The Mantle beneath the Slave Craton (Canada): Composition and Architecture

Suzanne Y. O'Reilly[1], W.L. Griffin[1,2], Yvette Poudjom Djomani[1], L.M. Natapov[1], N.J. Pearson[1], R.M. Davies[1], B.J. Doyle[3] and K. Kivi[4]

[1.] GEMOC ARC National Key Centre, Department of Earth and Planetary Sciences, Macquarie University, NSW 2109, Australia (www.es.mq.edu.au/GEMOC/)

[2.] CSIRO Exploration and Mining, North Ryde, NSW 2113, Australia

[3] Kennecott Canada Exploration Ltd., Vancouver, B.C., Canada

[4] Kennecott Canada Exploration Ltd., Thunder Bay, Ontario, Canada

Introduction

The Slave Province in Canada is a natural laboratory for the integration of geochemical, tectonic and geophysical data to map major lithospheric domains. The Slave craton is a small Archean nucleus within the larger North American craton. We have used robust geochemical methods based on mantle-derived xenoliths, heavy mineral concentrates from over 25 kimberlite intrusions, and representative diamond populations and their inclusions to construct rock-type sections of the lithospheric mantle that delineate the composition, structure and thermal state of the lithospheric mantle across the Slave Craton and in particular detail beneath the Lac de Gras region. Global compilations of topography and gravity data allow the examination of geological patterns at a regional scale, and have allowed us to map variations in the gravity/topography relationships across the Slave Province. In so doing, we delineate discrete tectonic domains within the Slave Province, areas with similar thermal and mechanical properties for the crust and uppermost mantle sections.

Geochemical results: composition and structure

The geochemical analysis of lithospheric material reveals a distinct two-layered lithosphere beneath the Slave craton: a shallow ultradepleted, olivine-rich layer and a deeper less depleted layer.

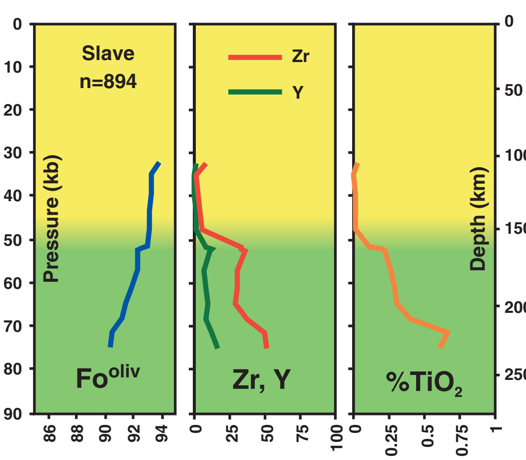

Figure 1: The layered structure of the Slave lithospheric mantle shown by key geochemical indicators. Note the ultra-depleted composition of the upper layer down to about 150 km

The two layers are separated by a sharp boundary at 140-150 km depth that is clearly defined by several geochemical parameters including olivine composition and the Zr, Y and Ti contents of garnets from mantle peridotites (Fig 1); the lithosphere-asthenosphere boundary lies at 200-220 km depth. Xenolith data and garnet compositions indicate that the shallow layer is more magnesian (Fo 92-94) than the deeper layer (Fo 91-92), and both layers are more olivine-rich than average South African or Siberian Archean peridotite xenoliths. Relative abundances of garnet types indicate that the shallow layer consists of ≈60% (clinopyroxene-free) harzburgite and 40 % highly depleted lherzolite, while the deeper layer contains 15-20% harzburgite and 80-85% lherzolite, most of which is relatively less depleted. Temperature estimates on eclogite xenoliths show that all were derived from the deeper layer. High-Ca, Al eclogites are concentrated near the bottom of the section, and are the source of most of the dominant eclogite-paragenesis diamonds (Pearson et al., 1999; Davies et al., 1999). Paleogeotherms derived from both xenoliths and concentrates lie near a 35 mW/m^2 conductive model at T ≤900 °C, and near a 38 mW/m^2 model at higher T, implying a marked change in thermal conductivity near the major lithosphere boundary, and/or a thermal transient.

