**Geoelectric structure of the Great Slave Lake shear zone in northwest Alberta: implications for structure and tectonic history**

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<th>Canadian Journal of Earth Sciences</th>
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<td>Manuscript ID</td>
<td>cjes-2017-0067.R1</td>
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<tr>
<td>Manuscript Type</td>
<td>Article</td>
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<td>Date Submitted by the Author</td>
<td>18-Sep-2017</td>
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<td>Complete List of Authors</td>
<td>Wang, Enci; University of Alberta, department of physics Unsworth, Martyn; University of Alberta, Department of Physics Chacko, Thomas; Dept of Earth and Atmospheric Sciences</td>
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<td>Is the invited manuscript for consideration in a Special Issue?</td>
<td>N/A</td>
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<tr>
<td>Keyword</td>
<td>magnetotelluric, Great Slave Lake shear zone, tectonic history, Laurentia, crustal structure</td>
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Geoelectric structure of the Great Slave Lake shear zone in northwest Alberta: implications for structure and tectonic history

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Abstract:

The study of ancient plate boundaries can provide insights into the past and present-day tectonic processes. Here, we describe a magnetotelluric (MT) study of the Precambrian basement of the Hay River Fault (HRF) in northwest Alberta, which is the southwest segment of the Great Slave Lake shear zone. New broadband MT data were collected to give a clearer image of the crustal structure. The Western Canada Sedimentary Basin was imaged as a low resistivity layer above the resistive crystalline basement. Four basement conductors were defined, and correlate with the terrane boundaries delineated with aeromagnetic data. These are (1) a major conductor in the Kiskatinaw domain, (2) a conductor on the boundary of the Ksituan and Chinchaga domains, (3) a conductor on the boundary of the Chinchaga and Buffalo Head domains and (4) a conductor near the Hay River Fault. Both (1) and (2) correspond to areas of high seismic reflectivity. The low resistivity can be explained by interconnected grain boundary graphite or sulfide phases deposited by metamorphic fluid migration. The HRF was not definitively located in previous studies. The new data show that the HRF could be thin (1 km) or wide (10 km) and located at the boundary of the contrasting aeromagnetic anomalies or further to the north. Various tectonic processes are proposed to interpret the possible locations of the HRF. No electrical anisotropy structure is required to interpret the MT data in this study.

Key words: magnetotelluric; Great Slave Lake shear zone; tectonic history; Laurentia; crustal structure.
1. Introduction

The modern North American craton known as Laurentia has been assembled over the course of more than two billion years of Earth history and produced the crustal structure present today (Hoffman, 1989). Despite many studies (Chacko et al. 2000; Ross 2002; Ootes et al. 2015), there are still many aspects of the crustal structure which are not well defined and which need to be verified by multi-disciplinary methods. It is important to learn more about the crustal structure because (1) it allows us to understand if past tectonic processes were similar to those in operation today and (2) knowledge of the crustal structure and history is useful in understanding the present-day distribution of resources.

In this paper, the crustal structure and tectonic history of the Precambrian basement of northwest Alberta is investigated using an electromagnetic geophysical method called magnetotellurics (MT). The Alberta basement is located within Western Laurentia, the Precambrian core of the North America continent. It was assembled in the Paleoproterozoic by both convergent and strike-slip plate motions. The major strike-slip features are the Hay River Fault (HRF; Fig. 1) and the Great Slave Lake shear zone (GSLSZ).

A number of major questions remain unresolved regarding the structure of this area, including (a) nature of deformation on the HRF and GSLSZ and (b) the polarity of subduction or underthrusting that led to terrane assembly. A better understanding of the basement structure is also important for a complete understanding of the development of the Western Canada Sedimentary Basin (WCSB; Ross 2002; Pană 2003). Furthermore, since the study area has the highest heat flow in Alberta, it is important to understand the crustal structure to determine how the
geothermal energy potential of the area might be utilized (Majorowicz et al. 2014; Nieuwenhuis et al. 2015).

The study area is covered by sedimentary rocks of the WCSB (Wright et al. 1994), which means that geological studies of the basement rocks are limited to drill core samples. Geophysical exploration can also be used to understand the subsurface structure. While seismic exploration is one of the most widely used geophysical techniques, electromagnetic (EM) methods can also be used and produce images of electrical resistivity of the subsurface (Unsworth and Rondenay 2012). Magnetotellurics (MT) is the most suitable EM technique for studies of crustal and upper mantle structure because it is capable of deep exploration by using naturally occurring electromagnetic signals. Furthermore, MT is sensitive to the presence of low resistivity bodies which makes it a very useful tool to study both present day and ancient plate boundaries such as subduction zones and shear zones (Jones 1993; Unsworth and Bedrosian 2004).

Previous MT studies of the study area detected several low resistivity bodies in the crust and a mid-crustal layer that was inferred to be electrically anisotropic (Boerner et al. 2000; Turkoglu et al. 2009; Yin et al. 2014). However, the existing MT data have some limitations. Firstly, the large station spacing (10-20 km) limits the horizontal resolution. In other words, the lateral boundaries of anomalies could have uncertainties on the same scale as the station spacing. Secondly, the lack of high frequency data (0.2-1000 Hz) means the near surface structure cannot be well resolved (upper 4 km in the study region, see details in Supplementary materials S1). This could further introduce ambiguity in the deeper resistivity structure. Lastly, more data are needed to better constrain the anisotropic inversion results of Yin et al. (2014). Together these factors mean that the resistivity structure of the basement rocks in the study area is poorly defined. Unresolved questions include the geometry of terrane boundaries and their depth extent.
To better address these questions about the crustal structure of NW Alberta, additional broadband MT data were collected in 2014 at 35 stations with 3-5 km spacing along a 100 km profile in NW Alberta (Fig. 1). The profile was chosen to provide a location where a geophysical transect could be made with road-based logistics. In this paper, the new broadband MT data are described and the inversion results are presented and interpreted.

2. Geological setting of study area

The Precambrian basement rocks in the area (Fig. 1) are part of Laurentia and were assembled in the early Proterozoic (Hoffman, 1989). During the assembly of Laurentia, a number of small Archean crustal elements collided and were sutured together. At the same time, a set of Early Proterozoic orogenic belts and magmatic arcs were formed. A number of major basement terranes are found in the study area and are truncated by the Hay River Fault (Villeneuve et al. 1993).

2.1 Hottah terrane

The Hottah terrane, which is a major component of the Wopmay Orogen, is older than 1.9 Ga but was largely overprinted by 1.89-1.85 Ga Great Bear magmatism (Ootes et al. 2015). Several models have been proposed for the evolution of the Hottah terrane: (a) an exotic microcontinent (Bowring and Grotzinger 1992), (b) an arc within the Slave craton (Reichenbach 1991), and (c) a rift-related terrane which formed to the south and was brought to its present location by dextral strike-slip faulting (Ootes et al. 2015).

