accepted composition of primitive mantle, have Os isotopic compositions that are equivalent to those of modern MORB (^{187}Os/^{188}Os ~ 0.13), and thus they may actually represent fragments of fertile convecting upper mantle. These Proterozoic ages for alkaline basalt xenoliths are in striking contrast, however, to the Archean Os model ages obtained for many kimberlite-hosted mantle xenoliths that sample the mantle roots beneath a number of Archean cratons.

All these data are consistent with the possibility that the composition of the Earth's mantle has evolved since the Hadean. In the proposed model, the fertile mantle sources for Archean high-Mg magmas were richer in both Si and Fe than modern primitive mantle, more similar to carbonaceous chondrites in terms of Al and Si than pyrolite (Figure 1). Archean harzburgite xenoliths from cratonic kimberlites are compatible restites for the extraction of Archean High-Mg magmas from such sources. According to this model, the increase in the Al content of komatiitic magmas from the early Archean through to the Mesozoic would reflect the evolution of the composition of fertile mantle towards that of pyrolitic primitive mantle over time.

The mechanism for the proposed mantle differentiation over the history of the Earth remains to be determined. The sense and magnitude of the proposed changes in Si, however, would be compatible with ~15% loss of Mg-Fe perovskite to a dense "abyssal" layer (Kellogg et al., 1999) in the lower mantle, assuming a bulk silicate Earth that resembles carbonaceous chondrites, with no Si in the core.

The compatible major, trace, and Os isotopic compositions of fertile Proterozoic mantle xenoliths and MORB suggest that the presently convecting upper mantle that produces MORB developed in the Proterozoic. Fertile remnants of this convecting upper mantle have been trapped around the edges of Archean cratons, and later sampled by alkaline basalts. The presently accepted composition of primitive mantle is based on such xenoliths and may thus be a Proterozoic feature of the Earth. Accordingly, the low Si/Mg ratio of the present upper mantle would not reflect processes during the Earth's accretion, but rather the magmatic evolution of the Earth's mantle over time.

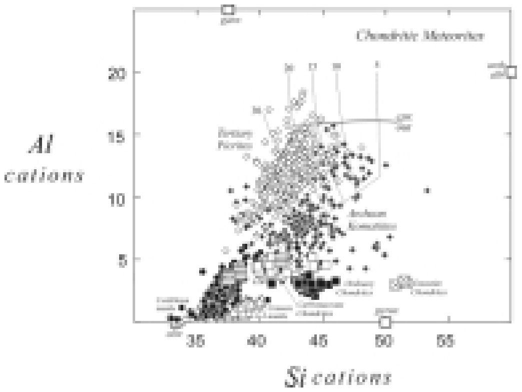

Figure 1: Al versus Si showing the relationships between primitive mantle, mantle xenoliths, chondritic meteorites, and high-Mg magmas.

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