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Magnetotelluric and teleseismic study across the Snowbird Tectonic Zone, Canadian Shield: A Neoarchean mantle suture?

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[1] The Snowbird tectonic zone (STZ) is a fundamental boundary within Canada's Western Churchill Province, one of the world's largest yet poorly-known fragments of Archean crust. Geophysical data from a collocated magnetotelluric and teleseismic transect across the northeastern segment of the STZ provide an image of its subsurface geometry and indicate that it may have been previously mislocated. The model suggests that (1) the STZ has played a major role in the Neoarchean assembly and Paleoproterozoic reworking of the western Canadian Shield, (2) it was reactivated in a manner comparable to other crustal-scale features such as the Kapuskasing zone of the Superior Province, Canada, and the Redbank thrust of the Arunta block, central Australia, and (3) it juxtaposes mantle blocks with contrasting geophysical properties, revealing a lithosphere-scale overlap of the leading edges of the Rae and Hearne domains. The STZ thus records plate interactions in the Neoarchean comparable in scale with that of modern orogenic belts. *INDEX TERMS:* 0925 Exploration Geophysics: Magnetic and electrical methods; 7205 Seismology: Continental crust (1242); 7218 Seismology: Lithosphere and upper mantle; 8110 Tectonophysics: Continental tectonics—general (0905); 9619 Information Related to Geologic Time: Precambrian. **Citation:** Jones, A. G., D. Snyder, S. Hanmer, I. Asudeh, D. White, D. Eaton, and G. Clarke, Magnetotelluric and teleseismic study across the Snowbird Tectonic Zone, Canadian Shield: A Neoarchean mantle suture?, *Geophys. Res. Lett.*, *29*(17), 1829, doi:10.1029/2002GL015359, 2002.

1. Introduction

[2] The Western Churchill Province, underlying much of the Canadian Shield west of Hudson Bay, constitutes one of the world's largest (~2,000,000 km^2) yet poorly known fragments of Neoarchean crust. It is divided into the Rae and Hearne domains by the ~2,000 km-long Snowbird tectonic zone (STZ), interpreted by *Hoffman* [1988] as a Paleoproterozoic suture. The STZ's trace was originally located using potential field data, but the Chesterfield Inlet segment (Figure 1) has heretofore been controversial. Previous active seismic surveys across a southwestern segment of the STZ, where it is buried beneath Phanerozoic cover, reveal a discrete Moho step; however, magnetotelluric (MT) data from the same area do not show any crustal expression of this feature [*Ross et al.*, 2000]. To provide geometrical constraints across an exposed segment of the STZ, we undertook an 8-station regional-scale collocated magnetotelluric (MT) and teleseismic survey across the STZ in 1998.

[3] Our 350-km-long helicopter-supported MT and teleseismic transect crossed eastern Baker Lake, east of where the northeast trending STZ was thought to re-orient and follow the north side of Chesterfield Inlet (Figure 1). The transect's orientation and site locations were largely dictated by logistical constraints in this isolated area. From the geophysical data we have obtained first-order information on the subsurface geometry of the STZ, including a lithospheric-scale overlap of the leading edges of the Rae and Hearne domains. These data provide critical geometrical constraints on the Neoarchean and Paleoproterozoic tectonic evolution of a major component of the western Canadian Shield, at the nucleus of the North American continent.

2. MT Experiment and Results

[4] MT data acquisition, using long-period magnetotelluric systems (GSC's LiMS), was undertaken from mid-July to mid-September, 1998. Acquisition was compromised at site 2 due to rodents, resulting in no E-W telluric measurements at that site. Robust, multi-remote-reference time series processing followed the Jones-Jödicke scheme (method 6 in *Jones et al.*, [1989]), with adaptations to avoid source field effects [*Jones and Spratt*, 2002]. The real induction vectors clearly indicate significant lateral variation in resistivity (Figure 2) with oppositely-directed vectors between sites 4 and 5 and between sites 6 and 7. Sites 1 and 2 sense the high seawater conductivity in nearby Hudson Bay.

