Teleseismic studies of the Canadian landmass: Lithoprobe and its legacy[1,2]

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Abstract: Although teleseismic research was only modestly represented within the Lithoprobe program, the analysis of deeper lithospheric structure beneath Canada using teleseismic methods has intensified in the past decade. This development is due in large part to a legacy of improved understanding of shallower lithospheric structures afforded by Lithoprobe. Most recent teleseismic experiments have been conducted in regions lying within Lithoprobe transects and coverage is particularly good in the Slave Province, southern and eastern Ontario, and southwestern British Columbia. A number of key results have arisen out of this collective body of work. Studies on the Slave Province and environs have placed strong constraints on the origin of the high-velocity continental root that underlies most of the Canadian Shield. Fine-scale, anisotropic stratigraphy in this region has been definitively tied to underplated lithosphere, indicating that shallow subduction has played a fundamental role in craton stabilization. Modification of continental lithosphere by the underlying convecting mantle has been extensively documented in the southeastern Canadian Shield and Slave Province, yielding insights into the forces driving plate motion and those that induce intraplate volcanism. Teleseismic investigations in British Columbia point to the importance of water in controlling the structure and dynamics of subduction zones, but have rekindled controversy concerning the location and characterization of the downgoing oceanic plate.

Résumé : Bien que la recherche télésismique n'ait été que peu représentée dans le cadre du programme Lithoprobe, l'analyse, par méthodes télésismiques, de la structure lithosphérique profonde sous le Canada, s'est intensifiée au cours de la dernière décennie. Ce développement est en grande partie dû à une meilleure compréhension des structures lithosphériques à faible profondeur qu'à permis Lithoprobe. Les plus récentes expériences télésismiques ont été réalisées dans des régions à l'intérieur des transects Lithoprobe et la couverture est particulièrement bonne dans la Province des Esclaves, le sud et l'est de l'Ontario et le sud-ouest de la Colombie-Britannique. Plusieurs résultats clés ont découlé de cet ouvrage collectif. Des études dans la Province des Esclaves et aux environs balisent solidement l'origine de la racine continentale à haute vitesse sur laquelle repose le Bouclier canadien. La stratigraphie, à grains fins et anisotrope, dans cette région a été définitivement reliée à une lithosphère sous-plaquée, indiquant que la subduction peu profonde a joué un rôle fondamental dans la stabilization du craton. La modification de la lithosphère continentale par le manteau sous jacent en convection a été documentée en détail dans le sud-est du Bouclier canadien et dans la Province des Esclaves, donnant des indications des forces qui font bouger les plaques et celles qui causent du volcanisme intraplaque. Les études télésismiques en Colombie-Britannique soulignent l'importance de l'eau dans le contrôle de la structure et de la dynamique des zones de subduction, mais elles ont ranimé la controverse concernant l'emplacement et la caractérisation de la plaque océanique descendante.

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Introduction

Over the past two decades, teleseismic methods have emerged as an essential means for investigating lithospheric and upper mantle structure beneath continents. The Canadian landmass is no exception and a considerable number of studies has now been undertaken in various regions of the country. The purpose of this contribution is to provide a summary of those studies that formed part of Lithoprobe transects, as well as successor studies, and to emphasize the constraints they collectively afford in piecing together our understanding of the evolution of the continent. We shall begin by outlining some defining concepts relevant to teleseismic studies and providing a brief historical context.

The teleseismic arsenal

Seismological techniques suitable for study of continental lithospheric structure can be generally classified into one of

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Fig. 1. (A) Location of Lithoprobe transects with respect to upper mantle *S*-wave velocity anomalies at 150 km depth from the model of van der Lee and Frederiksen (2005). SNORCLE, Slave – Northern Cordillera Lithospheric Evolution; SC, Southern Cordillera; AB, Alberta Basement; THOT, Trans-Hudson Orogen Transect; WS, Western Superior; GL, Great Lakes International Multidisciplinary Program on Crustal Evolution; KSZ, Kapuskasing Structural Zone; AG, Abitibi–Grenville; ECSOOT, Eastern Canadian Shield Onshore–Offshore Transect; LE, Lithoprobe East. (B) The names and locations of major broadband field experiments or campaigns and Lithoprobe seismic reflection lines plotted on a map of surface geology. Stations referred to in text are individually named: INK, DAWY, WHY, YKA, LKTN, MOBC, PNT, WALA, EDM, RSON, KAPO, SADO, GAC, LMN, DRLN, FRB, MBC, ALE. Transects and projects: as in (A), plus APT89, Archean–Proterozoic Transect 1989; BATHOLITHS, two margin-perpendicular lines traversing the Coast Mountains batholith; SATE, Southern Alberta Teleseismic Experiment; CANOE, Canadian North West Experiment; FED NOR, extension of POLARIS network through support from Federal Economic Development Initiative for Northern Ontario; HUBLE, Hudson Bay Lithospheric Experiment; TWIST, Teleseismic Western-Superior Transect. CSN, Canadian Seismograph Network; POLARIS, Portable Observatories for Lithospheric Analysis and Research Investigating Seismicity. GSLsz, Great Slave Lake shear zone.

two categories. "Transmission" techniques focus on the delineation of large-scale (relative to dominant wavelength) velocity variations in the subsurface through the analysis of travel-time (or phase) variations of a particular wavetype. "Scattering" techniques, in contrast, are used to interrogate shorter scale variations in Earth's subsurface elastic properties through the generation of secondary reflected or converted waves. This categorization applies to both active- and passive-source studies. Near-vertical seismic reflection profiling is a scattering technique that has spearheaded studies at all of the Lithoprobe transects by allowing surface geological information to be extrapolated to depth in detailed images of crustal reflectivity. Crustal refraction profiling, a transmission approach, has also been performed over many transects to provide complementary control on absolute velocities. The principal teleseismic techniques used to deliver information on subsurface structure are body wave tomography, surface wave dispersion tomography, SKS splitting, and receiver function analysis. The first two approaches can be considered transmission in nature whereas the receiver function analysis relies on the identification of scattered or, more specifically, converted waves. SKS splitting involves both transmission and scattering elements. It relies intrinsically on the forward scattering of quasi-*S*-modes, but it also provides integral constraints on bulk anisotropic fabric that can be related to deformation within the upper mantle.

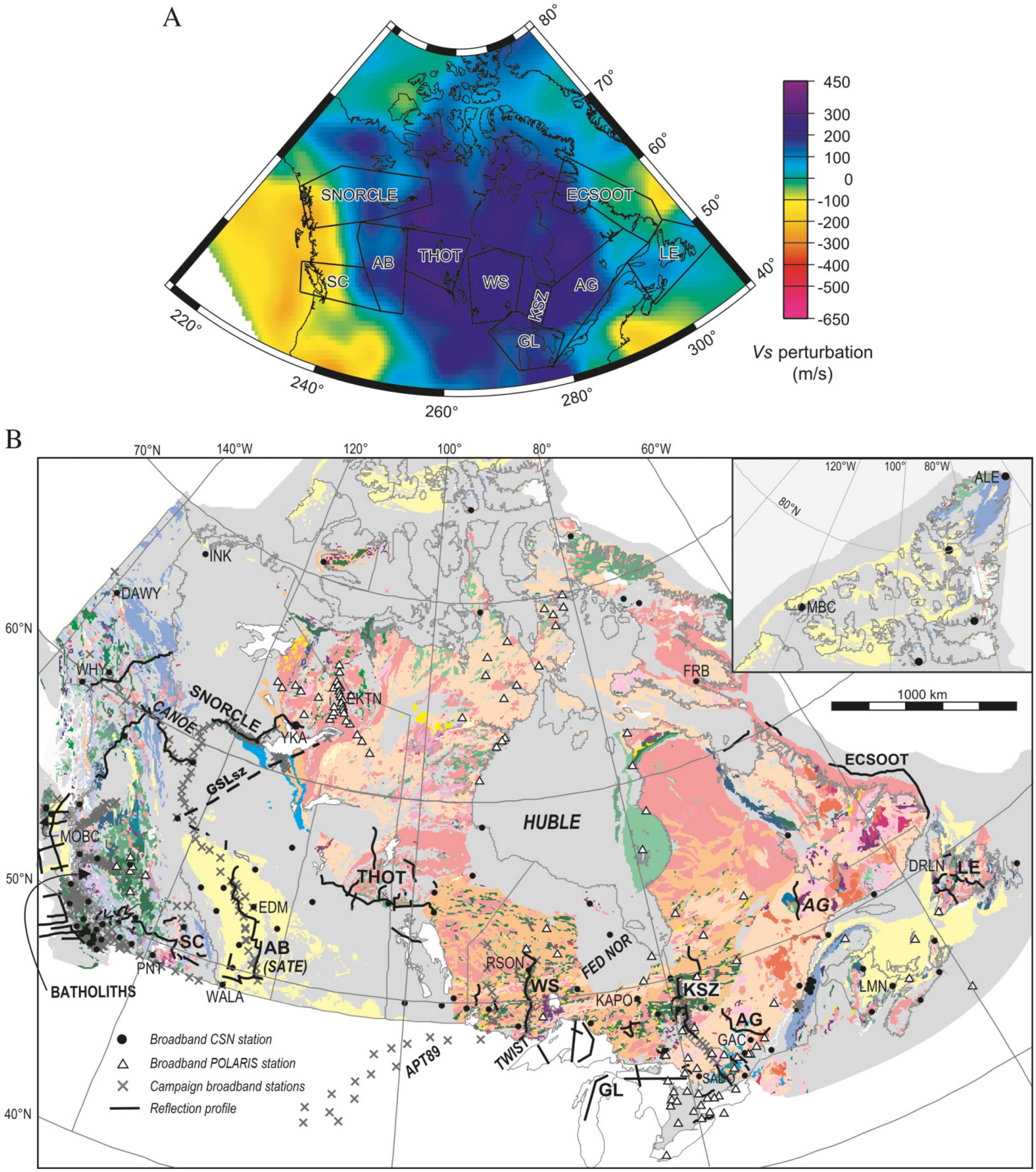
Teleseismic methods are well suited to the study of stable continental interiors because they employ earthquakes at epicentral distances $>30^\circ$ and so are not critically dependent on the presence of nearby, seismically active plate boundaries. The large propagation distances between source and receiver cause an attenuation of high frequencies within the teleseismic wavefield. Consequently, teleseismic waves have lower resolving capability than wavefields produced by active sources, but they hold the advantage that their sensitivity is not limited to dominantly crustal levels (as is the case for waves generated by active sources). Moreover, the bandwidth of broadband recordings is usually sufficient to identify signal polarity of scattered waves, which, in turn, allows the sign of velocity contrast (i.e., positive or negative) across an interface to be properly interpreted. This task is often considerably more difficult for deep seismic reflection data from lower crustal or upper mantle levels (e.g., Eaton et al. 2000).