2.2 Hay River Fault
The HRF is a major crustal-scale, right-lateral strike-slip fault that defines the boundary between the Hottah terrane and the Nova terrane. The HRF is continuous with the Great Slave Lake shear zone (GSLSZ). Together, these two deformation zones can be traced from the foothills of the Rocky Mountains to the Thelon Basin, giving a total length of 1300 km. They accommodate 300-700 km of horizontal offset between the coeval Thelon and Taltson zones (Hoffman 1987). The HRF and the GSLSZ were once considered to be a single fault system. However, the HRF is now known to be younger (ca. 1.84-1.75 Ga) than the GSLSZ (ca. 1.97-1.92 Ga; Plint and Ross 1993; Ootes, et al. 2015). Nevertheless, the HRF can be related to a brittle stage of deformation on the GSLSZ, which is also referred to as the McDonald Fault.

2.3 Terranes to the south of the Hay River Fault

The Nova terrane was once interpreted to be a crustal sliver of the Archean Slave craton (Ross et al. 1990). However, samples from the eastern Nova terrane yielded ages of 1.8 and 1.7-1.9 Ga, (Simandl and Davis 2005) and thus the Nova terrane is probably Proterozoic in age.

The Ksituan terrane is a magmatic arc of 1.98-1.90 Ga age. Similar ages were identified on samples from both the Kiskatinaw and Ksituan terranes. The Kiskatinaw terrane was interpreted as a deformed portion of the Ksituan magmatic arc (Villeneuve et al. 1993).

The Buffalo Head terrane is a complex magmatic belt with metaplutonic and subordinate felsic metavolcanic rocks dated 2.0-2.32 Ga, whereas the Chinchaga domain comprises metaplutonic and metasedimentary gneisses dated 2.09-2.18 Ga (Plint and Ross 1993).

3. Previous geophysical studies of the study area
Geophysical studies in the study area are limited to aeromagnetic, gravity, geothermic, and MT with limited spatial coverage (Boerner et al. 2000; Pilkington et al. 2000). About 400 km to the southwest, seismic refraction and reflection profiles crossed the same terranes found in the study area (Zelt et al. 1989; Ross and Eaton 2002).

3.1 Potential field data

The basement domains in Alberta have been largely defined from potential field data in combination with dating of drill core samples using U-Pb isotopic analyses of zircon and monazite (Fig. 2; Ross et al. 1990; Villeneuve et al. 1993; Pilkington et al. 2000). The aeromagnetic anomaly data were used extensively to define the domain boundaries, while the gravity data played a minor role. This was because some crustal blocks with dramatically different age are not associated with contrasts in the gravity data. The geochronology results were also used to confirm the division into domains (Villeneuve et al. 1993).

Gravity data available include isostatic anomaly data, Bouguer anomaly data and horizontal gravity gradient, and some of these are shown in Figure 2. The Bouguer anomaly data in Figure 2c shows long wavelength, regional trends and the details associated with crustal structures are relatively small (Villeneuve et al. 1993). The isostatic anomalies enhance the signals caused by crustal structures (Cook et al. 2005). However, they are very similar to the Bouguer anomalies in NW Alberta and are not plotted in Figure 2. The horizontal gravity gradient data suppress the long wavelength anomalies and emphasize density anomalies originating in the upper crust (Figure 2d). A high horizontal gradient is associated with the juxtaposition of crustal bodies of contrasting density or thickness. It can be seen that the whole MT profile is located in a region with low Bouguer anomaly (ca. -70 milligals). There are strong gravity horizontal gradients to
the north and west of the profile, and moderate gravity gradients (0.3-1 milligals/km) in the region where the profile is located. There is limited correlation between the geologic terranes and the gravity anomalies in the study area. This implies that there are no major density changes along the profile in the upper crust.

In contrast, the total magnetic residual field is closely related to the terrane boundaries in the study area (Fig.2). The amplitude of the magnetic anomalies is primarily controlled by the mineral assemblage of the rocks. Magnetite has the highest magnetic susceptibility of minerals commonly found in crustal rocks and is primarily responsible for the high amplitude magnetic anomalies. Detailed description about the magnetic anomalies in the study area is discussed below.

(1) The Hottah terrane is weakly magnetic and characterized by paramagnetic sources originating in low-susceptibility silicate minerals (Pilkington et al. 2000). (2) The Buffalo Head terrane is characterized by sinuous aeromagnetic patterns and discrete subdomains. (3) The Chinchaga domain is a pronounced magnetic low. (4) The Ksituan terrane has a strong, positive aeromagnetic signature which is typical of calc-alkaline magmatic belts. (5) To the west of the Ksituan terrane are the Kiskatinaw magnetic low with a negative aeromagnetic anomaly and (6) the Nova Domain with a positive aeromagnetic anomaly (Ross et al. 1990; Villeneuve et al. 1993).

The HRF was identified from the sharp juxtaposition of aeromagnetic domains with distinct characteristics. In contrast to the sharp magnetic character of the HRF, the GSLSZ is characterized by striated positive and negative anomalies (Pană 2002). The width of the northeastern outcrop of the GSLSZ in the Canadian Shield was mapped geologically to be about
25 km (Hanmer et al. 1992). The width of the HRF is difficult to estimate from the aeromagnetic map only. If the HRF is an aeromagnetic high, it cannot be distinguished from the Nova terrane to the south; if it is an aeromagnetic low, it cannot be distinguished from the Hottah terrane to the north.

3.2 Seismic studies

No crustal-scale seismic data are available in the study area to date. Teleseismic tomographic models have limited resolution above the Moho (Schaeffer and Lebedev, 2014; Chen et al., 2017). The seismic receiver function analysis of Gu et al., (2011) and the seismic reflection study of Bouzidi et al., (2002) only covered the southern end of the terranes found in the study area. The Moho depth defined by these studies was approximately 38 km. The closest crustal studies are the seismic refraction and reflection surveys in the Peace River Arch region (Fig. 1; Zelt et al. 1989; Ross and Eaton 2002).

Lines 11 and 12 of the Peace River Arch Industry Seismic Experiment (PRAISE) were collected in 1994 and cross the same terranes as the MT profile in this paper (Fig. 3; Ross and Eaton 2002). East-dipping reflections were observed in the Kiskatinaw terrane and can be traced from a depth of 10 km to the Moho at a depth of 40 km with an average dip of 25° (Ross and Eaton 2002). In contrast, the Ksituan terrane was only marginally reflective. In the western Ksituan domain, reflections are truncated against the dipping structures in the Kiskatinaw terrane (Ross and Eaton, 2002). The boundary of the Ksituan and Kiskatinaw terranes was defined by this cut-off relationship. At the eastern boundary of the Ksituan domain, an east-dipping reflection fabric can be traced from the top of the basement to the Moho. This dipping reflection appears to flatten out or intersect with more gently dipping reflections in the lower crust (Ross and Eaton 2002). In the
Chinchaga domain, there are west-dipping reflections in the upper crust, which are cut off by east-dipping reflections at the eastern edge of the Ksituan domain. The middle crust of the Chinchaga domain features east-dipping reflections (Ross and Eaton, 2002) and sub-horizontal reflections are observed in the lower crust of the Chinchaga domain. There is no obvious change in the character of seismic reflections between the Chinchaga and Buffalo Head domains (Ross and Eaton 2002).

