Juan de Fuca Subduction Zone from a Mixture of Tomography and Waveform Modeling

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Abstract

Tomographic images of the upper-mantle velocity structure beneath the Pacific Northwestern United States display a maze of dipping blobs. Many of these features produce diffraction patterns evident in the USArray observations indicative of sharp edges (Sun and Helmberger, 2010), which agree quite well with existing contour lines defining the plate's upper interface (McCrory et al., 2006). These features are particularly obvious in recent tomographic models, for example Schmandt and Humphreys (2009). Synthetics from these tomographic models fit the timing for teleseismic arrivals quite well and even some of the complexity. Regional and triplication data, however, requires substantial changes to tomographic models. In this study, a hybrid model satisfying the waveform data, the modified tomographic images and conventional slab wisdom will be presented. By modeling regional waveforms of the 2008 Nevada earthquake, we found that the uppermost mantle of velocity model AK135, the background model of most tomographic studies, is too fast for the western US. The background model is replaced by velocity model mT7, which is modified from an older Basin-and-Range model T7. The Juan de Fuca slab is 60 km thick and has a P-velocity increase of 5% with respective to mT7. A 10 km low-velocity layer with a P-velocity reduction of -10% is assumed on top of the slab representing the subducting oceanic crust. The JdF slab is set to a depth of 150 km beneath the Seattle region and terminating at a shallow depth at the Washington-Oregon border. In order to fit waveform complexities of the 2007 Gulf of Mexico earthquake and the South American event, a high velocity anomaly with velocity increases at 3% for P and 7% for SH is sitting on top of the 660 discontinuity beneath Nevada.

Introduction

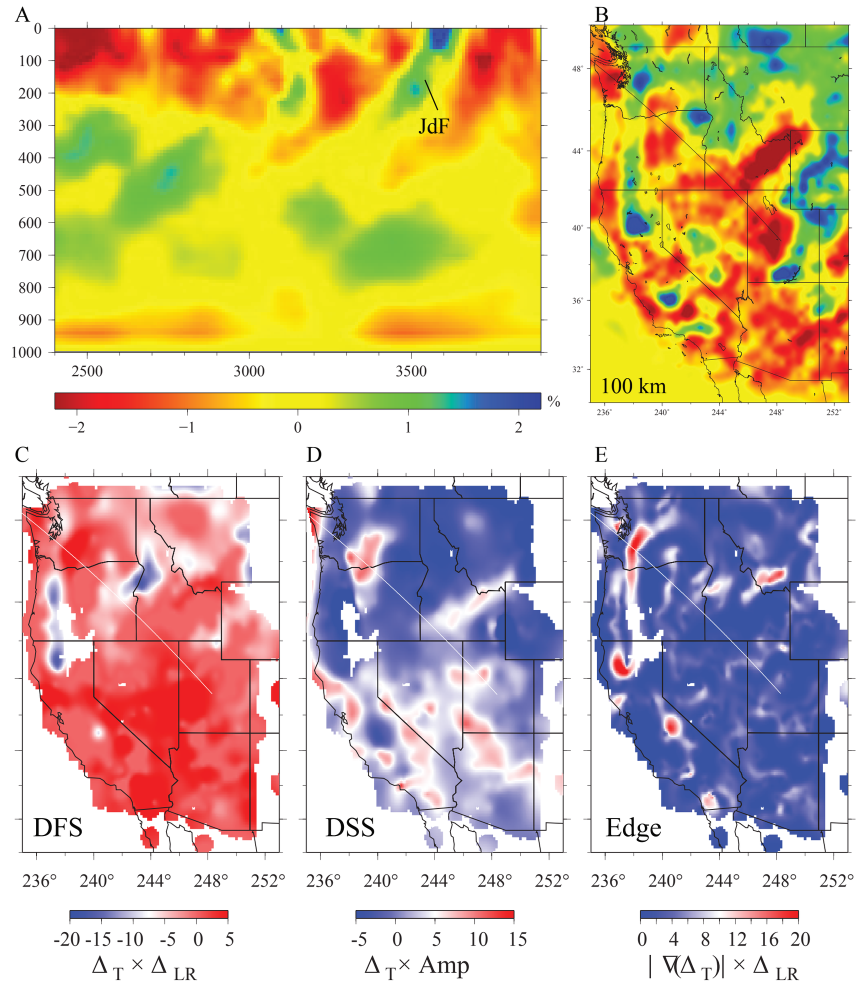

Fig 1. (A) Tomographic image of Juan de Fuca (JdF) slab from Schmandt and Humphreys (2010) along the profile shown in (B). Seismic structures derived from waveform complexities are displayed in C, D and E, respectively (Sun and Helmberger, 2010).

