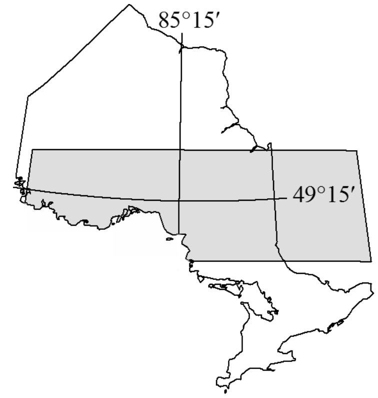
47. Magnetotelluric Data Collection in the Superior Province, Canada



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INTRODUCTION

The basic premise of the Metal Earth project is to understand the contrasting metal endowment of the Abitibi Subprovince versus terranes to the west in the Superior Province. Given that the geology at surface is broadly similar in endowed and lesser endowed Archean terranes, the differences in endowment must be accounted for by differences in the mid and lower crust. To investigate these differences, the Metal Earth project has undertaken both seismic reflection and magnetotelluric surveys across the Superior Province. Recent seismic reflection studies have shown extensional structures in the mid and lower crust (Calvert and Doublier 2018) and work in the Yilgarn craton of Australia has also shown that gold-mineralized structures penetrate the entire crust (Goleby et al. 2004). Recent integration of seismic reflection and magnetotelluric surveys has imaged hydrothermal pathways beneath the Olympic Dam deposit in the Gawler craton of Australia (Heinson et al. 2018). It is with these relationships in mind that magnetotelluric surveys were undertaken to integrate with the seismic reflection surveys within the Metal Earth project.

Measurements of the magnetotelluric (MT) impedance were made at over 700 stations across 13 transects throughout the Superior Province of the Canadian Shield. The MT impedance can be used to resolve the bulk electrical resistivity (or conductivity – the inverse of resistivity) of the Earth (Chave and Jones 2012). A combination of audio- and broadband-magnetotelluric data was collected. Audio-magnetotelluric (AMT) covers the frequency band approximately 10000 to 1 Hz and provides information on the structure of the uppermost crust (to depths of ~2 km), whereas broadband magnetotelluric (BBMT) covers the frequency band approximately 320 to 0.0001 Hz (depths of up to 50 km given favourable survey conditions) allowing characterization of lithospheric structure and processes from the shallow upper crust through the uppermost mantle (i.e., from ~0.5 to 50 km).

SURVEY PARAMETERS AND ACQUISITION

The MT data collection was carried out in the summer and early fall of 2018 by Complete MT Solutions using Phoenix V5 MT systems. Spectral analysis of the recorded electric and magnetic field time series and conversion to frequency-domain measurements of the MT impedance were performed by Complete MT Solutions, and response files were delivered in industry standard EDI (electrical data interchange) format. The MT impedance can be used to estimate the Earth's resistivity structure (Tikhonov 1950; Cagniard 1953). Data were collected along 13 transects, which are, west to east: Rainy River, Dryden, Atikokan, Sturgeon Lakes, Geraldton, Swayze, Matheson, Sudbury, Larder Lake, Cobalt, Rouyn–Noranda, Amos–Malartic and Chibougamau (Figure 47.1). All MT profiles are co-located with

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Ontario Geological Survey, Open File Report 6350, p.47-1 to 47-4.

the seismic survey conducted by Metal Earth in the summer of 2017. A "regional" profile of BBMT measurements with station spacing of approximately 5 km was collected for each transect. Additionally, within all but the Sturgeon Lakes and Rouyn–Noranda regional transects are high-resolution segments of alternating AMT and BBMT measurements, with station spacing of approximately 330 m.

The frequency of the measurement can be considered as a proxy for depth: higher frequency signals contain information on the Earth's shallow structure, whereas lower frequency signals carry information regarding deeper structure. The exact depth of penetration of the electromagnetic waves are dependent on the resistivity of the medium through which they are passing. For a homogeneous Earth, the depth in kilometres at which the signal attenuates to 1/e of the original magnitude, known as the skin-depth, is given by $\delta \approx 0.5\sqrt{(\rho/f)}$ where ρ is the resistivity of the Earth and f is the frequency of interest. The skin-depth is often used to approximate the depth of investigation of an MT survey. As the crust within the Superior Province is generally resistive (Ferguson et al. 2005; Roots and Craven 2017a, 2017b), the collected data should allow the Earth's structure to be imaged from within the top 500 m to 50 km.

