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Sources of enhanced conductivity in the Northern Canadian Cordillera: constraints from LITHOPROBE SNORCLE Transects

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Summary

Resistivity of the northern Canadian Cordillera was imaged at reconnaissance-scale using the magnetotelluric (MT) method in the LITHOPROBE SNORCLE Transect. Resistivity models define spatially-complex crustal resistivity in cordilleran crust. Conductive features can be interpreted in terms of lithological variations and alteration processes. Conductor crust in Stikinia is attributed to east-dipping Jurassic subduction and enhanced conductivity beneath the Eskay rift to crustal fertilization. A conductor in the Cache Creek terrane is attributed to listwanite alteration of ultramafic bodies on the King Salmon Fault, and high conductivity in the Slide Mountain terrane within the Sylvester Allochthon to localized carbonaceous alteration. Finally, a series of conductors above North American Basement is attributed to deformation and metamorphic processes associated with Mesozoic thrust faulting.

Introduction

The northern Canadian Cordillera and adjacent Laurentian margin were investigated in the Slave-Northern Cordillera Lithospheric Evolution (SNORCLE) Transect (Figure 1). Resistivity was imaged at reconnaissance-scale using the magnetotelluric (MT) method. Jones et al. (2005) review the MT studies. The current work is focuses on recent re-analysis and re-interpretation of the MT data from Corridor 2 (Habibian Dehkordi et al., 2019). Resistivity models derived from the MT data define a number of conductive features. However, the average 12 km site spacing of MT sites means that the conductors are defined at only relatively low resolution, with some conductors defined by data from only one or two MT sites. It is therefore necessary to introduce independent information from other geophysical methods (e.g. seismic reflection) and from geological studies (e.g., geochemistry, mineral exploration) to reliably define sources of the enhanced conductivity in these features.

Tectonic setting

The east part of the study area comprises the margin of Laurentia, its cover, and ancestral continental shelf platform and basin sequences (Figure 1). The Tintina Fault-northern Rocky Mountain Trench is a 2000 km dextral transcurrent fault that on Corridor 2 separates rocks of Ancestral North America from pericratonic and accreted terranes of the Cordillera (Figure 1). Seismic studies define a westward tapering wedge of high reflectivity in the middle to lower crust west of the Tintina Fault with internal similarities to features on the east side. It is interpreted as consisting of Proterozoic supracrustal rocks and as having acted as a tectonic accretion surface (e.g., Cook et al. 2012; Calvert 2016). Corridor 2 crosses the Foreland, Omenica, and Intermontane morphogeological belts. Along the corridor, the Omenica Belt contains pericratonic, para-autochthonous terranes related to Ancestral North America and consists of the Cassiar, Slide Mountain and Yukon-Tanana terranes. The Intermontane Belt includes accreted terranes and consists of the Quesnel, Cache Creek, and Stikine terranes.