The Peace River Arch region was also studied by Zelt et al. (1989) using seismic refraction data in the PRASE (Peace River Arch Seismic Experiment) project. Line B of Zelt et al. (1989) crossed the same terranes as in the present paper (Fig. 1). They observed that (a) there was a higher velocity in the basement 50-90 km away from shot B1. This anomalously high velocity zone is approximately located in the Kiskatinaw terrane (Fig. 1). (b) It was not possible to pick intracrustal reflections for shot B2. This was interpreted to be the result of a reflective zone at the sediment-basement boundary. Note that the shot B2 was located at the boundary of the Ksituan and Chinchaga terranes (Fig. 1). (c) The PmP (P-wave reflection from the Moho) character was diffuse for the shot B1 (located in the Nova terrane), whereas it appeared sharp for shot B3 and it is intermediate for the shot B2. This was proposed to be the product of a disturbed or transitional crust-mantle boundary at the west end of profile B whereas a sharp crust-mantle boundary occurs at the east end of the profile B (Zelt et al. 1989).

To sum up both seismic results, (a) the Kiskatinaw terrane is highly reflective and shows higher velocity in the crust than the Ksituan terrane. (b) At the boundary of the Ksituan and Chinchaga terranes, there is a highly reflective zone at the sedimentary basin-basement boundary. (c) The Moho boundary is disturbed near the Kiskatinaw terrane because of the reflective features in the Kiskatinaw terrane.
3.3 Electromagnetic studies

The first extensive MT study of the Alberta basement rocks was made during the Alberta Basement Transect (ABT) of the Lithoprobe project (Boerner et al. 2000) when 320 long-period MT stations were recorded and these included ten of the long-period MT stations used in this study. A major low-resistivity anomaly was identified along the trend of the Kiskatinaw magnetic low and called the Kiskatinaw conductor (KC; Boerner et al. 2000).

The ABT data in northwestern Alberta were further analyzed by Turkoglu et al. (2009) who applied 3-D inversions to the data. The resulting 3-D inversion model imaged the KC which was found to follow the Kiskatinaw domain and dipped to the southeast. The KC was largest and dipped to the southeast at 20° on the ‘L’ profile (Fig. 1). The KC was smaller and appeared as a vertical feature on the ‘C’ profile (Fig. 1). On the profile ‘A’ which overlaps the profile in this study, the KC was not clearly imaged. Another conductor was found at the boundary between the Chinchaga and Ksituan domains but was deeper and more resistive than the KC by Turkoglu et al. (2009). The shallow electrical structure was not clearly imaged in the 3-D inversion model, due to the lack of high frequency MT data.

The ABT long-period data were supplemented with long-period MT stations collected as part of the GEM (Geo-Mapping for Energy and Minerals) project and published by Yin et al. (2014). An east dipping anisotropic layer was found in the 2-D anisotropic inversion models. However, the resolution of the inversion models was not sufficient to locate the exact boundaries of the major conductors.
In conclusion, these prior MT studies have defined the general resistivity structure of the crust and upper mantle in the study area. However, new MT data, with closer station spacing, could resolve the crustal electrical structure in more detail than the previous data set.

3.4 Geothermics

The heat flow and the geothermal gradient near Rainbow Lake (RLK) and High Level (HL) are >76 mW/m² and 40-50 °C/km, respectively (Weides et al. 2014), which represent the highest values in Alberta. A temperature of almost 200°C was inferred at a depth of 5 km around Rainbow Lake (Majorowicz et al. 2014). Nieuwenhuis et al. (2015) predicted the highest temperatures at depths of 1.5 and 2.0 km in Alberta (Fig. 4; over 70 °C and over 90 °C, respectively). These depth ranges are within the low permeability Precambrian basement rocks. Therefore, an Engineered Geothermal System (EGS) was suggested to utilize this heat (Majorowicz et al. 2014).

4. Magnetotelluric exploration in northwest Alberta

4.1 Brief introduction to the MT method

The magnetotelluric (MT) method is a geophysical technique that uses naturally occurring electromagnetic (EM) signals to determine the subsurface resistivity structure. The penetration depth of these signals is defined by the skin depth equation. For a homogenous earth with resistivity $\rho$, the skin depth can be expressed as:

$$\delta(f) = \sqrt{\frac{\rho}{\pi f \mu}}$$

where, $f$ is the frequency, $\mu$ is the magnetic the permeability, and generally taken to be the free space value ($4\pi \times 10^{-7}$ H/m). Because of the wide range of frequencies present in the natural
electromagnetic signal, the MT method is the only electromagnetic exploration technique that can provide resistivity information of the subsurface as deep as 400 km (Chave and Jones 2012).

4.2 MT data used

To overcome the limitations of the previously collected data, a profile of 35 broadband MT stations was collected with Phoenix MTU/MTU-A instruments in 2014 extending from Rainbow Lake to High Level (Fig. 1). Two orthogonal electric field and three magnetic field components were measured as a function of time at each station. The locations of the stations were selected to be away from the highway and other sources of cultural noise. Details about how the new MT data improved the electrical resistivity model in the study area are included in the Supplementary Material (S1).

4.3 Data processing, characterization and dimensionality analysis

The broadband MT data were processed to give estimates of the impedance tensor and magnetic field transfer functions in the frequency range of 1000-0.001 Hz. Details about data processing and some typical data are presented in the Supplementary Material (S2).

Dimensionality analysis such as phase tensor plots, skew angles, strike analysis and induction vectors plots were applied to the MT data (details in the Supplementary Material - S3). Phase tensor analysis shows that the electrical structure is approximately 1-D at high frequency (near the surface) and 2-D at the intermediate frequency band (0.3-0.03 Hz) corresponding to greater depth. At low frequencies, high skew angles in the western part of the profile indicate 3-D or 2-D anisotropic electrical resistivity structure. The induction vectors show that the deep resistivity structure below the sedimentary layers is not 2-D. This is in contrast with the phase tensor analyses, which showed that the structure is 1-D/2-D except the lowest frequencies. This is
probably because the induction vectors are sensitive to low resistivity bodies and current flow, whereas, they are less representative of the depth of the anomaly (Chave and Jones 2012). Therefore, 3-D low resistivity anomalies off the profile and anomalies deeper than the resolution of the MT data could contribute to the non-2-D behavior of the induction vectors. However, it should be noted that the induction vectors still contain the information about the local subsurface structure.