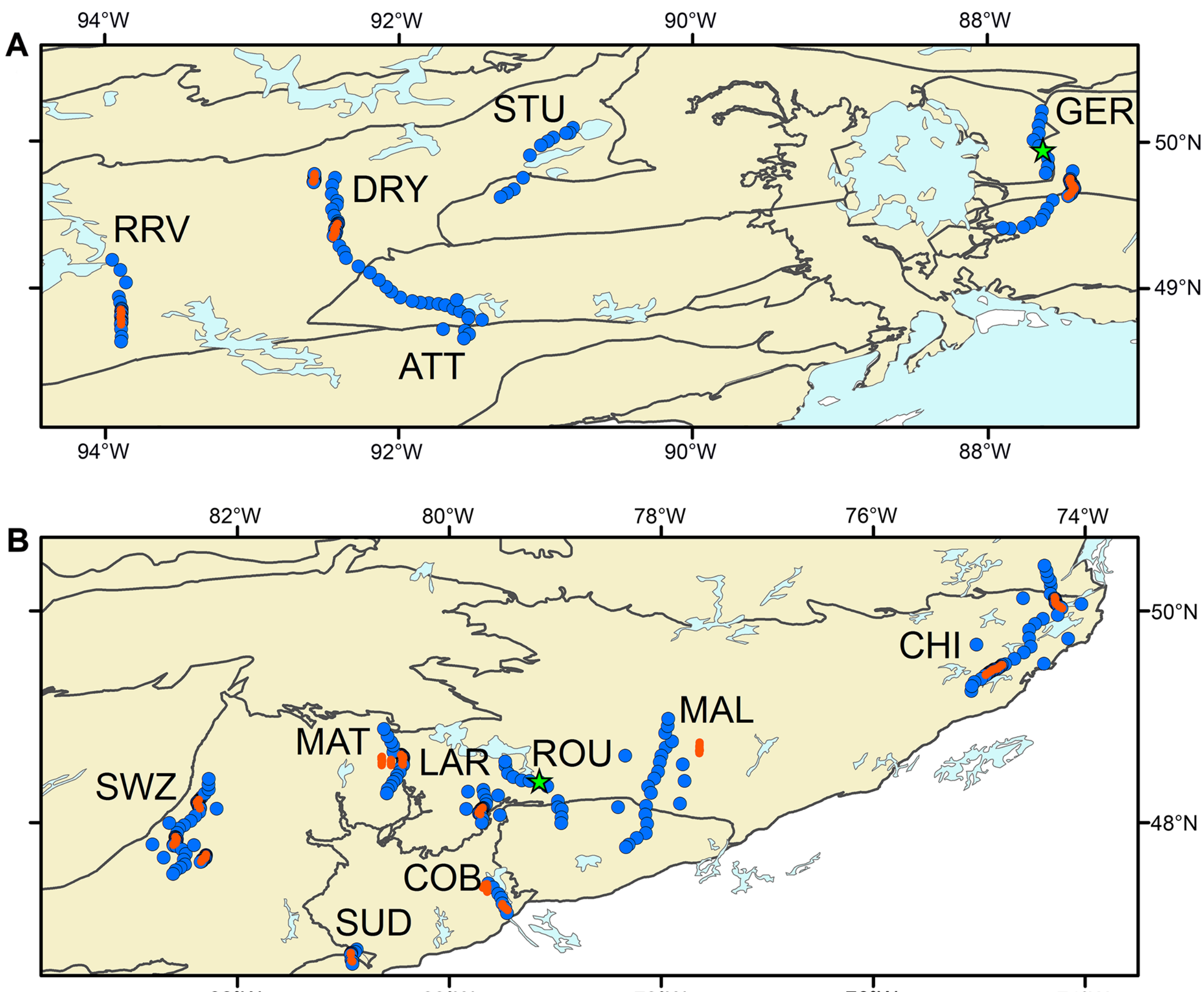

Figure 47.1. Map detailing the completed broadband- (blue dots) and audio- (red dots) magnetotelluric stations within the **A**) western and **B**) eastern regions of the Superior Province. Green stars near Geraldton ("GER") and Rouyn-Noranda ("ROU") represent the stations shown in Figure 47.2. Abbreviations: RRV, Rainy River; DRY, Dryden; ATT, Atikokan; STU, Sturgeon Lakes; GER, Geraldton; SWZ, Swayze; MAT, Matheson; SUD, Sudbury; COB, Cobalt; LAR, Larder Lake; ROU, Rouyn-Noranda; MAL, Amos-Malarctic; CHI, Chibougamau.