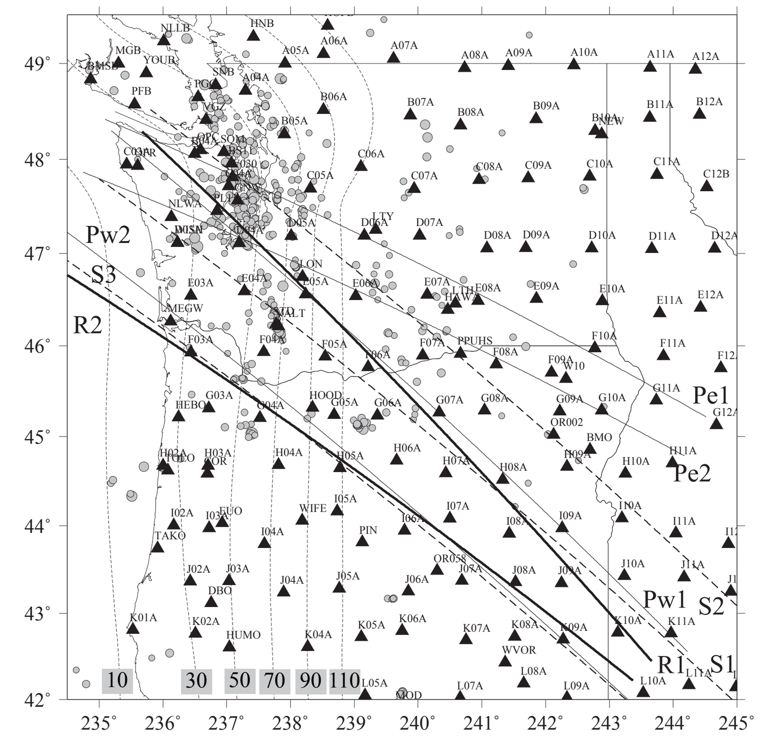

Fig 2. Map of the Pacific northwest shows seismic and tectonic features in this area. Gray dots are earthquakes with Mw ≥ 3.0 between January 1970 and June 2010. Black triangles denote broadband seismic stations deployed in this area. Dashed lines represent top of the subducting Juan de Fuca slab (McCrory et al., 2006). Thick solid line R1 and R2 are regional P profiles from the 2008 Nevada event. Thin solid lines are four P profiles from the 2006 and 2007 Gulf of Mexico earthquakes (Pe1, Pe2, Pw1, and Pw2). Dashed lines shows three SH profiles from the 2007 South American earthquake (S1, S2, and S3). The upper JdF structure is addressed along two corridors, R1 and R2, which have different lengths of slabs. Pw2 and S3 are profiles of P and S waveforms used in validating the R2 structure while the other sections sample the R1 corridor in more detail.

