GS2025-9

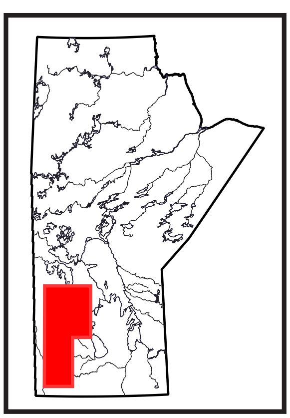
Expanded long-period magnetotelluric data coverage over the Trans-Hudson orogen in southwestern Manitoba (NTS 62N, O, J, G, F, K, parts of 63C, B)

by B.F.W. Chase[1], M.J. Unsworth[1], K. Moshtaghian[1], A. Redanz[1], J. Marks, A. Williamson[1], Z. Vestrum[1] and S. Palmers[1]

In Brief:

- Long-period magnetotelluric coverage in Manitoba was expanded southward to the US border
- The data will be used to produce a 3-D resistivity model of the lithosphere, and conductive anomalies will be interpreted within the mineral systems framework
- The data and resistivity model will serve as regional reconnaissance tools for mineral exploration in the province

Citation:
Chase, B.F.W., Unsworth, M.J., Moshtaghian, K., Redanz, A., Marks, J., Williamson, A., Vestrum, Z. and Palmers, S. 2025: Expanded long-period magnetotelluric data coverage over the Trans-Hudson orogen in southwestern Manitoba (NTS 62N, O, J, G, F, K, parts of 63C, B); *in* Report of Activities 2025, Manitoba Business, Mining, Trade and Job Creation, Manitoba Geological Survey, p. 94–103.



Summary

Information about the structure of the deep lithospheric mantle cannot be obtained from drilling and requires geophysical exploration. One of the most useful methods for this task is magnetotelluric exploration, which uses natural low-frequency radio signals to determine the electrical resistivity structure of the Earth to depths in excess of 200 km. The Manitoba Geological Survey, in collaboration with the University of Alberta, is continuing to develop a 3-D resistivity model of the deep lithospheric structure beneath the province. In 2024, long-period magnetotelluric (LMT) data were collected at 22 stations in west-central Manitoba. In 2025, LMT data were collected at an additional 13 stations in southwestern Manitoba with the goal of extending coverage over the boundary between the Trans-Hudson orogen and the Superior craton as far south as the border with the United States. The new LMT data will be combined with previously collected data in Saskatchewan and Manitoba to produce a 3-D resistivity model of the Trans-Hudson orogen beneath the provinces. The goal of developing the 3-D resistivity model is to improve the understanding of the deep lithospheric structure and how it may be used for predicting and analyzing the spatial distribution of mineralization. Ultimately, these LMT data and the resulting 3-D resistivity model would help to guide future mineral exploration in the province.

Introduction

The basement rocks of Manitoba include part of the eastern margin of the Trans-Hudson orogen (THO) and the boundary between the THO and the Superior craton (Figure GS2025-9-1). This part of Laurentia was assembled during the closure of the Manikewan Ocean in the Proterozoic ca. 1.9–1.8 Ga (Whitmeyer and Karlstrom, 2007). Terranes mapped in this region include the Flin Flon belt, the Lynn Lake–La Ronge belt and the Superior boundary zone and several subdomains of the Superior province (e.g., Superior craton; Figure GS2025-9-1). All of these terranes are associated with significant mineral endowment and host numerous active and historical mines. A relatively brief geological overview is provided by Chase et al. (2024) as part of prior data collection efforts in the THO. For more information, interested readers are directed to the work of Bleeker (1990), Lewry and Collerson (1990), Machado (1990), Weber (1990), Ansdell et al. (1995), Bleeker et al. (1995), Conners et al. (1999), Syme et al. (1999), Whalen et al. (1999), Percival et al. (2006, 2012), Zwanzig et al. (2007) and Clowes and Roy (2020).

The current understanding of the deep lithospheric structure of the THO is derived from geophysical studies that have used seismic, magnetotelluric (MT) and potential-field exploration methods (e.g., Jones et al., 2005; White et al., 2005). The depth of exploration in these previous studies has been largely limited to the crust. As a result, there is limited information about the deeper lithospheric mantle of the THO. Additionally, these geophysical studies have generally used 2-D approaches for data analysis, which provides limited information about the along-strike variability of the structure of the THO (e.g., White et al., 2002). In past studies, the structural complexity of the THO has led to differing interpretations of fundamental features such as the polarity of subduction (e.g., White et al., 2002). In the United States, 3-D modelling of deep-imaging, whole-lithosphere–scale geophysical data has helped improve understanding of the structure of the southern THO (from lat. 43 to 49°N) and has highlighted how the shallow complex crustal structure may overprint and obscure earlier structures at greater depths (Ye et al., 2019; Bedrosian and Finn, 2021). These data have provided greater insights into the tectonic evolution of the THO. Additionally, these geophysical data have suggested that several of the tectonic terranes associated with mineralization in Manitoba (e.g., the Flin Flon

