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Integrated Geophysical Imaging of the Western Superior Province, Canada

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Summary

We have integrated various geophysical models in the Western Superior Province of Canada for a better understanding of the Archean tectonics. The Lithoprobe seismic reflection profiles, along the north-south direction for ~500 km, show two relic subduction slabs penetrating into the mantel. These two slabs coincide with two high electrical conductivity anomalies observed from the 3D inversion of Magnetotelluric (MT) data. Also, the non-linear tomographic inversion of refraction seismic surveys in the northern part of profiles shows a high velocity anomaly in the lower and middle crust range. This high velocity anomaly matches with a dimmed reflectivity zone and high electrical resistivity anomaly. The physical properties of this anomaly are compatible with a massive mafic intrusion that might have been caused by the subducted slab.

Introduction

The Superior Province of Canada is the largest preserved Archean crust in the world. It contains a vast record of crustal growth from 3.22 Ga till 2.69 Ga (White et al., 2003). It comprises of east-west trending garnitoid, metasedimentary, and greenstone (metavelocanic) subprovinces that are interpreted to be a collection of micro-continents and subduction-related arcs (Figure 1). Whether the plate tectonics were active in the Archean eon is a controversial topic (van Hunen and Moyen, 2012).

During the Lithoprobe project in 1996, two perpendicular ~500-600 km long seismic refraction profiles were acquired in the Archean western Superior Province of the Canadian Shield. The north-south oriented seismic refraction profile was orthogonal to the regional geologic strike and also overlapps with 4 Lithoprobe reflection seismic profiles. Musacchio et al. (2004) used ray-based travel-time inversion of refraction data to estimate seismic velocity structure beneath the western superior provine. Recently, Roots and Craven (2017) have inverted 110 Lithoprobe Magnetotelluric (MT) stations to generate a 3D Electrical Resistivity model for the Western Superior Province.

In this article, we utilized a non-linear tomographic inversion (Zhang and Toksöz, 1998) for first-arrivals of Lithoprobe long-offset refraction surveys to obtain a velocity profile across north-south direction in the Western Superior Province. We have also applied dip-coherency filters to the Lithoprobe reflection profiles to enhance the continuity reflections for reliable interpretation purposes. Next, we have integrated all of the available geophysical models by properly modifying problematic coordinates in the seismic reflection SEGY files in order to accurately overlay different physical properties in a 3D model.

Geophysical Data and Modeling

Figure 1 shows the geological map of the Western Superior Province and its subprovinces. The Lithoprobe and Metal Earth reflection profiles are shown by blue and black lines, respectively. The Lithoprobe long-offset refraction survey was comprised of 23 explosive shots (red stars) at intervals of 30-50 kg with up to 1000-3000 kg charges buried in 50 meter deep holes. The seismographs (orange filled circles) of the refraction survey were deployed at intervals of 1-1.5 km along transects perpendicular (north-south, ~500 km long) and parallel (east-west, ~600 km long) to the dominate geological strike of the subprovinces. The MT stations acquired during the Lithoprobe project were depicted by filled black circles.

We integrated available reflection and refraction seismic data, 3D MT resistivity model, gravity, and magnetic anomalies to gain a comprehensive insight into the tectonic structure of the Western Superior province. The UTM coordinates of reflection seismic sections (downloaded from <*geoscan.nrcan.gc.ca*>) were modified and remapped in order to display them in a 3D visualization software. We have also applied dip-coherency filtering using curvelet transform in order to enhance the continuity of seismic reflections for interpretation purposes

