Upper mantle stratigraphy and thermal regime of the north-central Slave Craton, Canada.

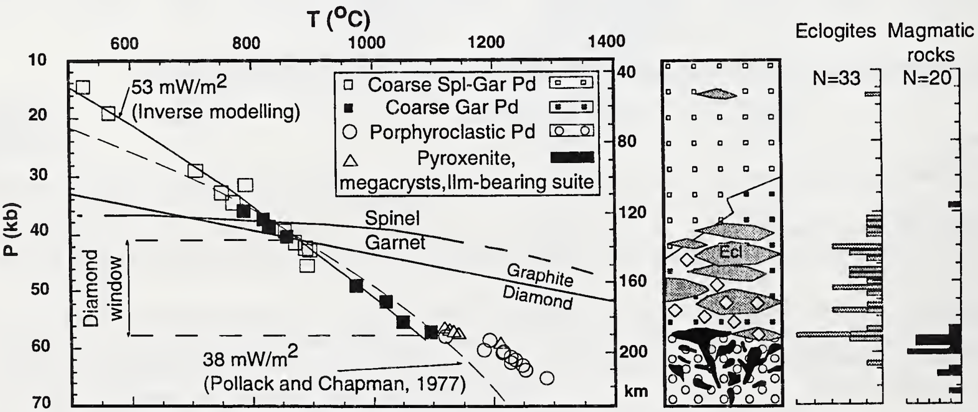
Kopylova, M. G.[1], Russell, J. K.[1], Cookenboo, H.[2]

1. Geological Sciences Division, Department of Earth and Ocean Science, The University of British Columbia, Vancouver, Canada, V6T 1Z4
2. Canamera Geological Ltd., 399 Mountain Highway, North Vancouver, Canada, V7J 2K9

Mantle xenoliths carried by kimberlite magma provide the only hard evidence of the rock types that constitute cratonic roots and the conditions under which they formed. Here, we present comprehensive petrological data for the Archean Slave craton (northern Canada) based on mantle xenoliths from the Jericho kimberlite pipe. Our study utilizes more than 90 xenoliths sampled from 33 drill holes and a large-tonnage underground sample collected for claim holders Lytton Minerals Ltd and New Indigo Resources Inc.

The xenoliths are assigned to one of five groups on the basis of mineralogy and texture: i) coarse peridotite, ii) porphyroclastic peridotite, iii) eclogite, iv) megacrystalline pyroxenite, and v) ilmenite-garnet wehrlite and clinopyroxenite (Kopylova et al., in press). Coarse peridotite and eclogite are dominated by equilibrium metamorphic textures, whereas porphyroclastic peridotite, pyroxenite and ilmenite-bearing rocks show mainly unequilibrated, deformed and/or magmatic textures. Peridotite and pyroxenite from the Jericho kimberlite is mineralogically and texturally similar to that described from other cratons. However, the ilmenite-garnet wehrlite-clinopyroxenite suite is petrographically distinctive. They comprise abundant zoned garnet, megacrystic ilmenite, variable proportions of olivine neoblasts and clinopyroxene. This suite of xenoliths contains the best textural and chemical evidence for melting and late igneous crystallization events among all of the mantle-derived xenoliths. Megacrystalline pyroxenite is also characterized by magmatic textures and shows a complete transition texturally and mineralogically, from pyroxenite to megacrystic intergrowths of garnet-pyroxene to isolated Cr-poor megacrysts.

A P-T array reflecting the ambient paleo-geothermal regime was derived from compositions of coexisting garnet-clinopyroxene-orthopyroxene (Finnerty and Boyd, 1987; MacGregor, 1974). Cores of mineral grains were used in order to circumvent the effects of compositional zoning observed in some garnet and clinopyroxene grains. The results are shown in the figure below. Beneath the Jericho pipe, coarse peridotite equilibrated at depths between 45 and 190 km and at temperatures from 500° to 1100°C. Spinel-garnet peridotite is distributed between 45-150 km, which is consistent with the spinel-garnet transformation curve calculated for the average Jericho mineral chemistry by the O'Neill (1981) equation.