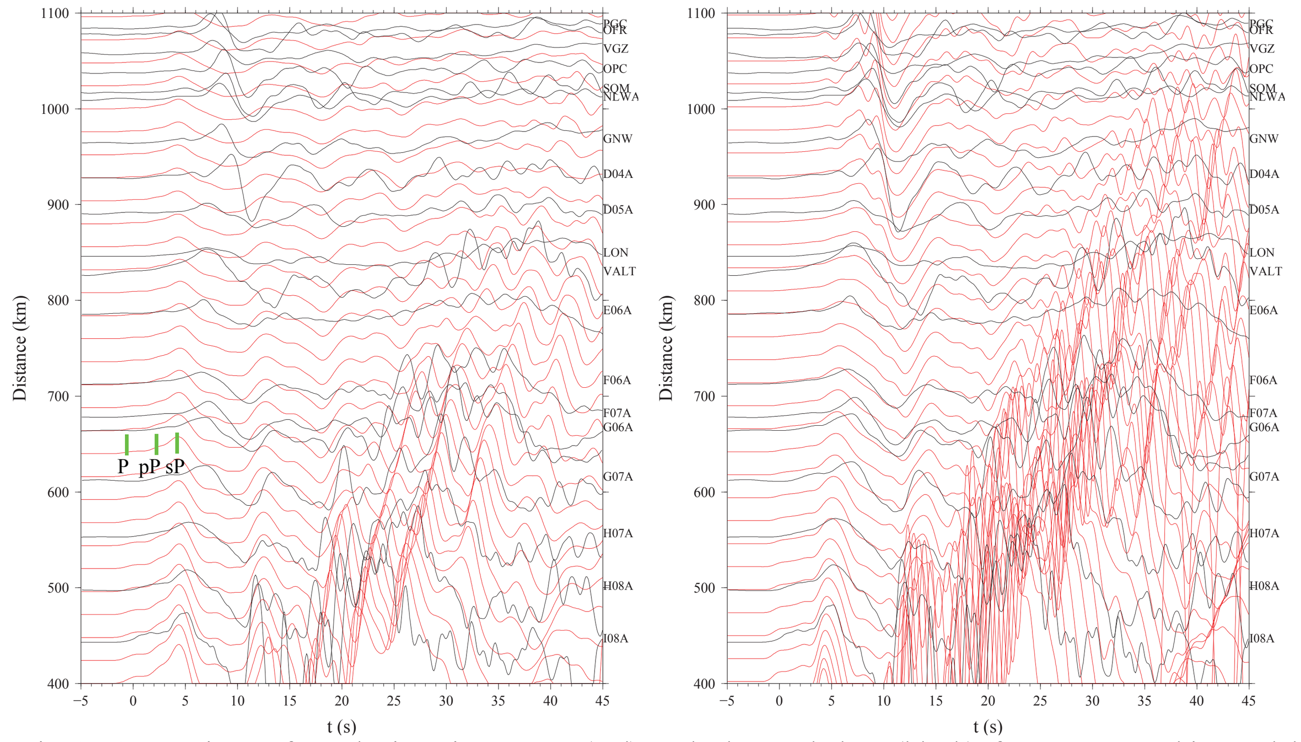

Fig 3. Comparison of synthetic seismogram (red) and observed data (black) from tomographic model (Schmandt and Humphreys, 2010) (left) and 1D velocity model mT7 (Burdick and Helmberger, 1978) (right) for regional profile R1 of the Nevada earthquake.

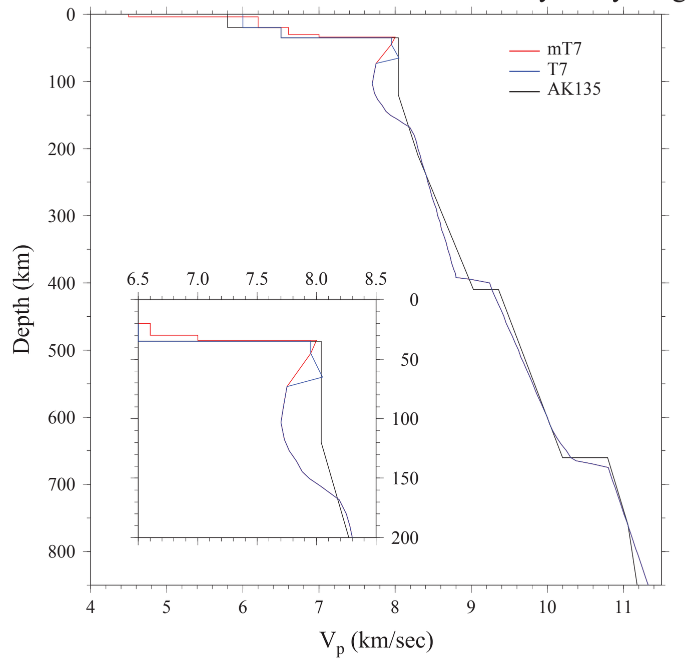

Fig 4. Comparison of 1D velocity models of AK135 (black), mT7 (red), and T7 (blue). Model mT7 is derived from T7 by removing the lid structure in the uppermost mantle. Top 200 km of the models are enlarged in inset.

