Imaging Petrological and Thermal Heterogeneity in the Lithospheric Mantle: Tectonic and Geophysical Implications

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Xenoliths from volcanoes show considerable variability in the subcontinental lithospheric mantle (SCLM). It is expensive and time-consuming to map small- to medium-scale compositional variations in the SCLM using xenolith data. However, considerable information can be extracted from suites of xenocrysts (fragments of xenoliths), and modern analytical technology allows the rapid acquisition of statistically meaningful datasets.

Single-grain temperatures can be determined for peridotitic garnet, clinopyroxene and chromite, and the information from each grain can be assigned a depth by reference to a local geotherm, derived from xenolith or xenocryst data. The relative proportions of populations derived from multivariate analysis reflect the distribution with depth of specific rock types and metasomatic processes. The mg# (%Fo) of olivine that coexisted with each garnet grain can be calculated, to give the variation of olivine composition with depth. Using these techniques, we map significant compositional boundaries within the upper mantle, as well as gradual changes in composition with depth, which may be less obvious in geophysical data sets.

Comparison of SCLM sections beneath crust of different tectonothermal age shows a secular evolution in SCLM composition, from highly depleted (olivine ≥Fo93) in the Archean to weakly depleted (Fo90) lherzolites beneath Phanerozoic areas. Archean and Proterozoic SCLM is intrinsically buoyant relative to the asthenosphere. It is difficult to delaminate or destroy, but becomes gradually refertilised from the bottom up by the passage of melts and fluids. Increased SCLM fertility is typically linked to higher geotherms, and both effects lead to lower seismic velocity. The positive correlations between fertility, density and geotherm, and the negative correlation (in peridotites) between density and seismic velocity, are the keys to integrating geophysical and petrological data to map the SCLM.

SCLM sections from several Archean and Proterozoic areas show pronounced layering, which may reflect the growth of the SCLM by the subcretion of plume heads. Archean SCLM apparently persists under many regions of Proterozoic and even Phanerozoic crust, and Archean lower crust may be more widespread than usually thought. Ancient buoyant SCLM determines the stability of cratonic blocks, while sutures between such blocks are natural zones of weakness that may be repeatedly reactivated during continental growth, breakup and re-arrangement. Fertile Phanerozoic SCLM is intrinsically much denser than Archean SCLM; it becomes inherently unstable and delaminates during post-tectonic cooling, leading to cyclic replacement by upwelling asthenosphere. The fundamental differences between Archean and Phanerozoic SCLM imply significant changes in tectonic styles through time.