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Investigation of Cascadia segmentation with ambient noise tomography

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ABSTRACT

Along strike variation in the characteristics of subduction zone processes has been observed throughout the Cascadia Subduction Zone through magmas analysis of arc magmas and the distribution of seismicity. We investigate links between these observations and subduction zone structure by imaging three-dimensional lithospheric scale shear velocity with ambient noise tomography (ANT). The crustal portion of the model is well resolved through typical ANT processing techniques. We expand the methodology to use longer period phase velocities in order to recover structure to ~120 km depth. The resulting model, PNW10-S, represents structural information in terms of relative shear velocity in the crust and uppermost mantle. Crustal structure mirrors surface geology to ~10 km depth and then transitions to a structure that is dominated by the subducting slab. The subducting slab and overriding crust appear segmented into three parts with boundaries near 43°N and 46°N. This three-way structural segmentation is aligned with the variation in recurrence of episodic tremor and slip along the subduction zone. Upper to middle crustal boundaries between the Klamath Mountains and Siletzia Terrane (43°N) and between the Crescent Formation and Olympic Peninsula (47°N) are also coincident with locations of increased occurrence of tremors raising the question of whether there is a link between the intensity of tremor activity and shallow (<10 km) crustal structure. The slab–segment boundary at 43°N is a stronger feature than the northern segment boundary at 46°N and appears to be the continuation of the Blanco Fracture Zone separating the Gorda segment of the plate from the rest of the Juan de Fuca plate. The southern half of the arc system, south of 45°N, shows lower velocities from the surface to ~80 km depth relative to the northern portion of the arc. We propose that this is due to clockwise plate rotation, which causes extension in the south, and results in increased melting. Along the arc, four broad low-velocity features are imaged just below the Moho and centered at 42°N, 44°N, 47°N, and 49°N. We interpret these as ponding of melt just below the crust where differentiation can occur before further ascent through the crust.

1. Introduction

The Cascadia Subduction Zone is where the last remnants of the Farallon Plate continue to subduct below continental North America (Van der Lee and Nolet, 1997). The southern terminus of the trench is the Mendocino Triple Junction, offshore northern California, and the northern terminus is the Queen Charlotte Triple Junction to the northwest of Vancouver Island (Fig. 1). The Juan de Fuca plate is small in a global context, but the length of the subduction zone is sufficient to generate magnitude 9 earthquakes (Goldfinger et al., 2011). The subduction zone is atypical for a variety of reasons. It has a distinct paucity of seismicity, with no earthquakes greater than ~75 km depth, and almost no sub-crustal earthquakes beneath Oregon. The trench is undergoing rollback and clockwise rotation as the Basin and Range expands to the southeast (Humphreys and Coblentz, 2007). Finally, the subduction zone exhibits anisotropic fast directions normal to the trench as observed from shear wave splitting (Currie et al., 2004; Eakin et al., 2010), whereas the vast majority of subduction zones have trench-parallel fast directions (Long and Silver, 2008).

In this paper we employ ambient noise tomography to image the lithospheric structure of the Cascadia Subduction Zone from southern Vancouver Island to California. Ambient seismic noise tomography has been used to study several regions including the western United States (Moschetti et al., 2007), the eastern United States (Liang and Langston, 2008), Taiwan (Huang et al., 2010; You et al., 2010), Costa Rica (Harmon et al., 2008), Norway (Köhler et al., 2011), Australia (Saygin and Kennett, 2010), and Europe (Yang et al., 2007). Ambient noise is particularly useful in seismically quiescent areas because recovery is primarily influenced by receiver array geometry and not the distribution of earthquakes. We make use of seismic stations from the Earthscope Transportable Array, regional seismic networks, and two Earthscope Flexible Array deployments resulting in an array covering most the United States with greatly increased density in