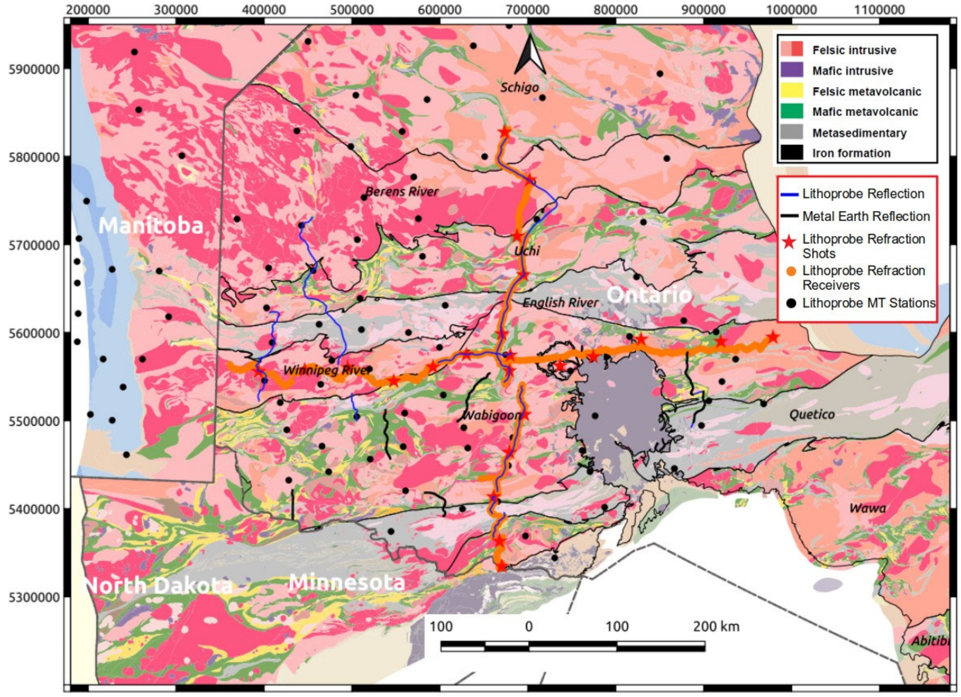

Figure 1 *The geological map of the Western Superior Province. The coordinates are in the UTM zone NAD83-N15. The locations of various geophysical transects and stations that were used in this research were shown on the map.*

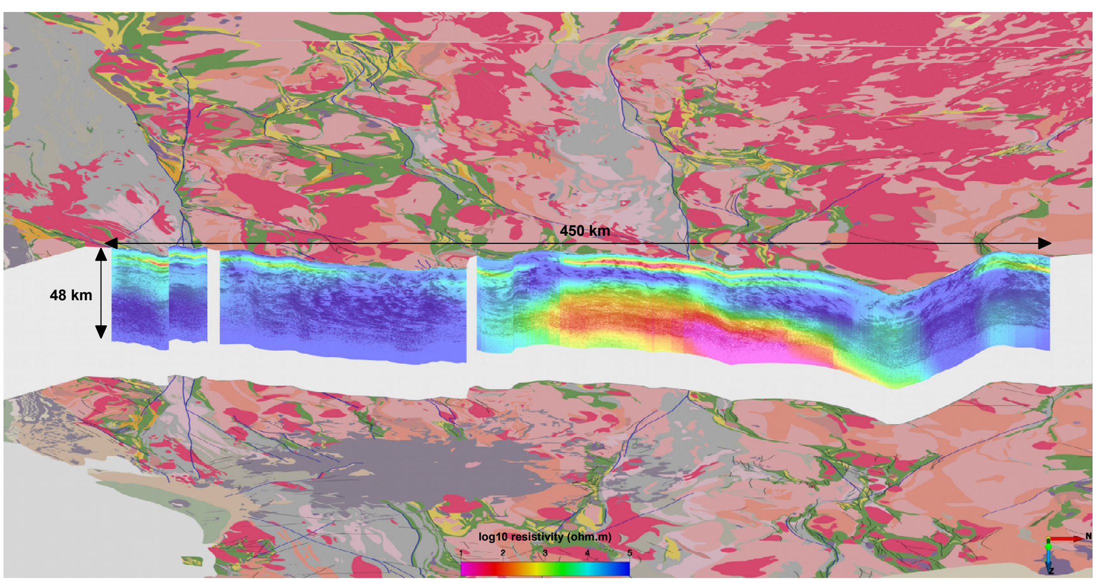

Figure 2 *A 3D orthographic view of Lithoprobe seismic reflection transects and projected electrical resistivity values estimated using 3D inversion of Lithoprobe MT data (Roots and Craven, 2017).*

