## PERSISTENCE OF ARCHEAN LITHOSPHERIC MANTLE BENEATH CONTINENTS AND OCEANS

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### **Summary**

High-resolution global seismic tomography (Vs) models reveal high-velocity domains beneath cratonic crust in Africa that extend to depths of 300-400 km. These high-velocity domains show a distinct contrast with the characteristics of "normal" asthenosphere and are interpreted as depleted, buoyant roots that formed in the Archean and have been metasomatised over time, but have remained attached to the overlying crust. Such deep roots are impediments to free horizontal convection in the upper mantle. As a result, movement of magmas and other fluids in such regions may be more vertically constrained (a shallow lava lamp regime). This process creates a geodynamic environment conducive to interaction of such magmas with the boundaries of deep mantle domains that would carry old "crustal" geochemical signatures.

The tomographic models and the recent world magneticanomaly map show that these continental roots, overlain by thinned continental crust, locally extend well out under the deep Atlantic Ocean basin. However, such high-velocity domains are not confined to the basin margins, but are scattered randomly through the basin, some quite distant from the continental margins of South America and Africa. These high-velocity domains are interpreted to be remnant lithospheric fragments isolated by disruption of the ancient continental regions during rifting. This interpretation is supported by the old Os depletion ages of mantle peridotites from mid-ocean ridges and oceanic islands.

## Archean mantle characteristics

Archean subcontinental lithospheric mantle (SCLM) is distinctive in its highly depleted composition, commonly strong stratification, and the presence of rock types absent in younger SCLM. Is Archean SCLM part of a compositional continuum that shows a secular evolution varying broadly with the age of the last major tectonothermal event in the overlying crust, or was the Archean mantle formed in a different way in a distinctive tectonic regime? Did subduction play a major role in Archean SCLM formation? What is the composition of original Archean mantle and how much persists today?

The "typical" Archean mantle composition used in geochemical/geophysical modelling is a depleted garnet lherzolite. This composition is derived from peridotite xenoliths in kimberlites, mainly from the SW Kaapvaal Craton, and a few from Siberia. However, most such "typical" Archean xenoliths have experienced repeated metasomatism, leading to a progression from dunite/ harzburgite through "depleted" lherzolite to "fertile" lherzolite, mirroring the secular evolution of the SCLM as a whole (Griffin et al., 2009), and this is discussed in more detail in Griffin et al. (2010).

Archean lithosphere is significantly less dense than asthenosphere at any depth, whereas young (Phanerozoic) lithosphere is initially less dense due to thermal buoyancy, but on cooling becomes denser and thus gravitationally unstable. Original (unmetasomatised) Archean lithosphere is depleted (Mg-rich and low in basaltic components such as Al, Ca, Fe), consists dominantly of dunite and Ca-poor harzburgite (e.g. Griffin & O'Reilly, 2007) and has high seismic wave velocities mainly due to the high content of Mg-rich olivine (Fo<sub>92-94</sub>). Young lithosphere is fertile (higher in Al, Ca and Fe) with more Fe-rich olivine (Fo<sub>88</sub> average) and higher modal pyroxene, resulting in lower seismic velocity (O'Reilly et al., 2001). These compositional variations alone can account for up to 25% of the observed seismic velocity differences between cratonic and tectonically active regions. However, the combined effects of composition and tectonic environment are intrinsically additive; the Mg-rich cratonic SCLM is also the coolest, and the young tectonic SCLM with its Fe-rich olivine and high pyroxene content is warmer. Thus the separate effects of composition and temperature on seismic wave speed are reinforced in Earth's different tectonic regimes (e.g. Poudjom Djomani et al., 2001; O'Reilly et al., 2001; Deen et al., 2006).

**Evidence for deep cratonic roots beneath Africa** Figure 1 shows a series of tomographic slices through the African continent from 100-175 km, 175-250km, 250-325km and 325 - 400km using a high-resolution global tomography model derived from SH body wave travel times based on the approach of Grand (2002) and fully described by Begg et al. (2009) and O'Reilly et al. (2009). The vertical resolution is estimated as 75-150 km in either direction. Note the colour reversal with red spectrum for fast and blue for slow velocities. The clear demarcation of cratonic domains persists in the 175-250km layer that extends to the lower level accepted for most subcontinental lithospheric mantle. At 250-325km, the cratons maintain coherence and relative velocity contrast at depths below traditional Archean SCLM regions. At 325-400 km, domains beneath the cratons still show higher Vs than the Earth model. Even allowing for considerable vertical smearing of velocity, the highervelocity roots beneath the cratons extend almost to the transition zone (410 km discontinuity).





Figure 1. Tomographic model images (Vs models) for four depth slices through the lithospheric mantle an upper mantle beneath Africa. See text for explanation and discussion. Note that red colours indicate higher velocities and cool colours lower velocities.

Figure 2. Tomographic model images at three depth slices for the Atlantic Ocean Basin (see text for details of the model). Note that "hot" (red-white) colours indicate higher velocities and cool colours lower velocities.

Figure 3. Modified extract from the global magnetic anomaly map (Korhonen et al., 2007) showing the Atlantic Ocean Basin and Atlantic coasts of South Africa and South America. Black lines outline the regions with crustal rather than oceanic magnetic characteristics.



# Ancient continental lithosphere domains in the Atlantic oceanic region

Figure 2 shows tomographic slices through the oceanic lithosphere and upper mantle of the Atlantic Ocean Basin at 0-100km, 100-175km and 175-250km. In the 0-100km section, high-velocity regions are obvious. Some are apparently continuous with continental regions (especially off the southwestern African and southeastern South American coasts) and some occur as discrete "blobs" extending towards the mid-ocean ridge from the continental margins such as those between the mid-Atlantic Ridge and the northwest African coast. In the layer from 100-175km, these fast domains persist, and some also show velocity contrasts in the 175-250km layer.

We suggest that these high-velocity volumes represent remnants of depleted (buoyant) ancient continental lithosphere, fragmented and stranded during the rifting process at the opening of the ocean basin. The highvelocity domains extending out from the coastlines are not uniformly distributed along the basin edge. The most marked high-velocity regions off SE South America and northwest and southwest Africa appear continuous with their respective continental deep structure as seen in the tomographic models. The new global magnetic-anomaly map (Figure 3) shows that these regions have a complex magnetic signature that is consistent with extended continental crust, and distinct from that of oceanic lithosphere. The seismic data suggest that this thinned continental crust is underlain by Archean to Proterozoic SCLM that has been mechanically disrupted and thinned during the formation of the ocean basins partly by listric detachment of continental crust from the underlying continental SCLM. Re-Os data on sulfides from mantle xenoliths from Cape Verde support this concept. Their depleted mantle model ages of 2.7 - 3.5 Ga (Coltorti et al., 2010) suggest that these xenoliths are disrupted fragments of the West African cratonic SCLM.

### Conclusions

The roots of ancient cratons may extend to near the transition zone, representing persistence of parts of these buoyant domains since their formation in the Archean. Throughout this time, rifting and reassembly may modify the original boundaries and the deep roots may be progressively modified, especially along domain margins, by interaction with ascending melts during tectonic events, and by percolation of fluids.

Opening of ocean basins may be largely by listric faulting, leaving significant continental lithospheric wedges at rifted margins, and stranding buoyant domains of ancient lithosphere in the upper part of the new oceanic crustmantle system (Figure 4), where they would "surf the convecting mantle".



Figure 4. Cartoon depicting listric faulting of cratonic margins during ocean-basin formation, and stranding of buoyant ancient mantle remnants in the oceanic domain.

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