Additional requirements for reliable imaging are adequate station density and survey aperture. Transects can be subdivided into low-resolution regional R1 and embedded high-resolution R2 sections. Extensions to a number of originally planned transects were collected to widen the survey aperture. Increasing the survey aperture in this manner provides control on both the location and requirement of deeper structures, such that features are indicated from multiple measurements—a requirement for producing robust model results.

Quality control of the data was performed in near real time, as data were made available by Complete MT Solutions throughout the survey. Apparent resistivity and phase curves (Figure 47.2) are expected in most cases to vary smoothly with frequency (period), as such data were analyzed for smoothness and robustness to noise. Further analysis via the phase tensor (Caldwell, Bibby and Brown 2004; Bibby, Caldwell and Brown 2005; Booker 2014) and induction arrow (Parkinson 1962) methods was completed on measurements which did not vary smoothly or showed non-standard or complicated phase response. The phase tensor approach will be used to determine the dimensionality structure of each transect (i.e., one- two- or three-dimensional (1-D, 2-D or 3-D)), in particular frequency bands, and the geo-electric strike direction. Both strike-direction and dimensionality are required when calculating

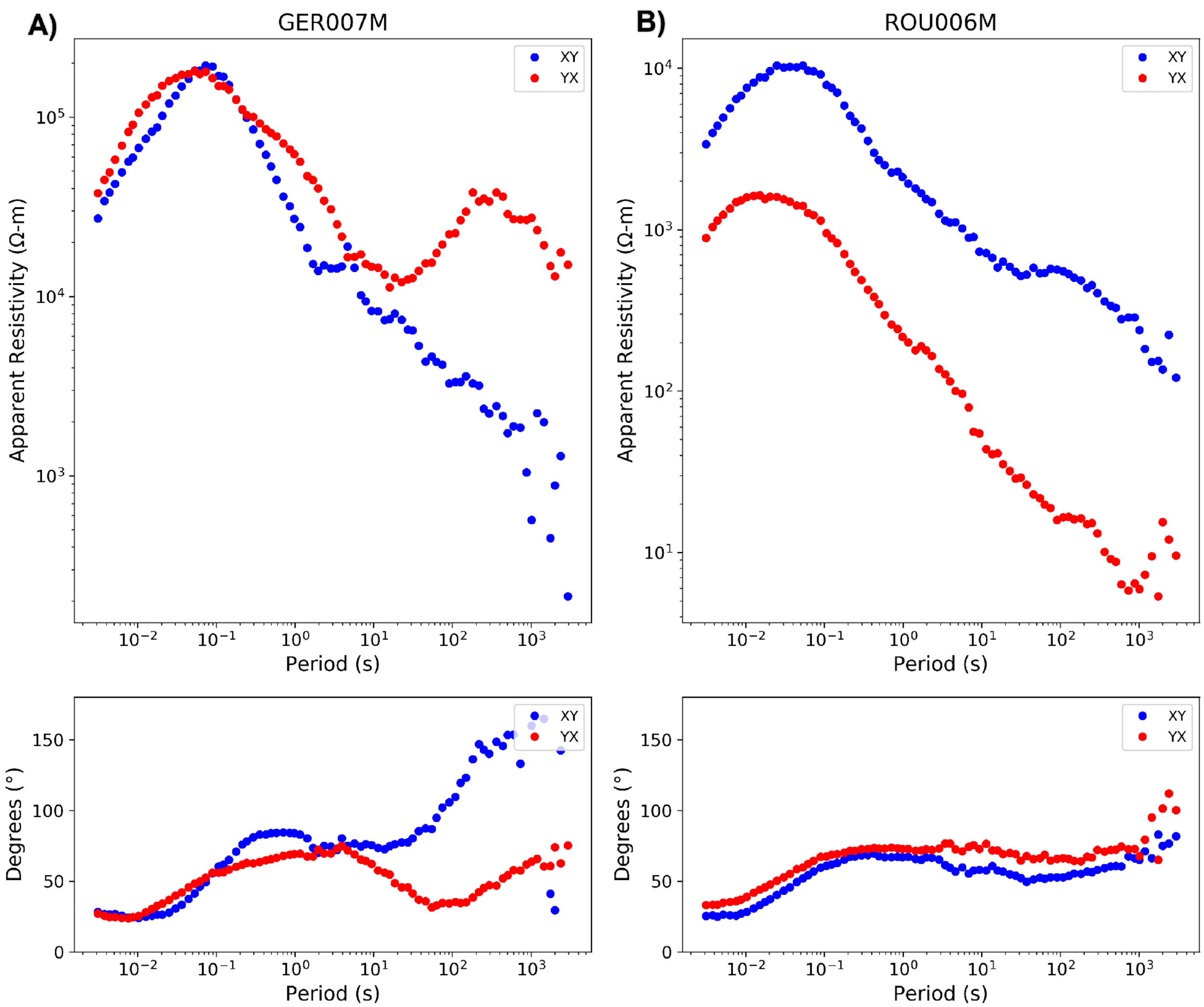

Figure 47.2. Representative apparent resistivity and phase curves from the **A**) western (Geraldton) and **B**) eastern (Rouyn-Noranda) regions of the Superior Province.

inverse models as different approaches are required for 2-D versus 3-D data sets. The robustness of the major features of the inverse models will be assessed to ensure that they are both required and identifiable in the data. Final inverse models will be integrated with other geophysical and geological work, allowing construction of conceptual models to explain the geological and physiochemical state of the region.

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REFERENCES

Bibby, H.M., Caldwell, T.G. and Brown, C. 2005. Determinable and non-determinable parameters of galvanic distortion in magnetotellurics; Geophysical Journal International, v.163, p.915-930. doi:10.1111/j.1365-246X.2005.02779.x.