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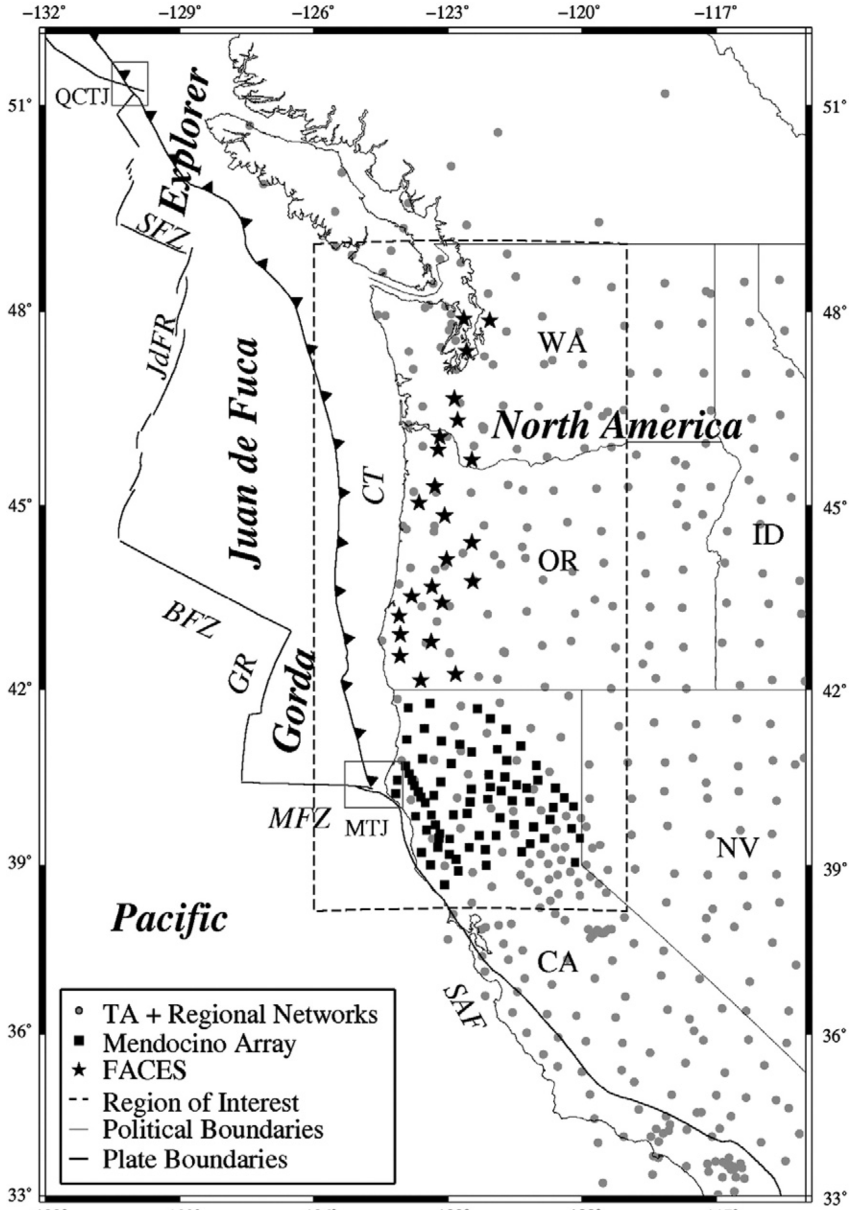

Fig. 1. Tectonic and station location map. The full station coverage extends to the eastern US coast and northwest to Alaska and includes the Earthscope Transportable Array, Regional Networks, and the Canadian National Network (gray circles). The densest coverage is in the Pacific Northwest due to the addition of the deployment of two temporary arrays, FACES and Mendocino (stars and squares respectively). Our region of focus (dashed box) covers the US portion of the Cascadia Subduction Zone and extends south of the Mendocino Triple Junction (MTJ) where the subduction zone terminates. Major plate boundaries labeled as follows: SAF — San Andreas Fault, MFZ — Mendocino Fracture Zone, GR — Gorda Ridge, BFZ — Blanco Fracture Zone, CT — Cascadia Trench, JdFR — Juan de Fuca Ridge, SFZ — Sovanko Fracture Zone, QCTJ — Queen Charlotte Triple Junction.

Cascadia (Fig. 1). The measurements typically derived from ambient noise are fundamental mode Rayleigh wave phase velocities between 7 and 40 s. These measurements have peak sensitivity between the surface and roughly 50 km depth and thus this method provides excellent sampling of the crust. In order to investigate the structure throughout and immediately below the lithosphere, we use measurements from noise cross-correlations to periods of 90 s. This requires manual data selection to ensure high signal-to-noise ratios. The benefit of this labor-intensive process is that the resulting model is able to resolve structure from the surface to ~120 km depth. It therefore provides the missing link between previous crustal studies (ambient noise, controlled source (Trehu et al., 1994), and seismicity studies) and the larger scale models using teleseismic surface- and body-waves, which have only longer wavelength or deeper sensitivity.

2. Cascadia segmentation

Several lines of evidence suggest that simple subduction with one downgoing and one overriding plate is an insufficient model of the Cascadia Subduction Zone. Instead, the subduction zone and arc are segmented, exhibiting variations in multiple characteristics along strike. A first order observation of this is the Sovanko and Blanco Fracture zones separating the Explorer and Gorda micro-plates from the main Juan de Fuca plate (Fig. 1). A similar scale feature is the distinct change in strike of the trench from nearly north–south in California and Oregon to northwest–southeast through northern Washington and Vancouver Island (Audet et al., 2010; McCrory et al., 2004). On a shallower scale, modeling of the GPS velocity field by McCaffrey et al., 2007 shows that the data is best fit by a series of crustal block motions rather than by pure plate motion based models.