GS2025-8

Preliminary results of a broadband magnetotelluric survey over the interior Reindeer zone of the Trans-Hudson orogen, northern Manitoba (parts of NTS 63O, P, 64B, C, F)

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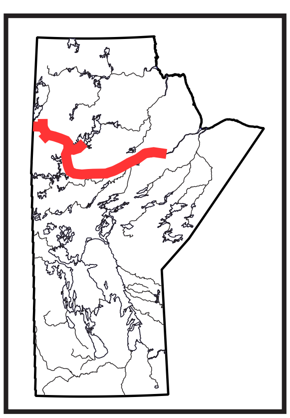
In Brief:

- A new broadband magnetotelluric dataset was collected along more than 500 km of roads between Lynn Lake and Gillam
- The data are being analysed and will be used to study the deep crustal structure beneath the region's historic mining districts

Citation:
Lee, B. and Tschirhart, V. 2025: Preliminary results of a broadband magnetotelluric survey over the interior Reindeer zone of the Trans-Hudson orogen, northern Manitoba (parts of NTS 63O, P, 64B, C, F); *in* Report of Activities 2025, Manitoba Business, Mining, Trade and Job Creation, Manitoba Geological Survey, p. 87–93.



Summary

As part of the Government of Canada's Critical Minerals Geoscience and Data Initiative, a new profile of broadband magnetotelluric (MT) data was collected in 2025 across the interior Reindeer zone of the Trans-Hudson orogen in northern Manitoba. The MT data generally have an apparent resistivity above 1000 ohm-metre (Ω•m) at periods shorter than 1 s. The apparent resistivity decreases at periods longer than 1 s, approaching 1 Ω•m along certain sections of a northwest-southeast profile. The MT impedance phase data are consistent with a decrease in apparent resistivity at greater depths. The presence of out-of-quadrant phases and large phase tensor skew angles suggest that the underlying electrical resistivity structure cannot be approximated as a two-dimensional model. Future work will use three-dimensional modelling to more accurately model the data. The resulting resistivity model will be interpreted in conjunction with existing geological and geophysical data to inform future mineral exploration activities in the region.

Introduction

The Geological Survey of Canada aims to support Canada's responsible development of natural resources through the Critical Minerals Geoscience and Data (CMGD) Initiative. A major aspect of the CMGD Initiative is to advance foundational geoscience data to accelerate responsible exploration of critical minerals within Canada that are necessary for developing future technologies. As part of the CMGD Initiative, a broadband magnetotelluric (MT) survey was conducted over the Trans-Hudson orogen (THO) in northern Manitoba. The study area was chosen because the role of deep crustal structure in mineral endowment is poorly understood in the prominent mining districts of the Thompson nickel belt and the Lynn Lake domain. The goal of this project is to use broadband MT data, along with existing geological and geophysical datasets, to provide new insights into crustal-scale geological controls on critical mineral occurrences.

Geophysical methods are crucial to understanding geological structures at inaccessible depths. Regional-scale geophysical studies have proven useful for imaging deeper structures correlated to near-surface mineralization (Heinson et al., 2018; Roots et al., 2022; Tschirhart et al., 2022; Adetunji et al., 2023). Previously, regional-scale seismic reflection and MT surveys have been conducted over the THO as part of the LITHOPROBE program (e.g., Lewry et al., 1994; White et al., 2000; Ferguson et al., 2005; Jones et al., 2005). These studies revealed the regional geophysical signatures of the THO, namely the seismic reflectivity and electrical resistivity of domains involved in the Paleoproterozoic continental collision and crustal accretion. In the current study, new MT data collected over the interior Reindeer zone of the THO, between Thompson and Lynn Lake, is analyzed.