[5] Distortion effects on the MT response estimates were removed, and strike direction defined (N110°E), using the method of *McNeice and Jones* [2001]. The strongest dimensionality was exhibited at sites 1, 4 and 5. The TE- and TM-mode regional MT impedance estimates were inverted for minimum structure using RLM2DI [*Rodi and Mackie*, 2001], with preference for fitting the phase responses to account for static shifts (only TM-mode responses available at site 2). Overall, the phases were fit to better than 5°. Salient features in the resistivity model of Figure 3a are:

1. There is a major upper-crustal boundary between sites 6 and 7. The shortest period (20 s) MT data for site 6 do not permit reliable resolution of this boundary to surface, but detailed forward modeling indicates that the shortest period data are better fit if the boundary surfaces to the south of site 6 rather than to the north of it.

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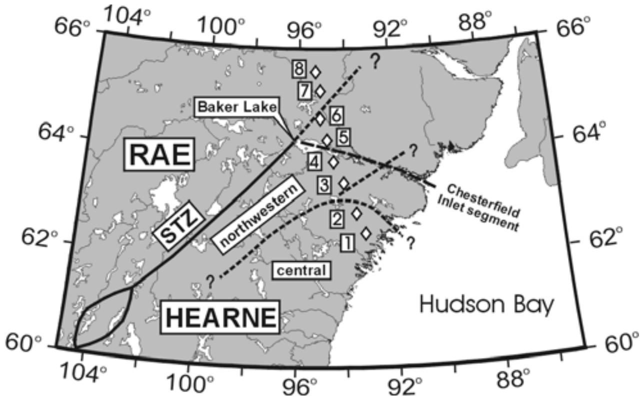

Figure 1. Map of the survey region showing the locations of MT and teleseismic data acquisition (numbered diamonds), the Rae and Hearne domains and their bounding Snowbird Tectonic Zone (STZ), and the Hearne subdomain boundary. The STZ has two trajectories, the traditional one that rotates clockwise at Baker Lake to follow Chesterfield Inlet, and one that continues on a NE trend.

2. Sites 7 and 8 show no evidence of conducting material in the crust at any depth, whereas the upper crust beneath sites 5 and 6 is relatively conductive (<6,500 Ω.m with regions of ~6.5 Ω.m), and the lower crust is resistive (>6,500 Ω.m).

3. There is a second crustal-scale boundary between sites 4 and 5, i.e., below Baker Lake. Based on directionality analyses, this structure has a strike of N110°E, consistent with the orientation of Chesterfield Inlet. The lower crust beneath the northwestern Hearne domain is relatively conducting, with resistivities of 6.5–6,500 Ω.m, compared to the Rae domain where lower crustal resistivity is >6,500 Ω.m. The northwestern Hearne lower crustal conductor potentially terminates at the location of the seismically-defined Moho boundary. To the south, the extension of this conductor is poorly constrained, given the lack of TE-mode data at site 2.

4. The lower 20 km of crust beneath the northwestern Hearne domain has a conductance of ~30 Siemens, consistent with values observed world-wide for Precambrian regions [*Jones et al.*, 1992]. In stark contrast, lower crust north of Baker Lake has a conductance of <1 S, which has only been observed in one other location world-wide- the southwestern part of the Slave craton [*Jones and Ferguson*, 2001]. This implies that tectonic processes of lower crustal development in the Rae domain and the southwestern Slave were similar, and different from processes that introduced conducting material into the lower crust of other Archean regions (Superior craton, Fennoscandian Shield, Siberian Shield, Kaapvaal craton, see *Jones et al.*, [1992]).

5. The sub-continental lithospheric mantle (SCLM) is less resistive to the south. Forward modeling demonstrates that a uniform upper mantle does not fit the data. An inferred interface dips toward the south and occurs between sites 2 and 3 at ~100 km.

6. The SCLM beneath the whole region is more resistive than beneath other cratons, and in situ resistivities approach those measured in laboratories for dry olivine [*Constable et al.*, 1992]. This is significant given the extensive (>240,000 km^2 minimum) ca. 1.83 Ga mantle metasomatism of the region [*Cousens et al.*, 2001] coupled with the suggestion that metasomatism should lead to reduced resistivity [*Boerner et al.*, 1999].

