

# Deep electromagnetic experiments: The Slave and Superior cratons compared and contrasted

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Long period magnetotellurics (MT), a deep-probing, natural-source electromagnetic geophysical method, offers a complementary technique to seismics for obtaining in-situ physical property information about the sub-continental lithosphere mantle (SCLM). Secondary electromagnetic fields, sensed at the surface of the Earth, are induced in vertical and lateral variations in electrical conductivity, and these variations are imposed by tectonic and magmatic processes during creation and subsequent evolution of the SCLM. The MT responses can be quantitatively modelled to image the geometry and conductivity of those variations, and appropriate conclusions can be drawn regarding their development. As an example of the contribution that deep MT studies can make, electrical conductivity is particularly sensitive to the onset of partial melt, and both laboratory and model studies have demonstrated that even a small amount of melt (0.1%) will connect efficiently and thereby increase conductivity by two or more orders of magnitude. Thus precise MT data offer the highest resolution possible of the lithosphere-asthenosphere boundary (LAB).

During the last five years there have been a series of deep-probing MT experiments performed on the Slave and Superior cratons as a contribution to Lithoprobe and GSC activities along the SNORCLE (Slave-NORthern Cordillera Lithospheric Evolution) and WS (Western Superior) transects. We report herein on the results of those experiments, comparing and contrasting the electrical images obtained of the two SCLMs.

## Slave Craton

The experiments on the Slave craton have revealed an anomalous region within the upper mantle beneath the central Slave (Jones et al. 2001). The Central Slave Mantle Conductor (CSMC) correlates spatially with the surface Eocene aged kimberlite field, and in depth with a geochemically-imaged ultra-depleted harzburgitic region (Griffin et al. 1999). Its top is at 80-100 km depth with a minimum thickness of 20 km, and its internal isotropic conductivity is of the order of 0.03 S/m or greater, compared to silicate minerals (olivine) which have a conductivity of 0.0001 S/m or smaller at those P-T conditions. Due to the high conductivity of the CSMC, it is not possible to image beneath it with the existing data to the LAB, expected to be at some 190 km based on xenolith evidence. The elongated axis of the conductor is roughly east-west, consistent with a subdivision of the Slave based on shear wave splitting observations (Bank et al. 2000) and with G10 garnet populations (Grütter et al. 1999). This orientation is suggestive of emplacement as a consequence of the 2620 Ma subduction of an exotic Archean craton to the southeast rather than as a result of the north-south suturing of the eastern arc (?) terrane with the western Central Slave Basement Complex (CSBC) at 2690 Ma (Bleeker et al. 1999a, b).

Off the conductor, the Slave's SCLM appears to be resistive and electrically isotropic (1-D). This is particularly the case beneath the Anton complex, the southwestern exposure of the CSBC, and the LAB is thought to be at depths in excess of 200 km.

### **Superior Craton**

Deep probing MT across the western Superior craton demonstrates a clear change in the dominantly east-west strike directions south of the Archean North Caribou terrane (NCT) to an azimuth of about 120 degrees north of the NCT (Craven et al. in press). The most striking feature in the Superior dataset is the correlation of electrical strike directions due to conductors deep in the SCLM with the major syn- and post-Kenoran zones of transpression on either side of the NCT. Also evident in the western Superior is a region closely approximating the area of the NCT where the MT data manifest a weak preference for an electrical strike and the SCLM is predominantly 1-D or layered.

A 3-D regional model, constrained by earlier investigation in the eastern Superior Province (Kellet et al. 1992), has been constructed to quantify the electrical structure in the lithosphere. The two dominant conductive features in the Superior 3-D model are 1) a sub-Moho anisotropic region, modelled here as a region south of the Uchi-North Caribou contact of east-west trending alternating 0.05 and 0.001 S/m material, at depths between 40 km and 100 km; and 2) a 0.05 S/m conductive layer commencing at ~100 km depth. The conductive features in the Superior Province 3-D model at approximately 40 km depth are aligned sub-parallel to the major zones of syn- and post-2.7 Ga transpression within the Transect area and may be related to other syn- and late-orogenic processes; perhaps the most pervasive of which is magmatism. Many types of syn- and late-orogenic magmatism occur in the Superior Province. The Superior magmatic suites evolve from calc-alkaline basalts to sanukitoids and develop into nephelinite syenites and rare carbonatites (Stevenson et al. 1999).

### **Carbon**

Carbon-based conductors are an attractive explanation for the conductive features observed in the Slave and Superior lithospheres above the graphite-diamond stability field (~150 km depth). Given our understanding of the conductivity of olivine from laboratory studies, features in our models are too conductive, by orders of magnitude, for an olivine-dominant mantle without the addition of an interconnected minor conducting phase. The observation of >0.03 S/m material within continental upper mantle requires olivine water contents of the order  $1000 \text{ H}/10^6 \text{ Si}$  (Hirth et al. 2000). Such an amount of water may be tenable at sub-Moho depths if the olivine a-axis is strongly aligned within a region, but would imply a strongly anisotropic conductor, which is not observed for the Slave's CSMC and the sub-100 km conductor beneath the Superior. Partial melting enhances conductivity due to the high mobility of charge carriers within a melt fraction; however, it is unlikely such shallow zones of partial melt exist as heat flow values at the surface of the Slave craton and Superior Province are low. Carbon in graphite form behaves as a metal and therefore has high conductivity. Grain boundary carbon may also contribute to elevated conductivity in the SCLM (Duba & Shankland 1982). Graphite is an accessory phase in xenoliths observed worldwide (Pearson et al. 1994).

A possible link between the MT data and magmatism seen in WS can be demonstrated with simple melting relationships. The pyrolite solidus (Green & Falloon 1998) is clearly depressed in the case of fluid present melting and, provided the oxygen fugacity is within approximately two log units of the iron-wüstite (IW) buffer, graphite, garnet and amphibole can be major phases present in the residual. Fugacity values within a few log units of the IW buffer have recently been demonstrated for large regions of the Kaapvaal craton (Woodland 2001) and at a depth range of approximately 80 to 100 km based on equilibrium pressure and temperature estimates. The re-

sidual phases near the IW buffer have notable geophysical properties and are possible sources of spatially correlated geophysical and geochemical anomalies preserved at depths of 50-100 km or more within a cratonic root. In the Superior Province, the graphite in the residual from syn to post-tectonic partial melting may have been deposited along the (weak) fault zones and may therefore be the source of the link we observe between the EM data and major zones of transpression.

Reduction and geochemical depletion are coupled processes as Fe<sup>3+</sup> is generally incompatible during partial melting. MT may therefore offer a view of regions where ancient C-H fluid-present partial melting occurred under reducing or depleted conditions. This view can be tested with xenolith information and deep seismic data as the partial melt model predicts that conductivity can be associated with major garnet in the residual. This interpretation also provides a new tool for geoscientists correlating the geochemical stratigraphy with the electrical stratigraphy. The regional conductivity structure coupled with the linkage to geochemical stratigraphy will provide an enhanced 3-D image of the lithosphere. Our goal is an increase in our understanding of the genesis of the Slave and Superior Provinces related to major magmatic and deformational events through better maps of the deep interior of the cratons.

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