Early transmission studies

Among the earliest transmission teleseismic studies dealing with lithospheric structure across Canada is that of Brune and Dorman (1963). These authors analyzed dispersion curves of Rayleigh and Love waves traversing paths across the Canadian Shield to assemble representative one-dimensional models using long-period analogue stations from the Canadian and Worldwide Standardized Seismograph networks. They noted that average upper mantle *S*-velocities were higher than those for any other continental region studied to that time, an observation that remains true to this day. More than a decade later, the measurement of short-period *P*-wave (Buchbinder and Poupinet 1977) and long-period *S*-wave delay times (Wickens and Buchbinder 1980) from the analogue Canadian network allowed some lateral variation in velocity to be documented, notably, substantially lower velocities in British Columbia and more modest decreases into the Appalachian region. With the installation of the modern digital, broadband Canadian National Seismograph Network (CNSN) by the early 1990s, data access and sophistication of analysis techniques (e.g., Aki et al. 1977; Woodhouse and Dziewonski 1984) had improved considerably over earlier studies. Digital data are routinely used in global and continental scale tomographic inversions employing both body waves (e.g., Grand 1994; Grand et al. 1997) and surface waves (e.g., Frederiksen et al. 2001; van der Lee and Frederiksen 2005). These and other studies show general agreement in structure within the upper mantle below the Canadian landmass, most notably a well-developed, high-velocity mantle root centered beneath Hudson Bay and a sharp transition in velocities across the Cordillera (Fig. 1).

Early scattering studies

As for seismic reflection profiling, analysis of scattered teleseismic body waves for lithospheric structure relies predominantly on the interaction of near vertically propagating waves with predominantly near-horizontal stratification. Unlike active-source studies, however, the incident teleseismic wavefield (usually direct *P* but sometimes other phases, e.g., PP, *S*, or SKS) impinges on Earth's stratification from below (versus above) and can be considered to be approximately planar by the time it interacts with receiver-side structure (versus a quasi-spherical wave generated by a point source). Most teleseismic work focuses on the identification and characterization of *P*-to-*S* conversions and employs the so-called receiver function approximation (Vinnik 1977; Langston 1979) to remove the effect of the earthquake source function. Early studies in Canada include the work of Jordan and Frazer (1975), who investigated the Moho beneath east-



ern Canada using *S*-to-*P* conversions recorded at analogue long-period stations, and that of Langston (1981), who first identified, using *P*-to-*S* conversions, the low-velocity zone beneath Vancouver Island that has since become the topic of some controversy (see section "Southern Cordillera"). Broadband, digital upgrading of the CNSN allowed point sampling of subsurface structure at individual stations across Canada to become a more practical exercise. Early receiver function studies employing the CNSN targeted crustal (Cassidy 1995*a*, 1995*b*) and transition zone (Bostock and Cassidy 1995*a*; Bostock 1996) discontinuities and, although sparsely sampled, allowed some direct associations between structure and tectonic environment to be made. Following the documentation of mantle anisotropy by SKS splitting by Vinnik et al. (1984) and its popularization in the west by Silver and Chan (1991), measurements of fast polarization direction and splitting delay for network stations have been compiled and augmented on several occasions (e.g., Bostock and Cassidy 1995*b*; Currie et al. 2004; Evans et al. 2006; Frederiksen et al. 2007).

Portable broadband seismology

The station distribution afforded by the national network (both the CNSN and its analogue precursors) enables surface wave dispersion and tomographic studies with resolution in the order of hundreds to thousands of kilometres, but detailed work with more immediate relevance to surface geology requires the deployment of portable broadband arrays. The potential of such arrays was first demonstrated in Europe with the Network of Autonomously Recording Seismographs (NARS) array (Nolet and Vlaar 1982) designed by Guust Nolet and co-workers. Its success provided motivation for the establishment of the IRIS-PASSCAL (Incorporated Research Institutions for Seismology - Program for Array Seismic Studies of the Continental Lithosphere) soon after, which has provided instrumentation for countless studies both within North America and internationally. In the decade between 1985 and 1995, Canadian seismology was focused predominantly upon continental seismic profiling through Lithoprobe with only minor emphasis on portable broadband studies. Robert Ellis (with then Ph.D. student John Cassidy) at the University of British Columbia procured three vintage Guralp instruments in the late 1980s, which were used to complement information from the imaging of the Juan de Fuca slab with seismic reflection performed as part of the first (Southern Cordillera (SC)) Lithoprobe transect in 1984. Over the following years, individual researchers at several universities and the Geological Survey of Canada had amassed sufficient instruments for more ambitious projects and eventually formed a consortium in 2000 (Eaton et al. 2005), known as POLARIS (Portable Observatories for Lithospheric Analysis and Research Investigating Seismicity), through which both satellite telemetered and autonomously recording seismographs became available for use to the national geophysical community.

Paper organization

In the following section, we briefly review the location of each of the 10 Lithoprobe transects with respect to the large-scale velocity structure underlying the Canadian landmass. We follow with a transect-by-transect summary of teleseismic studies undertaken in each of these regions and the major scientific findings that have resulted. We conclude with some general remarks concerning improvements in our understanding of continental evolution and open questions for future research.

Teleseismic studies and Lithoprobe transects

In Fig. 1*a*, we display the locations of the Lithoprobe transects superposed upon upper-mantle shear velocity perturbations at 150 km depth, as determined from waveform inversion of surface wave data recorded at Canadian and US stations (van der Lee and Frederiksen 2005). The dominant structure evident at this scale is the large, high-velocity cratonic root centered southwest of Hudson Bay and underlying a majority of the central portion of the continent, with velocities averaging 0.2 km/s higher than those for typical 1-dimensional (1-D) Earth models. Structure within this high-velocity region is weak, although, curiously, there is some evidence for slightly diminished velocities beneath the central Slave Province, northern Alberta, and the northwestern coast of Hudson Bay – Boothia Peninsula region. Given their present location in the continental interior, these diminished velocities are more likely due to compositional variations than increased temperatures. In contrast, velocities beneath coastal British Columbia are lowest, $\sim$0.5 km/s slower than cratonic values. As remarked by Frederiksen et al. (2001), the transition between the Cordilleran and cratonic regimes is sharp and appears in places to occur over length scales of no more than a few hundred kilometres. In Canada, this transition appears to lie parallel to, but slightly seaward of, the Rocky Mountain deformation front. At these scales, the signature of subduction off the west coast is not evident. The eastern boundary of the craton is more diffuse, and mantle underlying the Mesozoic terranes of Atlantic Canada is characterized by velocities that are intermediate to those of the craton and Cordilleran domains (van der Lee and Frederiksen 2005). A marked indentation or “divot ”of relatively low velocity penetrates into the Great Lakes region from the New England seaboard and has been associated with the plume track responsible for the Great Meteor Hotspot (van der Lee and Nolet 1997).