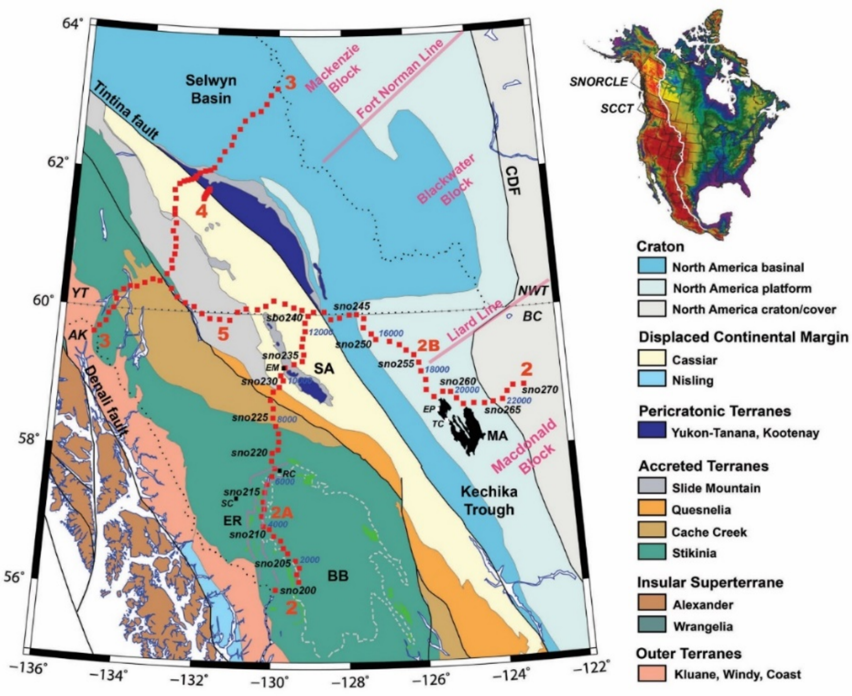

Figure 1. Tectonic map showing locations of LITHOPROBE SNORCLE corridors and geological features discussed in the text (Habibian Dehkordi et al., 2019). Geographic abbreviations: AK=Alaska; YT=Yukon Territory; NWT=Northwest Territories; BC=British Columba. Geological abbreviations: MA=Muskwa Anticlinorium; SA=Sylvester Allochthon; BB=Bowser Basin; ER=Eskay Rift and CDF=Cordilleran Deformation Front. Mine or deposit abbreviations: SC=Schaft Creek porphyry Cu mine; RC=Red Chris porphyry Cu mine; EM=Erickson Au mine; EP=Eagle Creek Cu-Ag-Pb-Co-Zn property; TC=Toro Churchill Cu property. Pink lines and labels denote lineaments and blocks of North American margin. Light green shading near margins of the Bowser Basin show the Upper Hazleton Group. Inset shows the location of the Cordillera and the LITHOPROBE SNORCLE and Southern Cordillera (SCCT) projects (Cook et al., 2012). White line on the inset is the Cordilleran deformation front.

Magnetotelluric survey, analysis, and resistivity models

Corridor 2 included 69 MT sites along the 800 km long profile. The data set has recently been analyzed using modern MT methods (Habibian Dehkordi et al., 2019). Results of dimensionality and strike analyses support the validity of 2-D inversion using a N45^{o}W strike azimuth. Strike analysis yields azimuths that are consistent between different methods, fairly consistent from site-to-site, and aligned with larger-scale geological features. Resistivity images of the crust were obtained using two independent sets of unconstrained 2-D inversions and constrained 2-D inversions incorporating seismic constraints. Figure 2 compares the new resistivity model for Corridor 2 with the model for Corridor 3.

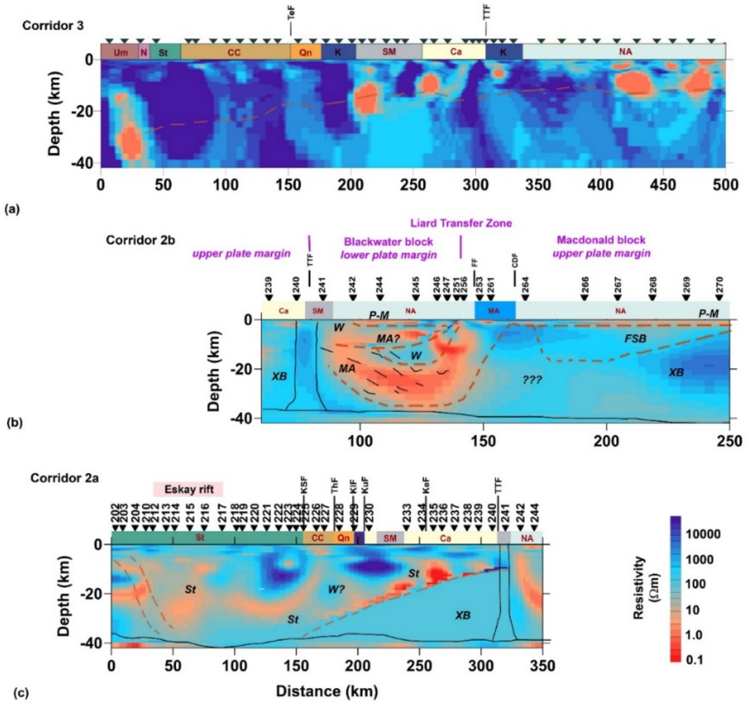

Figure 2. Comparison of resistivity models (Habibian Dehkordi et al., 2019). **(a)** Model for Corridor 3 (from Ledo et al. 2004). Dashed brown line defines upper surface of westward tapering seismic wedge. **(b)** Interpretation of crustal structure along LITHOPROBE Corridor 2B based on constrained inversion resistivity model. Purple text shows the location of different asymmetric plate margins and dashed brown line shows interpretations discussed in the text. (c) Interpretation of crustal structure along LITHOPROBE Corridor 2A based on constrained inversion resistivity models. All resistivity models are plotted using plotted using the colour scale in lower right. Abbreviations: KSF=King Salmon Fault; ThF=Thibert Fault; KlF=Klinkit Fault; KuF=Kutcho Fault; KeF=Kechika Fault; TTF=Tintina Fault; FF=Forcier Fault; St=Stikinia; CC=Cache Creek; Qn=Quesnellia; Y=Yukon-Tanana; SM=Slide Mountain; Ca=Cassiar; NA=North America; MA=Muskwa assemblage; Um=Undivided metamorphic rocks, N=Nisling terrane; XB=Crystalline basement, FSB=Fort Simpson Basin, W=Windermere assemblage, P-M=Paleozoic and Mesozoic rocks.

Integrated interpretation

Conductive crust in Stikinia

Resistivity models include a series of conductors (1-10 Ω·m) in the middle to lower crust of Stikinia near the southern end of the profile. The most conductive responses (<3 Ω·m) are observed beneath sno204 and sno216. Some models suggest the features connect to form a northeast dipping conductor that broadens into a moderately conductive zone (<10 Ω·m) in the lower crust beneath sites sno210 to sno215.