Strike analysis was done using the multi-site, multi-frequency distortion decomposition code of McNeice and Jones (2001; details in the Supplementary Material - S3). The most appropriate 2-D geoelectric strike direction found for all the data was N40°E. Therefore, all the MT data were rotated to a geoelectric coordinate system with geoelectric strike direction (N40°E) for further analysis.

4.4 Anisotropy

Electrical anisotropy means that the resistivity of the subsurface is directionally dependent. An anisotropic structure in the crust can be present if there is a preferred orientation of fluids, sulfide minerals or fractures (Wannamaker 2005, Liddell et al. 2016). An anisotropic dipping conductor was inferred to be present by Yin et al. (2014) in the depth range of 10-20 km. With the new MT stations, the anisotropy of this region can be rigorously reevaluated.

The dimensionality analysis in the Supplementary Material (S3) gives information that can determine if the resistivity structure is anisotropic or isotropic. The large phase splits, large skew angle values, complex patterns of induction vectors in the MT data are indicative of anisotropic structure. However, it can be difficult to distinguish a 2-D anisotropic structure from 3-D heterogeneities in an isotropic structure (Heise and Pous 2001). Details about the
characterization of the effects of anisotropy structure on the MT data are presented in the Supplementary Material (S4).

5. Inversion of the MT data

From the dimensionality analysis, the subsurface resistivity structure appears to be generally 2-D. Therefore, 2-D inversions were used to invert the data and produce resistivity models. Anisotropic resistivity structure was suggested by Yin et al. (2014) and is also believed to exist in other ancient shear zones (Weckmann et al. 2003). Therefore, 2-D anisotropic inversions were also applied to the new MT data to check if electrical anisotropy is present. Because the data at low frequencies (0.03-0.003 Hz) on our profile show some 3-D features, a 3-D inversion could be useful to image deeper structure.

5.1 2-D isotropic inversions

A profile was constructed perpendicular to the strike direction (N40˚E). Three stations (RLK025, RLK035, and RLK065) were excluded because of poor MT data quality, giving a total of 32 MT stations. In the geoelectric coordinate frame, the TE (transverse electric) mode is associated with the electric currents flowing in the strike direction while the TM (transverse magnetic) mode represents the electric currents flowing perpendicular to the strike direction. The data pseudo sections are shown in Fig. S3 in the Supplementary Material.

The NLCG inversion scheme of Rodi and Mackie (2001) was used for both the isotropic and anisotropic inversions. The mesh used in isotropic inversions has 122 vertical and 114 horizontal cells, giving a width of 480 km and a depth of 580 km for the total mesh area. The upper most row of cells had a vertical thickness of 16 meters, and the thickness increased geometrically with depth. The inversion started from a homogenous half space with a resistivity of 100 Ωm. For
each inversion, 200 iterations were done to ensure the inversion had converged. A total of 55
frequencies from 300-0.0013 Hz were used in all inversions.

The first inversions investigated single modes (TE/TM/tipper only inversions) until the final
r.m.s. misfit was lower than 2 and the data were considered to be well edited. Inversions of
combinations of different modes were then undertaken. The final inversion model is the result of
joint TE, TM and tipper inversion. Many inversions with different error floors were run as a test
to determine the optimum values for the error floors. For the inversion models presented here,
the error floors for apparent resistivity and phase were set to 10% and 5%, respectively, for both
the TE and TM modes. The error floor for the tipper was set as an absolute value of 0.04. A set
of values were tested on the smoothness parameter $\tau$ varying from 0.01 – 100 for 2-D isotropic
inversions. The model roughness and data fitting were plotted against each other (L-curve), in
order to find the best tradeoff. According to the L-curve, the tau selected for the final inversion
model was 3 for both the isotropic and anisotropic inversions. Additionally, the inversion was
allowed to estimate static shift coefficients at just two stations (RLK150, RLK190) at the east
end of the profile because they showed some distortion in the dimensionality analysis. However,
there was no obvious change in the inversion model or r.m.s. misfit, so the final inversion did not
consider static shift correction.

5.2 2-D isotropic inversion results

The preferred 2-D isotropic inversion model is shown in Fig. 5. It is evident that the shallow
structure is better constrained with the addition of extra stations and high frequency data. The
WCSB can be clearly seen and dipping gently to the west. The resolution of the major resistivity
anomalies is better because of denser model mesh and closer stations. A final r.m.s. misfit of 2.3
is achieved in the preferred model. The comparison of the model response and the measured data
are shown in pseudo-section format in Fig. S3 in the Supplementary Material.

In the inversion model, several significant resistivity features can be observed. Firstly, the
sedimentary layer near the surface is clearly imaged as a low resistivity layer (3-30 Ωm) that is
continuous along the profile. One feature to note is the more resistive region (about 30 Ωm)
between stations RLK085 and RLK100 in the 0-2 km depth range. Sedimentary rocks in this
region are older than in other parts of the profile (Prior et al. 2013), making this observation
consistent with the fact that older sedimentary rocks often have higher resistivity than younger
sedimentary rocks (Haak and Hutton 1986) because of the reduction of porosity and clay content.

Secondly, the basement is generally imaged with resistivity greater than 3000 Ωm (e.g. Nova
Resistor (NR) and Ksituan Resistor (KSR)), which is reasonable for old crystalline rocks. Finally,
there are four distinct conductors in the basement with very low resistivity. The four conductors
are described below in detail.

(1) Kiskatinaw conductor (KC): This is imaged from a depth of 10 km and extends to the
Moho at a depth of 38 km (Gu et al. 2011). The KC dips steeply to the southeast with a very low
resistivity (<1 Ωm) from 10-20 km. There is a less conductive tail (30-100 Ωm) from 20-40 km.
The penetration depths of MT signal are 10 km and 140 km using a resistivity of 1 Ωm and 100
Ωm and the lowest frequency – 0.0013 Hz. Therefore, the magnetotelluric signal may not
penetrate through the KC and the deeper tail could be an inversion artifact. Moreover, it should
be noted that while the MT method can define the upper boundary of a conductor very well, the
lower boundary can be poorly resolved. Only the conductance – the product of the conductivity
and the thickness of the conductor is well resolved. This is further discussed in sensitivity tests and synthetic modeling and inversions in the Supplementary Material (S5 and S1, respectively).

(2) Ksituan-Chinchaga conductor (KCC): This is located at the boundary of the Ksituan domain and Chinchaga domains. The KCC extends from the top of the basement at about 2 km to a depth of 18 km with a 45° dip to the southeast. Furthermore, there are two distinct smaller conductors in the KCC with resistivity <1 Ωm compared with the surrounding 3-10 Ωm resistivity. However, it is not clear if these features are resolved because the electromagnetic signals used in MT method are diffusive and are not sensitive to small structures. The resolution of this conductor is investigated by sensitivity tests and synthetic modeling and inversions in the Supplementary Material (S5 and S1, respectively).

