Heterogeneity of Archean continental roots: Evidence from chemical tomography

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The trace-element patterns of garnet and clinopyroxene grains in heavy-mineral concentrates derived from volcanic rocks contain detailed information about the composition and evolution of the lithospheric mantle (Griffin et al. 1999a). Novel statistical methods have been applied to a database of major- and trace-element data on mantle-derived Cr-pyrope garnets (n = 18,000), to define 15 natural populations (classes). Comparison with similar data on garnets from 195 well-characterised xenoliths has then been used to identify the rock types and processes corresponding to individual classes. These can be grouped into broader classes: depleted harzburgites and lherzolites, depleted rocks metasomatically re-enriched in LIL and HFSE elements (commonly with phlogopite), fertile lherzolites, and low-mg# rocks affected by melt-related metasomatism. The distribution of these broad groups, and of individual classes, in the subcontinental lithospheric mantle (SCLM) varies with the tectonothermal age of the overlying crust. The secular evolution of SCLM composition (Griffin et al. 1998b) is expressed as a decrease in the proportions of the depleted and depleted/metasomatised classes from Archon to Tecton; the % of metasomatised rocks is highest in Proton SCLM. The apparent dramatic change in lithosphere composition near the end of the Archean, and an apparent more continual evolution to more fertile compositions since then, implies a major change in Earth's geodynamics in the late Archean.

The use of single-element thermometers allows the geochemical information for each grain to be placed in a depth context, so that vertical, lateral and temporal variations in mantle lithology can be mapped (Fig. 1). Data from a 1000-km traverse across the Siberian craton (Griffin et al. 1999b) show sharp discontinuities in mantle composition and stratigraphy within the Archean part of the craton, and between the Archean and Proterozoic parts. These breaks correspond with terrane boundaries mapped at the surface, indicating that the terrane boundaries are translithospheric and steeply dipping. This implies that individual terranes each carried their own distinctive lithospheric keel into the amalgamation of the craton. A similar traverse through South Africa and Botswana shows that different terranes within the Kaapvaal-Zimbabwe craton are underlain by distinctively different types of lithospheric mantle (Figs 1, 2). Mapping of the lithosphere beneath the central part of the Slave Craton of northern Canada (Fig. 1) shows a strongly layered lithospheric mantle, in which an ultradepleted upper layer (<100-150 km) is separated from a less depleted lower layer (150-220 km) by a sharp boundary. Clinopyroxene data show that the boundary between the layers localised strong metasomatic activity. Inversion of the garnet-olivine thermometer (Gaul et al. 2000) allows the use of garnet concentrates to derive the mean Fo content of olivine at any depth in the lithosphere, and shows a distinct change in mean Fo at the boundary between the layers. The presence of abundant diamonds with lower-mantle inclusion parageneses suggests that the lower layer was produced by the accretion of plume-derived material to the lower lithosphere.

Application of this technique reveals that several other Archean and Proterozoic lithospheric sections worldwide show evidence for a layered structure similar to that mapped in the Slave craton (Fig. 2). Some of these sections also are known to contain lower-mantle diamonds, suggesting that plume-related contributions to lithospheric growth may be more common than previously recognised. In addition to these episodic growth events, the SCLM probably has undergone a more continuous changes in composition. Mapping of mantle sections in the same geographic region, but sampled by eruptions widely separated in time (e.g. older and younger kimberlites in the SW Kaapvaal craton; Fig. 1) allows recognition of the evolution of the mantle in specific areas. This approach, combined with data on the vertical distribution of metasomatic effects in lithosphere sections, suggests that Archean roots have been continuously modified over time by "leakage" of melts from the underlying asthenosphere.

