Three Dimensional Magnetotelluric imaging of the Precambrian Alberta Basement

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Summary

Long period magnetotelluric (MT) data collected in Southern Alberta have been combined with previous Lithoprobe MT data to study the structure of the Pre-Cambrian basement rocks. Previous analysis used a 2D approach to interpret the MT data, but the MT data show indications of 3D effects. The new dataset has been analyzed with a three dimensional approach and the 3D conductivity models give a new insight into the structure of the Precambrian basement rocks that underlay the Western Canada Sedimentary Basin (WCSB). In addition the data is being used to map the depth of the Lithosphere – Asthenosphere boundary beneath Alberta.
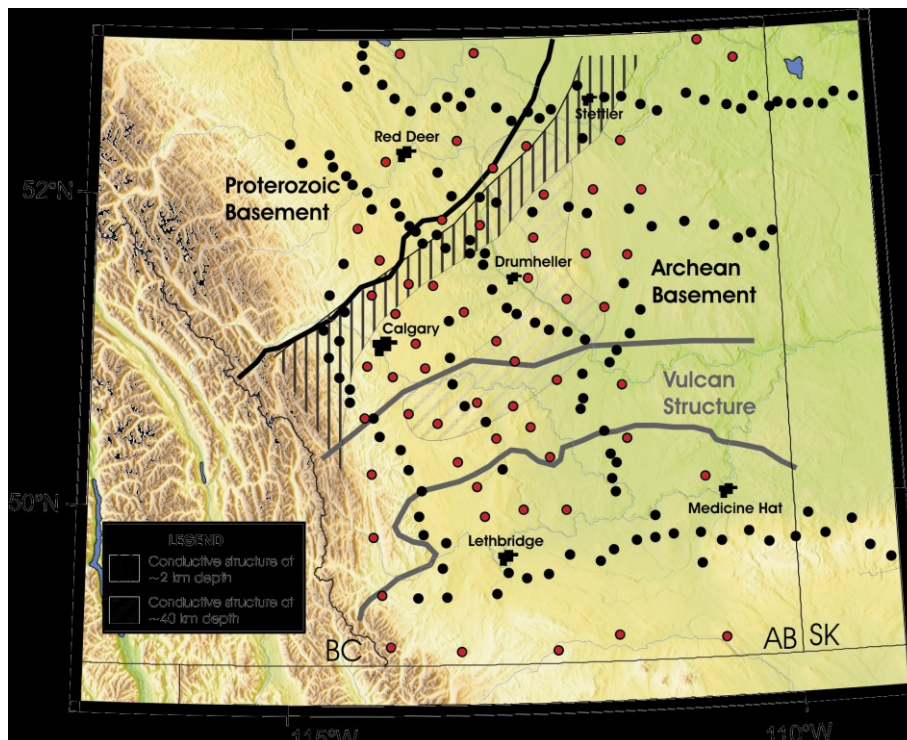
Figure 1: Map of MT stations in Southern Alberta, and primary conductivity structures defined by the 3D model. The dark black line represents the boundary between the Proterozoic Lacombe domain, and the Archean Hearne Province. The grey lines show the boundaries of the Vulcan structure as defined by Eaton et al. (1999). Red dots represent University of Alberta MT data, black dots represent Lithoprobe MT data.

Introduction

Long period MT exploration uses the measurement of low frequency (long period) electromagnetic waves (1 – 10,000s) to measure the electrical conductivity of the Earth to a depth in excess of 250 km. The long period MT data collected in Alberta reveal a model that shows 3 main layers: (a) the conductive strata of the WCSB, (b) the resistive crystalline basement, and (c) the more conductive asthenosphere.

Previous MT data revealed the three dimensional conductivity structure of Southern Alberta (Jones et al 2002). The regions with 3D effects appear to be associated with the Red Deer Conductor (RDC). The RDC is believed to be a shallow, highly conductive, linear body which follows the boundary between the Proterozoic Lacombe domain, and the Archean Hearne province. The top of the RDC is located at a shallow depth within the crystalline basement, near the base of the sedimentary cover. This three dimensional structure distorts the MT data so strongly that a two dimensional interpretation cannot be used with confidence.

Prior MT data collected in the region were collected along profiles during the Lithoprobe Alberta Basement Transect project. To reliably model the RDC and other three dimensional conductivity structures in southern Alberta, the University of Alberta collected additional MT data on a grid of MT stations to fill in the gaps between the Lithoprobe profiles (Figure 1).

The data density now available in this area has provided us with the unique opportunity to apply three dimensional MT modeling to long period MT data, without the limitation of spatial aliasing.

