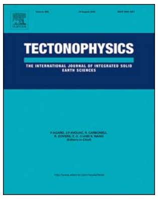
Tectonophysics 724–725 (2018) 28–41

Contents lists available at ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto



Structure and fabric of the crust and uppermost mantle in the northern Canadian Cordillera from Rayleigh-wave tomography

Morgan McLellan, Andrew J. Schaeffer*, Pascal Audet

Department of Earth and Environmental Sciences, University of Ottawa, Ottawa, ON K1N 6N5, Canada

ARTICLE INFO

Keywords:
Cordillera
Tectonics
Lithosphere
Surface wave tomography
Seismic velocity
Inversion

ABSTRACT

The seismic structure and fabric of the lithosphere and underlying mantle beneath the northern Canadian Cordillera provides important constraints on its evolution and current tectonics; however, it is poorly characterized due to historically sparse networks of seismic instruments. We use data from past and recently deployed networks of broadband seismic stations in northwestern Canada and measure Rayleigh waves propagating between all available pairs of seismic stations using two complementary techniques: ambient noise and teleseismic two-station interferometry. The Rayleigh-wave data are processed to obtain phase velocity dispersion curves that are inverted for phase velocity maps at periods between 8 and 80 s. To first order these maps show high velocity anomalies within the Canadian Shield and low velocity anomalies within the Cordillera at all periods. At short periods ($<$ 30 s; mostly sensitive to crustal depths), we observe high velocity anomalies within the allochtonous accreted terranes, and low velocity anomalies bounded by autochtonous sedimentary rocks forming the fold-and-thrust belt. At longer periods ($>$ 30 s; mostly sensitive to uppermost mantle depths), high velocity anomalies of the Canadian Shield extend west past the Cordilleran Deformation Front and suggest the presence of cratonic lithosphere beneath the Cordillera, whereas the lowest velocities underlie the allochtonous terranes. Anisotropy within the crust and uppermost mantle exhibits fast-axis orientations aligned with the major faults and fabric of the Cordillera, and show evidence for vertical changes in anisotropy. These results provide new constraints on geodynamic models proposed to explain neotectonic deformation in this area.

1. Introduction

The northern Canadian Cordillera (NCC) is a tectonically active, high-elevation and low-relief orogenic belt located in northwestern Canada. The NCC extends from the BC-Yukon border in the south to the Beaufort Sea and eastern Alaska in the north and west, and its eastern extension abuts the cratonic lithosphere of the Canadian Shield along the Cordilleran Deformation Front (CDF; Fig. 1a). The tectonic history of the NCC, summarized by Monger and Price (2002) and Nelson et al. (2013), began approximately 750 million years ago when extensional forces associated with the break-up of the supercontinent Rodinia led to rifting within Laurentia, the core of the North American craton (Hoffman, 1988), and formation of a passive margin. In the Middle Devonian (~390 Ma) a convergent margin generated magmatic arcs offshore from the North American continental plate. Through continued subduction, the continental margin eventually converged with the offshore oceanic arcs, resulting in the accretion of these arcs to the continental plate and the formation of the Cordillera.

The Cordillera itself consists of a variety of accreted terranes, which can be subdivided into 5 groups as described by Nelson and Colpron (2007): 1) Ancestral North America (Laurentia); 2) Intermontane terranes associated with the ancient oceanic plate that existed off the west coast of North America in the Early Jurassic; 3) Insular and Farewell terranes; 4) Arctic Alaska; and 5) Younger (Mesozoic) accretionary terranes (Fig. 1a). The Selwyn Basin is located east of the Tintina Fault, and is comprised of thick Cambrian sedimentary sequences associated with the basinal and platformal rocks of the Ancestral North American margin (Hayward, 2015). West of the Tintina Fault is the Intermontane belt that consists of terranes accreted during the early Jurassic (Johnston et al., 1996), which have subsequently been displaced northwestward along the Tintina fault. West of the Denali Fault are the Insular and Farewell Terranes that originated within the Arctic between Laurentia and Siberia (Nelson and Colpron, 2007).