[1] Department of Physics, University of Alberta, Edmonton, Alberta

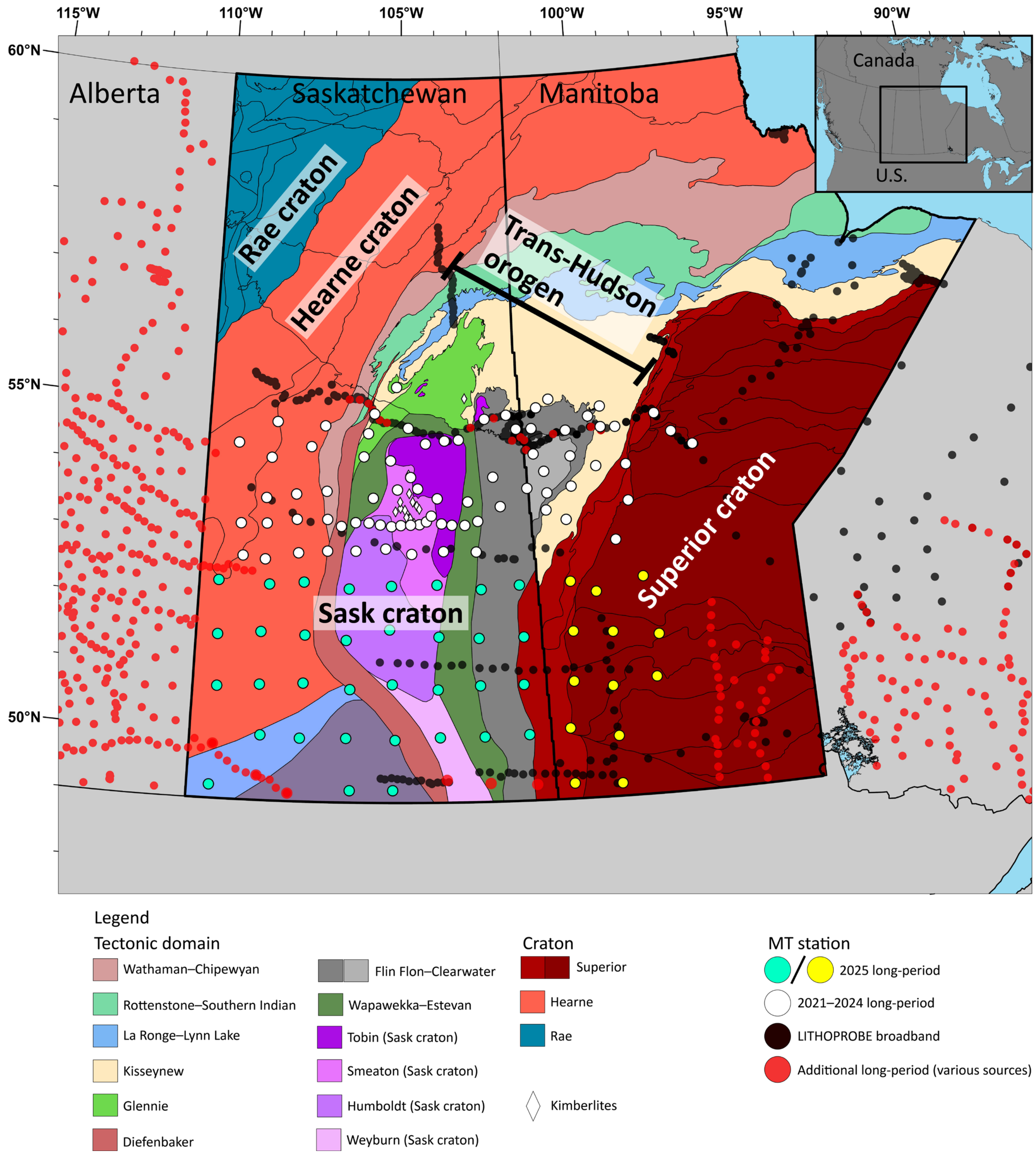


Figure GS2025-9-1: *Lithotectonic units of Manitoba and Saskatchewan. The Trans-Hudson orogen is composed of the various lithotectonic units between the Hearne and Superior cratons. Thin black lines indicate the boundaries of the subdomains within the Superior, Hearne and Rae cratons. Magnetotelluric (MT) data coverage is shown for the region (University of Alberta, unpublished data, 2024). Note that the additional long-period magnetotelluric (LMT) stations in Alberta represent stations where the data were collected for the LITHOPROBE program or by the University of Alberta, whereas in the rest of Canada, data were collected for the LITHOPROBE program and some smaller studies. The 2025 LMT stations in Manitoba are shown as yellow dots (also see Figure GS2025-9-4). The 2025 LMT stations in Saskatchewan, deployed as part of a companion survey, are shown as teal dots. The 2021–2024 LMT data were collected as part of the work of Chase and Unsworth (2024) and Chase et al. (2024). Data from the stations around the 2021–2025 LMT stations will also be used to create the 3-D resistivity model of the lithosphere of the Trans-Hudson orogen in this area. Manitoba lithotectonic units modified after Manitoba Geological Survey (2022). Saskatchewan lithotectonic units modified after Saskatchewan Energy and Resources (2021).*

terrane) continue south well into the United States (Bedrosian and Finn, 2021). This suggests that additional mineralization may be present further south in the basement beneath the Western Canada Sedimentary Basin. To improve the understanding of the structure of the THO and extent of additional mineralization in Canada, 3-D geophysical datasets with the capability of imaging the entire lithosphere are required.

The MT method is particularly well suited for imaging mineral systems because it is sensitive to conductive anomalies, which are commonly associated with the ore-related minerals and regions altered by the passage of mineralizing fluids during tectonic processes (e.g., Heinson et al., 2018; Kirkby et al., 2022; Chase and Unsworth, 2024). In particular, the long-period magnetotelluric (LMT) method is capable of imaging the entire lithosphere and the deep structure around regional mineral deposits and mining districts thus it was used for this project to help predict and analyze the spatial distribution of mineralization in Manitoba. Any major conductors identified in the lithosphere can be incorporated within a mineral systems framework to aid mineral exploration at a regional scale. The mineral systems framework is an emerging technique in exploration that is focused on understanding how mineralization develops from the deposit to the regional scale. In this framework, the individual deposit is treated as a small end-product of processes that operate on much larger spatial and temporal scales. A major focus of the mineral systems framework is determining the genesis, ascent and localization of mineralizing fluids throughout the lithosphere (McCuaig et al., 2010; McCuaig and Hronsky, 2014). In practice, to do this requires the use of regional deep-imaging geophysical methods. The data collected can then be used to determine which areas, both brownfield and greenfield, may have enhanced mineral potential. The LMT data are capable of imaging the entire lithosphere, and from a geophysical perspective, are well-suited for use in the mineral systems framework at the camp- to regional-scale (Figure GS2025-9-2).

The questions that the 2025 LMT dataset is intended to address include

- What is the electrical resistivity structure of the eastern margin of the THO and adjacent area of the Superior craton in Manitoba, extending as far south as the border with the United States?
- Are there additional low resistivity anomalies that may be associated with mineralization along the eastern margin of the THO?

Previous studies

The following section presents text first presented in Chase et al. (2024). Geophysical studies of the deep lithospheric structure of the THO in Canada have taken place since the 1980s through the LITHOPROBE program (Clowes et al., 1999). The LITHOPROBE program collected multiple seismic reflection, seismic refraction and MT profiles across the THO (Figure GS2025-9-1). The seismic datasets were used to delineate terrane boundary zones and determine the direction of subduction during closure of the Manikewan Ocean (e.g., Ansdell, 2005; White et al., 2005). The MT datasets were used in a similar manner and identified a northward extension of the North American central plains conductor, a crustal anomaly (or break) that is related to the suture zone observed in the THO both in the United States and Canada (Jones et al., 2005; Bedrosian and Finn, 2021). The MT data also showed that the North American central plains conductor was located beneath the La Ronge gold belt, suggesting a connection between deep conductive anomalies and mineral deposits (Jones et al., 2005). The LMT data collected in 2020–2022 (Figure GS2025-9-1) revealed a similar conductor beneath the Flin Flon region, suggesting that regional-scale conductors were likely associated with a major conductor in the lithospheric mantle beneath the Sask craton (Chase and Unsworth, 2024).

