Lithospheric geometry beneath Melville Peninsula, Nunavut, revealed by deep-probing magnetotelluric surveying

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SUMMARY

As part of a multi-disciplinary project to understand its tectonic development and economic mineral potential, the conductivity structure of the lithosphere beneath the Melville Peninsula, Nunavut, has been imaged using magnetotelluric (MT) methods. During the 2009 summer field season, 29 sites stations were collected along a regional 300-km-long MT profile that traverses variably reworked Archean orthogneiss and greenstone belts of the Rae Domain, and supracrustal Paleoproterozoic metasedimentary units. The primary goals of the survey were to determine the first order nature of major crustal and upper mantle boundaries and to define electric structures that may provide information on the structural and tectonic evolution of the region.

Resistivity models derived from the MT data show a strong correlation with geological features mapped at the surface. These include east-west trending faults that are imaged as less resistive structures cutting through highly resistive material, folding of strongly conductive Penrhyn Group units, and the presence of a deep penetrating near-vertical low resistivity anomaly that coincides spatially with a shear zone interpreted to mark the northern extent of the Archean-age Repulse Bay Block. The electric Moho is observed as a decrease in the overall resistivity at depths of 36 – 39 km. Images of the deep structure beneath the profile indicate that the lithosphere beneath the Archean Rae domain is resistive and thick, suggestive of a cold stable mantle root that is required for the presence of diamond-bearing kimberlites. Lateral variations at the south end of the profile indicates that changes exist in the mantle structure or composition beneath the Repulse Bay Block to the south and the exposed Paleoproterozoic units.

Keywords: Melville Peninsula, Rae Domain, lithospheric structure, magnetotellurics, electromagnetic

INTRODUCTION

The Melville Peninsula, mainland Nunavut, is part of the Rae Domain in the Churchill Province of the eastern Canadian Shield. Under the Geo-Mapping for Minerals and Energy (GEM) program, crustal-scale and deep penetrating magnetotelluric (MT) data were collected along a 300-km-long, approximately north-south profile to image the subsurface resistivity structure of the lithosphere beneath the project area. The main objectives of the study were to resolve the subsurface geometry of major crustal and upper mantle boundaries, provide information on structural evolution and tectonic processes of the region, and developing an understanding of the potential for mineral exploitation. Images of the resistivity structure of the crust and upper mantle beneath this regional profile derived from the MT data reveal important information on the thickness, mineral composition, and electrical properties of the lithosphere (Spratt et al., in prep).

The MT profile extends from the Archean Repulse Bay block to the south, through Paleoproterozoic metasedimentary units of the Penrhyn Group, across the variably reworked Neoarchean Prince Albert terrain, containing bands of supracrustal Prince Albert Group greenstone belts, and onto granulite facies orthogneiss to the north (Skulski et al., in prep). The regional geologic structure of the Melville Peninsula has a northeast-trending fabric that is likely related to deformation, initially from a 2.35 Ga collisional event and subsequently from the 1.88 – 1.86 Ga Trans-Hudson Orogen (Berman et al,, 2005). The regional Lyon Inlet shear zone, interpreted from the aeromagnetic data, appears to mark the northern extent of the Repulse Bay block to the south. The Prince Albert terrain and the Penrhyn Group, have been reworked within the Foxe Fold belt forming bands of metasediments and basement material. A series of east-west trending faults are mapped throughout the northern half of the Melville Peninsula, however little information is known as to the depth extent, age, or direction of movement along these faults.