General geology

The THO provides a record of craton collision and mountain building between 1.92 and 1.80 Ga, now observed in the rock record from present-day Baffin Island to the north-central United States (Lewry and Stauffer, 1990; Ansdell, 2005; Corrigan et al., 2009). The THO can be broadly divided into Archean cratons (Superior, Wyoming, Rae, Sask and Hearne) and the Paleoproterozoic accretionary arc complexes of the Reindeer zone. The study area spans the Superior boundary zone, Kisseynew domain, Lynn Lake domain, Southern Indian domain and Chipewyan domain (Figure GS2025-8-1). The arc volcanic rocks of the Lynn Lake and Southern Indian domains were accreted to the Hearne craton margin ca. 1.92–1.86 Ga (e.g., Baldwin et al., 1987; Martins et al., 2022). The Superior boundary zone, which contains the Thompson nickel belt, contains Archean gneisses of the Superior craton

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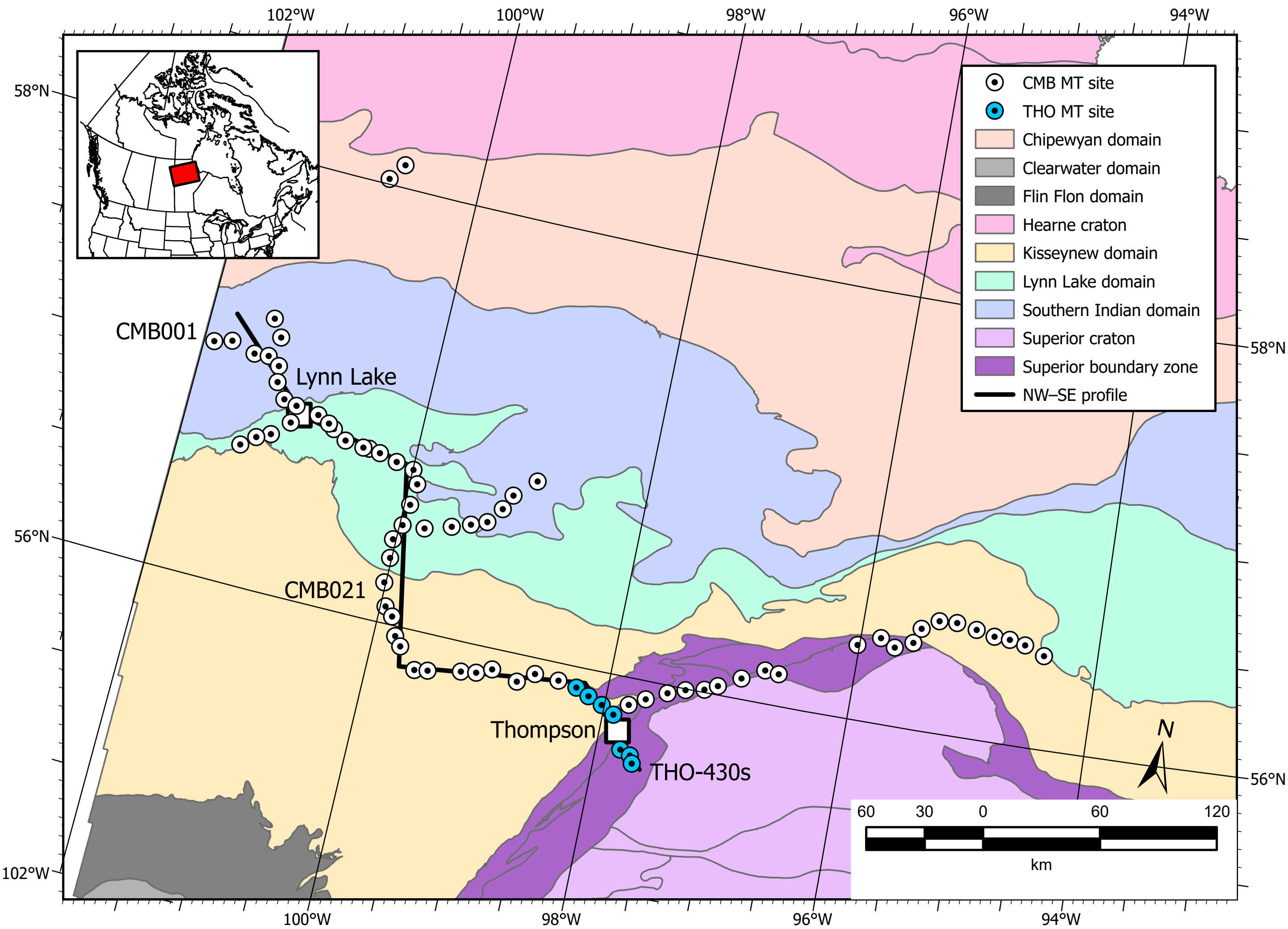

