Preliminary images of the lithosphere beneath the Melville Peninsula, Nunavut using magnetotelluric methods

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Summary

During the 2009 summer field season, magnetotelluric (MT) data were recorded at 29 stations along a 300-km-long regional profile across the Melville Peninsula, Nunavut. The overarching objectives of this survey were to determine the subsurface geometry of major geological boundaries and provide information on the mineral potential of the region, by characterizing the lateral and vertical variations in electrical resistivity beneath the profile. Initial resistivity models derived from the MT data show strong correlation with geological features mapped at the surface. These include the 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 extention of the Archean-age Repulse Bay Block. Resistivity information about the lithospheric mantle shows strong lateral contrasts indicative of varying temperature, composition, grain size, and/or the presence of small amounts of interconnected conducting materials in the mantle rocks.

Introduction

As part of the multi-disciplinary Melville Peninsula Project, under the GEM (Geo-mapping for Energy and Minerals) program, magnetotelluric (MT) data were collected along a 300-km -long profile extending from north to south across the Melville Peninsula, Nunavut (Figure 1). The primary objectives of the project are to resolve the nature of first order tectonic boundaries, to understand the structural evolution and tectonic processes from Archean to Phanerozoic times, and to determine the potential for mineral exploration in the region. This MT profile, designed to address the objectives by determining the relationships between the geological boundaries at depth, extends from the Archean Repulse Bay block to the south, across the Paleoproterozoic Penrhyn Group to the Neoarchean Prince Albert Group of the Rae domain to the north. In addition to crustal-scale MT recordings, deep-penetrating MT soundings were collected at every 4th site with the aim of providing information on the mantle lithosphere, especially its deeper part, and contributing to our knowledge of diamond formation and potential in the Canadian arctic region. Images of the resistivity structure of the crust and upper mantle beneath this regional profile reveal key information on the thickness, mineral composition, and electrical properties of the lithosphere.

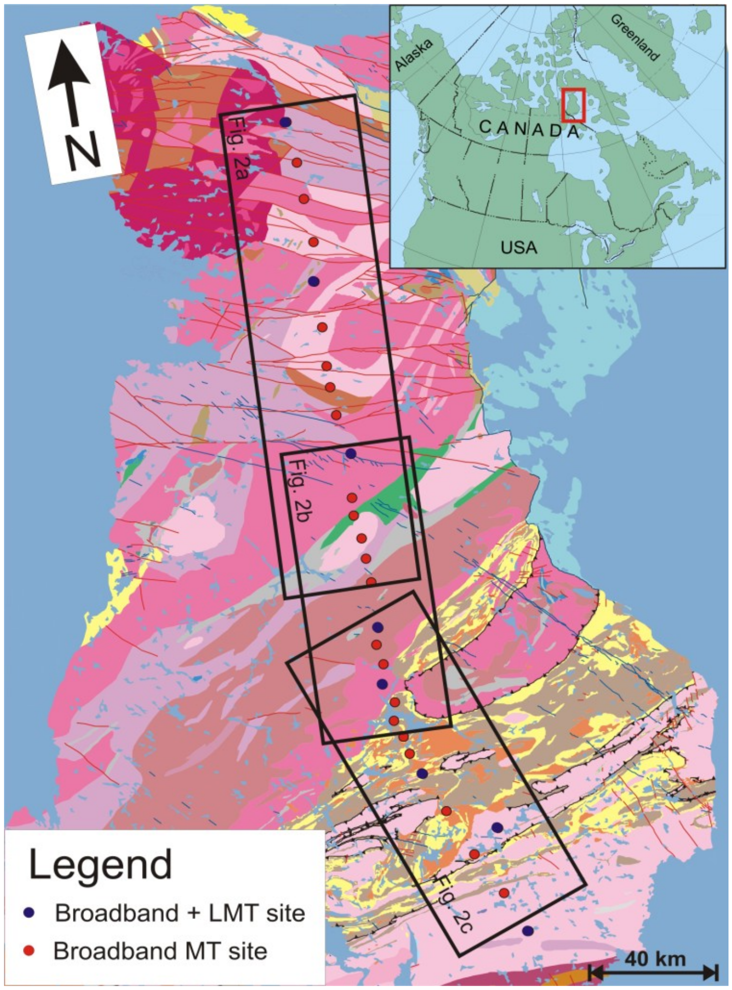

Figure 1: Map illustrating the MT site locations along with the regional geology of the Melville Peninsula. (Modified from Skulski et al., in prep.)

The Magnetotelluric Method

Magnetotellurics (MT) is a method that provides information on the electrical resistivity of the subsurface of the Earth by measuring the natural time-varying electric and magnetic fields at its surface. The depth of penetration of these fields is dependent on the measured period and the resistivity of the rocks below the site. Apparent resistivities and phase lags (between the electric and magnetic fields) are calculated from the measured fields at various periods, allowing estimates of depth to be made beneath each recording site.

The MT method is sensitive to contrasts in the resistivity values and can therefore distinguish between various lithologic units and can identify zones of anomalously low resistivity. Crystalline igneous plutons and granulite facies metamorphic rocks typical of Archean cratons commonly have high to very high resistivities values (> 1000 ohm-m) whereas sedimentary units are less resistive (some tens to hundreds of ohm-m). Factors that can greatly influence the overall resistivity of a specific unit include the presence of saline fluids, changes in porosity or grain size, clay content, and the presence of interconnected graphite films or metallic ores.