The majority of Lithoprobe transects follow the southern border of Canada and provide a near continuous traverse from the Pacific to Atlantic coasts (see Fig. 1*a*, 1*b*). Most transects have been sampled by teleseismic surveys to varying degrees. Southwestern British Columbia (Southern Cordillera transect), the Slave Province (SNORCLE transect), and southern Ontario (Great Lakes International Multidisciplinary Program on Crustal Evolution (GL) and Abitibi–Grenville (AG) transects) are particularly well sampled, for different reasons (see Fig. 1*b*). Vancouver Island and the British Columbia lower mainland are well instrumented due to elevated seismic hazard, and the southern Ontario region, although subject to lesser (though significant) seismic threat, is now also well instrumented as it hosts a substantial proportion of the nation’s population, industry, and infrastructure (e.g., nuclear power plants). The Slave Province is the site of Canada’s burgeoning diamond industry, which has provided strong financial and logistical backing to teleseismic work in that region to gain greater insight into the mantle diamond reservoir and the origin of kimberlites. Reconnaissance teleseismic work has been performed over the Prairie Provinces and western Ontario (Alberta Basement (AB), Trans-Hudson Orogen (THOT), and Western Superior (WS) transects) but additional work is required to address the nature of finer scale structures. Beyond analysis of data from permanent network (CNSN) stations, results of ongoing teleseismic studies covering parts of eastern transects (Eastern Canadian Shield Onshore–Offshore Transect (ECSOOT), Lithoprobe East (LE), and the eastern portions of the Abitibi–Grenville) have yet to be published.

Southern Cordillera

The region encompassed by the Southern Cordillera transect has the longest history of teleseismic investigation in the country due to (*i*) the tectonic setting, which provides opportunities unique in Canada for addressing fundamental questions related to the dynamics, structure, and evolution of convergent margins; and (*ii*) the (relatively) dense sampling of permanent broadband stations of the Canadian National Seismograph Network in this region, whose primary purpose is to monitor regional seismicity. Perhaps the most enduring and controversial structural target has been the downgoing Juan de Fuca Plate, whose position and characterization remain contentious issues.

The discovery of near-planar layering dipping landward beneath southern Vancouver Island represented an important early result from the active-source studies undertaken over the transect (Green et al. 1986). The most prominent of these layers, the so-called "E-layer," was originally identified as the top of the downgoing plate but was later interpreted to reside above the plate (e.g., Drew and Clowes 1990; Hyndman 1988). Coincident magnetotelluric sounding (Kurtz et al. 1986) indicated that the E-layer is also highly electrically conductive, leading to the inference that it is porous and saturated with saline fluids. Teleseismic receiver function analysis of data from a five-station array of broadband seismographs (Cassidy and Ellis 1991, 1993) corroborated these earlier studies by demonstrating that the E-layer is characterized by low *S*-velocities and, in particular, a high Poisson's ratio. Later arriving, weaker signals were inferred to represent *P*-to-*S* conversions from the underlying Juan de Fuca plate, including crust and mantle. A similar interpretation was invoked for two northern Vancouver Island stations at latitudes south of 50.5°N (Cassidy et al. 1998). In contrast, three stations north of this latitude appear to display more typical continental crustal signatures, a change that these authors inferred to demarcate the northern limit of the Cascadia subduction zone.

The interpretation that the subducting plate resides beneath the E-layer has, until recently, found general acceptance. It is based largely on the observation that Wadati–Benioff seismicity, which has been interpreted as due to prograde metamorphic reactions in oceanic crust, tends to lie near the base or below the E-layer in most instances. Results from more recent teleseismic studies have, however, called this interpretation into question. These studies have exploited a larger and more densely spaced array of seismographs that includes both CNSN and POLARIS instruments (Nicholson et al. 2005; Audet et al. 2009) and have mapped the E-layer from the west coast of southern Vancouver Island to depths of ~50–60 km below Georgia Strait (Fig. 2). On the basis of comparable signatures observed to the south beneath Oregon (Bostock et al. 2002) and at other subduction zones worldwide, these authors have argued that the E-layer must coincide with the oceanic crust of the downgoing plate, as originally suggested by Green et al. (1986). If valid, this interpretation implies that pore pressures within the oceanic crust are near-lithostatic and that the plate boundary is largely impermeable (Audet et al. 2009). It does, however, raise puzzling issues concerning the nature of shallow Wadati–Benioff earthquakes in the region, which must then be located dominantly within the oceanic mantle rather than oceanic crust. Shallow seismicity may, accordingly, be attributable to dehydration of mantle serpentine. Serpentine is also inferred to exist at shallow levels within the forearc mantle wedge, produced by water expelled by eclogitization of the underlying oceanic crust. The combined presence of water and serpentine serves to reduce mantle velocities to the extent that a seismic Moho (i.e., a well-defined velocity increase to >7.8 km/s) is no longer evident (Bostock et al. 2002; Nicholson et al. 2005; see Fig. 2).

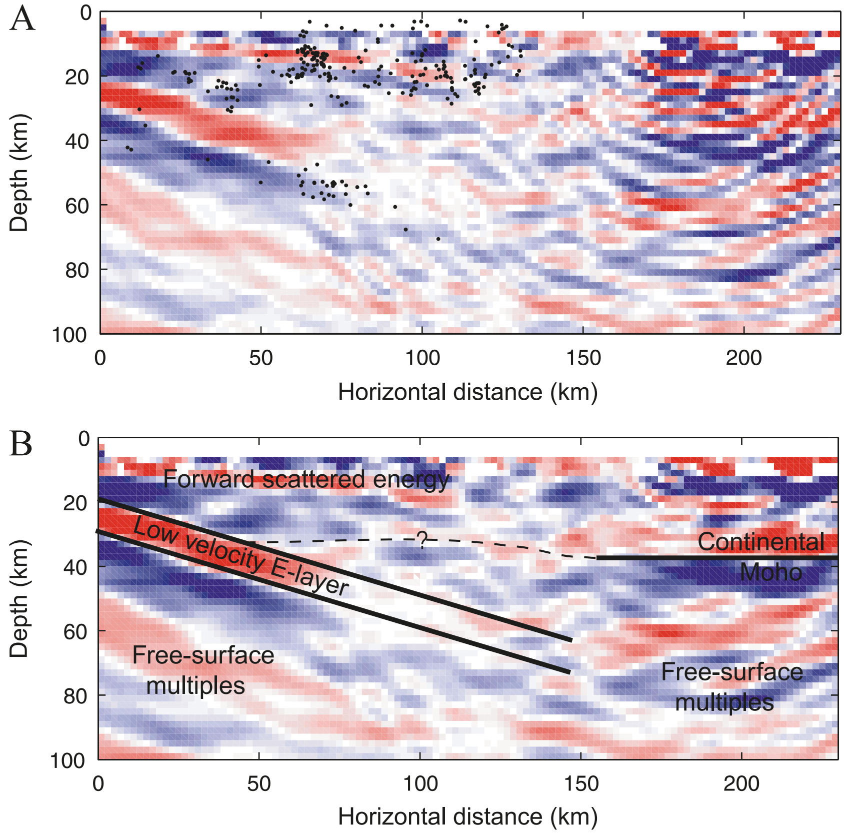
The signature of the subducting plate can be traced to still greater depths through the use of *P*-wave traveltime tomography. Using a compilation of travel times measured from short-period stations of the Western Canada Telemetered Network and the Pacific Northwest Seismograph Network, Bostock and VanDecar (1995) mapped the thermal signature of the downgoing Juan de Fuca Plate as a 3% high-velocity slab-like anomaly that bends in concert with the coastline. The excess volume forced beneath the concave plate boundary appears to be accommodated through the development of a fold structure beneath southwestern British Columbia. Moreover, the deep slab dips more steeply beneath British Columbia than it does to the south beneath Washington.

Analysis of SKS splitting has afforded additional insight into mantle dynamics in Cascadia. An early study by Bostock and Cassidy (1995*b*) first noted the margin-perpendicular orientation of fast direction for most stations in the region, a situation that is unusual in the global context (see Park and Levin (2002) and references therein). The dip-parallel direction was interpreted to reflect olivine *a*-axis alignment created by plate-driven mantle circulation. The margin-perpendicular pattern of fast polarization direction has persisted as data from additional, more recently deployed stations have been compiled (Currie et al. 2004). Moreover, this alignment pattern contrasts sharply with that determined for the overlying crust as recorded by the splitting of regional *S*-waves (Cassidy and Bostock 1996; Currie et al. 2001), thereby affording independent, corroborative evidence supporting the case for relatively weak coupling between the Juan de Fuca and North American plates (Wang 2000).

A POLARIS–BC experiment was completed on northern Vancouver Island in 2008, and involved some 20 three-component stations arranged in a cross-shaped array with dip- and strike-parallel arms. Audet et al. (2008) applied receiver function analysis and body-wave tomography to this data set to image the complex morphology of the Juan de Fuca – Explorer plate system at subcrustal depths beneath northern Vancouver Island. They noted a clear signature of subducted material extending as far northeast as Brooks Peninsula at shallow depths, and across the Georgia Strait and British Columbia mainland to 300 km depth within the mantle. Complexity in the morphology of the subducting plate systems was attributed to subduction of the Juan de Fuca ridge combined with toroidal flow around the slab edge, in agreement with other geophysical and geological data. The authors proposed a model wherein thermomechanical erosion of the slab edge and slab thinning at shallow levels retard convergence with North America and eventually lead to plate capture.