WKM

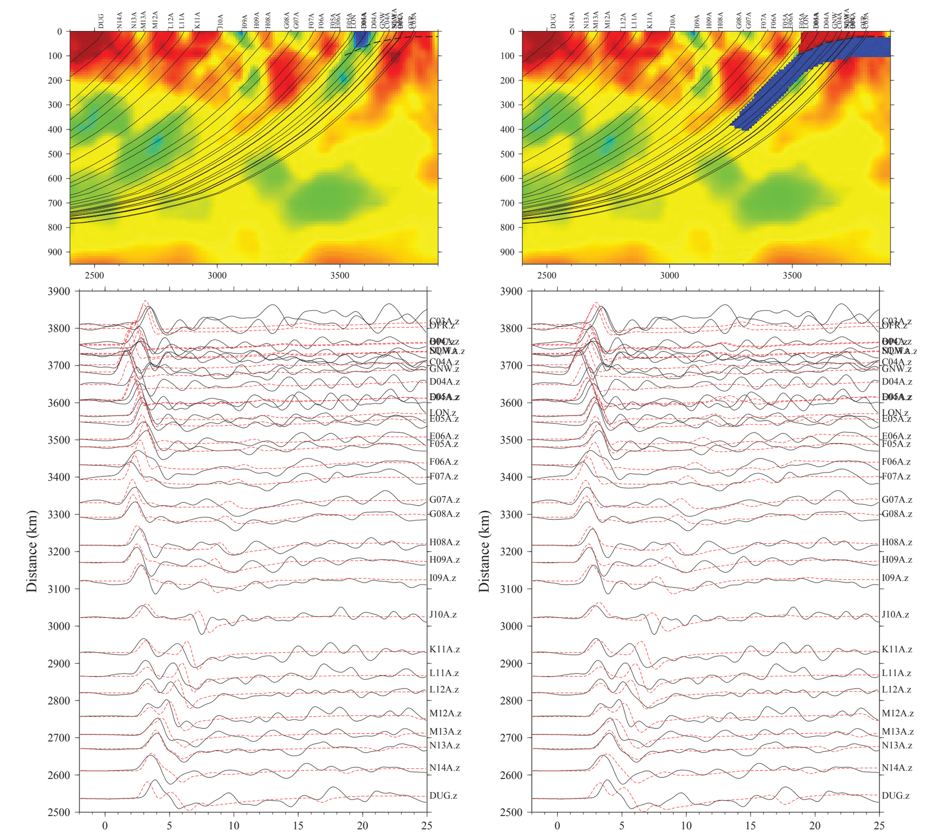

Fig 5. Velocity perturbations and ray paths along the profile Pw1. The ray paths are calculated using the WKM method. The Juan de Fuca slab can be replaced by a slab with a thickness of 80 km and velocity increase of 2.0% with respect to AK135.