The Yakutat Block is a continental-oceanic terrane that has been colliding with the North American continental plate since the Miocene (Mazzotti and Hyndman, 2002; Hyndman et al., 2005b). Outside of the main collision zone, seismic activity is concentrated along 3 corridors: 1) the right-lateral Denali and 2) Tintina strike-slip faults; and 3) the

---

* Corresponding author.
E-mail address: andrew.schaeffer@uottawa.ca (A.J. Schaeffer).

https://doi.org/10.1016/j.tecto.2018.01.011
Received 31 July 2017; Received in revised form 2 December 2017; Accepted 4 January 2018

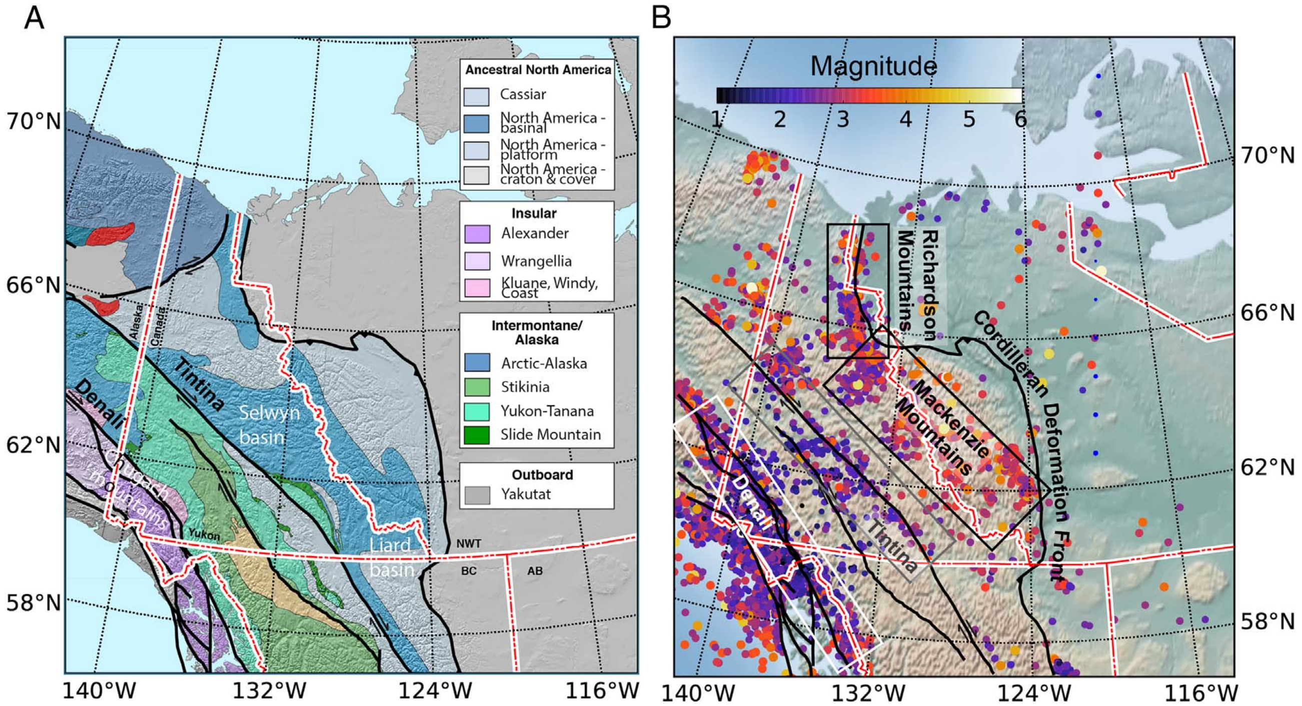


Fig. 1. Map of (a) tectonic boundaries and provinces (terranes; modified from Nelson and Colpron, 2007) and (b) seismicity in northwestern Canada and Alaska. The Selwyn and Liard basins are contained within the North American basinal boundaries. The boxes in (b) outline the 4 seismic corridors (Denali, Tintina, Mackenzie and Richardson) discussed in the text.