The two-layered structure extends over an area of ≥9000 km^2, from south of Lac de Gras to the Ranch Lake pipe. In the southern, northern and western parts of the craton, the deeper layer appears to rise to depths of ≤100 km and the ultradepleted upper layer is absent or thinned. Lithospheric

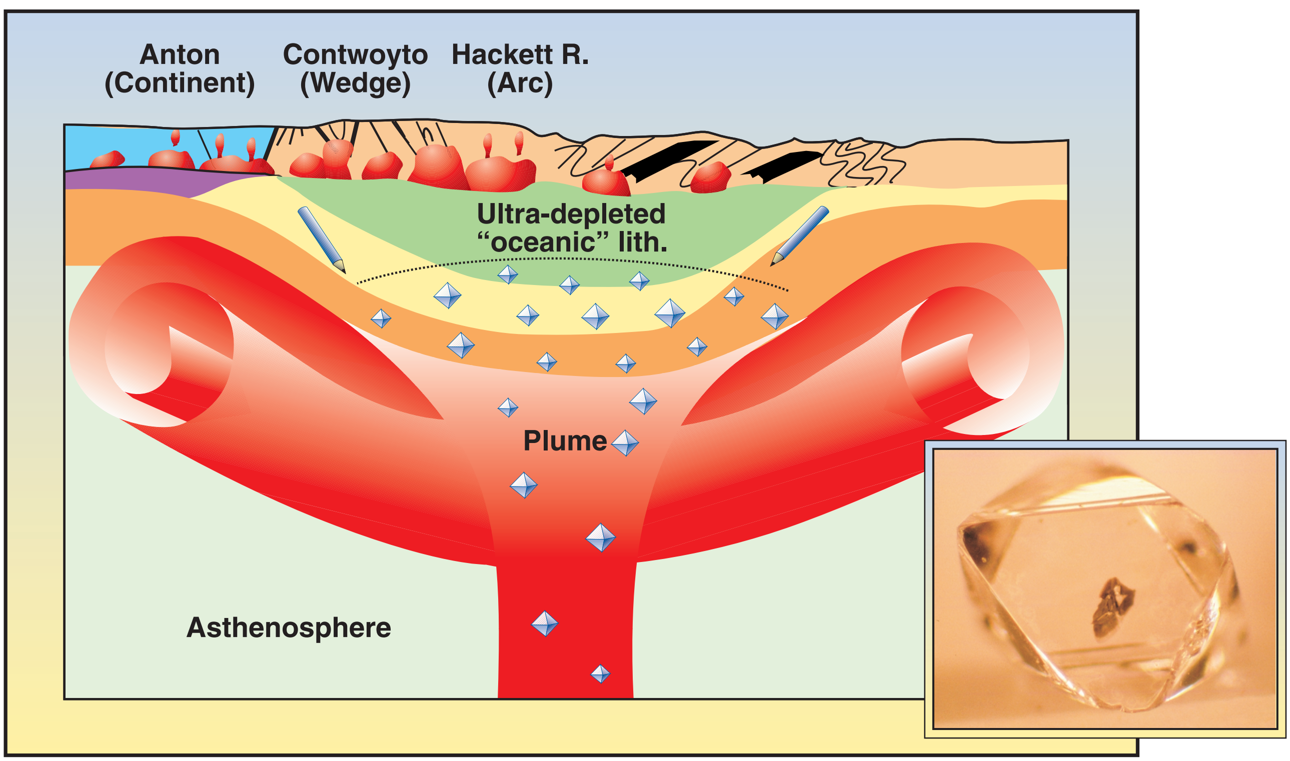

Figure 2: Plume model for generation of the two-layered lithospheric mantle beneath the Lac de Gras area (crustal model after Kusky (1989; 1990)). Inset: Lac de Gras diamond with ultra-deep ferropericlase inclusions.

mantle of typical Proterozoic character is sampled by the Torrie and Jericho pipes (eg Kopylova et al., 1998), and may reflect Proterozoic rifting associated with the Kilohigok Basin. Similar mantle is found further north on Victoria Island, and on the SW margin of the craton; the latter may reflect Proterozoic reworking.