Figure GS2025-8-1: *Geological map of major lithotectonic domains in the study area. Thin grey lines indicate the boundaries of the subdomains within the Superior and Hearne cratons. White circles show locations of magnetotelluric (MT) sites deployed in 2025 and blue circles show MT sites deployed in 1994 as part of the LITHOPROBE program (Natural Resources Canada, 2022). Location of the northwest (NW)–southeast (SE) profile is shown with the names of three MT sites for reference (CMB001, CMB021, THO-430s; see Figures GS2025-8-2 to -6). Inset map shows the study area location within Manitoba. Geological data from Manitoba Geological Survey (2024).*

and Paleoproterozoic sedimentary units of the Ospwagan group, reworked during extensional magmatism on the Superior craton margin ca. 1.88–1.86 Ga (e.g., Bleeker, 1990; Zwanzig et al., 2007). The Kisseynew domain contains metasedimentary rocks intruded by felsic to intermediate plutons during basin inversion in the Manikewan Ocean ca. 1.85–1.84 Ga (e.g., Zwanzig, 1990). The Chipewyan domain consists predominantly of a continental-arc batholith that was emplaced ca. 1.86–1.85 Ga in the Hearne craton margin and also intruded the accreted arc assemblages of the Lynn Lake and Southern Indian domains (e.g., Meyer et al., 1992).

Methodology

Magnetotellurics is a passive electromagnetic geophysical method sensitive to the electrical conductivity of the Earth. Magnetotellurics is a flexible method that can be used in a variety of applications from shallow upper-crustal exploration to deep lower-crustal studies. The focus of this study was the crust from a depth of 0 to 50 km, similar in scope to previous MT studies performed over the THO. This is the first regional-scale study of the interior Reindeer zone aside from seven MT sites over the THO–Superior boundary zone deployed under the LITHOPROBE program (blue circles in Figure GS2025-8-1). The new MT data were collected by Quantec Geoscience from 69 sites in the winter of 2025. Data were measured overnight at each site and processed with the remote reference method. A second phase of data collection on the Chipewyan domain and crossing the THO–Hearne craton boundary is planned for the winter of 2026.

New broadband magnetotelluric data

The processed MT data are of overall high quality and are displayed as apparent resistivity and phase pseudosections in Figures GS2025-8-2 to -5. The vertical axis in the pseudosections corresponds to the signal period in seconds, which can be considered a proxy for depth (i.e., longer period signals penetrate deeper into the Earth). As a routine exercise with MT data, some data points have been masked at the longest periods where the recording time was insufficient to obtain a precise estimate of apparent resistivity and phase. The displayed data are from MT sites along the northwest-southeast profile shown in Figure GS2025-8-1. The remaining sites to the east on the Kisseynew domain–Superior boundary zone will be analyzed in a future study.

Figure GS2025-8-2 shows the apparent resistivity of the xy component, corresponding to an electric field aligned with geographic north and a magnetic field aligned with geographic east. The apparent resistivity is generally high (>1000 Ω•m) at periods shorter than 1 s. A low apparent resistivity is observed at longer periods (>1 s) at sites on the Southern Indian domain and on