Farther north along the central British Columbia coast, the BATHOLITHS experiment (see Fig. 1*b*) comprised two

Fig. 2. (*a*) High frequency, teleseismic migration image from scattered Ps phases across Vancouver Island, northwestern Washington, and the British Columbia lower mainland, from Nicholson et al. (2005). Red and blue regions indicate low and high *S*-wave velocity contrasts, respectively, whereas dots indicate earthquake locations. (*b*) Lower frequency image with interpretation of structural features.



margin-perpendicular lines of ~20 seismometers each that traverse the Coast Mountains batholith (CMB). Calkins et al. (2009) have analyzed the times of crustal conversions on receiver functions from BATHOLITHS data to infer crustal composition along the two profiles. They argue that much of the CMB cannot possess a significant thickness of high-velocity residual root, and suggest that the Moho in the region is a tectonic feature rather than a petrologic transition from granitoid arc rock to complementary ultramafic residual.

In a large-scale tomographic study involving much of western Canada, Mercier et al. (2009) compiled a comprehensive set of teleseismic *P*- and *S*-wave travel times from a wide selection of permanent and temporary networks, including the POLARIS–BC and the BATHOLITHS arrays. One of their targets included a mantle structure beneath the Anahim hotspot track, which they demonstrated is underlain by a –2% low-velocity zone, possibly extending to 400 km depth beneath Nazko cone. The authors argued that the source of magmatism in this area is dominated by a mantle-scale rather than lithospheric-scale process.

Other teleseismic studies of structures within the Southern Cordillera Transect area east of the Coast Ranges have, to date, been limited to receiver function (Cassidy 1995*b*; Bostock and Cassidy 1995*a*) and SKS (Bostock and Cassidy 1995*b*; Currie et al. 2004) analyses made at the widely separated, permanent stations PNT and WALA of the CNSN.

Slave – Northern Cordillera Lithospheric Evolution (SNORCLE)

The SNORCLE transect covers a large area extending from the active Queen Charlotte transform fault off the northern Pacific Coast in the west to the Slave Province, which hosts the oldest dated rocks on Earth. Teleseismic studies in the Northern Cordillera portion of the transect are few owing largely to the difficulty and expense of access.

Receiver function analyses of permanent station MOBC (Smith et al. 2003) and additional temporary stations (Bustin 2006) on the Queen Charlotte Islands in combination with gravity, heat flow, and refraction seismic data have been used to explore the nature of the transform plate boundary. These studies document the presence of a well-developed 10 km thick, *S*-wave low-velocity zone dipping beneath the island and interpreted to represent oceanic crust of an underthrusting Pacific Plate. This observation provides strong evidence favouring underthrusting over crustal thickening as the primary means of accommodating the minor, but significant, component of convergence (20 mm/a) along the plate boundary.

To the north, on a profile extending from the Alaska panhandle across the southern Yukon into the western Northwest Territories, Frederiksen et al. (1998) mapped upper mantle *P*-wave velocity anomalies using traveltime data from a number of permanent and portable stations. High velocities immediately west of the Yukon–Alaska border were attributed to the seismic signature of the cold, subducting Pacific Plate, whereas a deep-rooted zone of low velocity centered beneath the southern Yukon was interpreted to reflect a thermal anomaly of 100–200 °C. The eastern margin of this structure was taken to correspond to the boundary between orogenic and cratonic mantles, and its location coincides with the spatial distribution of Mg-rich xenoliths inferred to represent excess mantle temperatures (Shi et al. 1998).

Lowe and Cassidy (1995) have examined structures at higher levels in the crust at permanent broadband stations DAWY at Dawson and WHY at Whitehorse. By combining crustal thickness measurements from receiver functions with Bouguer gravity anomaly maps, they argued that extension has occurred to the northwest because of some combination of transfer of motion between the Denali and Tintina fault systems since the early Tertiary and collision-related processes in the Cretaceous.

As part of their tomographic study of western Canadian upper mantle structure, Mercier et al. (2009) investigated the transition from Phanerozoic to cratonic mantle in the vicinity of the SNORCLE transect using data from the Canadian North West Experiment (CANOE; see Fig. 1*b*). The authors found that the dominant change in seismic velocity (4%) occurs below the Cordilleran deformation front over a distance of ~50 km, a significantly sharper variation than could be confidently identified using surface waves (Frederiksen et al. 2001).

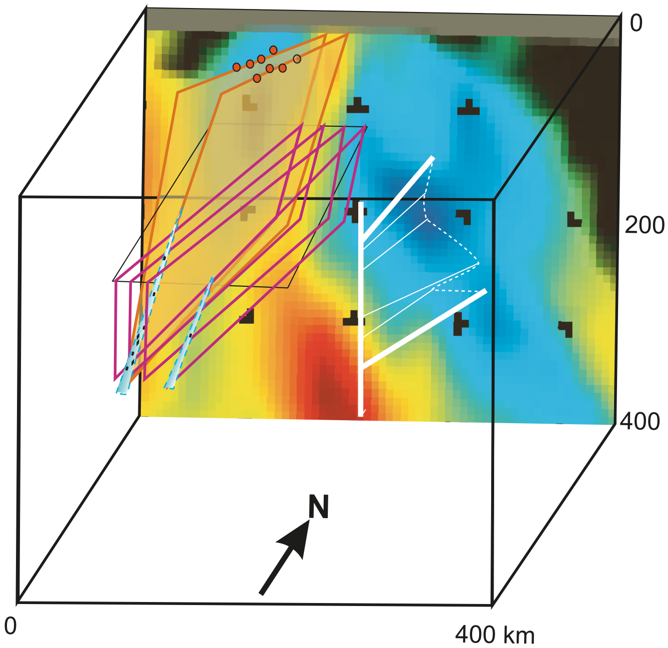
Teleseismic research over the Slave portion of the SNORCLE transect has been significantly more intense than parts westward, facilitated in large part through the interest and support of diamond exploration companies. Bank et al. (2000) provide a general seismological overview through the analysis of data from a temporary 13-station array spanning much of the Slave Province. *P*-wave tomographic models reveal fastest mantle velocities beneath the Central Slave Basement Complex, suggesting that it remains distinct well into mantle depths, and a curious low-velocity anomaly located at depths of 350 km below the Lac de Gras kimberlite field. This latter feature persists in more recent models derived from a significantly expanded data set (Rondenay et al.2006). Bank et al. (2000) noted crustal thicknesses near 36 km over most of the region, as determined from receiver functions. More recent estimates using the extensive POLARIS data set indicate that Moho depths increase from 38 km beneath Jericho to 39 km at Snap Lake (Snyder 2008) in the central Slave Province. EarthScope Automated Receiver Survey (EARS) crustal thickness estimates for the Yellowknife Observatory are bimodal and range from 30 to 40 km, with a best constrained value of 37 ± 0.2 km (Crotwell and Owens 2005) close to the earlier estimate of 38 km by Owens et al. (1987). In contrast, SNORCLE refraction thickness estimates are near 32 km beneath Yellowknife (Clowes et al. 2005). SKS splitting directions determined by Bank et al. (2000) were found to align broadly with North American Plate motion, although Davis et al. (2003) argue that variations from north to south show a statistically significant variability.

A detailed analysis of splitting parameters near the center of the Slave Province at station EKTN, in the Lac de Gras diamond field (see Fig. 1*b*), has been performed by Snyder et al. (2003). The observed azimuthal variations in delay time and fast polarization direction can be modeled using two layers. Polarization direction in the deeper layer aligns with North American Plate motion, whereas a distinct upper layer appears to result from regional structures in the uppermost mantle and crust. Incorporation of additional stations, together with analysis of directional dependence of Rayleigh waves (Snyder and Bruneton 2007) indicates that the two-layer model applies to much of the Slave Province, although there is evidence for some lateral variability in anisotropic parameters. An interesting correspondence between fast polarization direction in the deeper layer and trends in coeval kimberlite eruption indicate that eruptions may be controlled by an interplay between lithospheric-scale fractures and changes in continental-scale stress induced by plate motions (Snyder and Lockhart 2005; see Fig. 3). In a second surface wave study, Chen et al. (2007) also noted a well-defined azimuthal mantle anisotropy and reported phase velocities at mid-lithospheric depths that are significantly higher than the global average, as predicted from petrological analyses of xenoliths from local kimberlites (O'Reilly and Griffin 2006).