Booker, J.R. 2014. The magnetotelluric phase tensor: A critical review; Surveys in Geophysics, v.35, p.7-40. doi:10.1007/s10712-013-9234-2.

Cagniard, L. 1953. Basic theory of the magneto-telluric method of geophysical prospecting; Geophysics, v.18, p.603-635.

Caldwell, T.G., Bibby, H.M. and Brown, C. 2004. The magnetotelluric phase tensor; Geophysical Journal International, v.158, p.457-469. doi:10.1111/j.1365-246X.2004.02281.x.

Calvert, A.J. and Doublier, M.P. 2018. Archaean continental spreading inferred from seismic images of the Yilgarn Craton; Nature Geoscience, v.11, p.526-530. doi:10.1038/s41561-018-0138-0.

Chave, A.D. and Jones, A.G. editors. 2012. The magnetotelluric method: Theory and practice; Cambridge University Press, Cambridge, United Kingdom, 552p. doi:10.1017/CBO9781139020138.

Ferguson, I.J., Craven, J.A., Kurtz, R.D., Boerner, D.E., Bailey, R.C., Wu, X., Orellana, M.R., Spratt, J., Wennberg, G. and Norton, M. 2005. Geoelectric response of Archean lithosphere in the western Superior Province, central Canada; Physics of the Earth and Planetary Interiors, v.150, p.123-143. doi:10.1016/j.pepi.2004.08.025.

Goleby, B.R., Blewett, R.S., Korsch, R.J., Champion, D.C., Cassidy, K.F., Jones, L.E.A., Groenewald, P.B. and Henson, P. 2004. Deep seismic reflection profiling in the Archaean northeastern Yilgarn Craton, Western Australia: Implications for crustal architecture and mineral potential; Tectonophysics, v.388, p.119-133. doi:10.1016/j.tecto.2004.04.032.

Heinson, G., Didana, Y., Soeffky, P., Thiel, S. and Wise, T. 2018. The crustal geophysical signature of a world-class magmatic mineral system; Scientific Reports, v.8, p.1-6. doi:10.1038/s41598-018-29016-2.

Parkinson, W.D. 1962. The influence of continents and oceans on geomagnetic variations; Geophysical Journal of the Royal Astronomical Society, v.6, p.441-449.

Roots, E. and Craven, J.A. 2017a. 3-D modelling of magnetotelluric data from the western Superior Province, Ontario; Geological Survey of Canada, Open File 8237, 24p. doi:10.4095/306191.

——— 2017b. 3-D modelling of magnetotelluric data from the Abitibi and Pontiac subprovinces of the Superior Province, Ontario and Quebec; Geological Survey of Canada, Open File 8233, 24p. doi:10.4095/306190.

Tikhonov, A.N. 1950. On determining electric characteristics of the deep layers of the Earth's crust; Doklady Akademii Nauk SSSR, v.73, p.295-297.

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