[6] With respect to the Rae-Hearne domain boundary, there are two possible scenarios, depending on whether the conducting material forms a subdomain of the Rae footwall (Figure 3b) or part of the Hearne hangingwall (Figure 3c). In either scenario, the conductive crust separates Neoarchean juvenile Hearne domain from continental Rae domain with its Mesoarchean basement.

3. Teleseismic Experiment and Results

[7] Teleseismic stations were deployed from early May to early September, 1998. Events were picked with earthquake magnitudes ≥5.0 and were processed using the Seismic Analysis Code (SAC2000). Shear wave splitting analyses were undertaken on SKS and SKKS phases following *Silver and Chan* [1991]. Of the 582 earthquakes available, only five had appropriate epicentral distances, azimuths and signal-to-

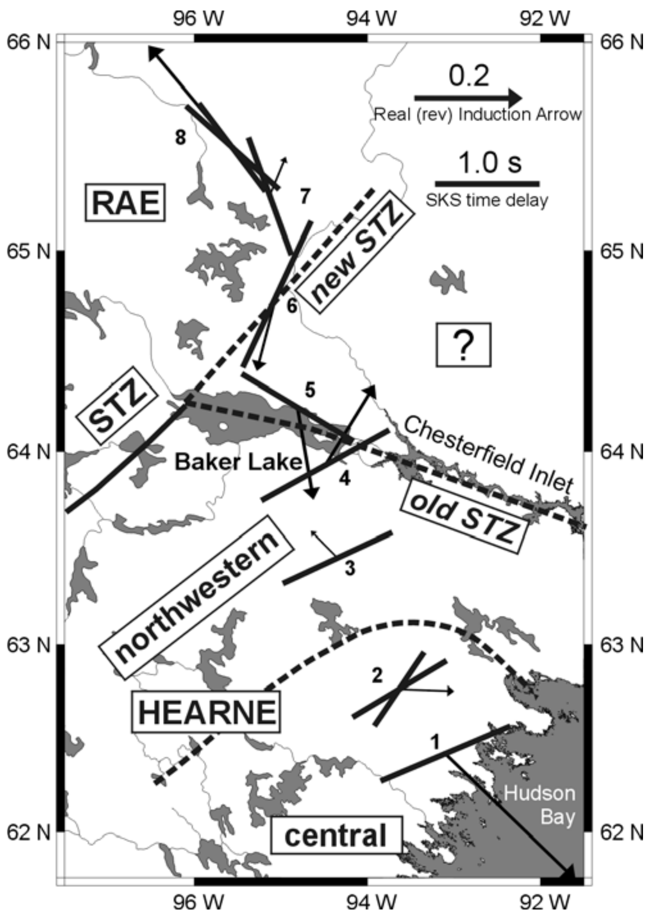

Figure 2. Headed arrows: Real (reversed) induction arrows at 320 s scaled to the 0.2 s arrow shown in the legend. The arrows point towards current concentration in anomalously conductive bodies, and their length is an indication of proximity and strength of the conductors. Unheaded arrows: single-event SKS splitting analyses scaled to the 1.0 s arrow shown in the legend. The azimuth of the arrow indicates the fast split direction, and the length gives the delay time between the split shear waves.