The southern border of the Slave Province has also been the focus of detailed anisotropy study owing to the presence of the Great Slave Lake shear zone, a major intracontinental, Proterozoic transform fault (see GSLsz in Fig. 1*b*). Eaton and Hope (2003) analyzed data from a 13-station, 150 km linear array across this structure. They noted that both SKS delay time and Moho depth increase toward the core of the fault zone. The back-azimuthal dependence of splitting parameters requires a two-layer crust–mantle lithospheric model wherein the cross-strike variability in delay time is dominated by crustal anisotropy. This data set was reanalyzed by Eaton et al. (2004*b*) in a comparison of magnetotelluric (MT) geoelectric strike directions with SKS fast polarization directions to test the hypothesis of Ji et al. (1996) that systematic obliquity between these two directions is a measure of shear sense. Although systematic obliquity was not observed, the joint interpretation of seismic and MT data sets provided better constraint on spatial contributions of crustal and mantle anisotropy.

The unprecedented depth and clarity with which mantle reflections were observed on the SNORCLE seismic reflection line 1 profile (Cook et al. 1999) have afforded interesting opportunities for comparison with teleseismic receiver function profiles. There are two major sets of mantle reflections, one that dips beneath the western margin of the Slave Province to at least the Yellowknife basin, and a second that is associated with the suture of the Fort Simpson Terrane with the Hottah Terrane. Bostock (1997, 1998) examined shallow mantle structures beneath the Yellowknife Seismic Array (YKA) using a comprehensive set of receiver function profiles organized in back-azimuth and epicentral distance. He identified a 10 km thick, anisotropic layer near the same depth as the Yellowknife reflections and interpreted it as an eclogitized, former oceanic crust emplaced through shallow subduction. Comparable anisotropic layers near 130 and 200 km depth were interpreted in similar fashion with one or the other inferred to represent the continuation of the dipping Fort Simpson reflections beneath the Slave Province. Collectively, this mantle stratigraphy was cited as evidence

Fig. 3. Cube showing hypothetical structures in the mantle beneath the Lac de Gras kimberlite field in the central Slave craton of northwestern Canada. Cube is 400 km in each dimension. The back face of the cube is a *P*-wave traveltime tomography study showing seismic wave speed anomalies from +1% (blue) to –1% (red) (Straub et al. 2004). The slower speeds are shown coincident with inferred, near-vertical conduit dykes (orange and magenta planes) composed of metasomatized peridotite and kimberlite (pale blue shapes in front face) within the lithosphere at depths <200 km. Some kimberlite dykes break into kimberlite pipes (orange ovals) within a few kilometres of the surface. Not all kimberlite dykes reach the surface; most metasomatic residue conduits (magenta planes) do not. A region of still slower *P*-wave speeds lies within the asthenosphere beneath the kimberlite field at 400 km depth and may represent pockets of low-degree melts. White bars about a vertical axis illustrate the variation in fast *S*-wave polarization direction in depth as determined from modelling of SKS (bold lines) and Rayleigh waves (dotted lines) (Snyder and Bruneton 2007).



that the diamondiferous, cratonic mantle root beneath the Slave Province was stabilized through successive episodes of shallow subduction. Snyder (2008) applied a similar approach to an array of POLARIS stations across the central Slave Province (POLARIS–Slave) and also found evidence for anisotropic layering. His interpretation incorporates surface geological constraints and posits stabilization of the Slave Province mantle via two episodes of subduction with opposing vergence from the northwest and southeast during the late Archean.

The analysis of receiver functions from leg A of the CANOE experiment (coincident with the easternmost SNORCLE reflection line; see Fig. 1*b*) has provided a key piece of information concerning the nature of anisotropic mantle layering (Mercier et al. 2008). These data illuminate the subducted plate of the Fort Simpson – Hottah suture as a 10 km thick, anisotropic layer with a sharp upper boundary that coincides with that of the seismic reflection Moho of the downgoing plate and a lower boundary that is better modeled as a discontinuity in elastic property gradient. Figure 4 displays the seismic reflection line drawing of Cook et al. (1999) superimposed upon the teleseismic result, where the lower boundary of the teleseismically defined layer is clearly seen to reside beneath the underthrust crust. This signature closely resembles that of the shallowmost mantle layer beneath Yellowknife (a revision to the original interpretation by Bostock (1998) as subducted *crustal* material), structures observed in the central Slave Province by Snyder (2008) and other layering identified beneath cratons worldwide (see Mercier et al. 2008). It thereby provides a direct connection between mantle fine-scale, anisotropic stratigraphy and underplated lithosphere.

Discontinuities at sublithospheric depths beneath Yellowknife (YKA in Fig. 1*b*) have been characterized by Bostock and Cassidy (1997) and Bostock (1998). Travel times of conversions from the 410 and 660 km discontinuities are consistent with moderately, but not exceptionally, high upper mantle velocities. A prominent, negative polarity conversion from a depth near 320 km suggests the presence of a dense fluid phase that may bear some relation to the generation of kimberlite magmas (Revenaugh and Sipkin 1994; Song et al. 2004).

Southern Alberta

To date teleseismic work focused on southern Alberta (see Fig. 1) has been limited to a combined receiver function and seismic reflection study involving CNSN station EDM (Eaton and Cassidy 1996), and a single portable teleseismic experiment (Shragge et al. 2002). The former study examined the nature of a prominent set of reflections recorded on a Lithoprobe seismic reflection profile. These reflections dip into the upper mantle below and strike parallel to the Rimbey domain, a Proterozoic magmatic arc situated within the Snowbird Tectonic Zone separating the Archean Rae and Hearne provinces. Receiver function analysis at the nearby CNSN site indicates the presence of a well-defined low *S*-wave velocity zone that is most easily interpreted to represent a mid-crustal sliver of serpentinized peridotite. Taken collectively, these observations support the presence of a fossil Proterozoic subduction zone dipping southeast below the Hearne Province.

The Lithoprobe Southern Alberta teleseismic experiment involved an array of nine portable and two CNSN seismometers on a line running from near the US border northwest to 54°N (Shragge et al. 2002). This line cuts across the strike of a number of major structures constituting the Hearne Province and was designed specifically to test a tectonic model for its evolution advanced by Ross et al. (2000). This model invokes the capture of a compliant Hearne Province within a tectonic vise at the center of two coeval, inward-dipping subduction zones, which resulted in significant shortening, thickening, and ultimately delamination of the cratonic mantle keel. The image of upper mantle *P*-wave velocity variations below the array by Shragge et al. (2002) stands at odds with this model as it indicates that the Hearne Province is underlain by relatively high-velocity material to significant depth, implying that the mantle keel remains. The authors suggested that evidence supporting delamination, namely high conductivity from mantle MT surveys (Boerner et al. 2000), manifests the presence of a volumetrically minor, but well connected, conductive phase emplaced