Introduction to the magnetotelluric method

In mineral exploration, airborne or ground-based electromagnetic (EM) surveys are routinely used to locate electrically conductive anomalies related to mineralization. As previously described in Chase et al. (2024), in these methods, the depth of investigation is determined by the skin depth, which is defined as

$$\delta = \frac{503}{\sqrt{\sigma f}} \tag{1}$$

where δ is the skin depth (metres), σ is the electrical conductivity (the inverse of resistivity) of the Earth (siemens/m) and f is frequency (hertz). These methods use a transmitter to generate the signals, and the depth of investigation is typically limited to a few hundred metres.

For deeper imaging, it is necessary to use natural lower-frequency EM signals to increase the depth of investigation (Equation 1). To do this, it is practical to use the MT method. While similar to many of the controlled-source EM methods used in exploration, the naturally occurring EM signals in MT are typically in the range of 10 000–0.0001 hertz (Hz; or 0.0001 to 10 000 seconds per cycle). In comparison, the frequencies for common controlled-source EM methods are in the range of 100 000–100 Hz. As a result, the MT method is capable of imaging considerably deeper than most controlled-source EM methods.

At frequencies above 1 Hz, these signals come from global lightning activity, and below 1 Hz they are primarily generated by interactions between the solar wind and the magnetosphere (Simpson and Bahr, 2005). The MT time-series data are Fourier transformed during processing into the frequency domain to give apparent resistivity curves, which show the resistivity of the subsurface as a function of frequency. Magnetotelluric exploration uses three distinct frequency bands, depending on the target depth. The first is audio magnetotellurics (AMT), which has the frequency range of 10 000–1 Hz, and it is useful for imaging the relatively shallow near surface, usually to depths of <1–2 km. It is often used in the mineral exploration industry for its ability to

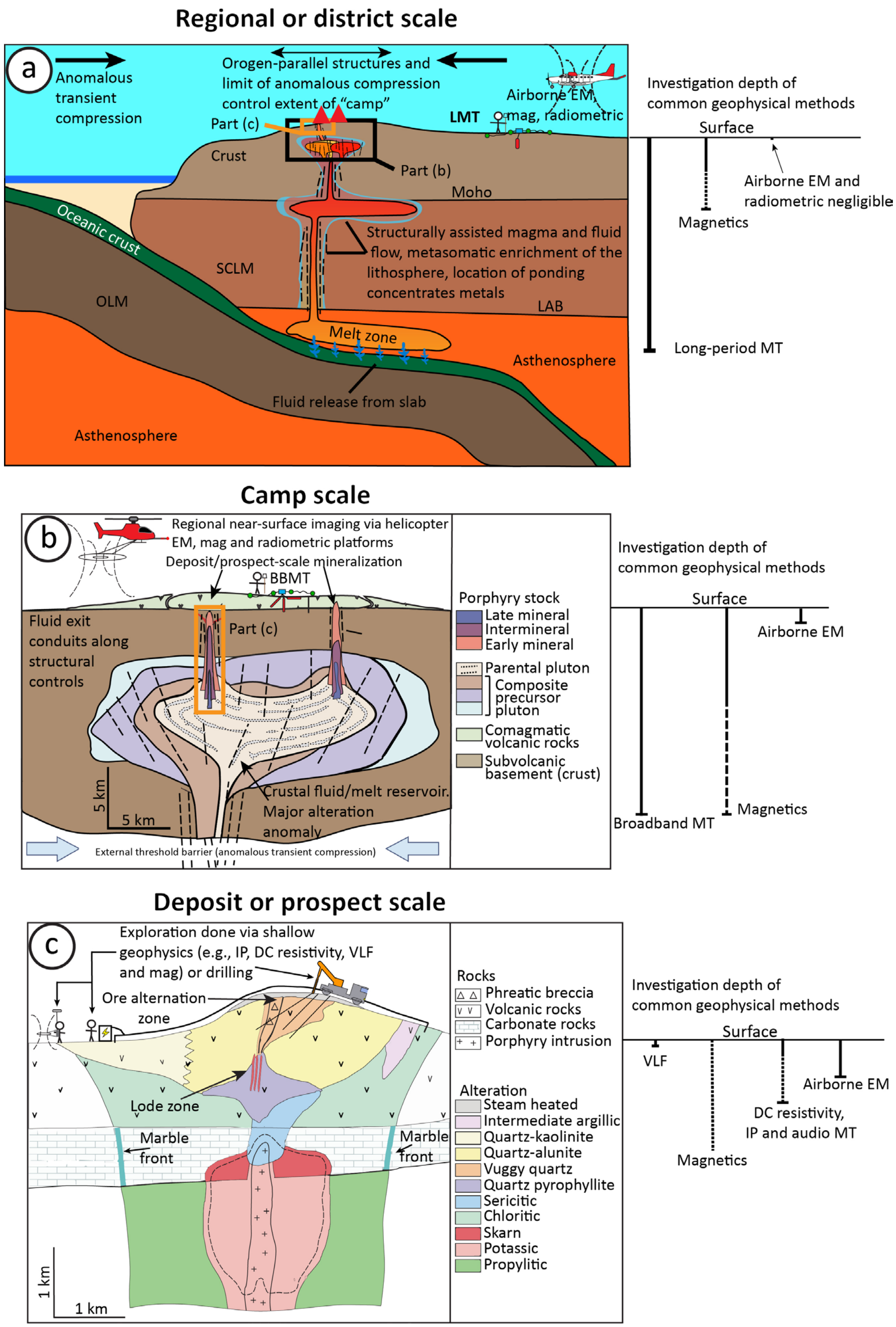


Figure GS2025-9-2: *General components and geophysical investigation criteria for the mineral systems framework at the* ***a)*** *regional or district scale,* ***b)*** *camp scale and* ***c)*** *deposit or prospect scale for an example porphyry deposit. At the tectonic regional scale, targets include major structures and fluid pathways exploited during tectonism as well as where these features are favourably situated and concentrated in discrete regions at the camp scale. At the camp scale, targets include major upper-crustal structures, alteration zones and centres of fluid concentration at deposit-scale depths. At the deposit scale, targets include ore zones (identifying and differentiating them from alteration haloes), ore-controlling structures and higher ore-grade zones. This scale commands the majority of expenditures and time during exploration. Geophysical methods, including the various magnetotelluric (MT) frequency bands, relevant to examining components of the mineral systems at each scale are shown with their typical depths of investigation. In this context, the long-period magnetotelluric (LMT) data collected here are best suited for analysis of mineral system criteria at the regional to camp scale. Black dashed lines denote hypothetical structures that acted as conduits for fluid movement. Adapted from McCuaig and Hronsky (2014) and Chase (2025). Abbreviations: BBMT, broadband magnetotelluric; DC, direct current; EM, electromagnetic; IP, induced polarization; LAB, lithosphere-asthenosphere boundary; mag, magnetics; Moho, Mohorovičić discontinuity; OLM, oceanic lithospheric mantle; SCLM, subcontinental lithospheric mantle; VLF, very low frequency.*