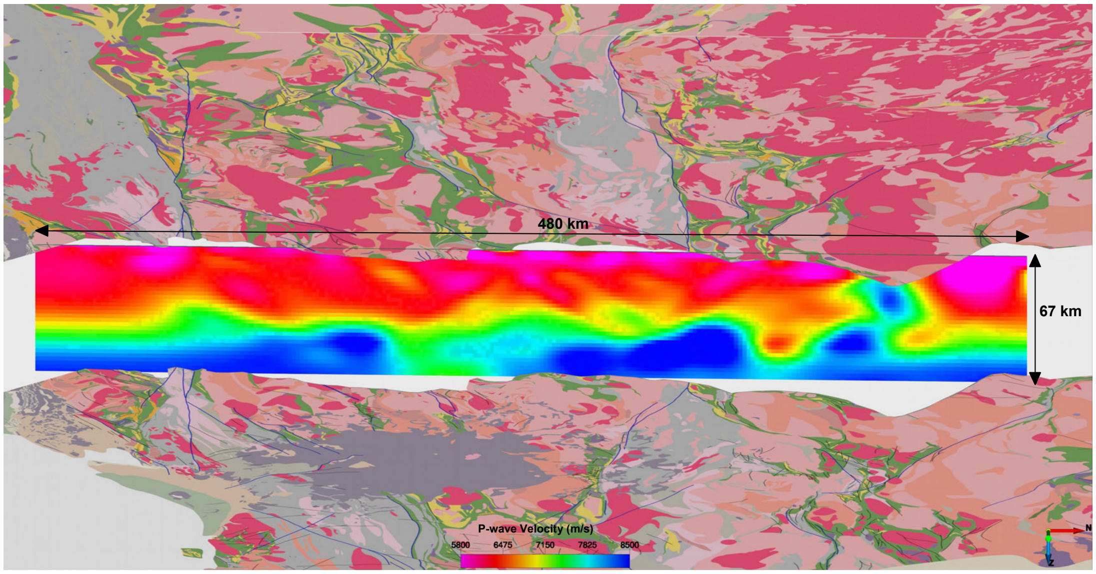

Figure 3 *The P-wave velocity profile across Western Superior province estimated from non-linear tomographic inversion of the first arrivals from Lithoprobe long-offset refraction surveys.*

(Naghizadeh and Sacchi, 2010). For electrical resistivity property, we have used the 3D MT inversion results from Roots and Craven (2017).

We have also re-processed and analyzed both wide-angle refraction surveys that were collected by the Lithoprobe project in the Western Superior province. These lines cross each other in the middle, and it was decided to reevaluate both of these separately with a non-linear tomographic inversion software. For each line, the processing sequence began by sorting the seismograms, into shot gathers and carefully picking the first arrivals of the P_g and P_n waveforms that correspond to waves that turn in crust and upper mantle, respectively. Following that, a three-layer initial tomographic velocity model was calculated by considering the gradients and intercepts of those arrival times. After a few trials, an optimal parameterization of the inversion was reached so that model could converge to a reasonable level of misfit. The sparsity of the dataset presented a challenge, but this was overcome by carefully gridding the model and minimizing the trade-off of norm to data misfit. A model of the calculated ray paths was used to de-emphasize the sparser, less reliable, regions of the final model.