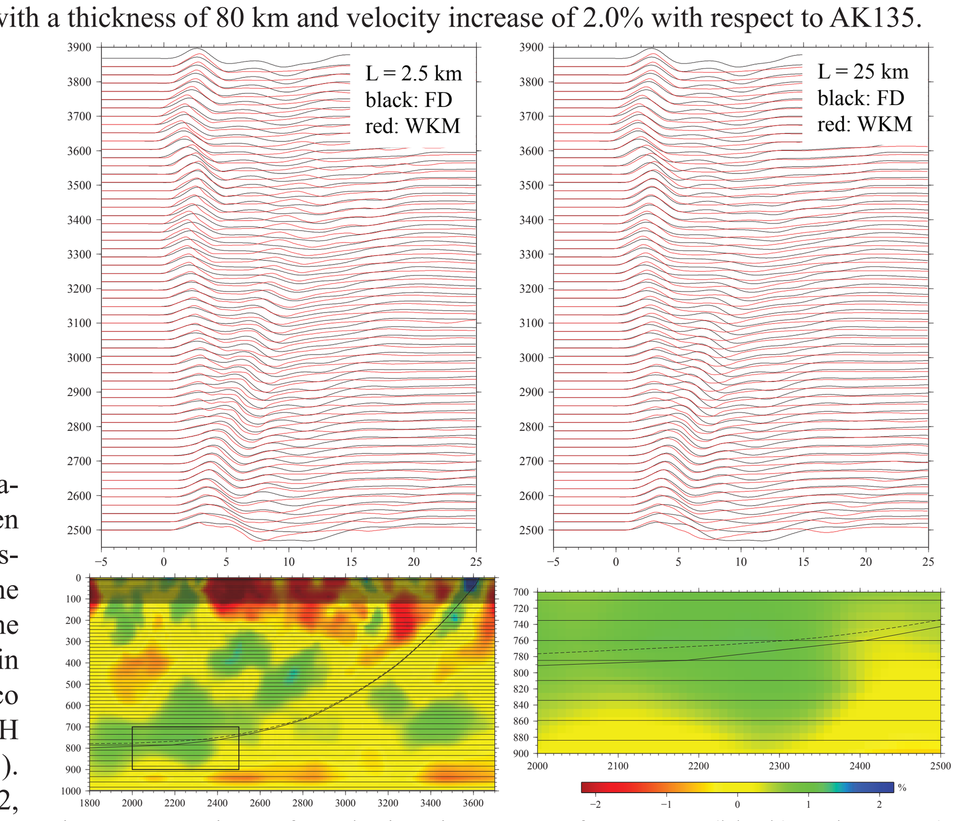

Fig 6. Comparison of synthetic seismograms from FDM (black) and WKM (red). Dashed and solid ray paths are for layer thickness of 2.5 km and 25 km for a station above the JdF slab. The paths in the box are enhanced on the right displaying the sensitivity to layering.

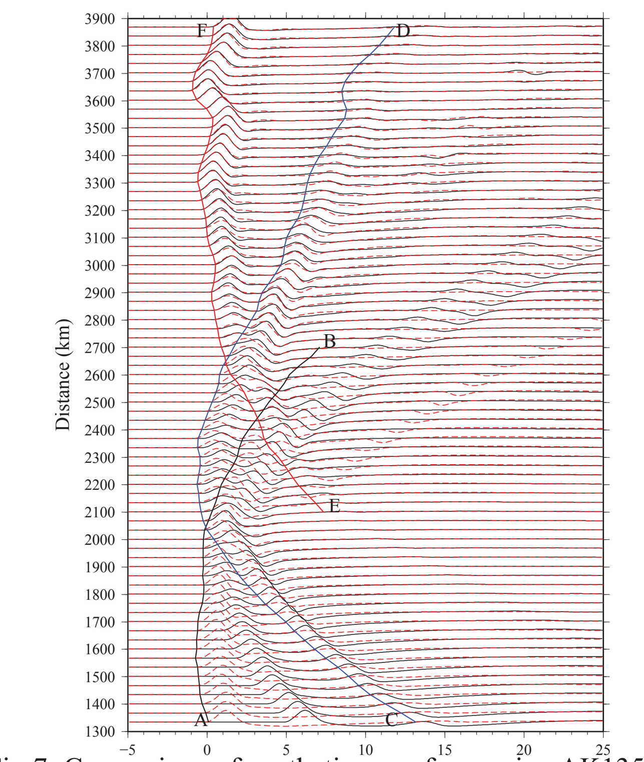

Fig 7. Comparison of synthetic waveform using AK135 (red) and mT7 (black) as background velocity model for profile Pw1. Red waveforms are shifted by 1.9s.