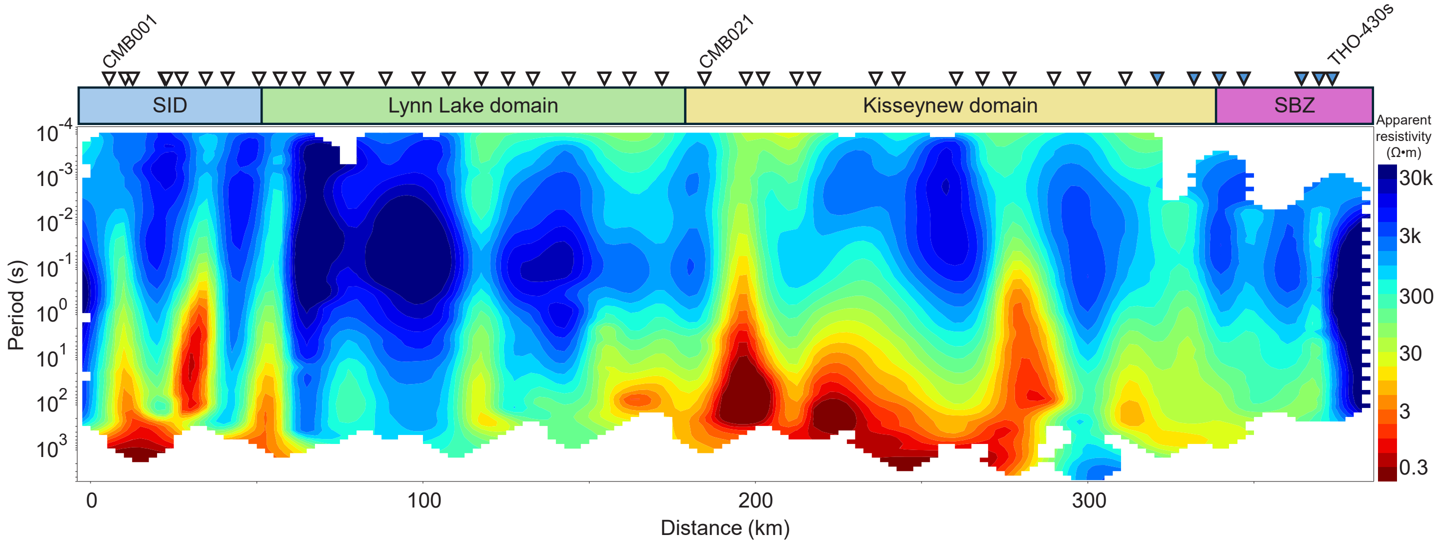

Figure GS2025-8-2: *Pseudosection of the xy component of magnetotelluric (MT) apparent resistivity along the profile shown in Figure GS2025-8-1. Cooler (blue) colours indicate higher apparent resistivity, warmer (red) colours indicate lower apparent resistivity. The xy component corresponds to an electric field aligned with geographic north and a magnetic field aligned with geographic east. Projected locations of MT sites are shown as inverted black triangles. Three MT sites are labelled for reference (CMB001, CMB021, THO-430s; see Figure GS2025-8-1 for locations). Abbreviations: Ω•m, ohm-metre; k, thousand; SBZ, Superior boundary zone; SID, Southern Indian domain.*