(3) Hottah conductor (HC): The HC is under the Hottah terrane near the HRF, with resistivity <1 Ωm and depth of approximately 10 km.

(4) Chinchaga-Buffalo Head conductor (CBHC): The CBHC is a small conductor with resistivity <1 Ωm at the boundary of Chinchaga and Buffalo Head terranes. The top of the CBHC is just below the sedimentary layer (2 km) with a lower boundary at about 5 km depth.

5.3 2-D anisotropic inversions

Two-dimensional anisotropic inversions were also applied to the data. The Supplementary Material (S6) gives details and results of the 2-D anisotropic inversions. It was found that (a) a slightly lower r.m.s. misfit (about 2.1-2.2) could be achieved with the anisotropic inversions, compared to the isotropic inversion (about 2.3), (b) the r.m.s. misfit and the anisotropic inversion models do not change too much with the change of the anisotropic tau, and (c) the anisotropic inversion models are quite similar for three directions. These all may indicate that the electrical resistivity model does not need to be anisotropic to give an acceptable fit to the measured MT
data. Therefore, it is concluded that the subsurface structure can, to a first approximation, be treated as electrically isotropic even though some anisotropy may be present. The large distortion of phase tensors, high skew angles and complex patterns of induction vectors observed in the MT data could be explained by along strike variations or 3-D effects instead. Details about this discussion are in the Supplementary Material (S6).

6. Interpretation and discussion

It has been proposed that the crustal blocks in the area have been assembled by subduction processes, although the locations and geometry were poorly defined. Past subduction can produce major conductors that remain to the present day (Jones, 1993). In the following sections, the four conductors will be interpreted with regards to their location and cause of the low resistivity to determine the nature of these past tectonic events.

6.1 The Kiskatinaw conductor (KC)

The Kiskatinaw conductor (KC) was first described by Boerner et al. (2000) based on 2-D inversions of the Lithoprobe MT data. Turkoglu et al. (2009) presented 3-D inversion models which showed that the KC is a crustal-scale conductor following the surface trend of the Kiskatinaw terrane, with a dip and size that vary along strike.

The structure of the KC defined with MT can be compared to other geophysical studies. (a) The geometry of the KC in the 2-D inversion model is comparable to that obtained with the seismic reflection by Ross and Eaton (2002; Fig. 6) who found that the crust of the Kiskatinaw terrane was highly reflective from 10 km depth to the Moho with east dipping features. (b) Seismic refraction showed that the Kiskatinaw terrane was characterized by higher velocities than neighbouring terranes and characterized by a disturbed Moho (Zelt et al. 1989). (c) The
resistivity model shows that the Kiskatinaw terrane is much less resistive than the Ksituan terrane and the KC starts from a depth of 10 km, which is same as the top of the enhanced seismic reflectivity. The bottom of a low resistivity anomaly is hard to define with MT data, so it is inappropriate to compare the base of the KC to the seismic result. (d) Lastly, the Kiskatinaw terrane is an aeromagnetic low while the Ksituan terrane is an aeromagnetic high. (e) A moderate Bouguer gravity high is associated with the Kiskatinaw and Ksituan terranes in the study area.

Along strike variation of the geometry of the KC may explain the difference between the MT and seismic results: the shallow part of the KC in the 2-D inversion model does not show the 25° dip angle observed in the seismic reflection data. The seismic profile crosses the southernmost part (at about 56˚N) of the Kiskatinaw terrane while the MT profile presented in this paper crossed the northernmost part (at about 58.5˚N; Fig. 1). These two profiles are located about 400 km apart. Furthermore, the MT profiles studied by Turkoglu et al. (2009) could link results of this study and the seismic study. The KC on profile ‘L’ shows a 20° dip which is close to the seismic result (25°). The ‘C’ profile from Turkoglu et al. (2009) imaged the KC, but it was weaker than in the profile ‘L’ and vertical. The KC was not imaged by Turkoglu et al. (2009) on profile ‘A’ at the expected shallow depth. However, a low resistivity anomaly was imaged in the depth slice at 41 km. This may be due to lack of high-frequency data and wide spacing between MT stations in the previous study. Consequently, the KC on the profile ‘A’ was imaged deeper than the actual location of the KC. Alternatively, another explanation is that the KC actually ends west of the profile ‘A’ and the KC imaged in this paper is a regional effect from the KC. In this case, the northern end of the KC should be less than 10 km from the profile, according to the skin depth equation.
Considering all results from these three studies, it can be concluded that the cross-sectional area of the KC is greatest at the southern end and decreases to the north i.e. the conductance of the KC decreases from the south to the north, and the dip of the KC changes from 25° in the south to vertical in the central and northern parts.

What is the cause of the low resistivity (1-3 ohm-m) of the KC? Possible explanations include fluid, partial melt, graphite, and sulfide minerals. Additional geological or geophysical information is needed to differentiate between the possibilities, which are considered below:

(a) Partial melt could not be the explanation for the low resistivity because the temperature of the crystalline rocks is far too low (300 °C at 10 km depth, Majorowicz et al. 2014).

(b) Aqueous fluids containing dissolved salts can produce a low resistivity and have been proposed as an explanation for crustal conductors observed in the stable continental crust (Wannamaker 2000). In this scenario, Archie’s Law can be used to relate the low resistivity with rock porosity, fluid resistivity and interconnection of the pores quantitatively (Archie 1942; Supplementary Material - S7).

Experimental results from Sinmyo and Keppler (2017) suggested that the resistivity of crustal fluids may be as low as 0.03 Ωm. To explain the observed resistivity of the KC (1 Ωm), and assuming the rock is fully saturated with a saline fluid of 0.03 Ωm resistivity, 3% and 17% porosity is required according to Archie’s Law using cementation exponents of 1 and 2, respectively. This porosity range is high, which means it is unreasonable to explain the low resistivity of the KC by saline fluids alone. Another problem with this explanation is that even though water may have been present when the KC was formed, water is not likely to have been
retained for almost 2 billion years without a source or a sealing mechanism to retain the water
(Frost and Bucher 1994).

(c) Graphite films could also explain the low resistivity of the KC, and were suggested as the
cause of the low resistivity of the North American Central Plains anomaly in the
Paleoproterozoic Trans-Hudson Orogen (Jones et al. 1997). Boerner et al. (2000) interpreted the
low resistivity of the KC to be associated with the concentration of carbonaceous material within
euxinic basins that transformed into graphite. The carbon from the euxinic basins could be
deposited as interconnected graphite by metamorphic processes. Another possible source of the
carbon could be carbon-bearing metamorphic fluids. If this low resistivity is because of grain
boundary graphite, and assuming that the pure graphite resistivity is 0.0001 $\Omega$ m, a volume
fraction of 1% of well-connected graphite is needed to explain the 1 $\Omega$ m anomalies observed,
according to Archie’s Law (Archie 1942).