refine targets at somewhat greater depths than other EM methods are capable of imaging. The second is broadband magnetotellurics (BBMT), which has the frequency range of 1000–0.001 Hz. BBMT is useful for imaging the crust and upper mantle and is often used in mineral exploration at the camp scale. The final frequency band is for LMT and has a frequency range of 1–0.0001 Hz; it is capable of imaging the entire lithosphere. Long-period MT data are typically collected to produce regional backbone data products that can be used to refine search areas or to identify areas to be followed up on by higher-resolution geophysical methods.

In the field, MT instruments record two orthogonal electric field components and three orthogonal magnetic field components as a function of time (Figure GS2025-9-3a–c). In LMT systems, the magnetic fields are recorded with a single three-component fluxgate sensor, whereas in BBMT and AMT systems they are recorded using three separate induction coil sensors. Installation of an MT site is not labour intensive, and can be accomplished in 2–3 hours with a crew of 2–3 people. Installation is also minimally invasive, requiring only a few temporary holes to be dug so that various components of the system (e.g., magnetic sensors and electrodes) can be buried. Due to the distance between stations in regional LMT surveys, usually only 2–3 stations are installed per day. It is also important to select station locations that are away from cultural noise. Powerlines, water pumps, pipelines and cattle fences are common sources of electromagnetic noise that will negatively impact MT data.

Magnetotelluric fieldwork

In the summer of 2025, LMT data were recorded at 13 stations in southwestern Manitoba with an average station spacing of 50–70 km (Figures GS2025-9-1, -4). At each location, the LMT station recorded time-series data for 10–20 days. The data were recorded with Narod Geophysics Ltd.'s NIMS (Narod Intelligent Magnetotelluric System), LMT instruments owned by the University of Alberta. Following best practices for LMT data collection, the electrodes were buried 30–40 cm below the surface to avoid the effects of daily temperature variations and precipitation. Bentonite was placed in the electrode holes to improve electrical contact with the ground. Stations were time synchronized using GPS in order to allow for comparison of the time-series data and the removal of noise. The LMT stations were installed at least 500 m away from major infrastructure to minimize cultural noise. Each station produced 100–220 MB of time-series data. Data were successfully recovered at all 13 stations.

Magnetotelluric data analysis

After data processing, reliable apparent resistivity curves were obtained in the period range 5–10 000 s. Figure GS2025-9-5a–d provides examples of data from the 2025 LMT survey. At each station, the measured apparent resistivity at the highest frequencies (>10^{-1} Hz) is determined by the structure of the near surface. The shallow structure in the study area has an apparent resistivity in the range of 1–10 000 ohm-metre (Ω•m; as shown by the variability in the soundings in Figure GS2025-9-5). Apparent resistivity values at sites in the south (e.g., MGS202) are closer to 1 Ω•m, and they increase to 10 000 Ω•m as the sites get farther north (e.g., MGS503). This is expected as sites farther south are located above the thicker portions of the conductive Western Canada Sedimentary Basin in Manitoba. Farther north, the basin gets progressively thinner, and its influence on the data decreases. The northernmost sites register high apparent resistivity values, consistent with a shield environment and resistive crystalline upper-crustal rocks.

At mid-frequencies (10^{-1} to 10^{-3} Hz), results from the southern sites show progressively higher apparent resistivity values, consistent with the stable lithosphere of the Superior craton and border of the THO. In comparison, results from the northern sites show progressively lower apparent resistivity, albeit slowly.

At low frequencies (>10^{-3} Hz), apparent resistivity values at all sites trend toward lower values, likely corresponding to either deeper conductive features or the asthenosphere. A 2-D or 3-D resistivity structure is indicated by the XY and YX curves diverging as a function of frequency to some degree at all stations. If the resistivity structure was 1-D the curves would be coincident.

Future work

Long-period magnetotelluric data are measured as a function of frequency and need to be converted into a resistivity model as a function of depth and horizontal distance using a process called inversion. The LMT data collected in Manitoba show some 3-D characteristics (Figure GS2025-9-5), implying that a 3-D inversion approach must be used. The 3-D inversion models will be produced using the ModEM (Modular system for Electromagnetic inversion) algorithm of Kelbert et al. (2014). Computer resources will be provided by the Digital Research Alliance of Canada. Prior inversions on the data collected in 2024 from 22 stations showed that a number of crustal conductors are located in the west-central portion of the data grid, approximately 30–80 km east of The Pas, west-central Manitoba (Chase et al., 2024). One major lithospheric conductor is present beneath the Snow Lake mining district, and is similar to those observed by Chase and Unsworth (2024) beneath mineralization in the Flin Flon and La Ronge mineral belts. This suggests the deep crust and upper lithospheric mantle have a role in the genesis and ascent of mineralizing fluids in both regions.