Regional waveform modeling

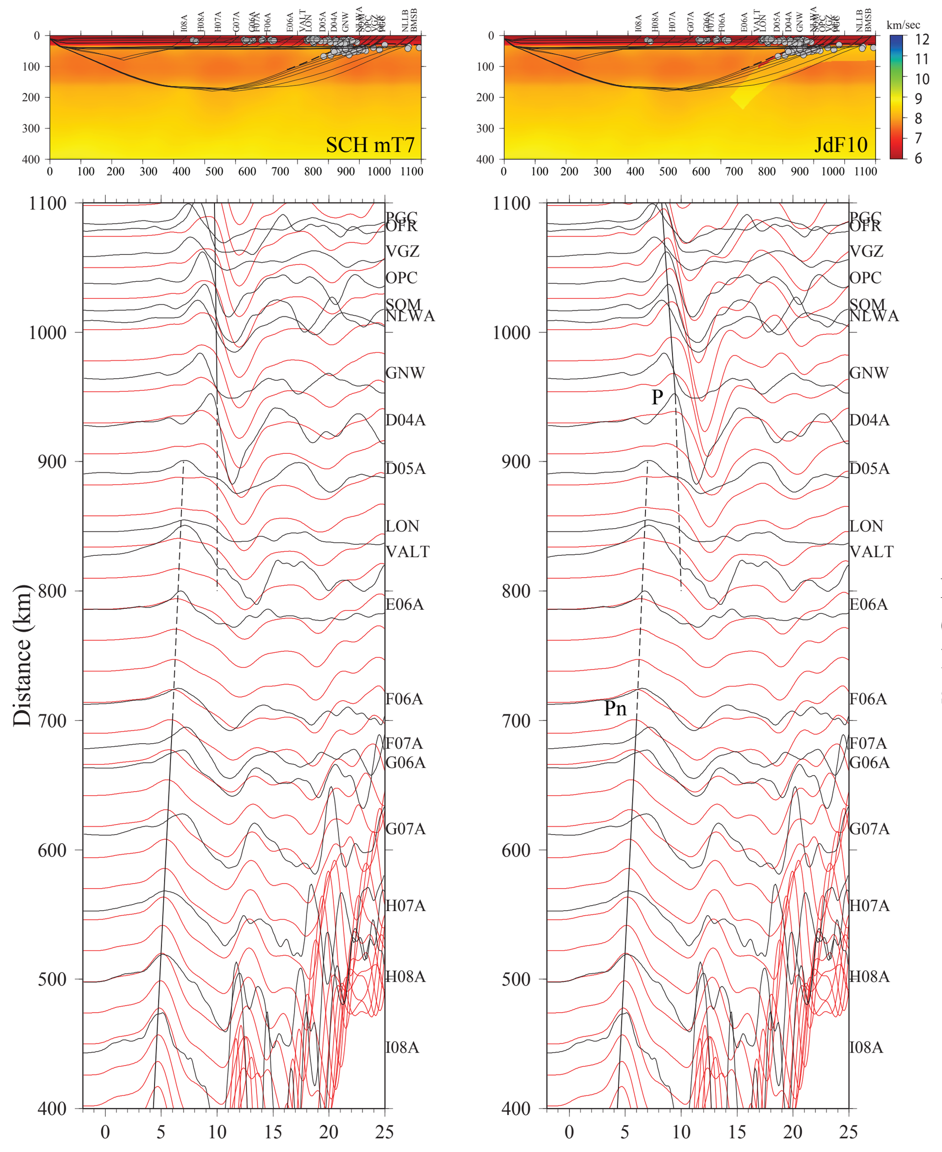

Fig 8. Comparison of synthetic seismogram (red) and observed data (black) for regional profile R1 of the Nevada earthquake. The velocity models are SCH-mT7 (left) and Jdf10 (right), respectively. In model JdF10, the JdF slab has a thickness of 60 km with the velocity increase of 5.0%. At distances greater than 1000 km where the Juan de Fuca slab is present, SCH-mT7 model is not fast enough to match the P arrivals.