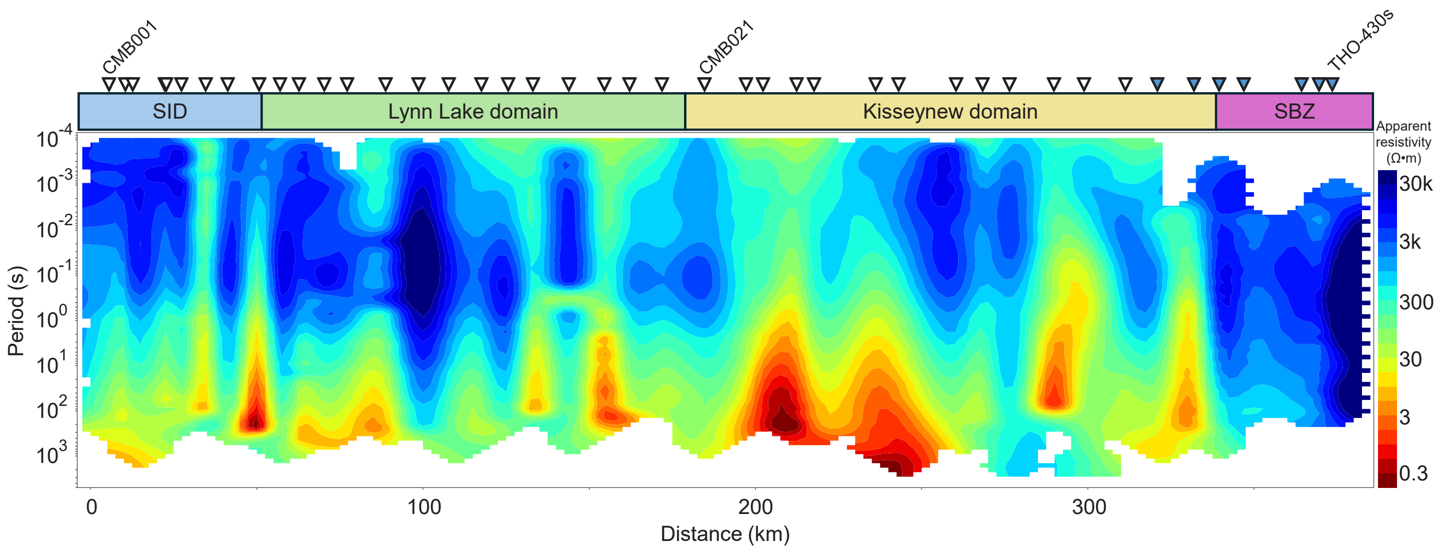

Figure GS2025-8-3: *Pseudosection of the yx component of magnetotelluric (MT) apparent resistivity along the profile shown in Figure GS2025-8-1. Cooler (blue) colours indicate higher apparent resistivity, warmer (red) colours indicate lower apparent resistivity. The yx component corresponds to an electric field aligned with geographic east and a magnetic field aligned with geographic north. Projected locations of MT sites are shown as inverted black triangles. Three MT sites are labelled for reference (CMB001, CMB021, THO-430s; see Figure GS2025-8-1 for locations). Abbreviations: Ω•m, ohm-metre; k, thousand; SBZ, Superior boundary zone; SID, Southern Indian domain.*

the Kisseynew domain (at approximately 0 to 60 km and 180 to 300 km, respectively; Figures GS2025-8-2 to -6). Figure GS2025-8-3 shows the apparent resistivity of the yx component, which is calculated from the electric field aligned with geographic east and the magnetic field aligned with geographic north. The same general trend can be seen as with the xy apparent resistivity, with high apparent resistivity at periods of shorter than 1 s and lower apparent resistivity at periods longer than 1 s.

Figures GS2025-8-4 and -5 show the phase angle computed for the xy and yx components, respectively. Note that 180 degrees has been added to the yx phase to simplify the comparison with the xy phase. Unlike the apparent resistivity data,