The inversion of the new LMT data collected in Manitoba is still in progress. The planned research will combine the 2025 LMT data with the MT data collected by LITHOPROBE (Jones et al., 2005), Chase and Unsworth (2024) and Chase et al. (2024), together with the LMT data collected in Saskatchewan in 2025 (see Figure GS2025-9-1). The integrated dataset will be inverted to produce a resistivity model that includes as much of the previously collected data as possible and that covers the extent of the LMT data collected since 2021. The resulting 3-D resistivity model

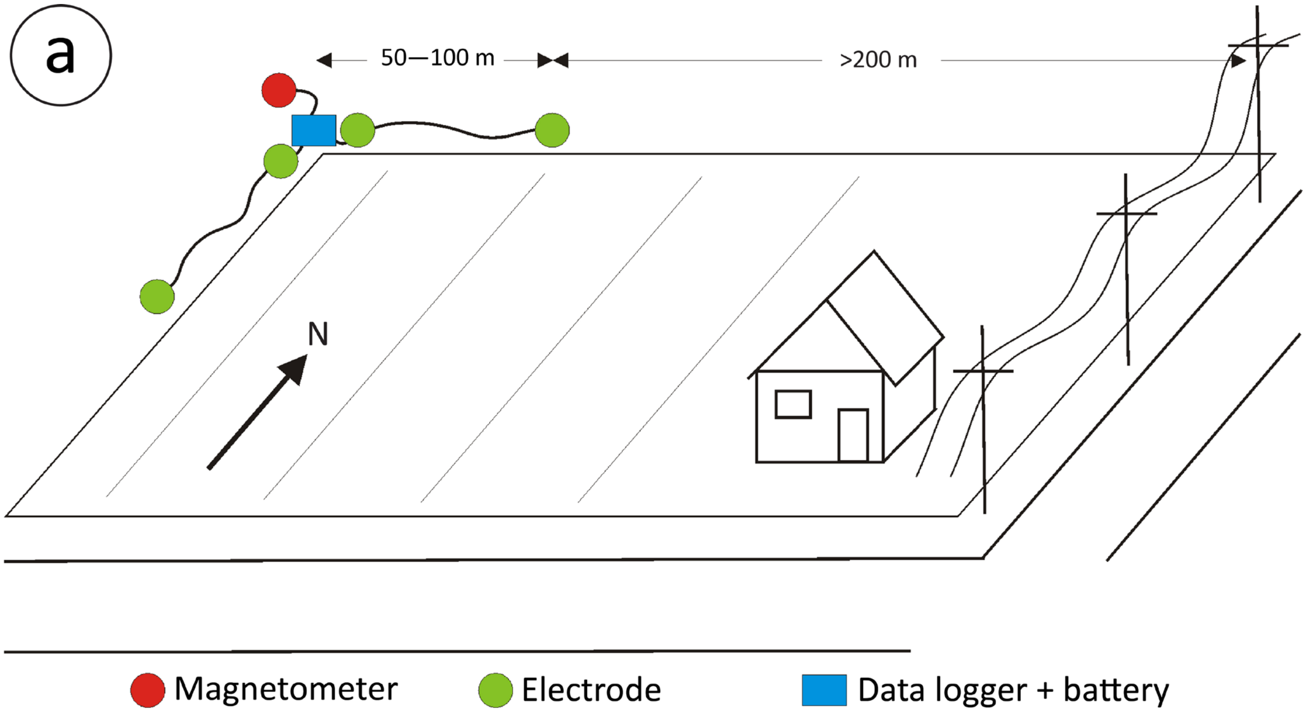


***Figure GS2025-9-3**: **a)** Layout of a long-period magnetotelluric (LMT) station. Installation only requires digging 4–6 temporary holes in the ground to a depth of 30–40 cm. The station typically occupies an area that is up to 100 by 100 m in size. Examples of an LMT system (Narod Geophysics Ltd.'s Narod Intelligent Magnetotelluric System [NIMS]) being **b)** deployed and **c)** recovered in the field in Manitoba.*

will be evaluated with a sensitivity analysis to determine which model features are required. This will be followed by a systematic interpretation of the 3-D resistivity model. Low-resistivity anomalies in this model will be quantitatively interpreted to determine the cause of the low-resistivity anomalies. Anomalies present in the crust will be evaluated using regional geology maps, drillcore and geophysical data, which will allow for a better understanding of the structural controls related to their formation and how they may relate to regional mineralization. The 3-D resistivity model will be interpreted within the mineral systems framework (e.g., McCuaig et al., 2010; McCuaig and Hronsky, 2014) to determine the factors that control the spatial distribution of mineralization. In the long term, it is hoped that partnerships with private-sector companies will allow for this grid to continue expanding north-

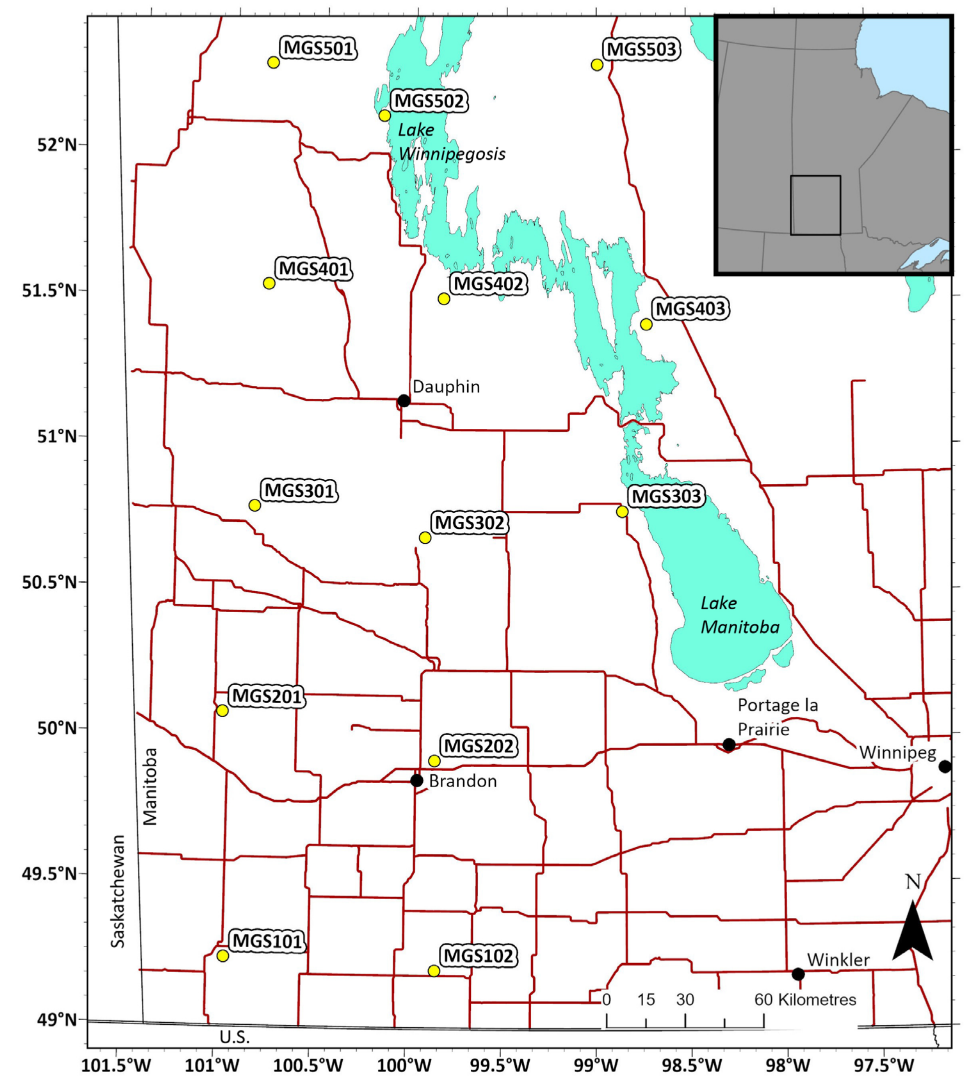


Figure GS2025-9-4: *Distribution of the long-period magnetotelluric (LMT) stations deployed in 2025 in southwestern Manitoba, shown as yellow dots here and in Figure GS2025-9-1. Provincial Trunk Highways shown as red lines. Inset map shows the location of the survey area at the Manitoba–Saskatchewan–United States border.*