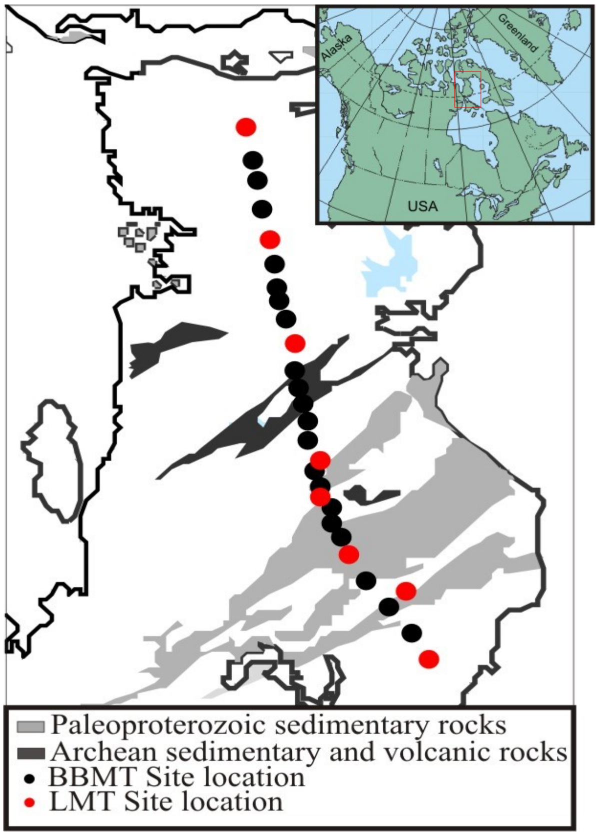

Figure 1. Map of magnetotelluric site locations along the Melville Peninsula, Nunavut. (Modified from Skulski et al., in prep.)

DATA ACQUISITION AND ANALYSIS

During the 2009 summer field season a total of 29 MT sites were acquired along the Melville Peninsula (Figure 1). Broadband MT (BBMT) data were collected every 15 km and long periods sites (LMT) were located at every fourth BBMT providing data to periods of ~10,000 s. Initial observations of the apparent resistivity and phase response curves shows that high resistivities are associated with Prince Albert terraine allowing the penetration of the electric and magnetic fields to depths > 300 km. Significantly reduced resistivities in the vicinity of the Penrhyn group limit the depth of penetration, in some cases to less than 25 km.

Local distortion and geo-electric strike analyses suggest that the northernmost sites have two distinct layers of differing geo-electric strike angles. The data at short periods (up to 1 – 10 s) have a preferred geoelectric strike direction of +9º/-81º. This is consistent with the strike of the abundant late stage, east-west faulting. Preliminary depth analysis suggests that these periods correspond to crustal depths, indicating that the faults extend to the crust-mantle boundary. At longer periods the geo-electric strike direction is similar to that of the regional geologic fabric, ~34º. At the southern sites, the phase splits between the TE- and TM-modes is low indicating that the data are weakly 2-D, but also have a preferred geo-electric strike angle consistent with the regional geologic structure. This indicates coupling between the upper mantle and the crust.

RESISTIVITY MODELS

The MT profile has been divided into 3 sections, and each section has been modelled separately at the appropriate geoelectric strike angle (Figures 2a, b, and c). The northernmost profile indicates that the bulk of the Prince Albert terraine is highly resistive (>10 000 ohm-m) and reveals less resistive near-vertical structures that closely correlate with east-west trending faults mapped along the surface (Figure 2a). Many of these faults extend through to the base of the crust, interpreted from a decrease in the bulk resistivity to ~4000 ohm-m that occurs at 37 to 39 km beneath the profile. At the north end of the profile, these faults appear in the vicinity of a known diamondiferous kimberlite field, and may be related to kimberlite emplacement. The middle profile shows complex structure in the vicinity of the exposed Prince Albert Group greenstone belt (Figure 2b), known to host exploitable mineral resources. The southernmost profile shows the rocks of the Penrhyn Group to be highly conductive (very low resistivity) with values < 4 ohm-m. The low resistivities likely result from the presence of interconnected graphite and black shales within the Penrhyn metasedimentary packages. The lateral continuity of the low resistivity layer suggests that the exposed basement material is present as thrusted, cored nappes versus windows into the underlying rocks. The low resistivities cause attenuation of the electric and magnetic fields, preventing penetration deep into the lower crust. The southern edge of the exposed Penrhyn Group is marked by a conductor that extends to at least 50 km. This structural feature corresponds to a shear zone interpreted from the regional aeromagnetic anomaly map, termed the Lyon Inlet shear zone, and may mark the northernmost extent of the Repulse Bay Block.

Models of the deeper structure beneath the profile indicate lateral changes in the conductivity of the uppermost mantle (Figure 2d). These may changes may suggest evidence for different tectonic environments associated with varying grades of Archean orthogneiss seen at the surface. In general, the mantle lithosphere beneath the Prince Albert terrane is generally resistive (~5,000 ohm-m). A decrease in resistivity is observed at ~200 km interpreted to represent the lithosphere-asthenosphere boundary. The southern most extent of the profile shows high resistivities that decrease beneath the northern margin of the Repulse Bay Block that may represent a mantle expression of the Lyon Inlet shear zone, or may mark a change from old cold lithosphere to the south, to younger more recently reworked mantle beneath the Paleoproterozoic units.