(d) It has also been suggested that the precipitation of sulfide minerals can be another way to
lower the resistivity of the KC (Boerner et al. 2000). Sulfide minerals could precipitate during
metamorphism, migrate with fluids and become disseminated within the rocks. The sources of
sulfides could be subducted sediments or sulfur-bearing metamorphic fluids. It was shown that 3-
7% of disseminated sulfide minerals could lower the bulk resistivity of rocks to 20-70 $\Omega$ m
(Nelson and Van Voorhis, 1983). However, this value is higher than the resistivity of the KC and
disseminated sulfide minerals alone cannot explain the low resistivity of the KC. Alternatively,
sulfide minerals can be concentrated in the rocks to give lower resistivity values of 3-8 $\Omega$ m
(Jones et al. 1997).
In summary, graphite and sulfide minerals are preferred explanation for the low resistivity of the KC. They could originate from metamorphic fluids or subducted sediments and transformed to conductive form during metamorphism and associated shear-related deformation.

6.2 The Ksituan-Chinchaga conductor (KCC)

The second major conductor is the Ksituan-Chinchaga conductor (KCC), which could be related to the conductor recognized by Turkoglu et al. (2009). However the conductors imaged in this study and by Turkoglu et al., (2009) are located at different depths (2-18 km and 40-65 km, respectively). There are two solutions here: it is the same conductor, but imaged with different depth and conductance. The greater depth inferred by Turkoglu et al. (2009) could be the result of the lack of high frequency MT data. As mentioned above, only the conductance of a low resistivity body can be resolved with MT. The high conductance as a result of the KCC anomaly is represented as the shallow feature in this study while as a deeper feature in the model of Turkoglu et al. (2009). Alternatively, the KCC in the present paper is distinct from the conductor imaged by Turkoglu et al. (2009). However, in this case there should be another low resistive body at depth of around 40 km. The absence of a deeper conductor favors the first explanation i.e. both studies have imaged the same conductivity anomaly. Furthermore, the KCC was imaged to be continuous along the boundary of the Ksituan and Chinchaga terranes from the north to the south in the 3-D inversion model of Turkoglu et al. (2009).

The KCC can be correlated with the seismic reflective features at the boundary of the Ksituan and Chinchaga domains (Ross and Eaton 2002). The reflective feature was also identified in the seismic refraction survey (Zelt et al. 1989). The KCC detected in this study shows the dip angle (45°) and the depth range (2-18 km) that are consistent with the seismic results. Moreover, the
KCC correlates with the boundary of the Ksituan (high) and Chinchaga (low) domain in the aeromagnetic data. However, because of its large width, it is hard to determine which side of the KCC corresponds to the boundary between the Ksituan and Chinchaga terranes.

The possible causes of low resistivity in the KCC are similar to those in the KC. Partial melt is an unlikely explanation. Is saline fluid possible explanation? Frost and Bucher (1994) concluded that in stable cratons, water could be gravitationally driven and migrate to the upper 10 km of the crust. The KCC is imaged with an upper boundary just below the sedimentary basin at 2 km depth and with a lower boundary at about 16 km. Additionally, it was suggested that at this location, the Ksituan and Chinchaga domains have a thrust fault contact (Ross and Eaton 2002), which could represent a pathway for groundwater flow. Therefore, the low resistivity can be the result of saline fluid trapped in the fractures of the fault. As for the KC, a porosity of 3-17% of porosity is needed to explain the 1 Ωm resistivity of the KCC. However, the porosity range seems too high for crystalline rocks at 10 km depth, and another source of low resistivity is required. As discussed for the KC, graphite and sulfide minerals can be deposited with interconnection during metamorphic events. A volume fraction of a few percent of these conducting phases could lower the resistivity effectively. The low resistivity in the KCC may be caused by the combination of saline fluid, graphite and sulfide minerals.

6.3 The Hay River Fault (HRF) and the Hottah conductor (HC)

The Hay River Fault was originally identified from the boundary between contrasting aeromagnetic signatures in the Hottah and Nova terranes, although the exact location of the HRF is still somewhat uncertain. Is it possible that the fault zone itself has a magnetic anomaly? Villeneuve et al. (1993) proposed that shear zones could be magnetic lows since demagnetization
could occur as a result of hydration and dynamic metamorphism such as occurred in the GSLSZ
(Villeneuve et al. 1993) and the Kiskatinaw terrane (Ross and Eaton 2002). Shear deformation
probably occurred at the HRF and if it was accompanied by fluid alteration and conversion of
magnetite to hematite (Frost et al. 1989), the HRF should be a negative aeromagnetic anomaly.
In this scenario, the location of the HRF is difficult to distinguish from the Hottah terrane to the
north with aeromagnetic data. Even if no demagnetization occurred as the HRF moved and it is a
positive aeromagnetic anomaly, the location of the HRF is still hard to distinguish from the Nova
terrane to the south with aeromagnetic data. No other geophysical data have been able to locate
the HRF to date. Because the HRF is covered by Phanerozoic sedimentary rocks, geological
studies cannot assist in this task.

Can the resistivity structure be used to locate the HRF? The HC is located close to the HRF and
the HC is imaged within the negative aeromagnetic anomaly in the Hottah terrane. Unlike the
KC and KCC, this resistivity feature does not have an obvious eastward dip. Modern-day strike-
slip faults sometimes exhibit a low resistivity in the upper crust (0 -10 km), owing to a region of
elevated porosity saturated with aqueous fluids (Unsworth and Bedrosian 1999). However, a
zone of elevated porosity is unlikely to be present in ancient faults, as the fluid
supply/connection would likely have been lost after 1.8 Ga. If the fluid flow in an active fault
deposited graphite and/or sulfide minerals, then this could produce a low resistivity anomaly that
would persist to the present day.

Another possibility is if the upper crustal part of the HRF was eroded and the rocks of the HRF
currently exposed at the surface was formed in a mid-crustal environment. At such depths
deformation in strike-slip faults will be ductile owing to the higher temperatures and pressures.
While this can cause low resistivity when active, it will result in high resistivity when the shear
zone becomes inactive and cools down. The GSLSZ in the Canadian Northwest Territories is an example of this phenomenon. It is believed that the upper crustal portion of the GSLSZ was eroded and the presently exposed part of the GSLSZ was developed under ductile conditions (Eaton and Hope, 2003). Wu et al. (2002) demonstrated that the GSLSZ was resistive in a 2-D inversion model based on MT data.