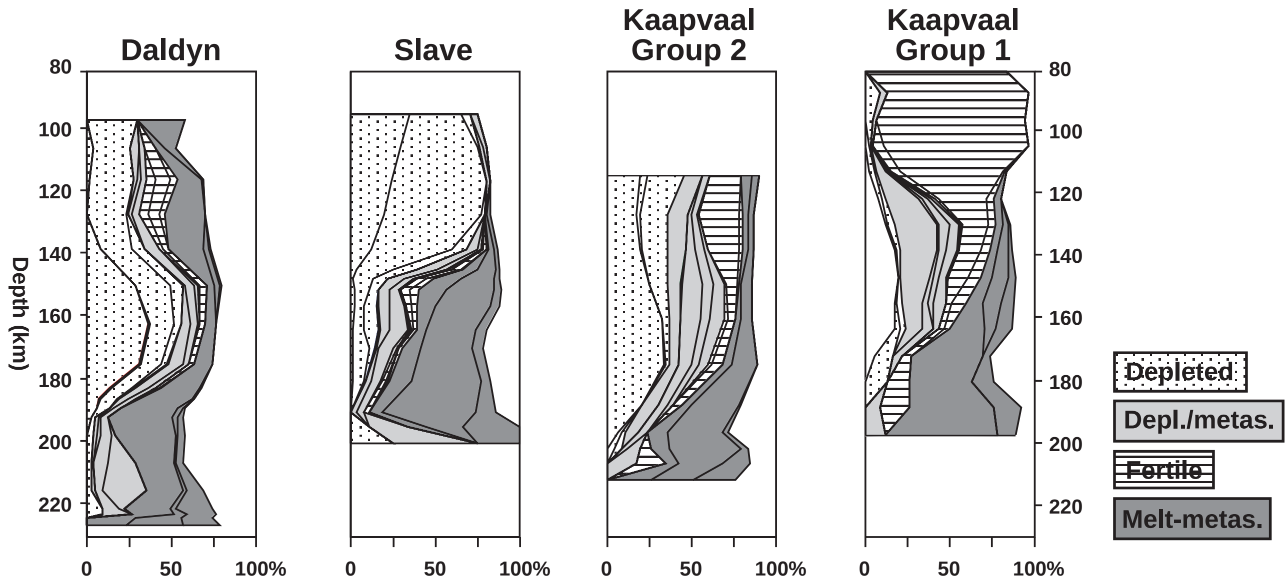

Figure 1. Mapping Archean Lithosphere. Columns show the distribution with depth of garnet xenocryst classes (thin lines), grouped into those derived parent rocks with different broad geochemical signatures: (1) Depleted harzburgites and lherzolites, (2) Depleted rocks that have been partially re-fertilised by metasomatism, (3) Fertile lherzolites, (4) Lherzolites infiltrated by asthenospheric melts. The two sections from the SW part of the Kaapvaal Craton represent different time slices; Group 2 kimberlites are mainly intruded before 100 Ma, and Group 1 kimberlites are intruded after 90 Ma. Plume-related metasomatism between these two events has changed the lithosphere toward a less depleted overall composition, raised the geotherm, and thinned the lithosphere by ca 30 km.

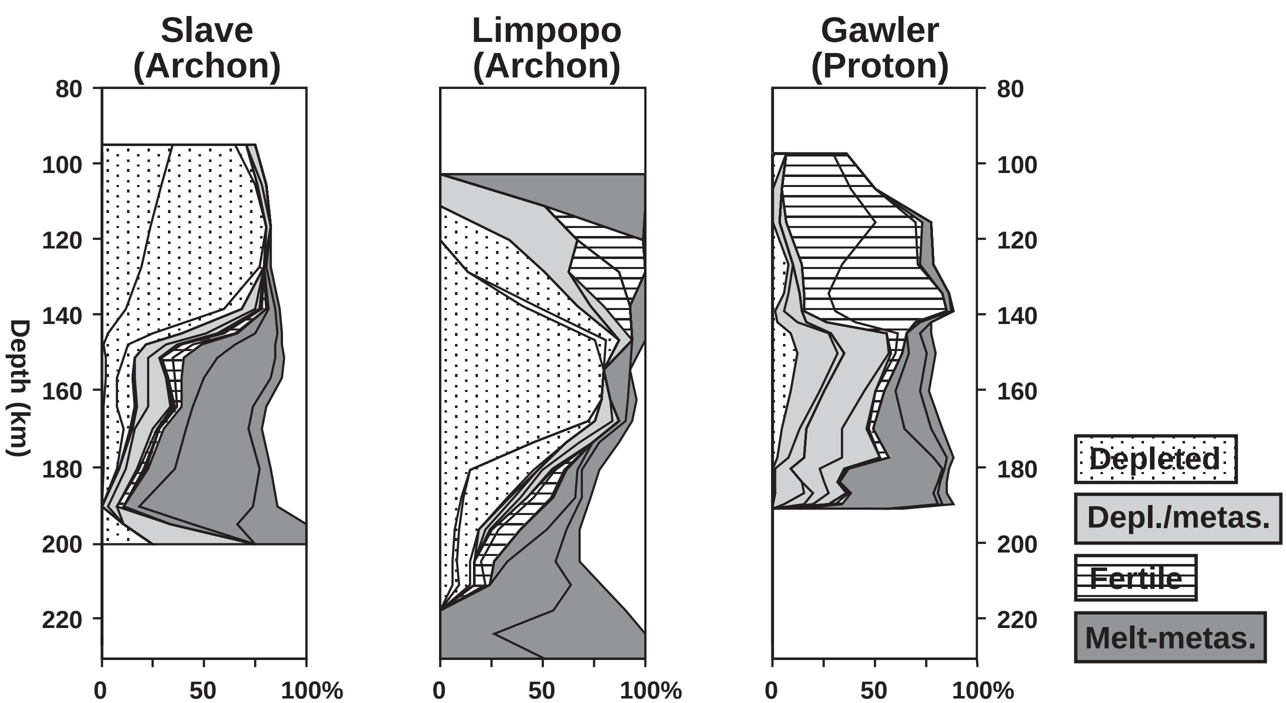

Figure 2. Examples of layered lithosphere, possibly related to plume subcretion. Columns constructed as in Figure 1. The Slave section shows a strongly depleted upper layer, underlain by a more normally depleted layer. The Limpopo section consists mainly of highly depleted rocks, underlain by a 15-25 km section of fertile lherzolites. The Gawler Craton (S. Australia) shows a relatively fertile upper part, separated by a sharp boundary from a more depleted lower half. All of these sections have yielded diamonds of the lower-mantle paragenesis, suggesting that plume-derived material has been added to the lithosphere; this process may account for the strong layering.

Estimates of the density of SCLM of different ages show that Archean SCLM is strongly buoyant relative to the underlying asthenosphere and will resist delamination, whereas Phanerozoic SCLM sections that have cooled to a stable conductive geotherm are neutrally buoyant and susceptible to delamination (Poudjom Djomani et al. 2001). However, data from several areas (e.g. eastern China; Griffin et al. 1998) show that Archean lithosphere, despite its buoyancy, can be disrupted and partially replaced by younger and less depleted mantle in extensional situations. This replacement, which involves major changes in bulk density and thermal state, has major tectonic consequences, including rapid uplift and subsequent basin formation (O'Reilly et al. 2001).

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