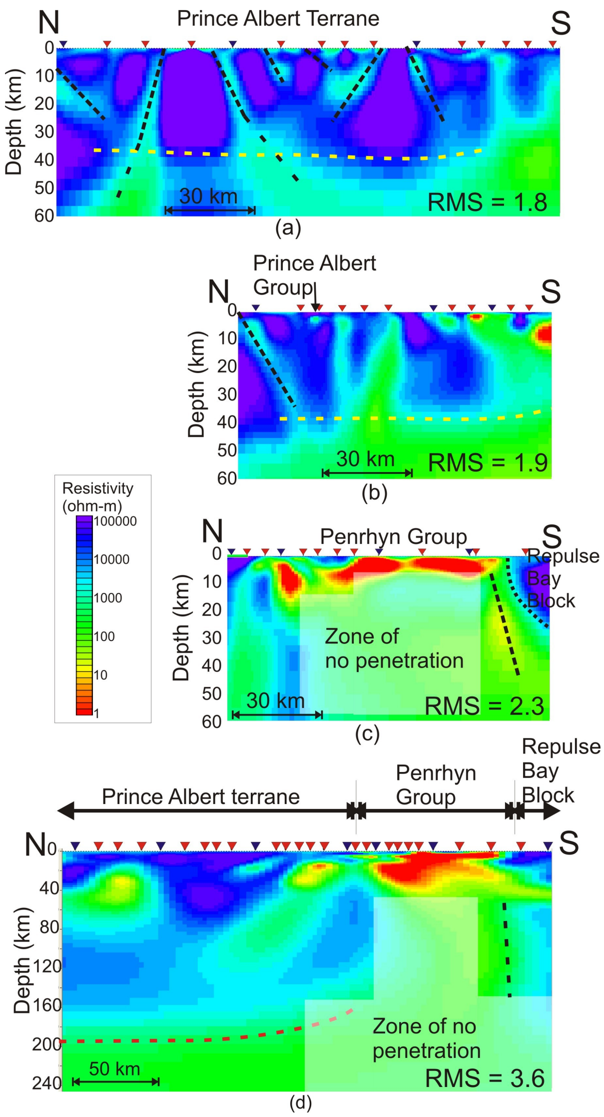

Figure 2. Two-dimensional resistivity models of the MT data. The dashed black lines mark fault lines that are mapped at the surface, the yellow dashed line marks the approximate crust-mantle boundary, and the red dashed line illustrates the base of the lithosphere.

CONCLUSIONS

Magnetotelluric data was collected along the Melville Peninsula, Nunavut and provides images of the conductivity structure of the lithosphere beneath the 2-D profile. Distortion and strike analysis suggest that the northern sites have two distinct layers, where the data in the period range corresponding to crustal depths have a strike direction of -81° likely resulting from the abundant east-west faulting. At all periods for the southern sites and higher periods (deeper depths) for the northern sites, the strike angle is 34°, similar to the regional geologic structure, suggesting coupling between the crust and mantle. Two-dimensional models of the MT data show that the Archean Rae craton is highly resistive (>10,000 ohm-m) however less resistive near-vertical structures that extend to the base of the crust are interpreted to represent the subsurface expression of the east-west trending faults. Extremely low resistivities (<10 ohm-m) are associated with the Paleoproterozoic metasediments of the Penrhyn Group, limiting penetration depths beneath the units. A comparison between response curves calculated at sites recorded on exposed basement units within the Foxe Fold belt indicate that they are underlain by high conductivities similar to the Penrhyn units. A decrease of 2 orders of magnitude in resistivity is observed between 36-39 km over most of the profile, interpreted as the crust-mantle boundary.

Beneath the Prince Albert terrane, a thickened resistive upper mantle is observed to depths of ~200 km where a decrease in resistivity is interpreted as the base of the lithosphere, well within the diamond stability field. At depths of 70 – 200 km towards the south end of the profile there is a change from moderate resistivities (~30 ohm-m) to high resistivity values (~3000 ohm-m) from north to south across the Lyon Inlet shear zone. This suggests changes in the mantle structure or composition between the Archean Repulse Bay Block to the south and the upper mantle beneath the Paleoproterozoic Foxe Fold belt.

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