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Geophysical studies of the deep lithosphere beneath Hudson Bay and environs: Implications for Paleoproterozoic assembly of Laurentia

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Summary

The Hudson Bay Lithospheric Experiment (HuBLE) is an international initiative to investigate the lithospheric architecture of the Hudson Bay region using geophysical observatories deployed around the periphery of the Bay. More than 30 portable broadband seismograph stations form a major component of HuBLE and have been operating since 2006-2007. Data from these sites are currently being analyzed using a variety of techniques. This paper focuses on the regional tectonic framework and reports some of the initial results from HuBLE, based on analysis of Rayleigh-wave dispersion and application of so-called S-Receiver Functions. Our analysis confirms the presence of thick (up to ~ 260 km), high-velocity lithosphere and suggests that the lithosphere-asthenosphere boundary (LAB) is relatively sharp. S-receiver functions indicate that shallow dipping mid-lithospheric discontinuities are common within this arc-acretionary tectonic setting, providing support for the formation of cratonic lithosphere by accretion of subducted slabs.

Tectonic subdivisions from potential-field interpretation

There is generally an excellent correlation between regional magnetic anomaly patterns and major geological structures on the Canadian Shield and contiguous platform regions. Fig. 1 shows an interpretation of tectonic domains based on magnetic data (Eaton and Darbyshire, 2010). In summary, regionally extensive magnetic highs in the Archean western Superior Province define the Kenoran magnetic fabric (K), which terminates abruptly against a north-south linear band of negative magnetic values that delineates the Thompson belt (TB) of the Trans-Hudson orogen. Similarly, magnetic anomalies in the Superior craton of northern Quebec, called the Ungava fabric (U), terminate abruptly against a regional magnetic low within the Paleoproterozoic Cape Smith belt (CSB). The Belcher domain (B) is a U-shaped region of magnetic lows in southeastern third of Hudson Bay, enclosing a wedge-shaped region named the Severn domain (SD) containing intense positive magnetic anomalies. The central Hudson Bay domain (CHBD) is a belt of magnetic highs that truncates the Severn domain and appears to merge into the Wathamun batholith (WB) near the western shore of Hudson Bay. The Narsajuaq Arc (NA) has oceanic affinity and appears as a recognizably distinct zone north of the CSB and east of the CHBD.

Eaton and Darbyshire (2010) correlate the CHBD with the Wathamun batholith, a giant continental magmatic arc formed by Paleoproterozoic subduction of the Pacific-scale Manikewan Ocean and suggest that the primary suture between the Superior plate and the Churchill plate is represented by the Owl River Shear Zone (ORSZ). The southeastern region of Hudson Bay, including SD and BD, is interpreted as island-arc domains that accreted to the Superior plate prior to terminal collision, in contrast to the Reindeer Zone (RZ) of Saskatchewan