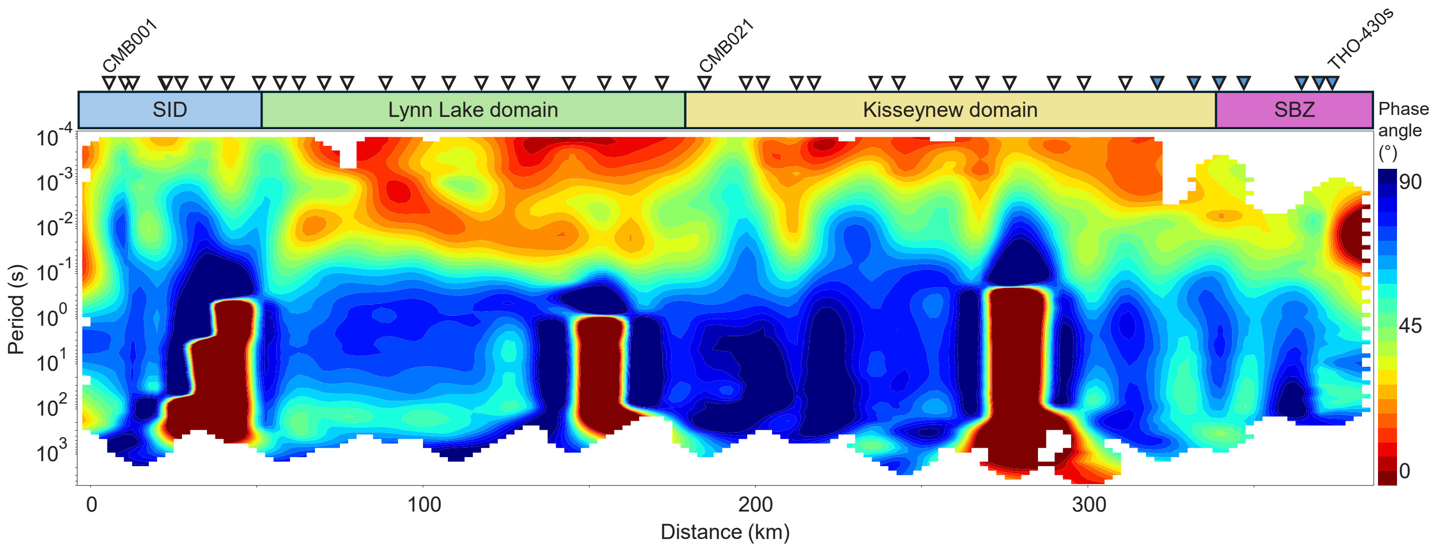

Figure GS2025-8-4: *Pseudosection of the xy component of magnetotelluric (MT) impedance phase angle along the profile shown in Figure GS2025-8-1. Cooler (blue) colours indicate higher phase angle, warmer (red) colours indicate lower phase angle. Phase angle between 45˚ and 90˚ indicates decreasing apparent resistivity with period, phase angle between 0˚ and 45˚ indicates increasing apparent resistivity with period. The xy component corresponds to an electric field aligned with geographic north and a magnetic field aligned with geographic east. Projected locations of MT sites are shown as inverted black triangles. Three MT sites are labelled for reference (CMB001, CMB021, THO-430s; see Figure GS2025-8-1 for locations). Abbreviations: SBZ, Superior boundary zone; SID, Southern Indian domain.*

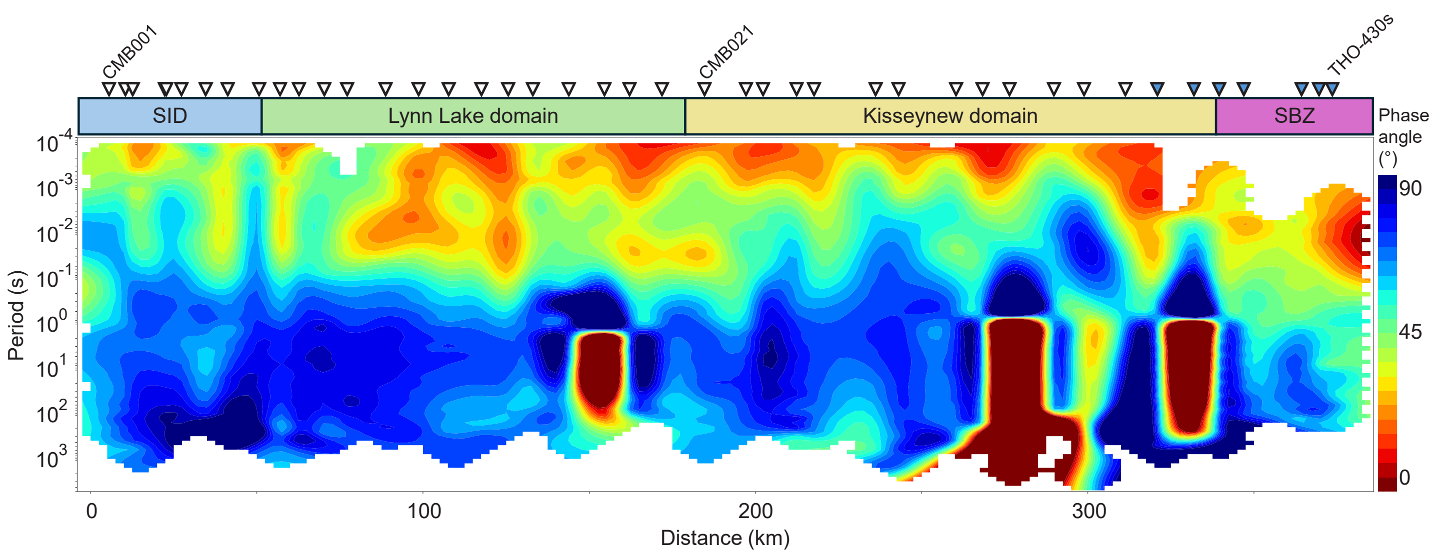

Figure GS2025-8-5: *Pseudosection of the yx component of magnetotelluric (MT) impedance phase angle along the profile shown in Figure GS2025-8-1. Cooler (blue) colours indicate higher phase angle, warmer (red) colours indicate lower phase angle. Phase angle between 45˚ and 90˚ indicates decreasing apparent resistivity with period, phase angle between 0˚ and 45˚ indicates increasing apparent resistivity with period. The yx component corresponds to an electric field aligned with geographic east and a magnetic field aligned with geographic north. Note that 180 ˚ has been added to the yx phase to simplify the comparison with the xy phase. Projected locations of MT sites are shown as inverted black triangles. Three MT sites are labelled for reference (CMB001, CMB021, THO-430s; see Figure GS2025-8-1 for locations). Abbreviations: SBZ, Superior boundary zone; SID, Southern Indian domain.*