ward where access is more challenging. The grid of LMT stations will also be combined with the EarthScope MT array in the contiguous United States (Murphy et al., 2023). This will produce a 3-D resistivity model of the lithosphere of the entire THO, which will offer improvements on tectonic evolution models for North America.

Economic considerations

The MT resistivity model developed by Chase and Unsworth (2024) for central Saskatchewan shows the presence of several major lithospheric conductors beneath the Flin Flon and La Ronge mineral belts. These conductors are connected to a conductive anomaly in the underlying lithospheric mantle, located beneath the Sask craton. These conductors were interpreted to be due to the presence of sulphide minerals and graphite films deposited by past episodes of fluid flow in the lithosphere. These sulphide minerals may be effective carriers of economically important base and precious metals (e.g., Tomkins and Evans, 2015; Walters et al., 2020). Thus, detection of these major conductors may help to locate areas favourable for mineralization and enhance the prospectivity of known areas. Ultimately, these conductors may help explain why economic mineralization is concentrated beneath the Flin Flon and La Ronge mineral belts. This may suggest that there are regional whole-lithosphere controls on the distribution of mineralization in this region of the THO. The LMT data collected in 2024 (Chase et al., 2024) will be used alongside the data collected in 2025 to evaluate if similar conductors are present in Manitoba and if they may be linked to potential mineralization. Critically, the new LMT data will be used to determine if potential mineralization may be present beneath the Western Canada Sedimentary Basin. At its northern reaches, where the basin rapidly thins, there may be additional targets

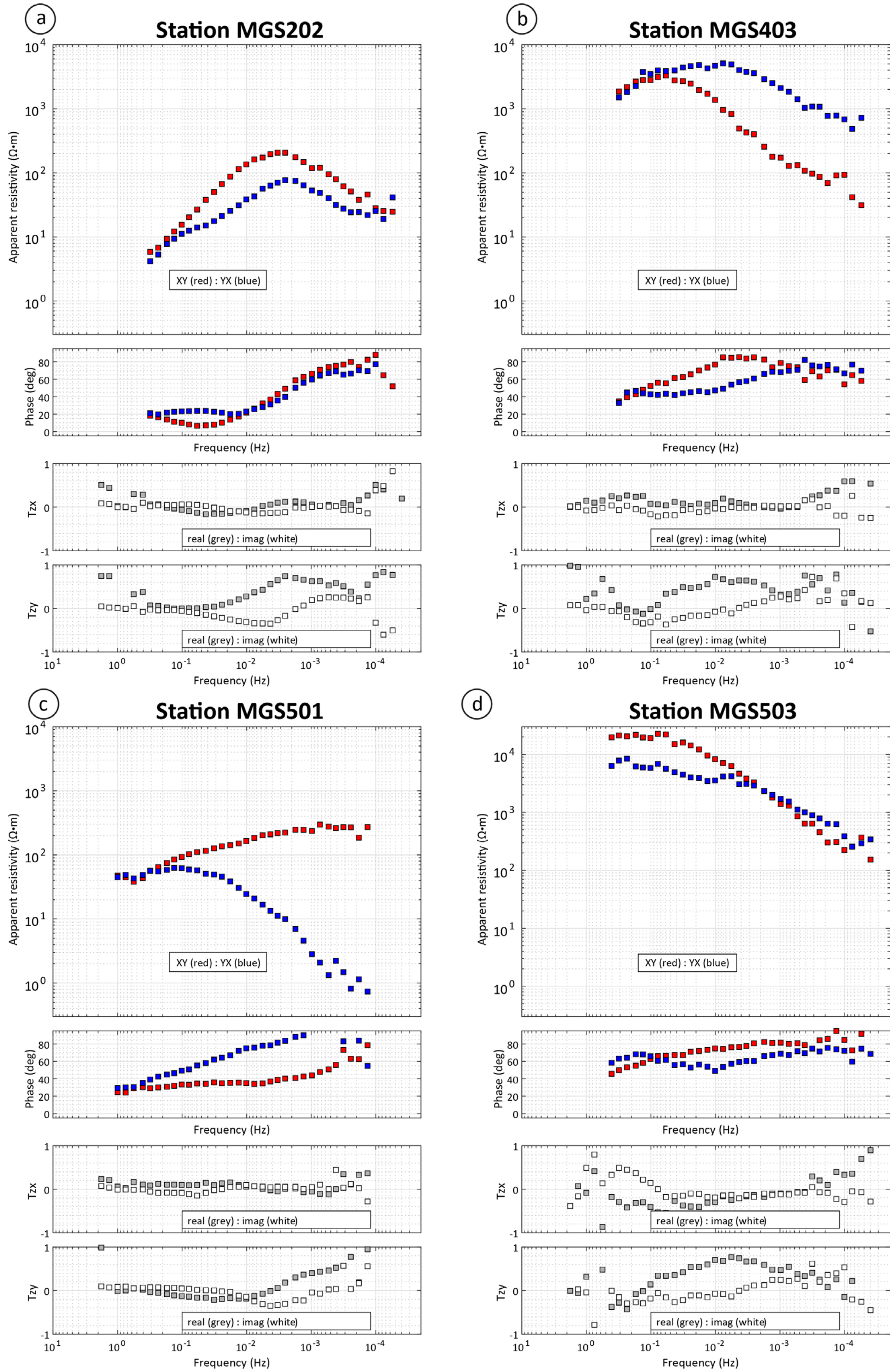


Figure GS2025-9-5: *Apparent resistivity and phase curves as a function of frequency for four long-period magnetotelluric (LMT) stations installed as part of this study:* ***a)*** *station MGS202;* ***b)*** *station MGS403;* ***c)*** *station MGS501;* ***d)*** *station MGS503. The apparent resistivity curves are obtained from the ratio of components of the electric and magnetic field measurements. The X and Y correspond to measurements of these fields in the north-south and east-west directions, respectively. Red curves are the transverse electric mode, which is highly sensitive to conductive features. Blue curves are the transverse magnetic mode, which is sensitive to both resistors and conductors, but the latter less so than the transverse electric mode. The functions labelled T_{zy} and T_{zx} are the components of the tipper (T) and are computed from the ratio of vertical (z) to horizontal (x and y) magnetic field components. The tipper is highly sensitive to conductive features. The real and imaginary (imag) components of the tipper are the in-phase and quadrature components, respectively. The locations of the stations chosen are shown in Figure GS2025-9-4. Abbreviations: Ω•m, ohm-metre; deg, degree; Hz, hertz.*