The survey area includes the Vulcan structure, a feature defined by prominent, roughly easterly trending potential field anomalies, with an orientation that is almost transversal to the northeast-trending potential field fabric (Figure 1). This anomaly has been interpreted in a number of ways, including an intra-plate Precambrian rift structure (e.g., Kanasewich et al., 1969) and a convergent orogen, defining the suture zone between the Archean Hearne and Wyoming provinces (e.g. Eaton et al., 1999; Hoffman, 1988). Due to the complex MT data in the area, the conductivity structure implied by the MT data around the Vulcan structure has not been accurately modeled in the past.
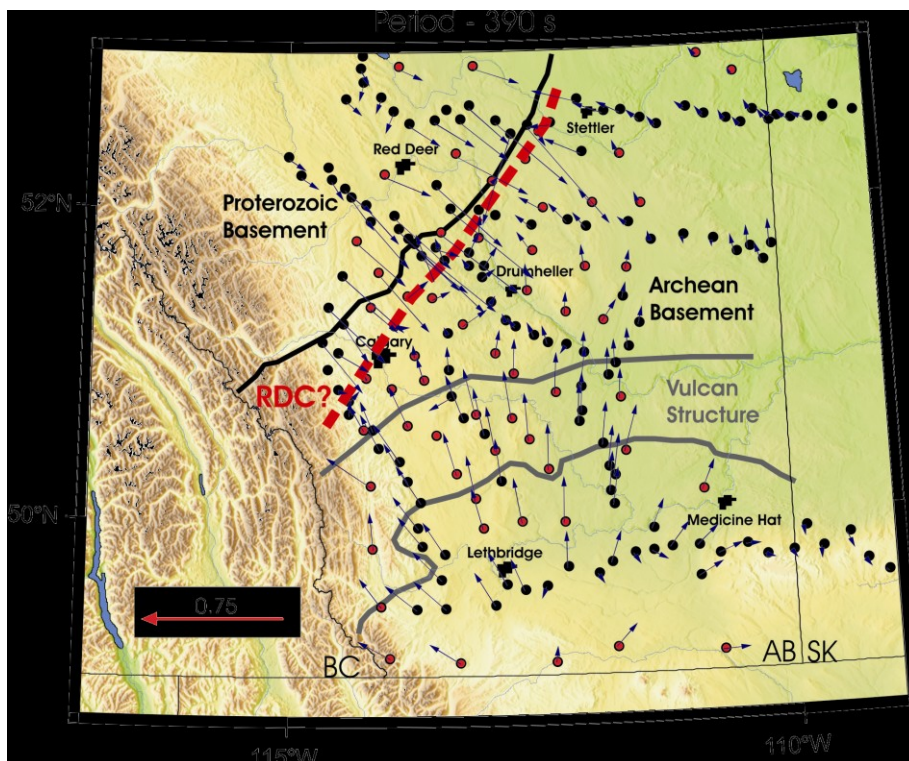

Figure 2 – Map of induction vectors at a period of 390 seconds plotted in the Parkinson convention. These vectors point at regions of high conductivity. The red vector in the bottom left corner represents a scale of 0.75. The red broken line represents a change in polarity of the induction vectors likely due to the Red Deer Conductor (RDC), and the grey lines represent the inferred boundaries of the Vulcan Structure.

This presentation is focused on the three dimensional conductivity model obtained in the inversion of this MT dataset. Special emphasis is placed on the conductivity structures within the crystalline basement, and on insights into the lithosphere-asthenosphere boundary provided by the 3D modeling.

Modeling Results

The measured MT data were converted into a 3D resistivity model using the 3D inversion algorithm of Siripunvaraporn (2005). Inherent in this inversion algorithm is the application of smoothing to regularize the inversion and overcome the inherent non-uniqueness. Figure 1 shows the location of two conductivity structures defined by inversion of the MT data at depths of 2 km (just below the sedimentary basin), and between 35 and 55 km. These structures show resistivities around 10 Ohm-m embedded in resistive crust (~10,000 Ohm-m) The shallow conductivity structure (2 km depth) is most likely associated with the Red Deer Conductor; the association of the deeper conductor to the RDC, although likely based on its location and shape, remains to be confirmed.

Owing to the coarse grid used in the inversion, it is possible that the identified conductivity structures actually cover a much smaller area. In an attempt to better define the location of conductors, we have investigated the induction vectors. Following Parkinson (1959), these induction vectors point towards conductors. The maps in Figures 2 and 3 depict the real induction vectors at 390 seconds, and 1255 seconds respectively. These maps highlight areas where induction vectors change polarity, indicating the presence of a subsurface conductor. Thus, Figure 2 shows the induction vectors at 390 seconds, representing the effect from relatively shallow structure within the crust, and Figure 3 shows deeper structure within the upper mantle at a period of 1255 seconds.

