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Body-wave tomography of western Canada

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ABSTRACT

In this study, we have produced *P*- and *S*-wave velocity models for western Canada using 23,420 delay times measured on vertical component seismograms, and 15,805 delay times measured on transverse component seismograms, respectively, from a range of permanent and temporary networks. Resolution is best in southwestern British Columbia, and along the CANOE (northwestern Alberta, southern Yukon and Northwest Territories) and BATHOLITHS (northwestern BC) arrays where the station density is the highest, and fair elsewhere. We focus our attention on two distinct features 1) the transition from Phanerozoic to Cratonic mantle in northwestern Canada, and 2) the complex tectonic environment at the northern terminus of the Cascadia subduction zone where the plate boundary changes from convergent to transform. We find that the main transition from Phanerozoic to Cratonic mantle in northwestern Canada occurs at the Cordilleran deformation front and represents a sharp jump in seismic velocity from −2% to +2% over a distance of ~50 km. In northern Cascadia, we have imaged and characterized the signature of the subducting Juan de Fuca plate and observed evidence of subduction beyond the northern edge of the slab. We also demonstrate that the Anahim hotspot track is underlain by a −2% low-velocity zone possibly extending to 400 km beneath Nazko cone that appears to be the source of volcanism in this area. Consequently, we associate the source of magmatism in this area to a mantle-scale rather than lithospheric-scale process.

1. Introduction

Continents, unlike ocean basins, possess a protracted and complex tectonic evolution that is encoded within seismic velocity heterogeneity of the crust and underlying mantle. Western Canada is particularly rich in its structural make-up and represents the most nearly continuous sampling of Earth's geologic history over the past 4.0 Ga (see Fig. 1). Accordingly, the region affords an ideal setting to study subsurface variations in upper-mantle structure, geometry and physical properties from Archean to the present day. Moreover, the western margin also provides an opportunity to explore the complex transition from convergent to transform plate boundary. In this paper we employ regional body-wave tomography to investigate mantle velocity structure beneath western Canada.

Studies of western Canada upper-mantle velocity structure began more than 3 decades ago when Buchbinder and Poupinet (1977), Wickens (1977), and Wickens and Buchbinder (1980) used short-period *P*-waves, surface-wave, and long-period *S*-wave traveltime residuals, respectively, to document a low-velocity region beneath British Columbia. More recently, global and continental-scale studies that include western Canada, using 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) have imaged a relatively sharp mantle transition from low to high velocity across the Cordilleran deformation front. At finer scales Bostock and VanDecar (1995) utilized body-wave traveltimes to constrain the geometry of the subducting Juan de Fuca plate below southwestern British Columbia whereas Frederiksen et al. (1998) and Shragge et al., (2002) focused on details of upper mantle velocity structure beneath the southern Yukon and south-central Alberta, respectively.

These previous studies have provided useful insights into western Canadian lithospheric and upper-mantle structure but are either global/continental-scale and suffer from low resolution, or local and lack a broader perspective. Until recently, the station density in most of western Canada precluded the undertaking of a comprehensive

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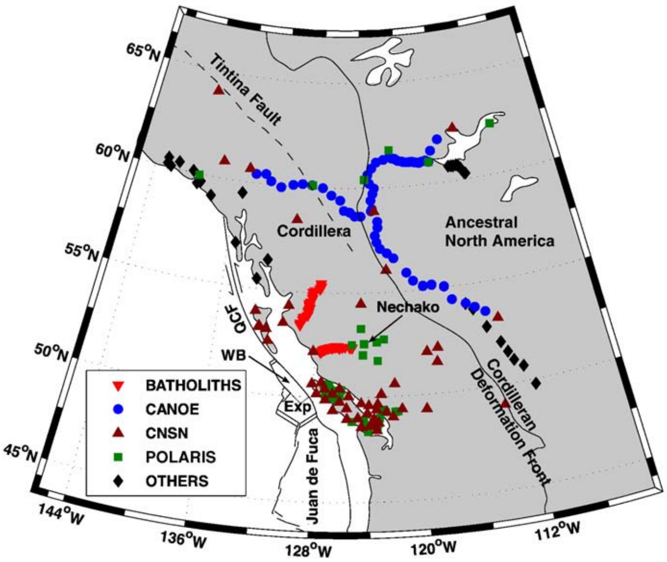

Fig. 1. Map of western Canada illustrating the distribution of broadband and short-period seismic stations used in this study, and the location of key tectonic features discussed in the text.(Exp: Explorer Plate, QCF: Queen Charlotte Fault, WB: Winona Block).

body-wave study over the entire region as performed for example, in the western United States (Humphreys and Dueker, 1994). However, the recent deployment of stations from several portable experiments (i.e. CANOE, BATHOLITHS, POLARIS BC and POLARIS-Nechako) have contributed to filling some major gaps in station coverage and afford opportunity for a broader scale study. In this paper, we exploit both newly available and previously analysed broadband and short-period data to examine the large-scale, upper-mantle *P*- and *S*-velocity structure beneath western Canada and hence provide constraints on the evolution and physical properties of this region. We focus our attention, in particular, on the location of the Cordillera/craton transition and on the northern edge of the Cascadia subduction zone.

