Persistence of ancient lithospheric mantle: consequences for geodynamics and basalt geochemistry

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Samples of the deep lithosphere are delivered to the surface as small xenoliths with restricted petrological context, and as tectonic slivers on the scale of km^2 but commonly with metamorphic petrological overprints. Geophysical information (especially tomography) allows us to extrapolate mantle rock-type domains between the magmatic virtual drill holes (kimberlites and basalts) that carry xenoliths, and to build up 3-D images of lithosphere composition, sometimes in time-slices (4-D) reflecting episodes of magmatic activity.

Xenolith data reveal significant differences in composition and physical properties between Archean and Phanerozoic mantle (Griffin et al., 1999); much intermediate “Proterozoic” mantle may represent reworked Archean material. Although depleted ancient SCLM cannot be recycled through convection due to its low density (eg O'Reilly et al., 2001), truly pristine Archean mantle may be very rare as these buoyant blobs undergo repetitive geochemical transformation to varying degrees.

Refined seismic tomography inversions image low density regions both in oceanic upper mantle and below the conventional lithosphere-asthenosphere boundary beneath continental and especially cratonic regions. In the latter, such low density domains persist, in some cases, down to the transition zone. Old Re-Os ages for some depleted mantle rock types beneath rift zones and oceanic areas suggest that these low-density blobs represent relict Archean SCLM, which has been mechanically disrupted and thinned. This implies that old lithospheric mantle is much more extensive, both laterally and vertically, than previously considered and proposed processes for the formation of Archean lithosphere have to consider this.

If coherent old SCLM persists at depth, this has important implications for the nature of global convection. Models involving large-scale horizontal components would be difficult to reconcile with these observations. Instead, convection may be dominantly in the form of upwelling vertical conduits with shallow horizontal flow (the "mushroom-cloud model" of Yuan, or the lava lamp model of Kellogg et al. (1999). The locus of these conduits may be controlled by the geometry of the margins and the coherence of the buoyant lithospheric blobs. The convective plate motions in the upper asthenosphere are “eddies” between these buoyant blobs and can be preserved in the observed plate stress directions and anisotropy (eg Simons and van der Hilst,). Mobile belts represent lithosphere accretion between the blobs.

The persistence of ancient SCLM beneath younger mobile belts and oceans also provides a logical explanation for the alphabet soup of mantle sources created by geochemists (EM1, EM2, HIMU etc; Zhang et al., 2001). All of these geochemical fingerprints are found in lithospheric material (eg xenoliths). If lithospheric volumes persist to very deep mantle levels (eg 400km) then interaction with upwelling mantle can "contaminate" these plumes and fluids. The requirement for mysterious hidden source regions to provide the geochemical alphabet is removed.

References

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