Conductors with east-dipping geometry are also observed on Corridor 3 (Ledo et al., 2004) and in Alaska (Stanley et al., 1990). Ledo et al. (2004) conclude that the conductor on Corridor 3 is due to metasedimentary rocks emplaced and metamorphosed during Paleocene Kula plate subduction. An alternative explanation of the conductors on Corridor 2 is that they record older subduction events. Marsden and Thorkelson (1992) suggest that the Stikinia terrane underwent plate subduction for 35 Myr on both its east and west sides during the Jurassic. In this case the east dipping conductor on Corridor 2, and possibly the structures observed on Corridor 3 and in

Alaska, can be interpreted as representing the result of Mesozoic subduction at ~170 Ma and earlier rather than Cenozoic subduction. Geochemical data provides evidence for extensive fertilization of the upper mantle beneath Stikinia indicating long-lived subduction beneath the terrane, and the geochemistry of basalts in the Iskut River Formation indicates spatially variable interaction of the mantle magmas with the crust (Barresi et al., 2015).

The resistivity model includes enhanced conductivity beneath the Eskay rift (Figure 2). The geometry of the conductive region is not accurately defined by the 2-D models, but in all models there increased conductivity extends eastwards in the lower crust northeast of the east-dipping conductive zone. All resistivity models also include a conductor at 10 km depth beneath sno216. This location is approximately midway between (and ~50 km from) the Red Chris ("RC" in Figure 1) and Schaft Creek ("SC" in Figure 1) porphyry copper deposits (Nelson and Colpron, 2007).

Cache Creek terrane

All MT models include a shallow east-dipping or synformal conductor (<10 $\Omega\cdot$m) extending to a~3 km depth in the Cache Creek terrane. In some models, the conductor is a synformal body extending between the King Salmon and Thibert Faults, and exhibits strong spatial correlation with shallow seismic reflections (e.g., Calvert, 2016). There are several possible sources of enhanced electrical conductivity in the Cache Creek terrane: (a) argillitic sedimentary rocks present in the Upper Triassic to early Jurassic accretionary prism and subduction related accretionary complexes (b) sulphide mineralization in arc rocks (Nelson and Colpron, 2007), and (c) altered serpentinites within dismembered ophiolite assemblages. The ultramafic rocks are the most likely source of the enhanced conductivity but higher resolution MT studies would be required to confirm this interpretation. In the Cache Creek terrane in the Atlin area, closer to Corridor 3, extensive serpentinization of harzburgite and dunite rocks is observed, and extensive carbonatization (CO_2 metasomatism) has occurred along fault zones forming listwanite. Alteration products also include sulphides (Ash and Arksey, 1988). Near the Dease Lake area on Corridor 2 (near sno223 and sno225), a number of small ultramafic bodies occur along the King Salmon Fault. These bodies consist of serpentinite that has also undergone listwanite alteration. The King Salmon Fault is interpreted to have a relative shallow eastward dip (Calvert, 2016) so the geometry of the conductor is consistent with it being associated with carbonatized serpentinite along the King Salmon Fault.

Slide Mountain terrane

The Slide Mountain terrane contains very conductive rocks. Although the data from the two sites in the terrane, sno232 and sno233, had to be edited extensively because of very high distortion and three-dimensionality, the remaining part of the data set define a strong shallow conductor (<6 $\Omega\cdot$m) at 2-3 km depth. Results from MT Corridors 3 and 5 indicate the enhanced shallow conductivity in the terrane is localized to Corridor 2 and the Sylvester Allochthon location (Ledo et al., 2004). The conductor is most reasonably attributed to localized mineralization rather than the ocean basin rocks themselves. There are numerous mines in the Cassiar area within 15 km of sno232. The rocks of the area have been extensively affected by Early Cretaceous carbonation alteration and mineralization (Sketchley and Sinclair, 1991). At the Erickson Mine ("EM" in Figure 1) disseminated and fracture controlled elemental carbon is present in sufficient abundance to form carbon veins. The mineralization in the Sylvester Allochthon required addition of an enormous volume of CO_2, which is best explained by a deep source rather than a local magmatic source (Anderson and Hodgson, 1989).

Conductive zones above seismic wedge

Inversion models for Corridor 2 resolve a series of conductors lying above the seismic wedge (Figure 2). The similarity of the conductors on Corridors 2 and 3 suggest a common geographically-widespread source and requires a broad distribution of appropriate source rocks and appropriate metamorphic and deformational conditions. Ledo et al. (2004) suggest that the conductors on Corridor 3 are related to the deformation associated with the thrusting of younger rocks over the Proterozoic crustal wedge and this model is also appropriate for the conductors on Corridor 2. The geometry of the conductors overlying the middle to lower crustal seismic wedge in the Cordillera suggests that they can be attributed to strain-related structural and metamorphic processes. In outcrops of Windermere Supergroup rocks to the north and south of Corridor 2 the rocks are considerably thickened by east-verging thrust faults and folds (Evenchick et al., 2005). Although it is not certain that these structures extend to the seismic wedge, the results suggest that suitable contractual conditions for enhancing conductors occurred near the wedge. The source rocks for the conductors above the seismic wedge are interpreted to be rocks from the Stikine terrane. Source rocks may be euxinic metasediments or sheared serpentinites derived from alteration of ultramafic rocks.

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