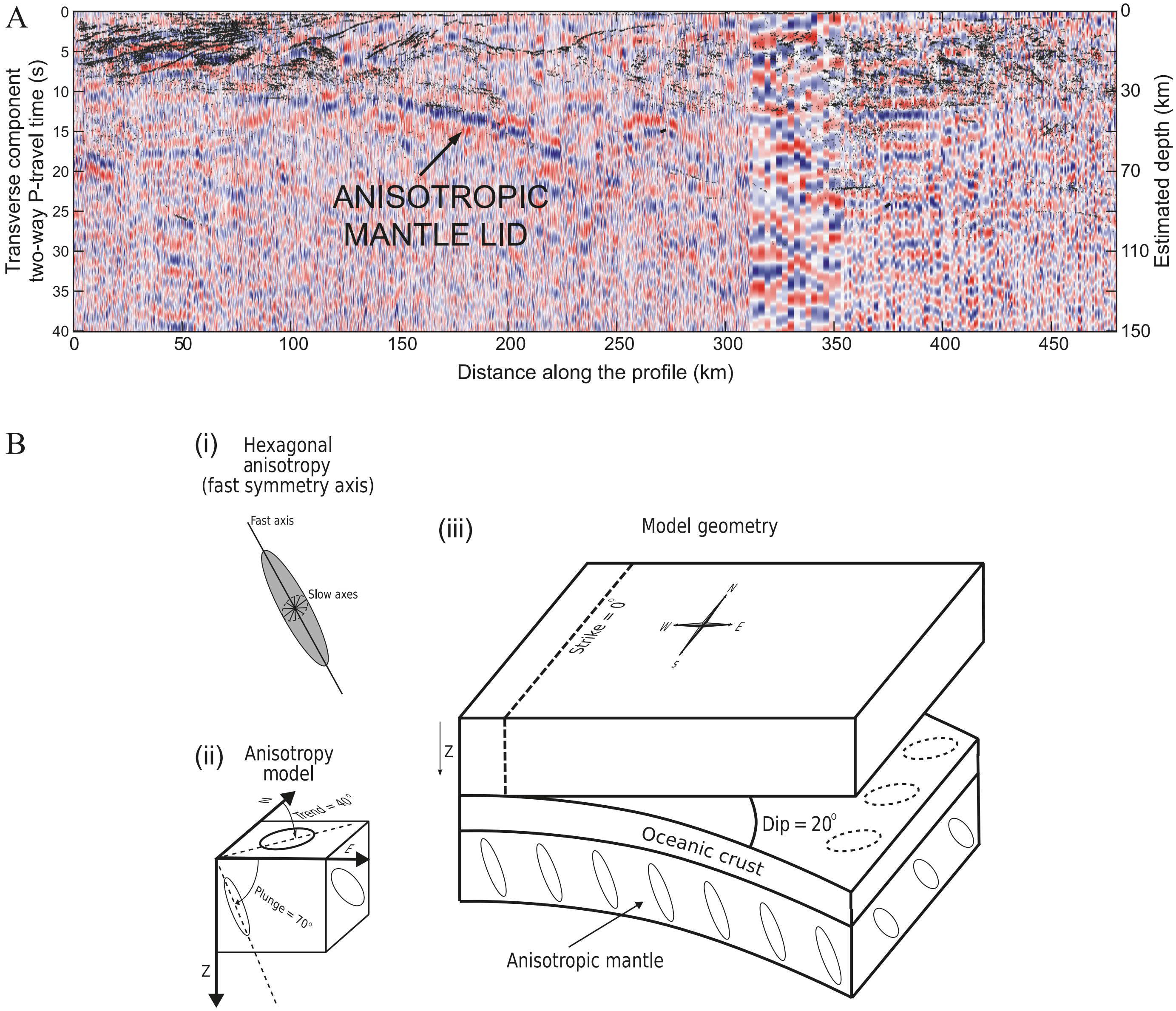


Fig. 4. Results from Mercier et al. (2008). (A) Superposition of line-drawing reflection section of Cook et al. (1999) upon transverse component receiver function. Note teleseismic signature of anisotropic mantle lid that parallels subducted reflection crust. (B) Cartoon showing structural elements of interpretation, including (*i*) definition of hexagonal anisotropy with fast symmetry axis, (*ii*) orientation of anisotropy, and (*iii*) tectonic configuration.

through hydration of the lithosphere by underlying subduction, causing minimal structural disruption to the high-velocity keel. A profile of receiver functions at stations along the array indicates that crustal thickness is constant near 38 km at northern stations increasing to >40 km beneath the Medicine Hat Block southward, generally consistent with values from active-source experiments.

Trans-Hudson Orogen

Two passive deployments of dominantly short-period instruments were undertaken within the Trans-Hudson Orogen of southern Saskatchewan (Fig. 1) in the early 1990s with the primary objective of better defining lithospheric structure to aid in diamond exploration. The initial feasibility study (Ellis et al. 1996) involved an eight-station array operating for 6 months in 1991–1992, from which *P*-wave travel-time residuals as large as 700 ms were mapped and for which a significant subcrustal contribution was inferred. These data were significantly augmented through a second deployment, using 17 seismographs over 22 months between 1994 and 1996 (Bank et al. 1998). The combined travel-time data set was formally inverted to reveal mantle slowness perturbations of ± 1.5% with strongest heterogeneity within the upper 250 km. A prominent low-velocity anomaly was identified below diamondiferous kimberlites and regions of high indicator mineral concentrations. Correlation of this anomaly with gravity and heat flow signatures led the authors to suggest that the lithospheric keel of the Sask craton had been thermomechanically eroded through Cretaceous plume activity leading to kimberlite volcanism.

Western Superior – Kapuskasing structural zone

The Superior Province is noteworthy as the largest contiguous area of Archean crust on the globe and, as mentioned in the "Introduction," it has long been recognized to overlie the most pronounced high-velocity mantle–lithospheric keel of any continent. In addition to earlier characterization of the keel in surface wave (e.g., Brune and Dorman 1963) and body wave (Wickens and Buchbinder 1980) studies, very large SKS splitting times observed at station RSON near Red Lake, Ontario, have played an important role in understanding the nature of upper mantle anisotropy by demonstrating the presence of a pervasive fabric internal to the keel. Silver and Chan (1988, 1991) cited these measurements as evidence for the notion that anisotropy develops within the lithosphere at the time of its formation (fossil anisotropy) and is preserved until further tectonic reactivation. The observations at RSON, it was argued, reflected the presence of a thick and coherently deformed cratonic keel. An ensuing debate concerning the relative lithospheric versus asthenospheric contributions to the splitting signal (Vinnik et al. 1992) prompted Silver and Kaneshima (1993) to examine variations in splitting parameters along a traverse (Archean–Proterozoic Transect 1989 (APT89)) extending from the Superior Province southwest across the Trans-Hudson Orogen onto the Wyoming craton. They noted good correlation of splitting signal with surface geology; specifically, stations within the Superior Province exhibit large delay times (>1 s) and a consistent ENE orientation that changes abruptly to lesser delays (<1 s) and fast polarization directions with a more east–west azimuth on the Trans-Hudson Orogen. The authors argued, accordingly, for a dominantly lithospheric contribution to anisotropy. A comparable and, within the Superior Province, parallel north–south array of seismometers (Teleseismic Western Superior Transect, or TWiST) was deployed ∼200 km east of the APT89 array as part of the Lithoprobe Western Superior Transect (Kendall et al. 2002). The array included two northern stations along the coast of Hudson Bay within the northern extension of the Trans-Hudson Orogen. Splitting parameters for the TWiST stations (Kay et al. 1999) are consistent with those from the APT89 experiment within the Superior Province and reveal no detectable splitting at either of the Trans-Hudson stations. In a recent compilation of all available splitting data, Frederiksen et al. (2007) argue that the Superior Province can be divided into two domains: a western domain at longitudes greater than 86°W wherein splitting directions are consistently ENE with large delays, and a domain to the east characterized by smaller delays and more variable splitting directions.

Bokelmann and Silver (2000) analyzed *P*- and *S*-wave delay times in conjunction with the previously documented SKS splitting times (Silver and Kaneshima 1993) from the APT89 experiment. They noted that both *S* and SKS measurements display a pronounced transition near the southwest edge of the Superior Province, whereas *P*-wave delay times do not. The authors explain these observations by invoking a model of dipping anisotropy, the strength of which is thermally controlled. Tomographic inversion of *P*-wave delay times from the TWiST experiment document the presence of a paired fast–slow lithospheric anomaly below and to the east of the array center (Sol et al. 2002). This feature was interpreted to represent abnormally thick, subducted and eclogitized relict oceanic crust and an associated, modified, overlying mantle wedge. This interpretation finds support from MT results that image a high-resistivity region approximately coincident with the dipping zone of high velocity (Craven et al. 2001; Percival et al. 2006; see Fig. 5).

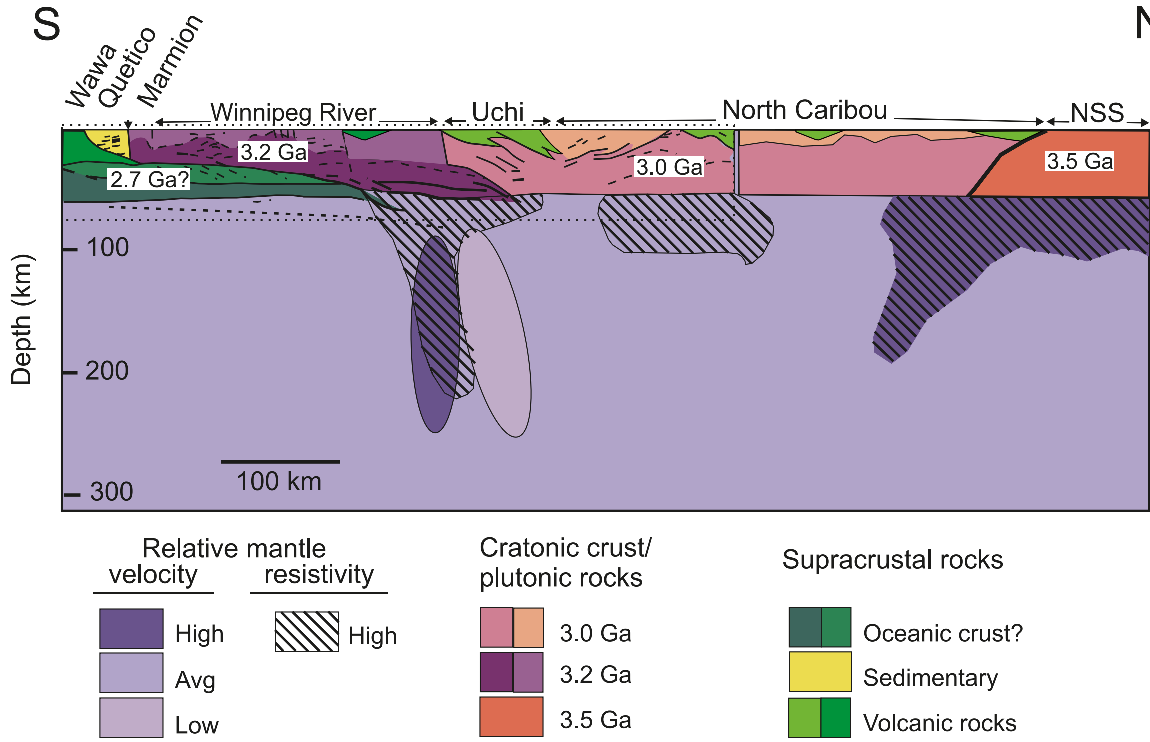
A second interpretation for the tomographic anomaly has emerged through joint inversion of *P*-wave delay times from the APT89, TWiST, and Abitibi–Grenville (Rondenay et al. 2000*a*, 2000*b*) experiments along with data from permanent short-period and FEDNOR (Federal Economic Development Initiative of Northern Ontario) stations (Frederiksen et al. 2007). The latter authors note that the slow anomaly identified by Sol et al. (2002) underlies the Nipigon embayment, a 1.0 Ga failed rift branch, and is surrounded by generally high mantle velocities west of the 86°W meridian. They interpreted slow velocities to be due to compositionally enriched asthenospheric material emplaced during rifting within an otherwise strong western Superior block, originally created through a series of Archean subduction and accretion episodes. The tomographic model in combination with the previously mentioned SKS splitting observations have led these authors to suggest that the western Superior Province is inherently stronger than parts eastward, a notion generally consistent with elastic thickness determinations (Wang and Mareschal 1999). Measurements of Rayleigh wave dispersion along >100 two-station paths within the Superior Province (Darbyshire et al. 2007) also indicate lateral variability with northeastern Ontario characterized by thick lithosphere (200–240 km), western and central portions displaying a thinner (140–180 km) but pronounced lithospheric lid, and the eastern Ontario region displaying the greatest heterogeneity in mantle properties. Receiver functions for stations across the Superior Province have been analyzed by the same authors for crustal thickness and bulk crustal V_P/V_S ratio. Crustal thickness varies between 32 and 48 km with the thickest crust beneath the Paleoproterozoic Kapuskasing Uplift and the Mesoproterozoic Midcontinent rift. The V_P/V_S ratios are highest in the Midcontinent rift area, consistent with the notion that voluminous mafic magmatism has altered bulk composition, and in the eastern Abitibi greenstone belt where mafic rocks are common.