Discussions

Figure 2 shows a 3D orthographic rendering of four reflection profiles and projected electrical resistivity values in Western Superior Province. Seismic reflection profiles show two regions of northward mildly dipping layers in the lower crust that penetrate into the mantle below the Moho boundary. These two features have been interpreted by previous researchers to be two relic subduction slabs from Archean Eon (White et al., 2003). Both of these dipping reflectors match with high electrical conductivity anomalies which in similar pattern are sloping from the lower crust into the mantle. The lower crust in the northern part of seismic profiles shows a zone of dimmed reflectivity that matches with a high resistivity anomaly. This could be interpreted as mafic intrusions caused by subduction.

Figure 3 shows the estimated P-wave velocity from Refraction surveys using the non-linear first-arrival tomography method. The northern part of the estimated velocity model shows a high velocity anomaly that intrudes into the shallower depth of 20 km. This high anomaly is in close proximity of the resistive intrusion zone in Figure 2. The refraction velocity model also shows two low velocity zones that extend below the Moho boundary. These low velocity zones can be related to the zones above the subduction slabs that are affected by the release of volatiles from subducted slabs. Figure 4 shows the reflection seismic profile with total magnetic anomaly map of the Western Superior Province. The magnetic anomaly map shows a broad high magnetic anomaly (marked by an ellipse) right above the zones of high velocity and high resistivity anomalies in the

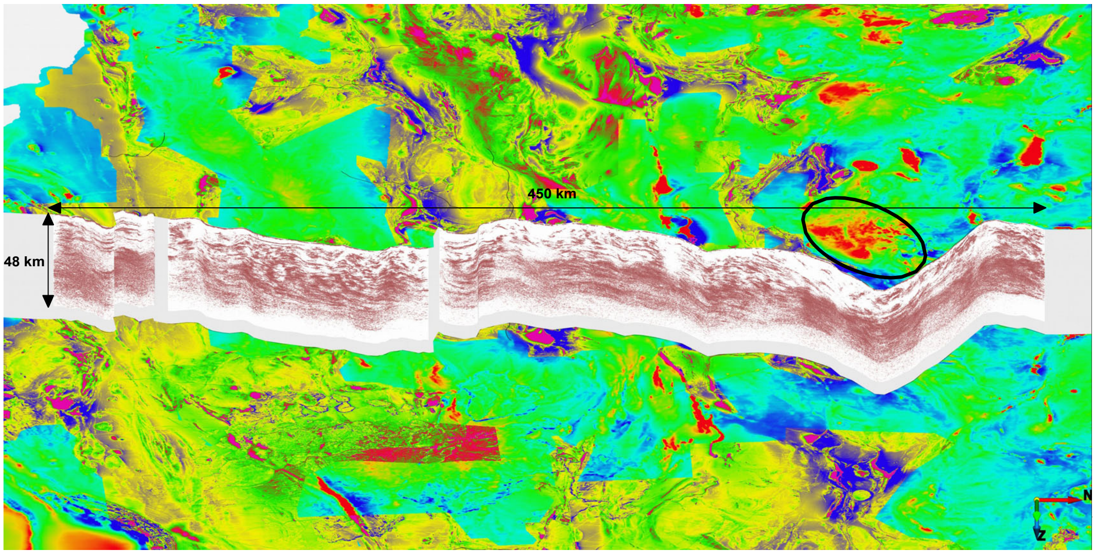

Figure 4 *The Magnetic Anomaly map of Western Superior Province and Lithoprobe seismic reflection profiles along the north-south direction.*

northern part of the profile. This strong high magnetic anomaly is an indication that a large mafic intrusive body might be sitting under that area which is in good correlation with the velocity and resistivity anomalies.

Conclusion

Various geophysical data and models were integrated to obtain a better understanding of Western Superior's tectonic evolution. The analysis and processing of seismic reflection and refraction, MT, magnetic, and gravity data reveals an intrusion of a large mafic body into the mid-crust under the Berens River subprovince. The relic subduction slabs under the Uchi subprovince, visible in seismic reflection and MT resistivity profiles, might be the cause of the mafic body intrusion under the Berens River subprovince.

Acknowledgments

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