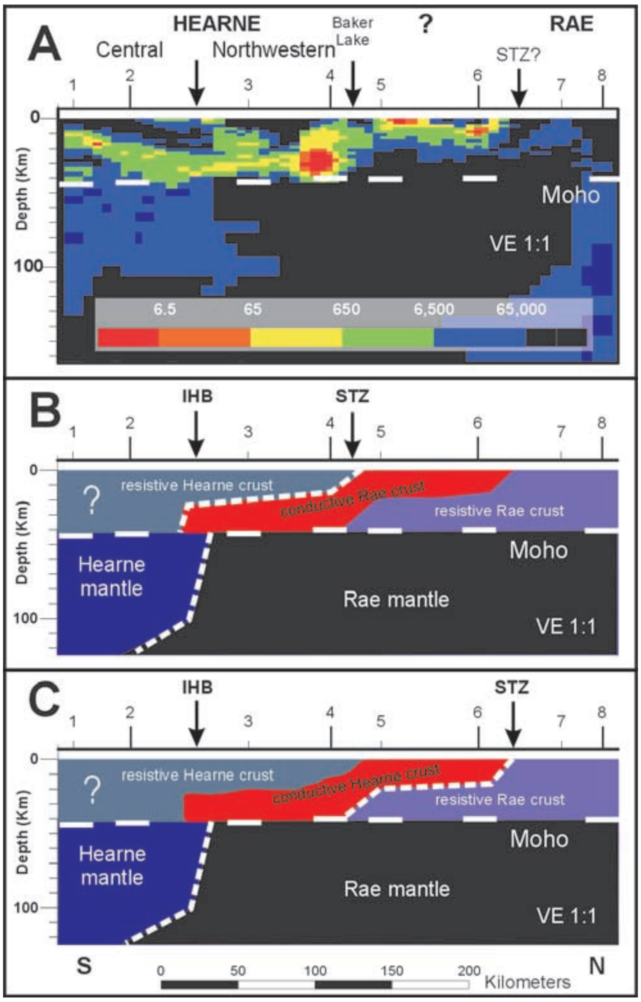

Figure 3. Resistivity model of the MT data (A) and cartoons of two possible end-member interpretations (B and C). Cold colors (blue→purple) show resistive regions whereas hotter colors (yellow→red) show regions containing interconnected conducting material. Also shown are the Moho depth estimates from the teleseismic data analyses (thick white bars at ~40 km depth). (B) The conducting material is footwall Rae domain rocks, leading to the Rae-Hearne boundary (STZ) being along Chesterfield Inlet. (C) The conducting material is hangingwall Hearne domain rocks, with the STZ continuing on its NE trajectory between sites 6 and 7. Implicit in this model is detachment at the Moho with ~100 km of translation of Rae mantle lithosphere beneath Hearne crust.

noise ratios suitable for reliable analysis. The single-event SKS directions and time delays are presented in Figure 2. Receiver function analysis followed *Ammon et al.* [1990]. Sixty-six station-event pairs were analyzed independently, with the Moho providing the most reliable event, and the resulting delay times averaged. The principal results are:

1. Sites south of Baker Lake gave fast shear wave directions of 34°–67°. In contrast, three of the four sites north of Baker Lake gave fast directions of 301°–340°, almost perpendicular to the southern sites. The time delays of the two subsets are statistically the same (1.07 ± 0.19 s cf. 1.23 ± 0.16 s), but their average directions are significantly different (61° ± 5° cf. 321° ± 12°). The nearest published SKS observation in the region is that for Fort Churchill, which exhibits a fast direction of 27° with a much lower time delay of about 0.55 s [*Silver*, 1996].

2. Observed receiver function lag times were converted to crustal thicknesses by assuming a laterally invariant crustal velocity structure based on a refraction survey in Hudson Bay [*Hobson*, 1967]. Slightly thicker crust is apparent beneath the Hearne domain (41–42 km) compared to the Rae domain (39 km), with minimum crustal thickness (38 km) directly beneath the southern side of Baker Lake. In addition, the waveforms arriving at the southern stations 1 and 2 are more complex compared to those recorded at the northern sites, suggesting greater crustal complexity, i.e., crustal layering.

4. Discussion

[8] The MT data highlight significant regional-scale upper crustal differences to the north and south of site 6. To the north the entire crust is resistive, whereas to the south the lower crust is resistive and the upper crust conductive. South of Baker Lake this resistivity pattern is inverted, with a conducting lower crust and a resistive upper crust. A regional-scale variation on either side of Baker Lake is also reflected in the seismic data, with seismically simpler (single layer) and thinner (~39 km) crust to the north, and seismically more complex (multilayered) and thicker (~41–42 km) crust to the south.