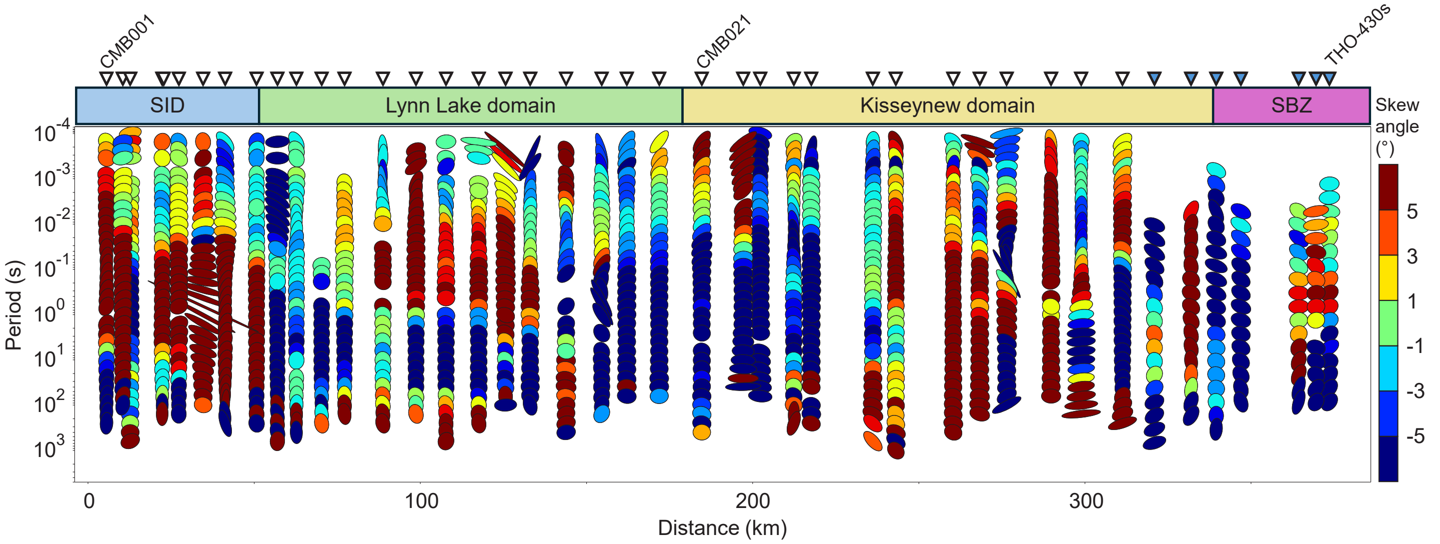

Figure GS2025-8-6: *Pseudosection of magnetotelluric (MT) phase tensor ellipses along the profile shown in Figure GS2025-8-1. Phase tensor ellipse fill colour corresponds to the skew angle (β), where β = 0 indicates 1-D geoelectrical structure. Length of ellipse principal axes corresponds to the degree of phase split in orthogonal directions, i.e., due to 2-D/3-D structure or electrical anisotropy. The ellipse at every second period is omitted for clarity. Projected locations of MT sites are shown as inverted black triangles. Three MT sites are labelled for reference (CMB001, CMB021, THO-430s; see Figure GS2025-8-1 for locations). Abbreviations: SBZ, Superior boundary zone; SID, Southern Indian domain.*