For the deep lithosphere (110-190 km) the P-T array can be approximated by a model conductive paleo-geotherm. Conventionally, P-T data have been matched to a series of conductive geotherms of Pollack and Chapman (1977); using this approach our data is consistent with a geotherm with surface heat flow (Qo) of 38 mW/m^2. However, depending on the thickness and heat producing properties of the crust, the P-T array can be fitted to a range of Qo values. To accommodate regionally-specific characteristics of the crust, we elected to use a modified approach which infers thermal geological parameters from the mantle P-T array. We fit our P-T array to a model equation for a steady-state conductive geotherm with an exponential decrease in heat producing elements over a critical depth D (Lachenbruch, 1968, Crowley, 1987), and solved for the parameters Qo (surface heat flow) and D. We have used geologically-constrained values of thermal conductivity (K = 2.5 W/mK) and surface heat production (Ao= 2.16 W/m^3). The latter was calculated for the 14,000 km^2 area around the Jericho pipe on the basis of chemistry of outcropping rocks weighted by their abundance (Davis, 1991). The optimal fit to the Jericho P-T data is a Qo of 53 mW/m^2 and a D of 20 km, which agrees well with the only measurement of surface heat flow (50 mW/m^2) for the Slave craton (Lewis and Wang, 1992).

The upper mantle beneath the north central Slave is relatively cold, as is typical of cratonic environments, but it is also associated with relatively high values of surface heat flow due to its highly radiogenic crust. The mantle beneath the central Slave probed by Jericho and Grizzly (Boyd and Canil, 1997) kimberlites seem to be colder than the surrounding mantle beneath North American Platform as inferred from xenolith P-T estimates for Somerset Island (Kjarsgaard and Petersen, 1992), Kirkland Lake (Schulze, 1996) and Montana, Colorado-Wyoming, and Kentucky (Meyer et al., 1994) pipes.

For depths greater than 190 km the P-T array established from Jericho xenoliths deviates from a model conductive geotherm towards higher temperatures and shows substantially higher geothermal gradients. This thermal disturbance in the geotherm is commonly thought to be a transient, kimberlite-related phenomena ascribed to convection processes in the magma-bearing zone at the lithosphere/asthenosphere transition (Boyd, 1987; Griffin et al., 1996).

For orthopyroxene-free rocks (eclogite, wehrlite and clinopyroxenite), equilibrium temperatures were calculated by the method of Ellis and Green (1979); an estimate of equilibrium pressure was obtained by finding the point of intersection between the garnet-clinopyroxene univariant curve for each sample and a best-fit curve to the "peridotite geotherm". Eclogite samples record temperatures between 850° and 1060°C and project onto the peridotite P-T array between 125 and 190 km (see right panel). Most samples of porphyroclastic peridotite derive from below 180 km (1100° to 1300°C). Samples of pyroxenite, megacrysts, and ilmenite-garnet wehrilte and clinopyroxenite record higher temperatures (1100° - 1250°C) and have apparent source regions between 190 and 210 km.

Our results constrain the nature of the Slave lithosphere in several ways. Firstly, in this portion of the Slave craton, we place the transition between the petrological lithosphere and asthenosphere at a depth of 190 km, at ~1100° C. This interpretation is based on the disappearance of coarse peridotite, and on the pronounced disturbance in the calculated P-T array.

Secondly, our results provide a stratigraphy for the lithosphere and asthenosphere underlying the Jericho pipe (Fig. 1 middle panel). The lithosphere itself comprised recrystallized and texturally equilibrated rocks, namely coarse peridotite with eclogite lenses and layers. In contrast, all rocks from the deeper asthenospheric horizon (porphyroclastic peridotite and magmatic rocks) have unequilibrated textures with respect to the deep mantle and, therefore, are inferred to be relatively young. The textures found in samples of porphyroclastic peridotite attest to deformational events essentially contemporaneous with the intrusion of the kimberlite magma. Preserved magmatic textures in the pyroxenite and ilmenite-bearing suite also have not had time to recrystallize and equilibrate texturally under ambient deep-mantle conditions. The Jericho pyroxenite and ilmenite-garnet wehrlite-clinopyroxenite therefore may represent samples of crystallized melts or cumulates of asthenospheric megacryst magmas. Fertile compositions of the Jericho porphyroclastic peridotite and megacrysts and their close association at depth support a widely accepted hypothesis that porphyroclastic peridotite was metasomatised and deformed by the emplacement of early megacryst magmas. Our observations provide spectacular evidence for a relatively-late pre-kimberlitic period of magmatism and an associated short-lived thermal perturbation within the deep mantle of the Slave craton. It is logical to suppose that the Jericho kimberlite derives from this magmatic event.

In summary, we have mapped an important petrological boundary at 190 km beneath the Jericho kimberlite in the north-central Slave. The boundary separates lithosphere from rocks which carry an asthenospheric signature and may have been chemically and texturally modified by pre-kimberlitic magmatism. This boundary represents a substantial change in the petrology, structure and thermal state of the mantle and could account for the major discontinuity at 195 km observed in seismic P-wave velocities (Bostock, 1997) and in magnetotelluric data at 200-250 km (Jones and Ferguson, 1997) for the SW Slave craton.

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