[9] The SCLM also exhibits significant changes: it is resistive with fast shear wave direction oriented NW-SE to the north, whereas it is less resistive with fast shear wave direction oriented NE-SW to the south. The interface between these contrasting physical properties lies beneath exposed Hearne crust south of Baker Lake.

[10] These crustal and mantle physical parameters suggest that the leading edge of Rae lithosphere has been underthrust beneath Hearne crust by ~150–200 km. Significantly, "Rae" mantle underlies the northwestern part of the Hearne domain, recently identified as a subdomain of penetrative crustal reworking at ~2550–2500 Ma and a regional, deep-crustal (>1.0 GPa) thermal event at ~1900 Ma [e.g., *Hanmer and Relf*, 2000; *Berman et al.*, 2000]. Accordingly, this suggests that the lithospheric scale of tectonic plate interaction during the Neoarchean was comparable to that of modern orogenic belts, such as the Himalaya [e.g., *Kosarev et al.*, 1999].

[11] The substantial difference in upper crustal resistivity between sites 6 and 7 implies the presence of an important boundary. Coupled with the lack of an obvious geological or metamorphic break across Chesterfield Inlet [*Tella et al.*, 2001; *Berman et al.*, 2000], we suggest that the STZ projects not along Chesterfield Inlet ("*old STZ*" in Figure 2), but to the northeast along the northern limit of conductive crust ("*new STZ*" in Figure 2). The Hearne domain north of 60°N is principally composed of Neoarchean juvenile crust, whereas the Rae domain contains Mesoarchean continental crust [*Sandeman et al.*, 2001; *Zaleski et al.*, 2001]. Accordingly, the relocated STZ could represent a major suture across which the Western Churchill Province had been assembled, potentially as early as the Neoarchean.

[12] If the Rae-Hearne boundary follows the new trace of the STZ proposed here, the conductive crust forms a

subdomain of the Hearne hangingwall (Figure 3c). Extension of the STZ to the NE potentially brings into question the identity of the area north of Chesterfield Inlet (marked by "?" in Figure 2) as part of the Rae domain. This will be discussed more extensively in future publications. In both interpretations (Figures 3b and 3c), north of 60°N conductive crust separates Neoarchean juvenile crust from continental Rae domain with its Mesoarchean basement. The Rae and Hearne domains were stitched together by plutons at ∼2600 Ma [*Davis et al.*, 2000], suggesting that the interface constitutes a Neoarchean feature. We conclude that we have imaged the boundary along which the Rae and Hearne domains were originally juxtaposed and that this boundary was a Neoarchean tectonic suture.

[13] At ∼2550–2500 Ma, the northwestern Hearne subdomain was penetratively reworked by southeast-vergent, thick-skinned thrusting [*MacLachlan et al.*, 2000; *Tella et al.*, 2001]. We interpret this shortening event as the hangingwall response to contractional reactivation of the Rae-Hearne interface at that time.

[14] Although the history of burial and exhumation of the northwestern Hearne subdomain is still subject to debate, *Relf and Hanmer* [2000] suggest a parallel between our image of the Rae-Hearne boundary and the Proterozoic Kapuskasing structure of the Superior Province. According to their scenario, further contractional reactivation of this boundary at ∼1830 Ma, driven by progressive collision in the Trans-Hudson orogen, resulted in emplacement of the high pressure crustal rocks of the northwestern Hearne subdomain over low pressure crustal rocks (0.35–0.4 GPa; *Zaleski et al.*, [2001]) of the Rae domain. Southward tilting of the Hearne domain exposed the deep-crustal rocks of the northwestern Hearne subdomain and preserved the overlying upper-crustal rocks to the southeast. Similar large-scale exhumation of deep crust and tilting of the hangingwall has been identified in Australia where the central and southern parts of the Arunta block are separated by a major, shallowly dipping, contractional fault system [*Ballevre et al.*, 2000].

[15] In conclusion, first-order geophysical imaging of the STZ/Rae-Hearne boundary has improved our understanding of the location, age and significance of the fundamental structure that divides a major portion of the western Canadian Shield. The STZ represents a lithospheric discontinuity that appears to have controlled the principal tectonic events during Paleoproterozoic reworking of the Western Churchill Province.

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