Red Deer Conductor

The spatial correlation between the RDC and the boundary between Proterozoic and Archean basement rocks (Figure 2), identified by initial MT studies, have led to the supposition that the RDC follows this boundary into southern Alberta. Our new data and modeling, suggest that the location of the RDC in the southwest, across southern Alberta, might deviate from this inferred
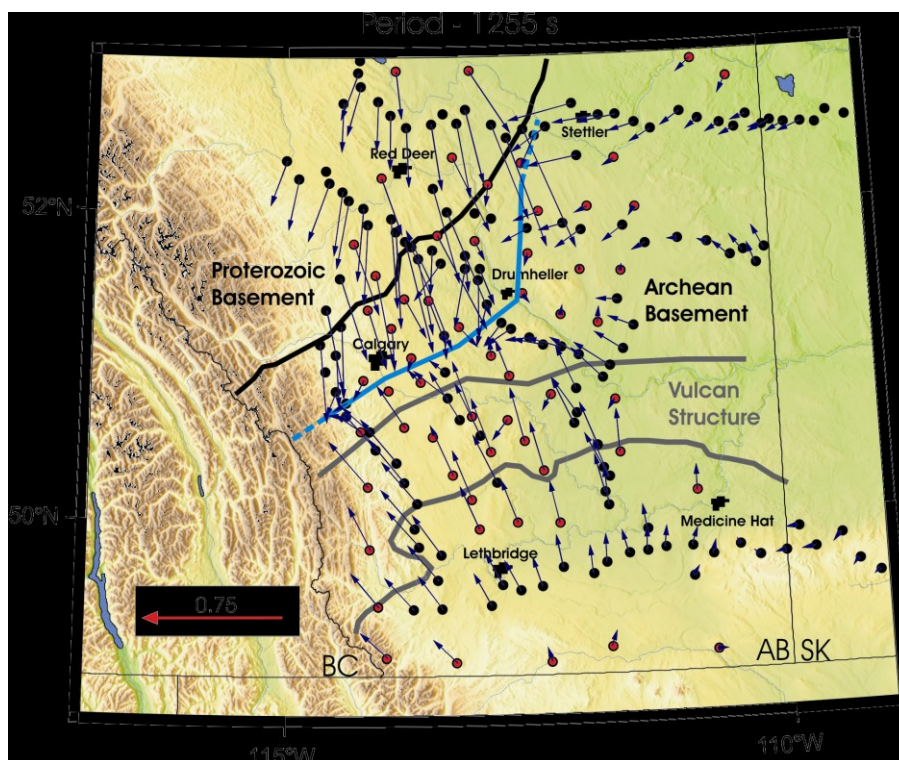

Figure 3 – Induction vectors at a period of 1255 seconds. The red arrow at the bottom left represents a scale of 0.75, The blue line denotes the approximate area where induction vectors change polarity, and the grey lines define the boundary of the Vulcan Structure

terrane boundary. In particular, the induction vectors reversal (broken red line in Figure 2), which is consistent with the location of the shallow conductor derived from the 3D modeling (Figure 1), is a more probable location for the RDC.

Deeper Resistivity Structure
Figure 3 shows the induction vectors measured at a period of 1255 seconds, indicating the response due to conductivity structures within the upper mantle (deeper than Figure 2). At this period, another induction vector reversal is evident just north of the Vulcan structure (blue line in Figure 3). This conductor is the same conductor modeled by the 3D inversion at a depth of approximately 40 km, showing the general agreement between the induction vectors and the 3D inversion model.

Lithosphere – Asthenosphere Boundary
Previous long period MT studies in Alberta have proven the utility of mapping the depth to the lithosphere – asthenosphere boundary below Alberta (Turkoglu et al., 2009). The MT data in this grid has shown a similar usefulness in mapping the depth to the LAB, showing a trend of lower resistivity at depths ranging from 200 to 250 km throughout the grid.

Conclusions
The MT data collected in southern Alberta has offered us the opportunity to test the ability of a three dimensional inversion scheme to fit complex data, without issues of spatial aliasing. The induction vectors have outlined areas where significant geoelectric structures exist, and the geoelectric model generated from these MT data has provided the first depiction of the depth to the lithosphere-asthenosphere boundary beneath Southern Alberta.

Acknowledgements

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