Griffin et al. (1999) interpreted the lower layer as plume material accreted from the lower mantle (Fig. 2). This interpretation is consistent with the recognition that a high proportion of the diamonds contain evidence of an ultra-high pressure (lower-mantle) origin, in the form of inclusions of ferropericlase, Ca- and Mg-silicate perovskite and majoritic garnet (Davies et al., 1999). Some eclogites may have been part of this mantle plume but the more calcic varieties may have been emplaced near the base of the cratonic root during Proterozoic subduction events (Wopmay orogen).

Geophysical results

Gravity data have been enhanced to map large-scale structures on the Slave craton. A map of the gravity data upward continued to 100 km (Fig. 3) shows long wavelength negative Bouguer anomalies on the central part of the craton; the major kimberlite fields cut across these. The northern part of the craton is characterised by relative positive anomalies, which probably reflect the head of the Mackenzie plume that produced major dyke swarms across the craton. Maps of vertical and horizontal derivatives of the Bouguer anomalies highlight NS-oriented structures (eg the eastern and western margins of the craton), as well as near EW-oriented structures (eg Great Slave Shear Zone).

Gravity and topographic data have been inverted to estimate the flexural strength or effective elastic thickness (*Te*) of the lithosphere of the Slave craton. The regional *Te* map shows variations from 14 km to 66 km (Fig. 4). The northern part of the craton is characterised by relatively weak lithosphere (*Te* < 25 km), and the strongest lithosphere is in the eastern part of the craton (*Te* > 56 km). A zone of low *Te* (oriented N-S) defines the western edge of the strong lithosphere on the eastern side of the craton. This feature may map the deep extension of the suture between the ancient continental block (up to 4 Ga old) making up the western part of the craton, and the younger (2.7-2.9 Ga) accreted terranes that make up the eastern part. The area where long-period magnetotelluric studies have defined a strongly conductive upper mantle (Jones et al., 2001) overlies the area with two-layered lithospheric mantle, and lies along the strong N-S T*e* gradient. At this stage, the reasons for the correlation between *Te* and the conductive upper mantle are not obvious. The diamond fields on this part of the Slave Province also are concentrated along the strong *Te* gradient, and within the area of anomalous mantle conductivity. This geochemically and geophysically anomalous zone probably represents a major lithospheric discontinuity in the Slave craton.

Mantle structure inferred from inversion of a seismic dataset of three-component seismograms places the lithosphere-asthenosphere boundary at 250±50km, consistent with our petrological and Jones et al.'s (2001) magnetotelluric studies. The highest seismic velocities are found beneath the