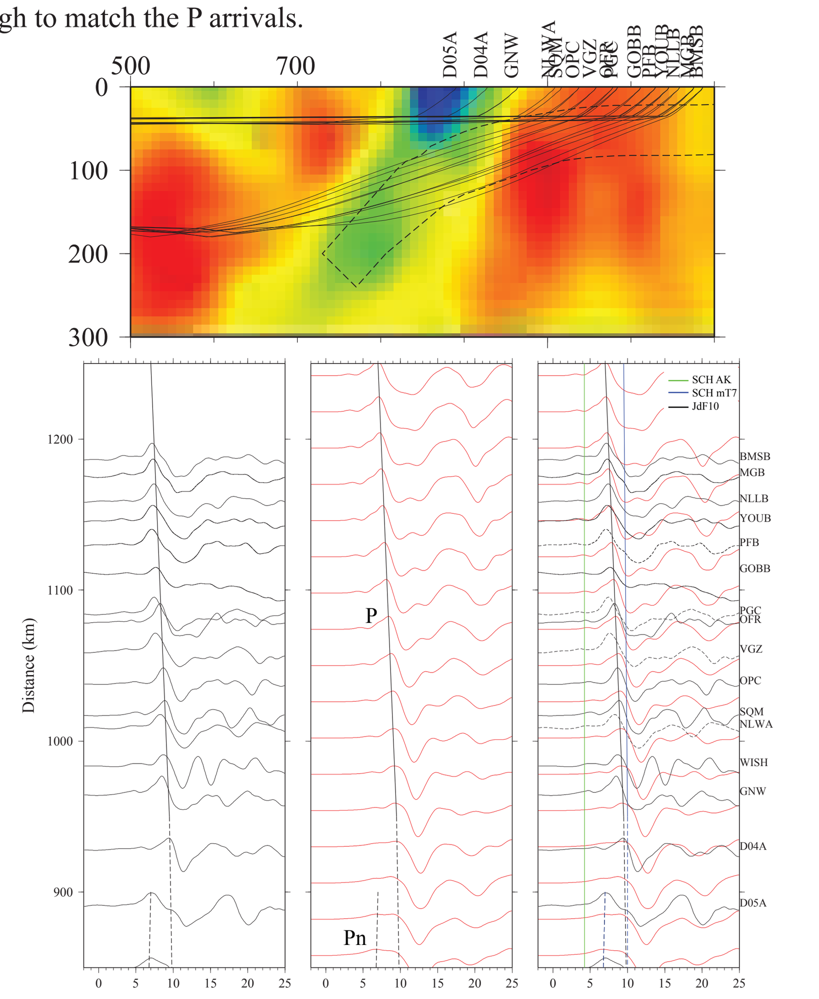

Fig 9. (Top) Ray paths for stations between 850 km and 1200 km. Shallow horizontal paths are Pn waves and deeper paths are P arrivals. Dashed lines mark boundaries of the JdF slab in model JdF10. Data from the Nevada earthquake (black) and synthetic waveforms (red) are plotted on the bottom as well as their direct comparison. Black lines denote P and Pn arrivals. Green and Blue line are arrivals from velocity model SCH-AK and SCH-mT7, respectively. Dashed seismograms are about 1 sec earlier than predictions of JdF10, which is the 3D effect of the slab because they have relative larger azimuth and perhaps longer travel in the fast slab.

Teleseismic waveform modeling

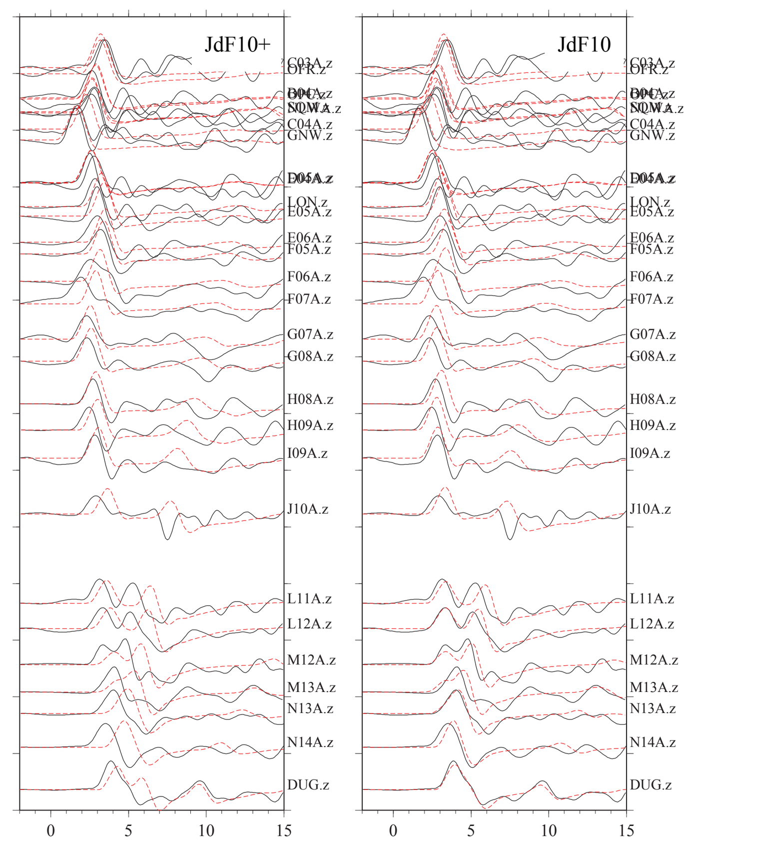

Fig 10. Comparison of data and synthetics for JdF10+ (left) and JdF10 (right) velocity models. The JdF10+ model consists of JdF10 model and velocity perturbations below 300 km from SCH. The JdF10 synthetics are shifted back 0.4s to compensate delays by fast anomalies below 300 km.