Mackenzie and Richardson Mountains (Fig. 1b). Despite a much lower rate of seismicity around the Tintina Fault, earthquakes of magnitude ~4.5 indicate persistent activity (Mazzotti and Hyndman, 2002). Further east, the Mackenzie Mountains consist of a fold and thrust belt that formed as a result of east-west compression (Hyndman et al., 2005b). Earthquakes with magnitude ~6.9 have been observed within the Mackenzie Mountains, despite being located ~800 km away from the Yakutat collision zone (Wetmiller et al., 1988). The Richardson Mountains, located further north, exhibit a right lateral strike-slip component (Cassidy et al., 2005) with earthquakes of magnitude ~6.5 along the north-south fault system (Mazzotti and Hyndman, 2002). The high rate of seismicity far from the collision zone implies that tectonic stresses are either transmitted across long distances, or that stresses are caused by a different process. Geodynamic models that address this question need to take into account the variations in lithospheric structure across this landmass.

Previous studies of crustal thickness in the region indicate an average thickness of 30–35 km throughout the North American Cordillera (Clowes et al., 1995; Perry et al., 2002; Kao et al., 2013; Tarayoun et al., 2017). In contrast, thicknesses of 40–45 km are observed in the surrounding craton (Kao et al., 2013; Hyndman et al., 2005a). The lack of a crustal root to support the high Cordilleran elevation can be explained by thermal expansion of the uppermost mantle from elevated geotherms (Mazzotti and Hyndman, 2002; Currie and Hyndman, 2006; Hyndman et al., 2005a), consistent with high heat flow (Lewis et al., 2003), low elastic thickness (< 10 km; Audet et al., 2007), as well as low mantle-refracted P-wave (Pn) velocities (Hyndman and Lewis, 1999; Lewis et al., 2003). Furthermore, previous seismic tomography models of uppermost mantle structure beneath northwestern Canada have inferred first-order contrasts between the Cordillera and the Craton (e.g., Frederiksen et al., 2001; Bedle and van der Lee, 2009; Mercier et al., 2009; Dalton et al., 2011; Schaeffer and Lebedev, 2014), with much lower seismic velocities beneath the Cordillera compared to those of the adjacent Canadian Shield, interpreted as a large lateral contrast in uppermost temperature (~250 °C; Hyndman and Currie, 2011). Studies of radial and azimuth seismic anisotropy in the crust and mantle also appear to show significant differences across the Cordillera-Craton boundary (e.g., Courtier et al., 2010; Dalton and Gaherty, 2013; Audet et al., 2016; Tarayoun et al., 2017). Unfortunately, the sparse networks of broadband seismograph stations in this region have hampered a detailed investigation of lateral and vertical variations in crust and uppermost mantle structure.

Following the installation of new seismic networks in southern Yukon, western Northwest Territories and northern British Columbia as well as the progressive installation of stations in eastern Alaska and western Yukon from the Transportable Array of USArray, a high-resolution seismic tomography model of the NCC is now possible. In this paper, we estimate Rayleigh-wave phase velocity dispersion curves between every possible pair of seismic stations surrounding the NCC using both ambient noise cross-correlation as well as teleseismic two-station interferometry techniques. From these data, we compute anisotropic phase velocity maps, which provide insight on lithospheric structure and fabric that can help constrain geologic, tectonic and geodynamic models of the NCC.

2. Data and methods

We calculate the Rayleigh wave phase velocity structure of the NCC and surrounding regions using fundamental-mode Rayleigh wave observations from available broadband seismograph stations located in northwestern Canada and eastern Alaska. We use 69 stations (Fig. 2) belonging to various networks including the Canadian National Seismograph Network (CNSN; CN), the USArray Transportable Array (TA), the Portable Observatories for Lithospheric Analysis and Research Investigating Seismicity (POLARIS; PO) network, the United States National Seismic Network (US), the Alaska Regional Network (AK), the Canadian Northwest Experiment network (CANOE; XN), and the Yukon-Northwest Seismograph Network (YNSN; NY).

Fundamental-mode Rayleigh wave dispersion measurements (i.e., the variation in surface wave propagation speed as a function of period or frequency) were carried out between pairs of stations using two different and complementary methods: ambient seismic noise cross-correlation (e.g., Bensen et al., 2007) and teleseismic two-station interferometry (e.g., Meier et al., 2004). In both cases, the measurements