Origin and evolution of Archean lithospheric mantle

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Analysis of an extensive database of xenolith and xenocryst material has shown that the composition of the subcontinental lithospheric mantle (SCLM) varies in a systematic way with the age of the last major tectonothermal event in the overlying crust (Griffin et al. 1999). This secular evolution in SCLM composition implies quasi-contemporaneous formation of the crust and its underlying mantle root, and that crust and mantle in many cases have remained linked through their subsequent history. Archean SCLM is distinctively different from younger mantle; it is highly depleted, commonly is strongly stratified, and contains specific rock types (especially subcalcic harzburgites) that are extremely rare or absent in younger SCLM. Some, but not all, Archean SCLM also has higher Si/Mg than Proterozoic or Phanerozoic SCLM.

Attempts to explain the formation of Archean SCLM by reference to Uniformitarian processes, such as the subduction of oceanic or island-arc mantle ("lithospheric stacking"), founder on the marked differences in geochemical trends between Archean xenolith suites and modern examples of highly depleted mantle, such as island-arc xenolith suites and ophiolites. Data from Archean xenolith suites show that Fe and especially Cr are positively correlated with Al at Al_2O_3 contents <1.5%, indicating that all three elements behaved incompatibly at the high degrees of depletion reflected in these xenoliths (Fig. 1). By contrast, in highly depleted peridotites from modern intraplate and convergent-margin settings, the presence of spinel and/or garnet during melting produces a trend of constant Fe and constant or increasing Cr, with decreasing Al (Fig. 1). This behaviour implies that no Cr-Al phase (i.e. spinel or garnet) was present on the liquidus during the melting event that produced the Archean SCLM. It therefore is unlikely that the Archean peridotites were produced at shallow depth (e.g. MOR or arc environments) and were subducted to form continental keels.

Attempts to diminish these differences and to explain the high Si/Mg of some Archean xenoliths, by Si metasomatism of the Archean roots over time, fail to explain why such effects are not seen in younger SCLM samples, or why Archean harzburgites and lherzolites with high Si/Mg are not enriched in other elements (such as Fe, Ca and K) that would be carried by such Si-rich melts. Instead, the observations summarised in Figure 1 support suggestions by Herzberg (1999) that Archean SCLM represents residues and/or cumulates from high-degree melting at significant depths, perhaps related to plume tectonics or major mantle overturns.

Existing data on mantle depletion ages in cratonic roots, based on whole-rock Re-Os analyses of xenoliths, show a wide range in ages, which might suggest that SCLM growth has been a semi-continuous process. However, the Re-Os (and PGE) systematics of mantle-derived peridotites are almost completely controlled by trace amounts of sulfide mineras (Alard et al. 2000). *In-situ* Re-Os dating of these sulfide minerals in mantle-derived peridotites by LAM-MC-ICPMS (Pearson et al. 2001) shows that most whole-rock "ages" must reflect a mixture of =2 generations of sulfides; the *in-situ* data provide much tighter constraints on the ages of mantle depletion events. Preliminary *in-situ* Re-Os data on sulfides in peridotite xenoliths and olivine macrocrysts from the Kaapvaal, Siberian and Slave cratons suggest that most Archean SCLM may have formed in a small number of major events >2.8 Ga ago, and has been subsequently modified by metasomatism.

The extreme depletion of Archean SCLM makes it highly buoyant relative to the underlying asthenosphere (Poudjom Djomani et al. 2001). Large bodies of such material, produced by major melting events at moderate to high pressure, would have risen and accumulated at relatively shallow depths. The survival of Archean crust may have been critically determined by the availability of large plugs of this very buoyant SCLM (a "life-raft" model of craton formation). Conversely, less depleted types of mantle, and much of the mafic crust, may have been recycled and lost, so that our present record of Archean SCLM and continental crust may be incomplete and biased.

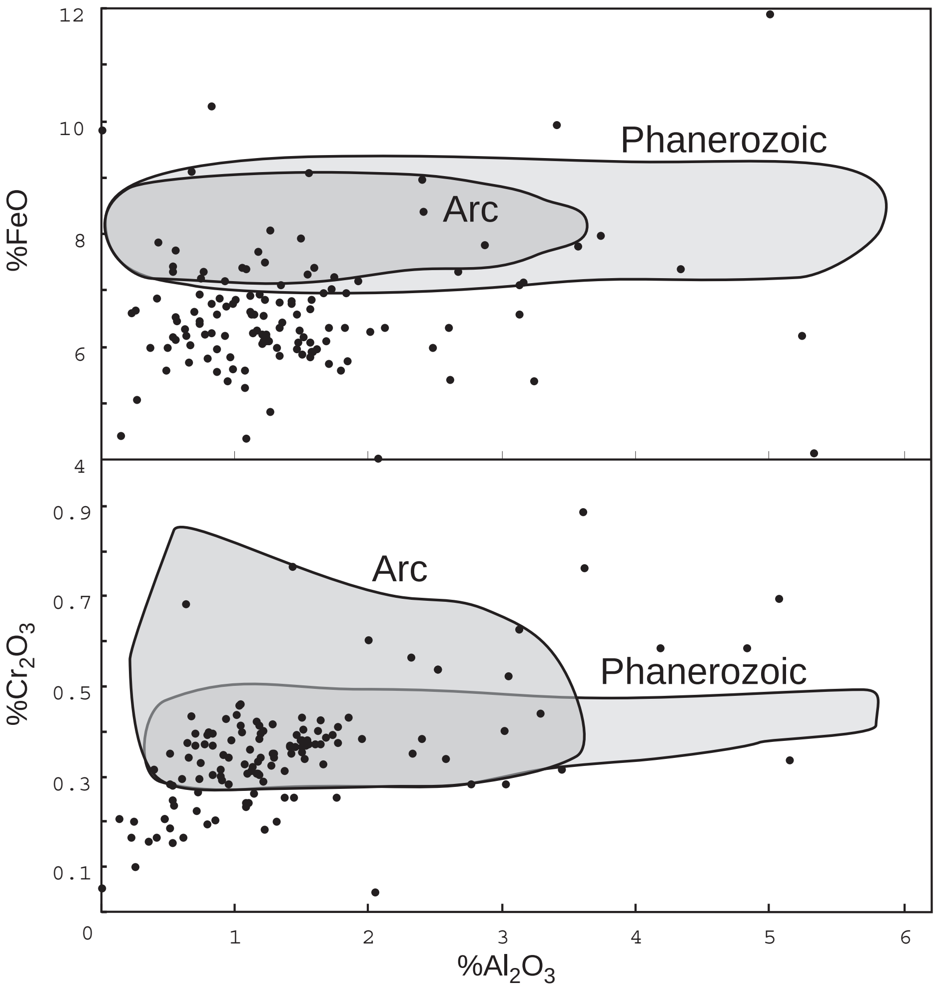

Figure 1. FeO and Cr_2O_3 vs Al_2O_3 content for peridotite xenoliths from the Kaapvaal Craton (black dots), compared to the fields for spinel and garnet xenoliths from Phanerozoic intraplate settings, and spinel peridotites from convergent-margin settings ("Arc"). Data compiled from literature sources listed by Griffin et al. (1999) and original data by Abe (unpublished). The distinctly lower Fe content of the Archean xenoliths, and the marked positive correlation between Cr and Al at low Al, imply that no Cr-Al phase was present on the liquidus during the melting event that produced the Archean peridotites. This makes it unlikely that Archean SCLM was produced by shallow processes like those operating at modern convergent margins and subsequently subducted to form continental roots.

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