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Seismic imaging of the lithosphere beneath Hudson Bay: Episodic growth of the Laurentian mantle keel

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ABSTRACT

The Hudson Bay basin in northern Canada conceals one of the major collisional zones of the Canadian Shield, the Trans-Hudson Orogen (THO), which marks the Paleoproterozoic collision between the Archean Superior and Western Churchill cratons at ~1.9–1.8 Ga. Improved knowledge of upper mantle structure beneath the region is essential to establish the nature of the THO, specifically whether Himalayan-style plate tectonics operated in Paleoproterozoic times. Detailed seismological constraints on lithospheric architecture are also required to advance our understanding of the mechanism and timing of keel formation.

We use surface wave tomography to illuminate new details of the lithospheric architecture of the Hudson Bay region, resolving both seismic wavespeed and azimuthal anisotropy. Phase velocity maps are calculated from fundamental-mode Rayleigh wave dispersion curves, then used to construct a 3D model exploring upper mantle structure to depths of ~300 km. Fast shear wavespeeds suggest a lithospheric thickness varying from ~180 km to almost 280 km beneath the Hudson Bay region. The new study confirms previous inferences that there is no correlation between crustal ages and lithospheric thickness.

Patterns of shear wavespeed and azimuthal anisotropy indicate a layered lithosphere. In the uppermost mantle, both the highest velocities and the anisotropic fast directions wrap around the Bay. This structure is likely related to the formation processes of the Paleozoic intracratonic basin. At greater depth (~70–150 km) we resolve two high-wavespeed cores separated by a relatively narrow near-vertical lower-velocity curtain. This internal architecture is suggested to result from the terminal phase of a modern-style plate-tectonic collision between the Archean Superior and Churchill cratons during the Trans-Hudson orogeny, entrapping juvenile Proterozoic material.

The lower lithosphere (≥160 km depth) has a relatively homogeneous wavespeed structure across the region, with distinct patterns of anisotropy closely resembling the subsurface geometry of the THO. We interpret this basal layer as juvenile or reworked material accreted to the base of the existing cratonic lithosphere during or soon after the Trans-Hudson orogeny. The formation of the Laurentian keel thus likely occurred in multiple phases, with a basal layer developing in post-Archean times, during the THO.

1. Introduction

Hudson Bay, Canada, is a large inland sea that masks a significant proportion of the Trans-Hudson Orogen (THO), a 1.8 Ga Paleoproterozoic collision that marked the final stages of assembly of central Laurentia (e.g. Hoffman, 1988; Eaton and Darbyshire, 2010). The THO is proposed to have been a tectonic event of similar spatial extent and deformation rate to the Himalayan–Tibetan–Karakoram orogen of Asia (e.g. St.-Onge et al., 2006). Whether modern-style plate tectonics operated at this time is debated, however (e.g. Stern, 2005; Hamilton, 2003, 2011; Thompson et al., 2010; Bastow et al., 2011), as are processes responsible for development of a thick cratonic keel. An improved knowledge of present-day lithospheric structure is thus vital to understand the formation and evolution of the central Laurentian keel.

Himalayan-style collisional plate tectonics would likely result in the development of plate-scale deformation fabrics, manifest as measurable seismic anisotropy. New constraints on seismic wavespeed beneath the region also have the potential to distinguish between the Archean cores of Laurentia and Proterozoic material trapped between the cratonic nuclei during Trans-Hudsonian orogenesis. Some studies propose that the highly depleted Archean lithosphere is characterised by inherently faster seismic

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wavespeeds than younger Proterozoic mantle (e.g. Lebedev et al., 2009), while others suggest that there is little clear correlation between inferred lithospheric age and seismic characteristics (e.g. Fishwick et al., 2005). The timing and nature of keel development are likewise under question; is the entire thickness of the present-day keel a relict of initial craton formation in the Archean (e.g. Sleep, 2003), or do later tectonic processes play a role, resulting in vertically stratified lithosphere? Support for the latter hypothesis comes from converted-phase seismic studies (e.g. Rychert and Shearer, 2009; Abt et al., 2010) and continent-scale tomography (Yuan and Romanowicz, 2010) which yield evidence for a mid-lithospheric discontinuity, but detailed constraints on keel architecture are lacking.

To address these issues we present a surface-wave tomographic study of seismic wavespeed and azimuthal anisotropy using data from seismograph networks that encircle Hudson Bay. By placing new constraints on the deep lithospheric architecture of Hudson Bay, we show that the region retains a strong signature of THO tectonics. The internal structure of the present-day lithospheric keel suggests multiple stages of formation of a layered cratonic lithosphere, not confined to Archean times.