Abitibi–Grenville – Great Lakes

Our understanding of lithospheric structures in the southern Grenville and adjoining southern Great Lakes regions has benefited greatly from the establishment of POLARIS and, in particular, the POLARIS–Ontario subprogram. The initial phase of POLARIS–Ontario involved the deployment of ∼30 stations across southern and eastern Ontario between 2001 and 2005, of which 20 continue to operate under contract with Ontario Power Generation, with the remainder available for portable deployments. In addition to the POLARIS stations and several CNSN stations (GAC, SADO, KAPO), the joint Lithoprobe – IRIS-PASSCAL – Abitibi–Grenville Teleseismic Experiment (Rondenay et al. 2000*b*) was performed along an array extending from Algonquin Park through the northwestern Grenville Province, and across the Abitibi greenstone belts, ∼20 km east of and parallel to the Ontario–Quebec border.

A major focus of subcrustal work has concerned the Great

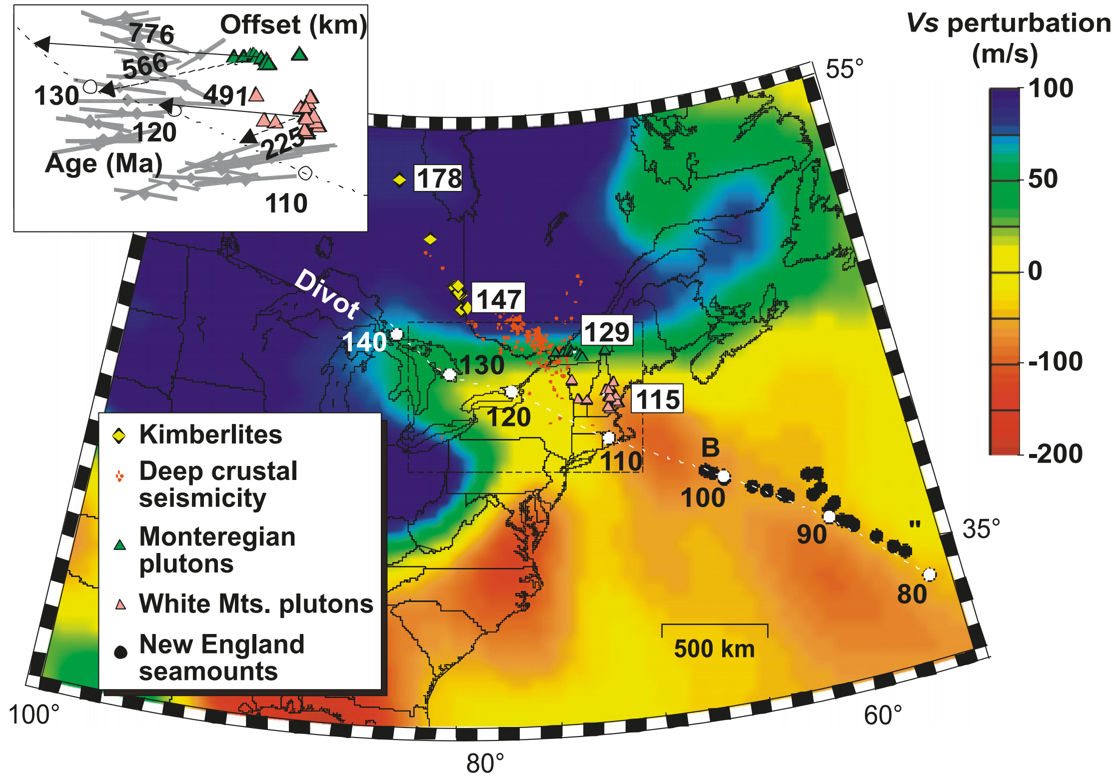
Fig. 5. Schematic representation of western Superior Province crust and mantle lithosphere as defined by seismic and magnetotelluric data from Percival et al. (2006). Dipping, paired fast–slow anomalies identified by Sol et al. (2002) are shown as dark and light purple ellipses between 100 and 250 km depth. Fast anomaly corresponds with zone of high electrical conductivity and overlying suture inferred from geological and active seismic studies. NSS, Northern Superior superterrane.



Meteor hotspot (Morgan 1972; Crough 1981) and its influence on the southeastern Canadian Shield. Seismic evidence for a mantle velocity signature extending into the craton was first noted by van der Lee and Nolet (1997), whose continental-scale images from surface waveform inversions reveal a major lithospheric divot of low *S*-wave velocity extending across New England and penetrating into the Great Lakes region (see Fig. 6). The seismic extension of the hotspot track northwestward into the Canadian Shield was suggested by Rondenay et al. (2000*a*), who identified a low-velocity corridor crosscutting the Grenville Front into the Abitibi subprovince with a northwest trend, in line with volcanic centers associated with the hotspot track. They proposed that this anomaly formed through the interaction of the Great Meteor plume with zones of weakness developed within the craton during earlier rifting episodes. The more recent tomographic model for northern Ontario by Frederiksen et al. (2007) extends this low-velocity corridor farther to the north and identifies its westerly juxtaposition against a rheologically stronger western Superior lithosphere. To the south, Aktas and Eaton (2006) employed the Abitibi data together with POLARIS–Ontario recordings to better image the low-velocity structure as dipping at 60° to the southwest, and suggested it represents an element internal to and located at the northern edge of the larger, low-velocity halo imaged by surface waves and attributed to the hotspot track (van der Lee and Nolet 1997; Fig. 5). Aktas and Eaton (2006) also imaged a tabular, high-velocity body striking northwest parallel to surface geological belts and suggested it may represent a relict slab associated with subduction beneath the Composite Arc Belt. Eaton and Frederiksen (2007) have noted the southward misalignment of the low-velocity divot, as defined by surface waves with the surface expression of hotspot volcanism, and cite it as evidence for asthenospheric-driven motion of the North American Plate (Bokelmann 2002). The large variability in Rayleigh wave dispersion for paths crossing eastern Ontario (including paths with some portion within the Grenville Province), observed by Darbyshire et al. (2007), was presented as evidence for heterogeneous lithospheric structure possibly generated through passage of the plume responsible for the Mesozoic Attawapiskat – Kirkland Lake – Timiskaming kimberlite trend.