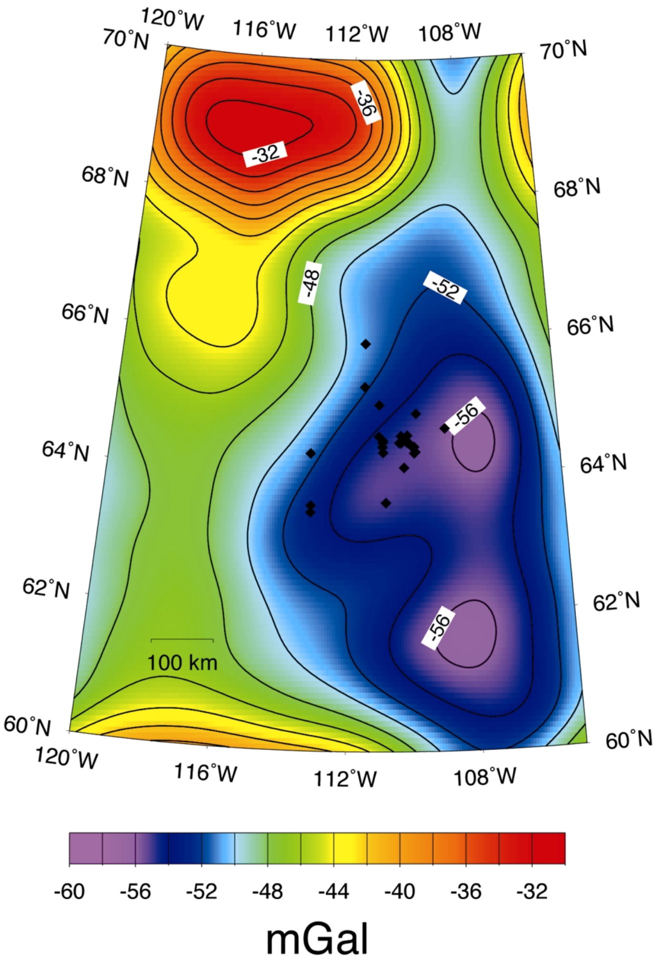

Figure 3: Contour map of the Bouguer gravity anomalies on the Slave craton, upward continued to 100 km. The filter applied to the gravity data in this case attenuates shallow features and enhances long wavelength or regional features > 100 km. Note that most of the diamond-bearing kimberlites (black diamonds) coincide with an area of large negative Bouguer anomalies (less dense lithosphere).

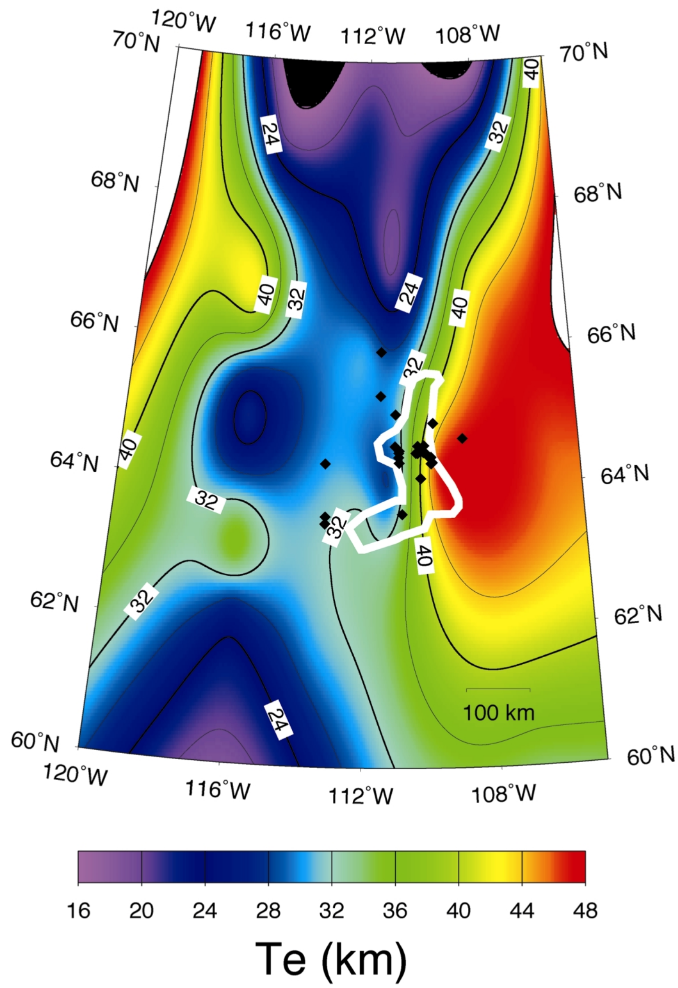

Figure 4: Color contour map of the Effective Elastic Thickness (Te) of the lithosphere on the Slave craton showing a zone of strong Te gradient (oriented N-S), defining the western edge of the strong lithosphere (Te > 56 km) on the eastern side of the craton. The white polygon outlines the area where magnetotelluric studies have defined a strongly conductive upper man

Central Slave Basement Complex showing that this lithospheric block is distinct from the adjacent terranes to a depth of ~150km into the mantle. Shallow low velocity anomalies are found between the Central Slave Basement Complex and the eastern edge of the craton (eg Cook et al., 1999). These anomalies are interpreted as regions of fertile mantle material (lherzolite rich) within the surrounding harzburgitic lithosphere. No xenolith data are so far available from this area that could be used to test this interpretation.