1.1. Tectonic setting

The Hudson Bay region (Fig. 1) is a complex collage of Archean cratons and Proterozoic terranes whose tectonic history is dominated by the THO, representing a vast collision zone between the Archean Superior craton and Western Churchill Province following the closure of the Pacific-scale Manikewan Ocean (Eaton and Darbyshire, 2010). The Superior craton wraps around the south and east of Hudson Bay. Its “double-indentor” shape (Gibb, 1983) is thought to be largely responsible for the complexity and

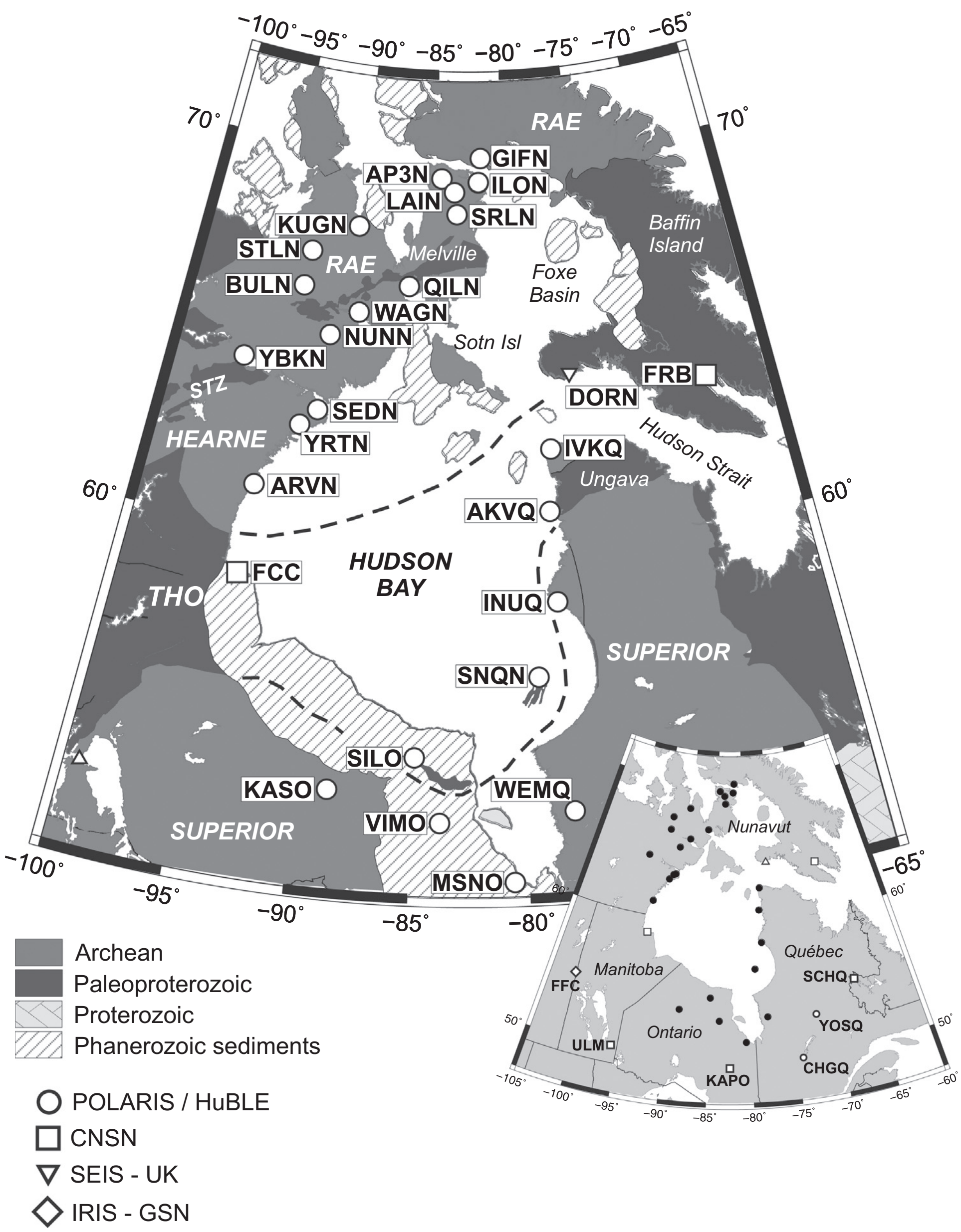

Fig. 1. Main map: simplified tectonic map of Hudson Bay, plus seismograph stations used in this study. THO—Trans-Hudson Orogen, STZ—Snowbird Tectonic Zone, Soton Isl—Southampton Island. Inset: wider view of central and eastern Canada, showing peripheral seismograph stations used to enhance the azimuthal path coverage in the Hudson Bay region.