The low-velocity divot evident in continental-scale surface wave inversions is also expressed in the regional SKS splitting pattern (Eaton et al. 2004*a*; Frederiksen et al. 2006). Although the average splitting direction closely coincides with North American Plate motion, perturbations in both splitting delay time and direction within the divot area are consistent with mantle flow predictions (Fouch et al. 2000). In addition, coherent variability is also present in splitting parameters over the Ottawa–Bonnechere graben, a Proterozoic failed rift. The relation between SKS and electrical anisotropy has been extensively investigated over the region. Sénéchal et al. (1996) first documented the strong electrical anisotropy across the Grenville front and its approximate alignment with SKS splitting directions measured in a small pilot deployment in advance of the Abitibi–Grenville experiment. Ji et al. (1996) observed a slight systematic obliquity between SKS and MT anisotropy directions in these measurements and suggested that it might provide a means of determining shear sense since the seis-

Fig. 6. Long-wavelength *S*-wave velocity variations beneath eastern North America showing low-velocity divot displaced from Great Meteor hotspot track, from Eaton and Frederiksen (2007). Numbers inside boxes represent ages of volcanic centers in Ma. Upper left inset compares inferred displacement of the hotspot trace with fast splitting directions (light gray arrows) within the area outlined by the dashed rectangle.



mic signal depends on crystallographic preferred orientation, whereas directional variations in conductivity should be controlled by shape preferred orientation. Upon compilation of further measurements, Frederiksen et al. (2006) have, however, shown that the obliquity does not persist away from the Abitibi–Grenville array. These authors have also documented the presence of finer scale anisotropic layering within the mantle lithosphere at several CNSN stations in the region from azimuthal variations in radial and transverse receiver functions that may be related to past subduction episodes. Eaton et al. (2006) presented a compilation of crustal thickness and average V_P/V_S ratio for stations in southeastern Ontario and western Quebec based on receiver function analyses. They compared these values with results from Lithoprobe and other crustal refraction surveys and found good general agreement. Crustal thickness variations noted in this study exhibit a strong correlation with geological belts but do not correlate with surface topography and are far in excess of relief required to maintain local isostatic equilibrium.

Lithoprobe East – ECSOOT

Lithospheric structure and basin evolution are the foci of the ongoing 10-station POLARIS–Atlantic experiment around the Gulf of St. Lawrence in eastern Canada. Results from this study have not yet been published, but earlier studies based on permanent stations DRLN (Deer Lake, Newfoundland) and LMN (central New Brunswick) shed some light on crust and mantle structure in this region (e.g., Cassidy 1995*a*; Bostock and Cassidy 1995*a*). An interesting observation made from receiver functions at LMN and other Appalachian stations in New England is the presence of a well-defined base to a low-velocity (3%–11% contrast) zone that ranges in depth from 90 to 100 km as one proceeds eastward (Rychert et al. 2005). The authors interpreted this feature to represent the lithosphere–asthenosphere boundary. The frequency response of the receiver functions requires the boundary to be sharp and occur over a transition of <11 km. This constraint can be explained by an asthenosphere that contains a few percent partial melt or, alternatively, is enriched in volatiles relative to the overlying lithosphere.

Arctic Canada and Hudson Bay

Although Arctic Canada does not figure prominently within the array of Lithoprobe transects, Global Seismic Network (ALE) and CNSN (INK, FRB, RES, and the former MBC) stations provide some sparse coverage in the region. The permanent stations have been analyzed in earlier compilation studies of receiver functions (e.g., Cassidy 1995*a*; Bostock and Cassidy 1995*a*), and more recently by Darbyshire (2003), who examined their responses in combination with temporary stations in both the Canadian High Arctic and western Greenland. She found evidence for relatively simple crustal structure at shield stations and variable responses at stations that have experienced more recent tectonism. In a study of surface wave dispersion across the region using a comparable grouping of stations, Darbyshire

(2005) identified high-velocity mantle (4%–5% higher than global reference models) below shield stations in the south, grading northwestward to typical "off-craton" mantle beneath the Arctic Islands.

The Hudson Bay Lithospheric Experiment (HuBLE), an ongoing, teleseismic project involving POLARIS and SEIS-UK (a seismic instrumentation facility run through the Natural Environmental Research Council located in Leicester, UK) is probing the northeastern flank of the North American lithospheric keel, as well as crustal structure of the Trans-Hudson Orogen. HuBLE, which was timed to coincide with the International Polar Year 2007–2008, is a joint investigation led by David Eaton (The University of Western Ontario, London, Ontario), David Snyder (Geological Survey of Canada), and Mike Kendall and George Helffrich (University of Bristol, UK).

Discussion and conclusions

Teleseismic studies have contributed in a number of important ways to our understanding of how the Canadian landmass has evolved. Large-scale mantle velocity structure beneath Canada has been extensively documented through global (e.g., Grand 1994), continental (Frederiksen et al. 2001; van der Lee and Frederiksen 2005), and regional (Darbyshire 2005) tomographic studies employing long-period shear waves and surface waves. The resulting models consistently point to the predominance of a high-velocity mantle keel underlying most of the Canadian Shield. The presence of mantle keels beneath cratons plays a central role in models for the long-term preservation of ancient continental crust (e.g., Jordan 1988; Hoffman 1990). Despite considerable knowledge of crustal-scale processes of assembly of the North American continent (much of it arising from Lithoprobe studies), a clearer understanding of keel formation and evolution is only beginning to emerge. The high-velocity signature of cratonic mantle is generally considered to be due to a combination of cooler temperature and a more refractory composition than ambient mantle (Jordan 1988). These trends in temperature and composition produce competing effects on density, thereby stabilizing the mantle keel and rendering it generally resistant to disruption by the convecting mantle. The mechanism by which this thermocompositional signature originates has been a matter of some debate over the past couple of decades with favoured models, including advective thickening through plate-scale orogenesis (Jordan 1988) and lithospheric underplating via shallow subduction (Vlaar 1986; Helmstaedt and Schulze 1989; Abbott 1991). Teleseismic work on the Slave Province and environs has led to a clear preference for the latter hypothesis through the identification of a well-developed anisotropic mantle stratigraphy within the cratonic root (Bostock 1997, 1998; Snyder 2008) that can be directly associated with underthrust, already differentiated lithosphere (Mercier et al. 2008). The identification of comparable anisotropic stratigraphy beneath a range of cratons worldwide (Levin and Park 2000; Saul et al. 2000; Snyder et al. 2003) suggests that shallow subduction may be a generic mechanism for the formation and stabilization of lithospheric keels beneath cratons.

Although the cratonic keel is a long-lived and stable feature, it is prone to modification through interaction with mantle plumes and the imposition of plate-scale stress fields. The Great Meteor hotspot track has, in recent years, become arguably the best documented example of plume–craton interaction on the globe. The aberrant surface volcanism associated with the passage of the Great Meteor hotspot across the transition from cratonic to oceanic lithosphere has been known for some time (Crough 1981), but its seismological imprint on underlying lithosphere has only recently become appreciated. At larger scales, this imprint takes the form of a major low-velocity divot within the high-velocity keel that extends well into cratonic portions of eastern Ontario (van der Lee and Nolet 1997; Frederiksen et al. 2001; Fouch et al. 2000). The divot location corresponds well with the hotspot track over oceanic lithosphere but diverges increasingly from the trace of continental volcanism farther into the craton. Eaton and Frederiksen (2007) have employed this observed discrepancy to argue in favour of Bokelmann's (2002) asthenospheric-driven plate motion model for North America. Despite its displacement away from the low-velocity divot, the surface trace of volcanism into the craton does appear to have a mantle signature in the form of an underlying, narrow, low-velocity corridor (Rondenay et al. 2000*a*; Aktas and Eaton 2006; Frederiksen et al. 2007), which is interpreted to represent the interplay between the broader plume halo and zones of weakness previously created by late Precambrian rifting. Plate motion reorganization also appears to have played an important role in creating conditions conducive to kimberlite volcanism in the Slave Province as evidenced by the coincidence of coeval kimberlite trends with bulk mantle anisotropy (Snyder and Lockhart 2005).

In Cascadia, the location of the subducting Juan de Fuca plate and, in particular, its relation to the low-velocity, high-reflectivity E-layer identified on early seismic (Green et al. 1986) and teleseismic (Cassidy and Ellis 1991) profiles alike remain controversial. The most recent teleseismic work documents the extension of the E-layer from the west coast of Vancouver Island to 50–60 km depth below Georgia Strait (Nicholson et al. 2005). Coupled with comparable signatures recorded at subduction zones worldwide, this latter work affords strong argument favouring the interpretation of the E-layer as the expression of subducting oceanic crust. A reduction in strength of the low-velocity zone at greater depths and a disappearance in the overlying forearc Moho are predictable consequences of metamorphic dehydration and hydration reactions, respectively (Peacock and Wang 1999; Bostock et al. 2002; Hyndman and Peacock 2003). Although the geometry and scale of the modern active margin closely match those of the fossil subduction zone imaged by seismic reflection beneath Wopmay orogen (van der Velden and Cook 1999; Eaton 2006), the teleseismic responses (Nicholson et al. 2005; Mercier et al. 2008) display a number of interesting contrasts that remain to be explained. Future teleseismic surveys coupled with the extensive documentation of fossil subduction within the Lithoprobe seismic reflection database (e.g., van der Velden and Cook 2005) hold the promise of still further insights into continental lithospheric structure and evolution.

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