the phase data are not susceptible to local anomalies in electric field amplitude (i.e., static shifts), which appear as vertical stripes in the apparent resistivity pseudosections (e.g., at 150 km in Figure GS2025-8-3). The xy and yx phases are generally less than 45 degrees at periods shorter than 0.1 s, indicative of an increasing apparent resistivity as a function of period. At periods longer than 1 s, the xy and yx phases are mostly greater than 45 degrees, which represents decreasing apparent resistivity as a function of period. A few sites have phases outside of their typical quadrants (dark red in Figures GS2025-8-4, -5), a phenomenon known as out-of-quadrant phase, which can be caused by strong resistivity contrasts, complicated 3-D resistivity structure or electrical anisotropy (Heise and Pous, 2003; Lezaeta and Haak, 2003). Therefore, a 2-D anisotropic inversion code or 3-D inversion code is required to accurately model the out-of-quadrant phase data.

A pseudosection of the MT phase tensor data (Caldwell et al., 2004) is shown in Figure GS2025-8-6. The phase tensor provides information on the dimensionality of the MT data, which determines which type of modelling is appropriate for the dataset (2-D or 3-D). The phase tensor can be displayed as an ellipse at each period, with the principal axes oriented according to the direction of the regional induction current. For a 1-D Earth where there is no defined geoelectric strike direction, the principal axes are equal in length, and the ellipse is a circle. Alternatively, an elongated ellipse with principal axes of different lengths indicates the presence of 2-D/3-D structure or electrical anisotropy. In Figure GS2025-8-6, each phase tensor ellipse is filled with a colour corresponding to the skew angle (β), which is a measure of the phase tensor asymmetry. The skew angle for an ideal 2-D Earth is equal to zero; thus, many MT studies have used the skew angle to determine whether the underlying resistivity structure can be approximated as 2-D (Booker, 2014). If the 2-D approximation can be justified, then a 2-D inversion algorithm is suitable for modelling the MT data. The threshold of an acceptable skew angle for the 2-D approximation is subjective, but a threshold of $|\beta|<3^{\circ}$ has been widely used, with some caveats (i.e., Booker, 2014). As seen in Figure GS2025-8-6, the majority of MT sites do not meet the condition of $|\beta|<3^{\circ}$, especially at the long periods, which are sensitive to the deepest resistivity structures. The sites and periods with a large skew magnitude are also spatially correlated with the previously shown out-of-quadrant phases in Figures GS2025-8-4 and -5. The orientations of phase tensor ellipse axes vary considerably between sites, which further suggests a 2-D approximation cannot be used for the entire study area as there is changing geoelectric structure between different geological domains. Therefore, a 3-D approach will be employed in future work as a 2-D analysis of the data would not produce reliable results.

Future work

After preliminary analysis of the newly collected MT data, the next step is to use an inversion algorithm to obtain an electrical resistivity model consistent with the MT data. As evidenced by the out-of-quadrant phases and high phase tensor skew angles, the regional resistivity structure cannot be approximated as 2-D. If carefully used, a 3-D inversion algorithm can be used to model MT data collected along a profile (e.g., Siripunvaraporn et al., 2005). The interpretation of the electrical resistivity model will be integrated with previous geological and geophysical data, including a seismic reflection profile collected along the same highway above the Kisseynew, Lynn Lake and Southern Indian domains (White et al., 2000).

Economic considerations

A new broadband MT dataset has been collected over the interior Reindeer zone of the THO, which will help to elucidate the regional electromagnetic signature, similar to what the LITHOPROBE transects over other parts of the THO have done in the past. The new MT profile crosses the historic Lynn Lake and Thompson mining areas and will provide new information to de-risk future exploration activities in the area, including highlighting potential deep-seated structures that may be related to critical mineral endowment and pointing out additional areas of interest. The MT studies targeting the entire crustal depth range, such as those conducted as part of the Metal Earth program over the Superior Craton (Adetunji et al., 2023, 2025; Smith et al., 2023), have shown an improved knowledge of deep crustal features is crucial as they may be spatially and temporally linked to near-surface mineral occurrences.

Acknowledgments

The authors thank T. Martins for assistance in co-ordinating magnetotelluric site locations, as well as J. Marks, K. Reid and S.M. Ansari for their reviews, which improved this manuscript. The magnetotelluric data used in this study were collected by Quantec Geoscience. This study was supported by the Critical Minerals Geoscience and Data (CMGD) Initiative of the Geological Survey of Canada.

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