Jaupart et al. (1998) used heat flow and radioactive heat production data to estimate the crustal heat production and the mantle heat flow on the Canadian shield. Their results give an average mantle heat flow of 13mW/m^2 on the craton. Considering a thermally stable lithosphere, this heat flow value requires a compositionally defined lithosphere to be less than 240 km thick.

Summary and global context

The mantle lithosphere beneath the Lac de Gras area has a structure and composition that are unique within our limited knowledge of Archean mantle sections, which currently is dominated by studies of xenoliths from the Kaapvaal craton and from the Udachnaya kimberlite pipe in Siberia. However, the strongly layered structure seen in the Slave Craton lithospheric mantle is also observed in other regions where ultra-deep diamond inclusions have been documented (eg Gawler craton, southern Australia and the Limpopo Belt, southern Africa). This emerging evidence of sub-cratonic lithosphere showing both layering and the presence of ultra-deep diamonds may indicate a globally repetitive mechanism of growth for some lithospheric mantle regions by plume subcretion.

References

Bostock, M.G., 1998. Mantle stratigraphy and evolution of the Slave province, *J. Geophys. Res*., **103**, 21183-21200.

Cook, F.A., A.J. van der Velden, K.W. Hall and B.J. Roberts, 1999. Frozen subduction in Canada's Northwest territories: Lithoprobe deep lithospheric reflection profiling of the western Canadian shield, *Tectonics*, **18(1),** 1-24.

Davies, R.M., Griffin, W.L., Pearson, N.J., Andrew, A.S., Doyle, B.J. and O'Reilly, S.Y., 1999. Diamonds from the deep: pipe DO-27, Slave Craton, Canada *Proceedings 7th International Kimberlite Conference, Cape Town,* Red Roof Design, Cape Town. Volume 1, 148-155.

Griffin, W.L., B.J. Doyle, C.G. Ryan, N.J. Pearson, S.Y. O'Reilly, R.M. Davies, K. Kivi, E. van Achterbergh and L.M. Natapov, 1999a. Layered mantle lithosphere in the Lac de Gras area, Slave Craton: Composition, Structure and Origin. *Jour. Petrol*., **40**, 705-727.

Griffin, W.L., B.J. Doyle, C.G. Ryan, N.J. Pearson, S.Y. O'Reilly, L. Natapov, K. Kivi., U. Kretschmar and J. Ward, 1999b. Lithosphere Structure and Mantle Terranes: Slave Craton, Canada. Proc. 7th Int. Kimberlite Conf., Red Roof Design, Cape Town, volume 1, pp. 299-306.

Jaupart, C., J.C. Mareschal, L. Guillou-Frottier, and A. Davaille, 1998. Heat flow and thickness of the lithosphere in the Canadian shield, *J. Geophys. Res*., **103**, 15269-15286.

Jones A.G., Ferguson I.J., Chave A.D., Evans R.L. and McNeice G.W., 2001, The electric lithosphere of the Slave Craton. Geology, **29**, 423-426.

Kopylova, M.G., J.K. Russell and H. Cookenboo, 1998. Upper-mantle stratigraphy of the Slave craton, Canada: insights into a new kimberlite province, *Geology*, **26**, 315-318.

Kusky, T.M., 1989. Accretion of Archean Slave Province, *Geology*, **17**, 63-67.

Kusky, T.M., 1990. Evidence for Archean ocean opening and closing in southern Slave Province, *Tectonics*, **9**, 1533-1566.