Mapping the Lithospheric Mantle: Tomography meets Geochemistry and Geothermics

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Xenoliths from volcanic rocks show considerable variability in the subcontinental lithospheric mantle (SCLM). It is difficult to map small- to medium-scale compositional variations in the SCLM using xenolith data: the acquisition of statistically meaningful data sets is expensive and time-consuming, even where material is available. However, considerable information can be extracted from suites of xenocrysts, which are derived from the fragmentation of mantle wall rocks. Modern analytical technology allows the rapid analysis of many compositional variables in hundreds of grains from single localities, and the determination of their stratigraphic variation.

Single-grain temperatures currently can be determined for peridotitic garnet, clinopyroxene and chromite, and each grain can be placed in a depth context by reference to a local geotherm, which can be derived either from xenolith data, or from the mineral suites themselves. These geotherms tend to follow conductive models within the lithosphere; stepped geotherms are observed in SCLM with strong lithological layering, reflecting sharp changes in thermal conductivity. The base of the lithosphere should in principle involve a decrease in geothermal gradient (approaching the asthenospheric adiabat) but commonly is marked by a rapid increase in T with depth over short distances, reflecting advective heat transport associated with volcanic eruption.

The information contained in xenocryst analyses is plotted against depth; it can be simple variables, or the relative proportions of populations derived from multivariate analysis. The latter can be ground-truthed against xenolith suites to allow the mapping of specific rock types and metasomatic processes. An inversion of the garnet-olivine thermometer allows calculation of the mg# (%Fo) of olivine that coexisted with each garnet grain, and hence the mapping of olivine composition with depth. This parameter is especially significant for the realistic interpretation of seismic and gravity data. Using these techniques, we can map significant compositional boundaries within the upper mantle, including the lithosphere-asthenosphere boundary, as well as gradual changes in composition with depth, which may be less obvious in geophysical data sets.

Comparison of SCLM sections beneath regions with crust of different tectonothermal age has demonstrated a secular evolution in SCLM composition, from highly depleted (olivine $\geq Fo_{93}$) in the Archean to weakly depleted (Fo_{90}) lherzolites, essentially cooled asthenosphere, beneath Phanerozoic areas. Archean and Proterozoic SCLM is intrinsically buoyant relative to the asthenosphere, and thus cannot be "delaminated"; it persists under many areas of younger reworked crust, though it may gradually become denser (and less stable) through metasomatic refertilisation. Phanerozoic SCLM is intrinsically much denser than Archean SCLM, but much of this density difference is offset (under young mobile belts) by higher T. Increased SCLM fertility is typically associated with higher geotherms, and both effects lead to lower seismic velocity; ca 25% of the observed range in Vs and Vp is due to composition. The positive correlations between fertility, density and geotherm, and the negative correlation between density and seismic velocity in peridotites, are the keys to using combined geophysical data sets to map SCLM composition. With broad constraints imposed by our knowledge of mantle composition, Vs data can be inverted to provide maps of the regional variation in the geotherm within the lithospheric mantle. These maps can then be combined with an understanding of regional crustal history and xenolith-derived compositional data, to map compositional variation within the SCLM.

Detailed maps of SCLM variability in space and time over several continental areas show how these may be correlated with geophysical data and tectonic history. In the Siberian Craton, we map vertical translithospheric terrane boundaries, and see the erosion of the SCLM by the plume associated with the Siberian Traps. In the Slave Craton, the SCLM is strongly layered, with a marked boundary at 140-150 km. The upper layer shows strong provinciality, while the lower layer, interpreted as a subcreted plume head, is laterally homogeneous across the province. In the Kaapvaal Craton, sampling of the SCLM by several generations of kimberlite shows changes in the composition and thermal state of the SCLM through time, and lateral variations that correlate with seismic tomography.

The current vertical resolution of these methods, constrained by thermometry uncertainties, is 5-10 km. The lateral resolution has, until now, been limited by volcano spacing. However, the ability to correlate SCLM composition with geophysical data (especially seismic properties) means that the mapping of compositional variability in the SCLM will improve to whatever resolution can be provided by better seismic data.