that are largely accessible but have escaped detection due to burial beneath relatively shallow sedimentary overburden.

Acknowledgments

The authors thank the Manitoba Geological Survey and T. Martins for their logistical support, assistance in survey planning, and communication with local communities about the survey. The authors thank M. Rinne and X.M. Yang for reviews of this report and D. O'Hara is thanked for the layout of the report. C. Epp, P. Belanger and E. Ralph are thanked for their assistance with vehicle, expediting and equipment maintenance. RnD Technical is thanked for technical editing assistance.

References

Ansdell, K.M. 2005: Tectonic evolution of the Manitoba-Saskatchewan segment of the Paleoproterozoic Trans-Hudson orogen, Canada; Canadian Journal of Earth Sciences, v. 42, no. 4, p. 741–759, URL <https://doi.org/10.1139/e05-035>.

Ansdell, K.M., Lucas, S.B., Connors, K. and Stern, R.A. 1995: Kisseynew metasedimentary gneiss belt, Trans-Hudson orogen (Canada): back-arc origin and collisional inversion; Geology, v. 23, no. 11, p. 1039–1043, URL <https://doi.org/10.1130/0091-7613(1995)023<1039:KMGBTH>2.3.CO;2>.

Bedrosian, P.A. and Finn, C.A. 2021: When Wyoming became superior: oblique convergence along the southern Trans-Hudson orogen; Geophysical Research Letters, v. 48, no. 13, art. e2021GL092970, URL <https://doi.org/10.1029/2021GL092970>.

Bleeker, W. 1990: New structural-metamorphic constraints on Early Proterozoic oblique collision along the Thompson nickel belt, northern Manitoba; *in* The Early Proterozoic Trans-Hudson Orogen of North America, J.F. Lewry and M.R. Stauffer (ed.), Geological Association of Canada, Special Paper 37, p. 57–74.

Bleeker, W., Nagerl, P. and Machado, N. 1995: The Thompson nickel belt, Manitoba: some new U-Pb ages; Geological Association of Canada–Mineralogical Association of Canada, Joint Annual Meeting, May 17–19, 1996, Victoria, British Columbia, Program with Abstracts, v. 20, p. A8.

Chase, B.F.W. 2025: Tectonic studies of the lithosphere of Laurentia using magnetotelluric data and the implications for diamond resources; Ph.D. thesis, University of Alberta, Edmonton, Alberta, 326 p.

Chase, B.F.W. and Unsworth, M.J. 2024: Magnetotelluric evidence for the formation of the layered Sask Craton by flat slab subduction; Earth and Planetary Science Letters, v. 647, art. 119027, URL <https://doi.org/10.1016/j.epsl.2024.119027>.

Chase, B.F.W., Marks, J., Williamson, A., Maki, A., Moshtaghian, K. and Unsworth, M.J. 2024: Initial results from a long-period magnetotelluric survey in the Flin Flon, Snow Lake and The Pas area, west-central Manitoba (NTS 63F, G, J, K, parts of 63B, I, N); *in* Report of Activities 2024, Manitoba Economic Development, Investment, Trade and Natural Resources, Manitoba Geological Survey, p. 145–152, URL <https://www.manitoba.ca/iem/geo/field/roa24pdfs/GS2024-17.pdf> [July 2025].

Clowes, R.M. and Roy, B. 2020: Crustal structure of the metasedimentary Kisseynew domain and bounding volcanic–plutonic domains, Trans-Hudson orogen, Canada; Canadian Journal of Earth Sciences, v. 58, no. 3, p. 268–285, URL <https://doi.org/10.1139/cjes-2020-0062>.

Clowes, R., Cook, F., Hajnal, Z., Hall, J., Lewry, J., Lucas, S. and Wardle, R. 1999: Canada's LITHOPROBE Project (collaborative, multidisciplinary geoscience research leads to new understanding of continental evolution); Episodes Journal of International Geoscience, v. 22, no. 1, p. 3–20, URL <https://doi.org/10.18814/epiiugs/1999/v22i1/002>.

Connors, K.A., Ansdell, K.M. and Lucas, S.B. 1999: Coeval sedimentation, magmatism, and fold-thrust development in the Trans-Hudson orogen: propagation of deformation into an active continental arc setting, Wekusko Lake area, Manitoba; Canadian Journal of Earth Sciences, v. 36, no. 2, p. 275–291, URL <https://doi.org/10.1139/e98-090>.

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, art. 10608, URL <https://doi.org/10.1038/s41598-018-29016-2>.

Jones, A.G., Ledo, J. and Ferguson, I.J. 2005: Electromagnetic images of the Trans-Hudson orogen: the North American Central Plains anomaly revealed; Canadian Journal of Earth Sciences, v. 42, no. 4, p. 457–478, URL <https://doi.org/10.1139/e05-018>.

Kelbert, A., Meqbel, N., Egbert, G.D. and Tandon, K. 2014: ModEM: a modular system for inversion of electromagnetic geophysical data; Computers & Geosciences, v. 66, p. 40–53, URL <https://doi.org/10.1016/j.cageo.2014.01.010>.

Kirkby, A., Czarnota, K., Huston, D.L., Champion, D.C., Doublier, M.P., Bedrosian, P.A., Duan, J. and Heinson, G. 2022: Lithospheric conductors reveal source regions of convergent margin mineral systems; Scientific Reports, v. 12, no. 1, art. 8190, URL <https://doi.org/10.1038/s41598-022-11921-2>.

Lewry, J.F. and Collerson, K.D. 1990: Trans-Hudson orogen: extent, subdivisions, and problems; *in* The Early Proterozoic Trans-Hudson Orogen of North America, J.F. Lewry and M.R. Stauffer (ed.), Geological Association of Canada, Special Paper 37, p. 1–14.