Given this background, there are three possible explanations for the observed resistivity pattern across the HRF. (1) The location of the HRF could be 5 km further northwest of the boundary of the negative and positive aeromagnetic signatures and the HC actually defines this fault, with the low resistivity due to graphite and/or sulfide minerals. (2) The HC is not related to the HRF and the high resistivity anomaly (NR) is either the unaltered basement, or the consequence of ductile shear deformation, similar to that observed on the GSLSZ to the northeast. (3) The HRF could be the resistive-conductive boundary between the Hottah and Nova terranes. This could occur if the HC was an internal feature of the Hottah or the Nova terrane and deformation associated with the HRF occurred in a localized belt.

6.4 The Chinchaga-Buffalo-Head conductor (CBHC)

The Chinchaga-Buffalo-Head conductor (CBHC) is the smallest and shallowest conductor detected in the study area, and no seismic structure was found in this location. The CBHC is located just below the sedimentary basin which indicates that groundwater from the sedimentary basin could be penetrating the basement rocks and causing the low resistivity. Since this conductor is located on the boundary of two terranes, explanations due to conducting phases such as graphite and sulfide minerals are also possible, as was the case for the KC and KCC.

6.5 Tectonic implications
According to the seismic reflection data and geochronology studies, a tectonic model was proposed by Ross (2002) for the study area. It suggested that the Chinchaga and Buffalo Head domains collided early in the assembly (Ross 2002; Ross and Eaton 2002). This was followed by the westward subduction of the oceanic lithosphere between the Chinchaga and Nova domain which resulted in the formation of the Ksituan domain and Kiskatinaw domain as a magmatic arc during 1.90-1.98 Ga (Ross and Eaton 2002). It should be noted that the Kiskatinaw terrane was interpreted as a sheared equivalent of the Ksituan domain formed during the final stage of the collision between the Ksituan terrane and Nova terrane (Villeneuve et al. 1993; Ross and Eaton 2002).

The westward subduction direction was preferred because of the lack of coeval plutonic rocks within the Buffalo Head and Chinchaga domains. Ross and Eaton (2002) interpreted the apparent contradiction between the eastward dipping seismic reflections and the postulated westward subduction as a result of overprinting by a younger collision. This is possible and Van der Velden et al. (2005) argued that different vergence of the subduction zone and the crustal suture is relatively common and could be caused by lithospheric delamination.

Alternatively, geochemical and isotopic study of granitoids from the Taltson magmatic zone by Chacko et al. (2000) implied that eastward subduction occurred to the west of the Ksituan terrane, or perhaps even to the west of the Hottah terrane in the current coordinate system. This hypothesis is also consistent with the seismic reflection and the MT results. In this case, the suturing process has the same polarity as the subduction process.

The structure defined from the MT data generally correlates with the seismic reflection results. This study also compliments the aeromagnetic mapping by providing information about the
subsurface geometry of the terrane boundaries. The change of the gravity field in the study area is subtle and no obvious correlation between the gravity and resistivity anomalies is observed.

Combining the previous and new MT results, potential field data and the seismic reflection data, it is believed that there is a thrust fault between the Ksituan and Chinchaga domains from the top of the basement to a depth of about 18 km. This interpretation is consistent with (a) the cut-off reflections observed in the seismic reflection profile, (b) the reflective zone mapped in the seismic refraction profile, (c) the low resistive body imaged at the boundary of the Ksituan and Chinchaga terranes, (d) the contrasting aeromagnetic anomaly in the Ksituan (positive, high amplitude) and Chinchaga domain (negative, high amplitude) (e) No associated gravity anomaly is observed at the Ksituan-Chinchaga boundary which implies density and thickness of the basement rock are similar in the two terranes.

The properties of the Kiskatinaw domain can be explained if it is a shear-deformed part of the Ksituan domain, with faults on the eastern and western boundaries of the Kiskatinaw domain. This is consistent with geochronology results which show that the Ksituan and Kiskatinaw have the same age (1.98-1.90 Ga, Villeneuve et al 1993). Lithology studies also found that the rock samples from the Kiskatinaw terrane show foliated and gneissic features that indicate the Kiskatinaw terrane may be a deformed portion of the Ksituan terrane (Villeneuve et al 1993). It is speculated that the Kiskatinaw terrane and Ksituan terrane were the same unit before shear deformation of the Kiskatinaw terrane. As the terrane assembly progressed, the Kiskatinaw terrane was compressed by the Nova terrane and was sheared along the margin of the Ksituan domain. Possible demagnetization during the shearing process may have transformed the Kiskatinaw terrane from being a high amplitude magnetic high to a low amplitude magnetic feature. The seismic reflections at the mid-crustal depths and the high velocity observed could
also be a result of the deformation (i.e. compression and shearing). The low resistivity of the Kiskatinaw conductor can be explained by graphite or sulfide minerals formed through metamorphism. The short wavelength (ca. 20 km, trending N45°E; Fig. 2) Bouguer gravity high and gravity gradients observed along the Kiskatinaw and Ksituan terranes in the study area indicate lower density or thicker crustal rocks. Moreover, the Bouguer high does not appear to extend along strike. Therefore, the Bouguer high may be unrelated to the basement structure, but originated from the sedimentary layers.

Three different explanations were proposed for the structure and location of the HRF in the previous section. Constraints on the structure of the HRF were heavily dependent on the MT results because there is no seismic data in the study area.

Terrane accretion is believed to account for the assembly of the crust in the study area, even though it is impossible to decide which tectonic setting of the two discussed above is more reliable. The high correlation between the seismic reflection result and MT resistivity profile give indications about the terrane assembly process. (a) Although it is believed that the tectonic terranes in the study area have been attenuated to the northwest along the HRF, the major crustal features are preserved along strike in the process. (b) The strike-slip motion of the HRF occurred after the assembly of the tectonic terranes in northwest Alberta.

6.5 Geothermics

Studies of the fracture patterns in the Hay River fault zone could be a significant factor regarding the development of an EGS in this location (Majorowicz et al. 2014). Previous studies at EGS projects such as Soultz, France showed that (a) the movement of fluid between the two wells can be controlled by natural fracture structures and (b) it is possible that the fluid injected has been...
mixed with the natural brines (Genter et al. 2010). Moreover, (c) it was argued that while
naturally occurring fractures could provide natural porosity, they could also represent a pathway
for fluid loss or result in low heat transfer due to reduced contact between the fluid and the rocks
(Fritz and Gerard, 2010). A better understanding of the subsurface structure can be important to
evaluate these factors. The structural information listed in the tectonic implication section should
be considered when exploring the geothermal energy in the area.

7. Conclusions

This MT study advances our knowledge about the structures of the crust in northwest Alberta.
The sedimentary layer was imaged as a conductive feature on top of the resistive crystalline
basement and four conductors are identified in the basement. Even though anisotropy was
suggested by Yin et al. (2014), the present study suggests that electrical anisotropy is not
required to explain the data.