Examples

Broadband MT (BBMT) data, recording at period ranges that typically penetrate to crustal depths (0.003 – 3000 s) were collected every 15 km along the profile, and long periods sites

(LMT) were located at every fourth BBMT provided data to 10,000 s. In general the data quality is excellent with low error bars and smooth response curves that span up to 8 decades of period. Data analyses indicate that higher resistivities are observed at the northernmost sites and obtain a penetration of over 300 km; however 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 geoelectric strike analyses suggest that the northernmost sites have two distinct anisotropic layers. The data at periods that correspond to crustal depths (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 suggesting that these faults extend into the lower crust. At longer periods (deeper depths) for the northernmost sites, and all periods for the southern sites, the data are weakly 2-dimensional with a geoelectric strike direction of ~34º. This angle is similar to that of the regional geology indicating coupling between the upper mantle and the crust.

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, modelled at a strike angle of -81°, indicates that the bulk of the region is highly resistive (>10 000 ohm-m) and reveals less resistive near-vertical structures that spatially correlate closely to the east-west trending faults mapped along the surface (Figure 2a). Many of these faults extend in the model 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. The middle profile, also modelled at a geoelectric strike angle of -81°, shows complex structure in the vicinity of the exposed Prince Albert Group greenstone belt (Figure 2b). The southernmost profile, modeled at +34°, shows that the rocks of the Penrhyn Group are highly conductive (very low resistivity) with values < 4 ohm-m and reveals folding of the unit (Figure 2c). The low resistivities likely result from the presence of interconnected graphite and shales within the Penrhyn sedimentary packages. These 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 mapped at the surface, likely marking the northernmost extent of the Repulse Bay Block.

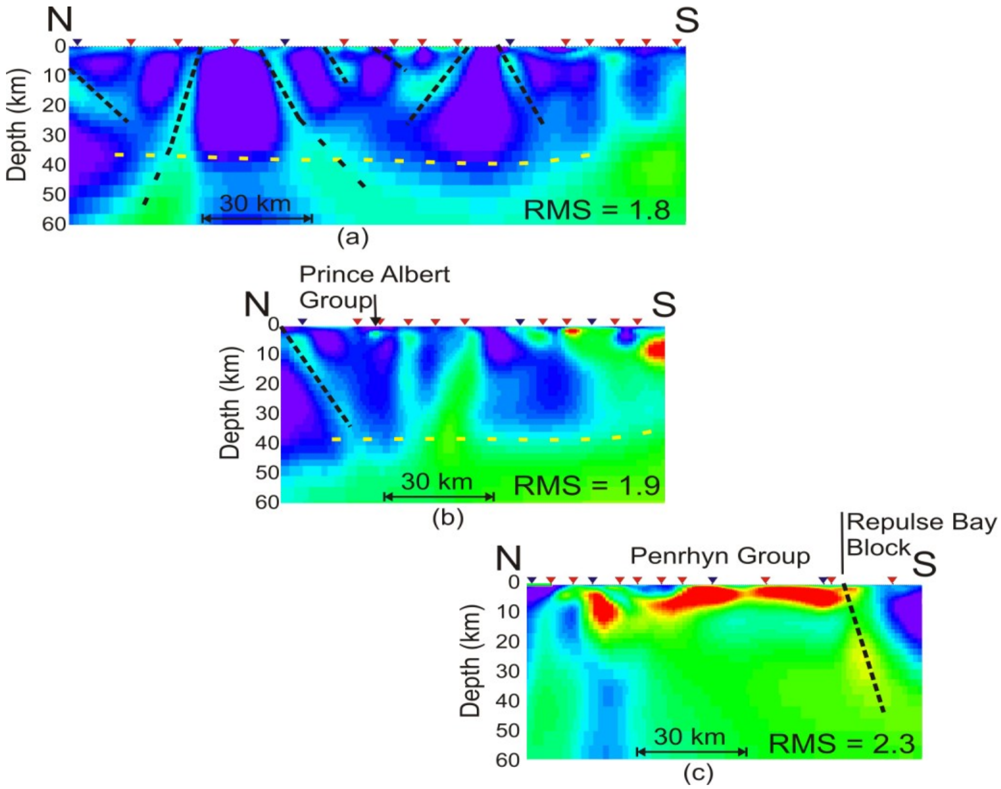

Figure 3: Two-dimensional resistivity models of the MT data. The warm colours (reds) represent low resistivities and the cool colors (blues) resistive regions. The dashed black lines mark fault lines that are mapped at the surface and the yellow dashed line marks the approximate crust-mantle boundary.

Conclusions

Preliminary interpretations of the magnetotelluric data collected across the Melville Peninsula indicate that the northern half of the profile has two anisotropic layers with the crust preferring a geoelectric strike of -81° that is likely controlled by east-west trending faults. The southern half of the profile, as well as the regional upper mantle structure, has a preferred strike angle of +34°, consistent with major geologic trends. Two-dimensional modelling of the data at the appropriate strike angles show distinct similarities between the resistivity structure at depth and geological features observed at the surface. The models illustrate that the northernmost crust is highly resistive and indicate that the east-west trending faults extend to lower crustal depths. Folding structures with a low resistivity are observed and interpreted to represent the graphite bearing rocks of the Penrhyn Group. Additionally, a major near-vertical conductive anomaly south of the exposed Penrhyn Group is interpreted to represent a major shear zone at the north end of the Repulse Bay Block.

Acknowledgements

This work has been funded by the federal Canadian government through Natural Resources Canada. Instrumentation and technical support were provided by the Dublin Institute for Advanced Studies, Dublin, Ireland.

References

Skulski, T., Paul, D., Buckle, J., Sandeman, H., Berman, R., Pehresson, S., Rainbird, R., Davis, W., Kerswill, J., and Sandborn-Barrie, M., in prep. Bedrock geology and regional synthesis of the north-central Rae domain, western Churchill Province, Nunavut, Canada: Geological Survey of Canada, Open File 5577, 1:5500,000 scale.