Machado, N. 1990: Timing of collisional events in the Trans-Hudson orogen: evidence from U-Pb geochronology for the New Quebec orogen, the Thompson belt and the Reindeer zone (Manitoba and Saskatchewan); *in* The Early Proterozoic Trans-Hudson Orogen of North America, J.F. Lewry and M.R. Stauffer (ed.), Geological Association of Canada, Special Paper 37, p. 433–441.

Manitoba Geological Survey 2022: Bedrock geology of Manitoba; Manitoba Natural Resources and Northern Development, Manitoba Geological Survey, Open File OF2022-2, scale 1:1 000 000.

McCuaig, T.C. and Hronsky, J.M.A. 2014: The mineral system concept: the key to exploration targeting; *in* Building Exploration Capability for the 21st Century, K.D. Kelly and H.C. Golden (ed.), Society of Economic Geologists, Special Publication 18, p. 153–175.

McCuaig, T.C., Beresford, S. and Hronsky, J. 2010: Translating the mineral systems approach into an effective exploration targeting system; Ore Geology Reviews, v. 38, no. 3, p. 128–138, URL <https://doi.org/10.1016/j.oregeorev.2010.05.008>.

Murphy, B.S., Bedrosian, P. and Kelbert, A. 2023: Geoelectric constraints on the Precambrian assembly and architecture of southern Laurentia; *in* Laurentia: Turning Points in the Evolution of a Continent, S.J. Whitmeyer, M.L. Williams, D.A. Kellett and B. Tikoff (ed.), Geological Society of America, Memoir 220, p. 203–220, URL <https://doi.org/10.1130/2022.1220(13)>.

Percival, J.A., Sanborn-Barrie, M., Skulski, T., Stott, G.M., Helmstaedt, H. and White, D.J. 2006: Tectonic evolution of the western Superior Province from NATMAP and Lithoprobe studies; Canadian Journal of Earth Sciences, v. 43, no. 7, p. 1085–1117, URL <https://doi.org/10.1139/e06-062>.

Percival, J.A., Skulski, T., Sanborn-Barrie, M., Stott, G.M., Leclair, A.D., Corkery, M.T. and Boily, M. 2012: Geology and tectonic evolution of the Superior Province, Canada; *in* Tectonic Styles in Canada: the LITHOPROBE Perspective, J.A. Percival, F.A. Cook and R.M. Clowes (ed.), Geological Association of Canada, Special Paper 49, p. 321–378.

Saskatchewan Energy and Resources 2021: Geological domains for the province of Saskatchewan, CSRS NAD83 Zone 13; *in* Mining and Petroleum GeoAtlas, Saskatchewan Ministry of Energy and Resources, URL <https://gisappl.saskatchewan.ca/Html5Ext/index.html?viewer=GeoAtlas> [September 2022].

Simpson, F. and Bahr, K. 2005: Practical Magnetotellurics; Cambridge University Press, Cambridge, United Kingdom, 254 p.

Syme, E.C., Lucas, S.B., Bailes, A.H. and Stern, R.A. 1999: Contrasting arc and MORB-like assemblages in the Paleoproterozoic Flin Flon belt, Manitoba, and the role of intra-arc extension in localizing volcanic-hosted massive sulphide deposits; Canadian Journal of Earth Sciences, v. 36, no. 11, p. 1767–1788, URL <https://doi.org/10.1139/e98-084>.

Tomkins, A.G. and Evans, K.A. 2015: Separate zones of sulfate and sulfide release from subducted mafic oceanic crust; Earth and Planetary Science Letters, v. 428, p. 73–83, URL <https://doi.org/10.1016/j.epsl.2015.07.028>.

Walters, J.B., Cruz-Uribe, A.M. and Marschall, H.R. 2020: Sulfur loss from subducted altered oceanic crust and implications for mantle oxidation; Geochemical Perspective Letters, v. 13, p. 36–41, URL <https://doi.org/10.7185/geochemlet.2011>.

Weber, W. 1990: The Churchill-Superior boundary zone, southeast margin of the Trans-Hudson orogen: a review; *in* The Early Proterozoic Trans-Hudson Orogen of North America, J.F. Lewry and M.R. Stauffer (ed.), Geological Association of Canada, Special Paper 37, p. 41–55.

Whalen, J.B., Syme, E.C. and Stern, R.A. 1999: Geochemical and Nd isotopic evolution of Paleoproterozoic arc-type magmatism in the Flin Flon belt, Trans-Hudson orogen, Canada; Canadian Journal of Earth Sciences, v. 36, no. 2, p. 227–250, URL <https://doi.org/10.1139/e98-026>.

White, D.J., Lucas, S.B., Bleeker, W., Hajnal, Z., Lewry, J.F. and Zwanzig, H.V. 2002: Suture-zone geometry along an irregular Paleoproterozoic margin: the Superior boundary zone, Manitoba, Canada; Geology, v. 30, no. 8, p. 735–738, URL <https://doi.org/10.1130/0091-7613(2002)030<0735:SZGAAI>2.0.CO;2>.

White, D.J., Thomas, M.D., Jones, A.G., Hope, J., Németh, B. and Hajnal, Z. 2005: Geophysical transect across a Paleoproterozoic continent–continent collision zone: the Trans-Hudson orogen; Canadian Journal of Earth Sciences, v. 42, no. 4, p. 385–402, URL <https://doi.org/10.1139/e05-002>.

Whitmeyer, S.J. and Karlstrom, K.E. 2007: Tectonic model for the Proterozoic growth of North America; Geosphere, v. 3, no. 4, p. 220–259, URL <https://doi.org/10.1130/GES00055.1>.

Ye, G., Unsworth, M., Wei, W., Jin, S. and Liu, Z. 2019: The lithospheric structure of the Solonker suture zone and adjacent areas: crustal anisotropy revealed by a high-resolution magnetotelluric study; Journal of Geophysical Research: Solid Earth, v. 124, no. 2, p. 1142–1163, URL <https://doi.org/10.1029/2018JB015719>.

Zwanzig, H.V., Macek, J.J. and McGregor, C.R. 2007: Lithostratigraphy and geochemistry of the high-grade metasedimentary rocks in the Thompson nickel belt and adjacent Kisseynew domain, Manitoba: implications for nickel exploration; Economic Geology, v. 102, no. 7, p. 1197–1216, URL <https://doi.org/10.2113/gsecongeo.102.7.1197>.