2. Data and method

2.1. Data

The traveltime data employed in this study to construct *P*- and *S*-wave velocity models were recorded at stations of the following permanent and temporary networks (see Fig. 1): Advanced National Seismic System (ANSS), Alaska Tsunami Warning System (ATWS), Alaska Regional Network (ARN), BATHOLITHS, CAnadian NOrthwest Experiment (CANOE), Canadian National Seismograph Network (CNSN), and several experiments of the Portable Observatories for Lithospheric Analysis and Research Investigating Seismicity (POLARIS). The *P*-wave data-set consists of 23,420 teleseismic *P* delay times from 1609 earthquakes recorded at 234 broadband and short-period stations at epicentral distances from 30° to 100°. The *S*-wave data-set includes 15,805 teleseismic *S* delay times from 884 events recorded at 194 broadband stations. Azimuthal coverage is good for both data-sets with only one unsampled sector between 200° and 250° (Fig. 2).

Owing to the region's large expanse, source waveforms often exhibit considerable systematic variation between stations at geographic extremes, especially for large earthquakes. Therefore, to facilitate picking *P* and *S* data were divided into independent subsets based on station location. For each subset, *P* and *S* traveltimes were obtained from visual picks of the vertical and transverse component, respectively, which were subsequently refined through multichannel cross-correlation (VanDecar and Crosson, 1990). Frequency bands of 0.4 Hz–1.6 Hz and 0.5 Hz–0.4 Hz were used for *P* and *S* phases, respectively. The timing uncertainty is estimated using the standard deviation of the residual associated with each trace and is on average ~30 ms for *P* and ~120 ms for *S*.

2.2. Model parameterization

The region of interest in this study extends over more than 23° of latitude from 43.5°N to 67.27°N, over 41° of longitude from 105°W to 146°W and from the surface to 700 km depth. For both the *P*- and the *S*-wave inversions the velocity models are parameterized in splines under tension constrained by a series of regularly spaced knots (Fig. 3). The grid is composed of 175,770 knots, 81 in longitude, 70 in latitude and 31 in depth. The dimensions of the smallest elements of the model are 0.33° longitude by 0.5° latitude by 20 km depth, whereas the dimension of the largest elements are 1° longitude by 1° latitude by 25°km. The absolute dimension of the element spacing varies considerably due to the large latitudinal range. The 1D radial earth model IASP91 (Kennett and Engdahl, 1991) was chosen as a reference.

2.3. Traveltime inversion

The traveltime inversion procedure adopted in this study to recover slowness perturbations at every point of our model grid is discussed in detail in VanDecar (1991). This technique produces a solution that represents the minimum variation in seismic velocities required to fit the data by imposing conditions on the first and second spatial derivatives of the model which control the flatness and smoothness, respectively. We chose this form of regularization, as opposed to a more traditional damping, to avoid biasing the solution toward the IASP91 reference which may not necessarily represent a good background model in all portions of the study area.

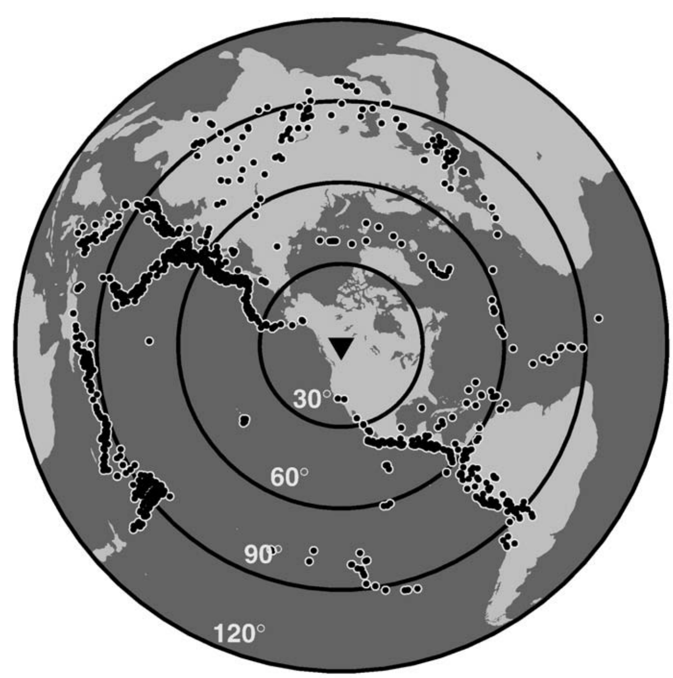

Fig. 2. Equidistant azimuthal projection centered at 55°N and 118°W illustrating the distribution of events with sufficiently high signal-to-noise ratio recorded at one or more stations of the array. Note the relatively uniform azimuthal coverage with only one region between 200° and 250° which is unsampled.