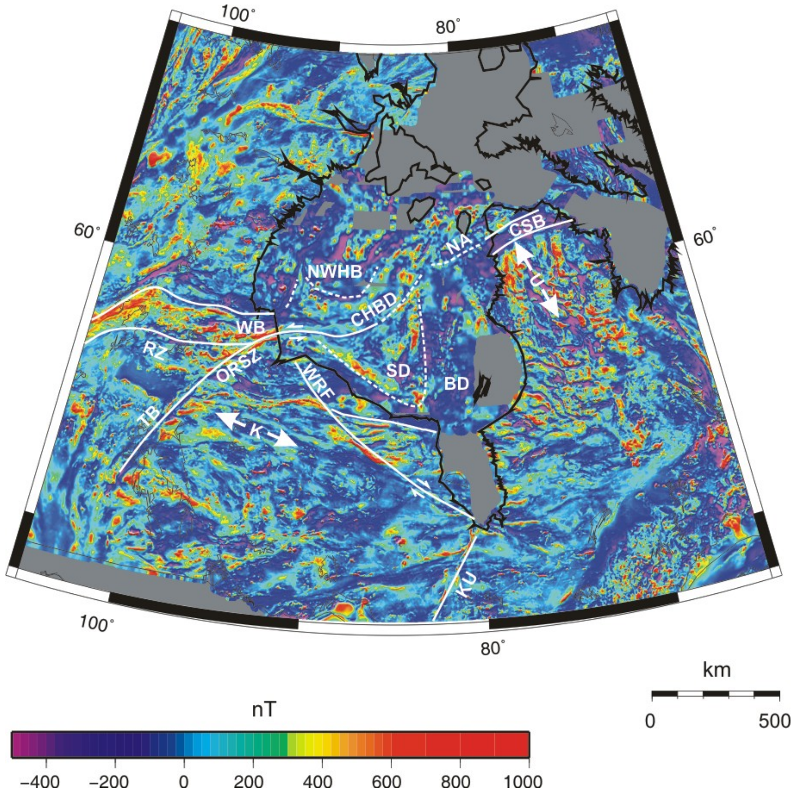

Fig. 1. Total-field magnetic anomaly map of the Hudson Bay region, showing inferred tectonic subdivisions (after Eaton and Darbyshire, 2010). KU is the Kapuskasing Uplift and WRF is the Winisk River Fault; other abbreviations are defined in the text.

and Manitoba that accreted to the Churchill plate. The present-day configuration of SD and BD within Hudson Bay reflects extrusion processes controlled by the double-indentor geometry of the Superior craton (Gibb, 1983). The northwest Hudson Bay (NWHB) domain may correlate with the Archean Hearne craton, located to the west, or it may be a distinct crustal block analogous to the Sask craton (Eaton and Darbyshire, 2010).

Surface-wave analysis

Darbyshire and Eaton (2010) characterize the nature and thickness of the seismological lithosphere beneath Hudson Bay based on dispersion analysis of fundamental-mode Rayleigh waves along two-station paths crossing the region. The dispersion data sample a period range of ~15-220 seconds, which is primarily sensitive to depths from the mid crust to about 300 km depth. Monte-Carlo modelling is used to estimate 1D shear wave velocity profiles for each of the dispersion curves. In general, the models are characterized by a high-velocity 'lid', interpreted as the seismological expression of subcontinental lithosphere, beneath which velocities decrease gradually toward global reference values. The lithosphere-asthenosphere boundary (LAB) correlates approximately with the base of the lid, and occurs in the range 185-260 km beneath the Hudson Bay region. Maximum lithospheric shear wave velocity perturbations are 4.5-7.3% above global reference values. Figure 2 shows representative examples of 1D velocity profiles for 4 paths across Hudson Bay. In each of these cases, the base of the high-velocity lid (i.e., the depth at which the velocity model merges with the global model) occurs at depths greater than ~200 km.

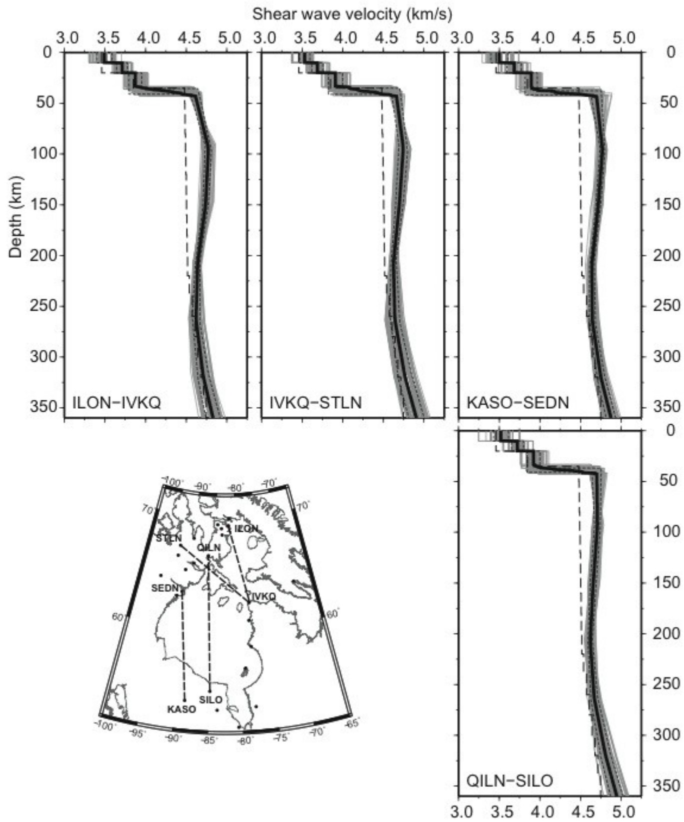

Fig. 2. Representative 1D shear wave velocity models for Hudson Bay, based on inversion of Rayleigh-wave dispersion measurements (after Darbyshire and Eaton, 2010). The dashed line is the global reference model ak135, modified to fit the crustal thickness of the Hudson Bay region. Inferred lithospheric thickness is in the range of 220-240 km.

