SECULAR EVOLUTION OF SUBCONTINENTAL LITHOSPHERIC MANTLE

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ABSTRACT

Chemical and petrographic observations on mantle-derived xenoliths and xenocrysts define a fundamental distinction between Archean cratonic mantle and Phanerozoic circumcratonic mantle. Archean xenoliths are more depleted on average, and those from South Africa and Siberia, the best-studied areas, have higher Si/Mg than Phanerozoic xenoliths of similar Mg#; subcalcic harzburgites are well-represented in Archean xenolith and xenocryst suites, but rare in younger ones.

Analysis of >13,000 garnet xenocrysts from volcanic rocks worldwide shows a correlation of garnet composition with the tectonothermal age of the crust penetrated by the volcanic rocks. Typically, garnet suites from volcanics penetrating Archean crust have higher Cr#, lower Y, Y/Ga and HREE/Sc, and higher Zr/Y than those from volcanic rocks in Proterozoic and Phanerozoic terranes. These differences, and the rarity of subcalcic garnets in mantle beneath Proterozoic and Phanerozoic crust, are consistent with a decrease in mean modal cpx/gnt and (cpx+gnt) from Archean to Proterozoic to Phanerozoic mantle.

Temperatures calculated from the Ni content of peridotitic garnets (T_{Ni}) can be referred to a local paleogeotherm to map the distribution of garnet types with depth. These maps show that Archean mantle sections are typically strongly stratified, with concentrations of harzburgitic rocks and depleted lherzolites in the middle to lower parts of the sections, and more fertile lherzolites at depth. Proterozoic mantle sections are less depleted and typically less strongly stratified, while the garnet-facies parts of Phanerozoic sections are still less depleted and essentially homogeneous. Inversion of T_{Ni} and composition data on garnets allows mapping of the vertical distribution of the X_{Fo} of coexisting olivine in mantle sections. Archean sections typically show decreasing X_{Fo} with depth; Proterozoic sections are less regular, and many show the lowest X_{Fo} in the upper parts of the sections. These differences imply changes in the processes that have produced subcontinental lithospheric mantle (SCLM) at different times in Earth history.

In xenolith suites, the Cr content of peridotitic garnet correlates well with the Al content of the host peridotite, and Al is closely related to the contents of other major and minor elements. These correlations allow calculation of the mean composition of a mantle section, given the Cr content of garnet xenocrysts from that section. The calculated mean composition of SCLM beneath Archean, Proterozoic and Phanerozoic terrains shows a secular evolution in all measures of depletion, such as Al, Ca, Mg#, and Fe/Al; Proterozoic SCLM is intermediate in composition between Archean and Phanerozoic SCLM. Cenozoic SCLM, exemplified by garnet peridotites from young extensional areas (China, Siberia, Australia) is only mildly depleted (≤10% melt extraction) relative to Primitive Mantle.

Similar compositions are found in some exposed spinel lherzolite massifs in extensional settings, such as Zabargad Island. Shallow spinel-facies SCLM beneath some Phanerozoic terrains, especially in Europe (both xenolith suites and exposed massifs), is more depleted and may represent reworked Proterozoic SCLM; this is consistent with some Re-Os depletion ages. Archean xenolith suites show positive correlations between Al, Fe and Cr that are not present in younger mantle samples; these correlations indicate that no Cr-Al phase was present on the liquidus during the melting event that produced Archean mantle.

We suggest that most Archean SCLM was derived by high-degree melting at depths ≥150 km, and that subduction processes have not been significant in its genesis. Phanerozoic circumcratonic xenolith suites are typically much less depleted than ophiolitic and abyssal peridotites; this suggests that subducted oceanic mantle is not a major component of Phanerozoic SCLM. Instead, the fertile composition of circumcratonic xenolith suites, and comparison with the Zabargad situation, suggests that most existing Phanerozoic SCLM probably has been generated in extensional post-orogenic environments.

Density modelling shows that Phanerozoic SCLM, once it has cooled to typical conductive geotherms, will be gravitationally unstable with respect to the asthenosphere. This instability provides a mechanism for removing such lithosphere and replacing it with upwelling fertile material on a short time scale. In contrast, typical sections of Archean and Proterozoic SCLM are gravitationally stable, allowing their long-term preservation. The broad correlation of SCLM composition with crustal age implies quasi-contemporaneous formation of crustal volumes and their underlying SCLM, and crust-mantle coupling over periods of aeons beneath Archean and Proterozoic terranes; it also requires an evolution in fundamental processes involved in the formation of continents and their roots. This evolution may be related to the secular cooling of Earth, and a consequent decrease in the melting temperature and depth of melting in mantle plumes.