The main conductor imaged in the study region is the Kiskatinaw conductor (KC) and may be
traced as a continuous feature for over 400 km along the strike of the Kiskatinaw terrane. The
location of the KC is coincident with a seismically reflective and high-velocity zone (Zelt et al.
1989; Ross and Eaton 2002). The low resistivity of the KC may be the result of sulfide and
graphite phases which were deposited during metamorphic event. The Kiskatinaw terrane was
previously interpreted as a deformed and altered part of the Ksituan terrane (Ross and Eaton
2002) and this hypothesis is confirmed by this study. The second significant conductor is the
Ksituan-Chinchaga conductor (KCC) which is also coincident with a zone of seismic reflectivity
and the boundary of the Ksituan magnetic high and the Chinchaga magnetic low. The low
resistivity of the KCC is most likely due to a combination of saline fluid, graphite film and
sulfide minerals. The KCC may well be related to thrust movement at the boundary of the Ksituan and Chinchaga domains (Ross and Eaton, 2002). The Hottah conductor (HC) may be related to the Hay River Fault (HRF) if demagnetization occurred during shear deformation which transforms ferrimagnetic Fe-oxides into antiferromagnetic Fe-silicates (Villeneuve et al. 1993). In this scenario, graphite resulted from metamorphism could explain the low resistivity of the HC. If the HC is not related to the HRF, then the HRF could be associated with an aeromagnetic high anomaly and high resistivity. This could be explained by ductile deformation that resulted in the shear zone being depleted in volatiles after shearing, as is interpreted to have occurred in the GSLSZ (Wu et al. 2002). Another possibility is that very localized deformation occurred and the HRF behaves as an impermeable boundary between the HC and the adjacent crystalline rocks.

Aeromagnetic data can locate the terrane boundaries (Pilkington et al. 2000), and this MT study extends this analysis by imaging the geometry of these boundaries at depth. The resistivity anomalies imaged in this study generally correlate with terrane boundaries derived from aeromagnetic data.

The results complement previous studies of the tectonic evolution of the region by Ross and Eaton (2002) and Chacko et al. (2000). They both suggested that a combination of subduction and terrane accretion caused the amalgamation of the basement domains which is confirmed by this study.

Majorowicz et al. (2014) and Nieuwenhuis et al. (2015) suggested that an enhanced geothermal system (EGS) may be viable in the study area because of the high temperature at shallow depth.
The results of this study supplement information about the subsurface structure that can be used for the evaluation and future development of an EGS.

Acknowledgements

This research was financially supported by grants from NSERC and Helmholtz-Alberta Initiative (HAI). Field help from Benjamin Lee, Greg Nieuwenhuis, Juliane Huebert and Mitch Liddell is greatly appreciated. Reviews by Editor Ali Polat, Associate Editor Randy Enkin and two anonymous reviewers improved this paper. Proofreading from Darcy Cordell is appreciated. Three-dimensional MT inversions were run using computational resources from WestGrid (Compute Canada). Luke Ootes is acknowledged for sharing his geological database. Greg Nieuwenhuis is thanked for providing the temperature database of Alberta. We thank Alan Jones and Gary McNeice for providing their tensor decomposition program. Enci Wang thanks the financial support from China Scholarship Council (CSC).

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Fig. 1: Generalized tectonic map of northern Alberta and southern Northwest Territories (modified after Hoffman 1989; Villeneuve et al. 1993; Ross 2002; Ootes et al. 2015). B1, B2, B3 are shot points for seismic refraction line B (Zelt et al. 1989). Profiles A, C, and L are the MT profiles studied by Turkoglu et al. (2009).

AB, Alberta; BC, British Columbia; GSLSZ, Great Slave Lake shear zone; HRF, Hay River fault; Kw, Kiskatinaw domain; NWT, Northwest Territories; SK, Saskatchewan; RLK, Rainbow Lake; HL, High Level. The MT profile for the current study runs from RLK to HL.

236x308mm (300 x 300 DPI)
Fig. 2: (a) Aeromagnetic map of the total residual field for northern Alberta and (b) in the study area. Data from the Geological Survey of Canada (2017). (c) Bouguer anomaly of northern Alberta and (d) gravity horizontal gradient of the study area. Data from Geomatics Canada (2017). The black rectangle in (a) and (c) shows the location of (b) and (d). The gray lines mark the Precambrian terrane boundaries from Pilkington et al. (2000). Broadband MT stations are shown by triangles. The white triangles in (b) represent stations not used in the 2-D inversion due to low data quality. The two white rectangles in (b) mark the stations with typical data shown in Fig. S2 in the Supplementary Material. The black circles mark the locations of nearby towns. The dashed line indicates the location of the trace of the Kiskatinaw conductor according to Boerner et al. (2000). H, Hottah; N, Nova; Kw, Kiskatinaw; Ks, Ksituan; Ch, Chinchaga; BHH, Buffalo Head High; BHU, Buffalo Head Uricuma; FS, Fort Simpson; GSLSZ, Great Slave Lake shear zone; HRF, Hay River fault; GB, Great Bear; T, Talson; RLK, Rainbow Lake; HL, High Level.
Fig. 3: Interpreted seismic data of lines 11-12 from Peace River Arch Industry Seismic Experiment (PRAISE). Figure adapted from Fig. 5 in Ross and Eaton (2002). The location of this profile is shown in Fig. 1. WCSB, Western Canada Sedimentary Basin.

236x308mm (300 x 300 DPI)
Fig. 4: Temperature map at 1.5 km depth in Alberta (left) and the study area (right). The gray contour lines with numbers show the depth of the basement rocks. Temperature is not extrapolated in the basement rocks because there is little well control under the Western Canada Sedimentary Basin (WCSB, Nieuwenhuis et al. 2015). The black triangles represent the MT stations. The thickness of the WCSB is plotted according to the isopach map from Wright et al. (1994).
Fig. 5: The preferred 2-D isotropic inversion model. CBHC, Chinchaga-Buffalo-Head conductor; HC, Hottah conductor; KC, Kiskatinaw conductor; KCC, Ksituan-Chinchaga conductor; NR, Nova resistor; KSR, Ksituan resistor; WCSB, Western Canada Sedimentary Basin. The dashed line shows the Moho according to Gu et al. (2011).

236x308mm (300 x 300 DPI)
Fig. 6: Comparison of the 2-D isotropic inversion model with the seismic reflection profile from Ross and Eaton (2002). The two seismic sections presented here are from the seismic profile shown in Fig. 3. The top of the basement and the base of the crust (Moho) in the two results were aligned. No vertical exaggeration was applied. The red lines mark the terrane boundaries defined from the seismic reflection study. The red arrows indicate the direction of relative movements of crustal blocks. The three curves on the top show the magnetic total field, horizontal gravity gradient, and Bouguer anomaly data along the MT profile. The magnetic and gravity data sources are same as in Fig. 2.