S-receiver functions

The S-receiver function (SRF) method is used to image discontinuities beneath a receiver based on Sp converted phases that form precursors to teleseismic S. It is better suited to mapping the LAB than conventional (P) receiver functions, because the latter often suffer from strong crustal multiple reflections in the range of ~10-25s (depending upon crustal thickness) in the P coda. Although S waves have lower frequencies than P waves due to their greater attenuation in the mantle, they are well suited for gradient transition zones or boundaries, which may be the case for the LAB.

Figure 3 shows a SRF profile for 5 broadband seismograph stations, constructed using 94 events of magnitude 6 and greater. Many of the SRF traces were noisy and removed prior to depth conversion and stacking. The polarities of the SRF's were reversed so that the Moho appears as a positive event, in which case the LAB is expected to be expressed as a weak negative event. In our interpretation, the LAB deepens from ~ 200 km at the Shield margin (FRB) to more than 250 km in the Hudson Bay region, consistent with the surface-wave results. At Churchill (FCC), no clear LAB is observed. Based on synthetic seismograms computed using 1D models derived from the surface-wave, a sharp (< 20 km thick) LAB transition is required to fit the observed LAB signal at other stations.

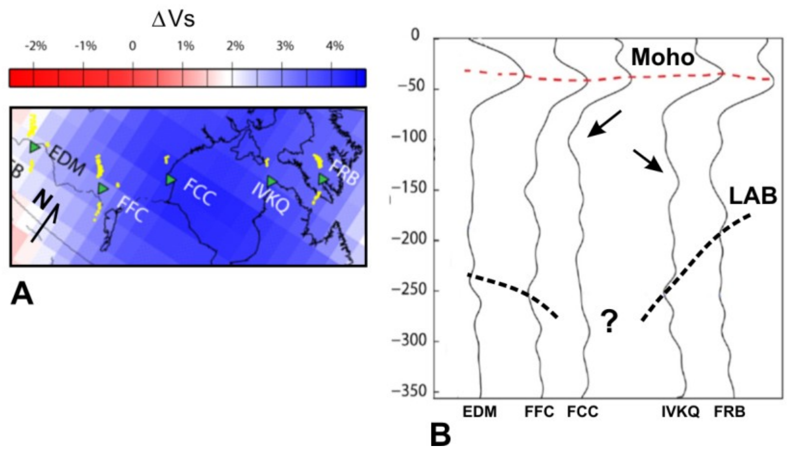

Fig. 3. S-Receiver function profile from Edmonton (EDM) to Iqaluit (FRB), extending a distance of approximately 2600 km. Station locations (A) are plotted as green triangles on a model for shear-wave velocity perturbation at 225 km depth (Grand, 2002). Yellow symbols indicate Sp piercing points at 150 km depth. Stacked SRF profile (B) shows the LAB and interpreted dipping mid-lithospheric discontinuities (arrows).

Conclusions

Careful analysis of magnetic anomaly data in Hudson Bay suggests that the giant Wathamun batholith likely continues across the Bay, astride the primary suture between the Churchill and Superior plates. The Severn and Belcher domains in the southeastern segment of Hudson Bay are interpreted as island arc terrane and/or deformed passive margin terranes that accreted to the Superior before collision, in contrast to the Reindeer Zone. Analysis of teleseismic surface waves confirms the presence of a thick, high velocity mantle lid beneath Hudson Bay, but does not reveal any clear seismological distinction between Archean and Proterozoic cratonic lithosphere. S-receiver functions (SRFs) provide a tool for mapping the lithosphere-asthenosphere boundary (LAB), which we interpret to deepen to > 250 km beneath the Trans Hudson orogen in the core of Laurentia. If our inferred LAB depth is correct, shallower discontinuities are present within the cratonic mantle, in the 100-200 km depth interval. Although the sparse station sampling and obliquity of the SRF profile preclude a quantitative estimation of dip, these discontinuities cannot be horizontal and are likely dipping at a shallow angle. Given the arc-accretionary tectonic setting and prevalence of giant, subduction-related batholiths (e.g., Wathamun near FCC and Cumberland near FRB) associated with Paleoproterozoic assembly of Laurentia, we interpret these mid-lithospheric discontinuities as evidence for formation of cratonic lithosphere by accretion of subducted slab material.

Acknowledgements

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