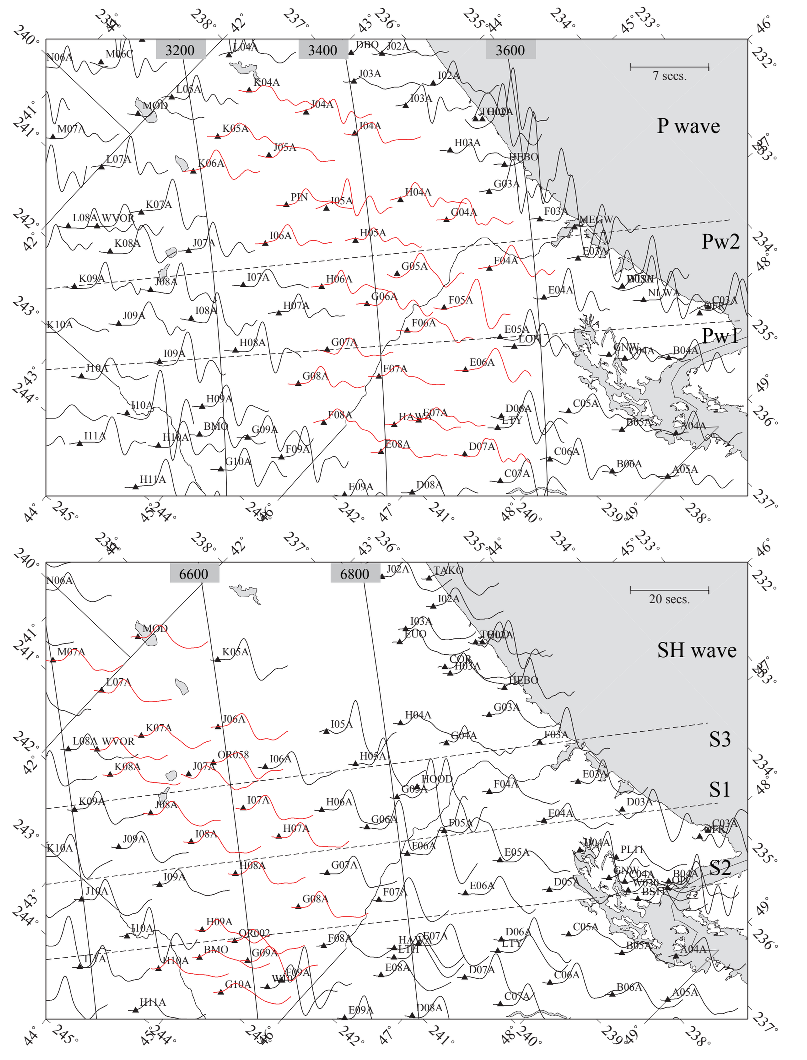

Fig 11. P and SH waveform complexities for the 2007 Gulf of Mexico (top) and South America (bottom) earthquakes. Red traces have lower amplitudes and complex arrivals, which appear to be the multi-pathing caused by the DNTS. Because the South America earthquake has larger distances and smaller incident angles, the multipathing effects appear closer to the anomaly. Dashed lines are their profiles in Fig. 2. Note that the complexity is continued in about a 3 degree strip in the upper panel.

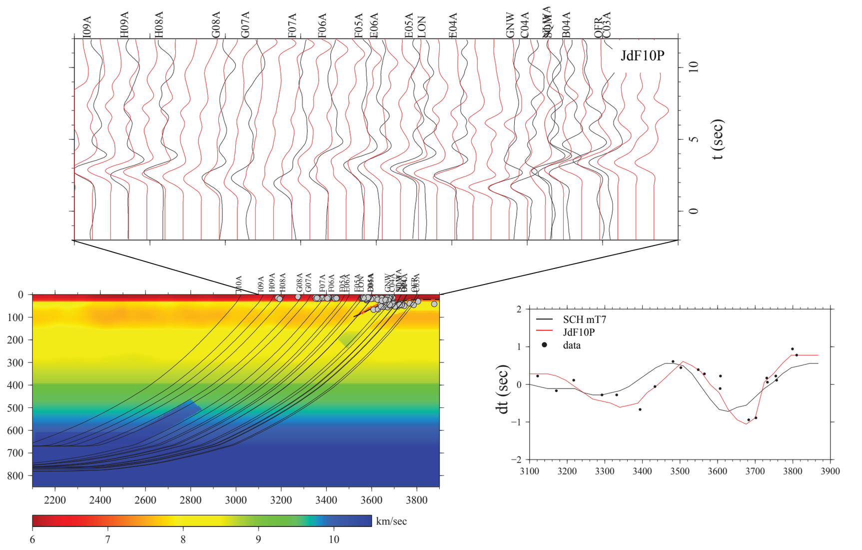

Fig 12. Comparison of data and synthetics for velocity model JdF10P. Travel time residuals for SCH-mT7, JdF10P, and data are also plotted on the right. The velocities are given in absolute levels where the JdF slab and DNTS are obvious.

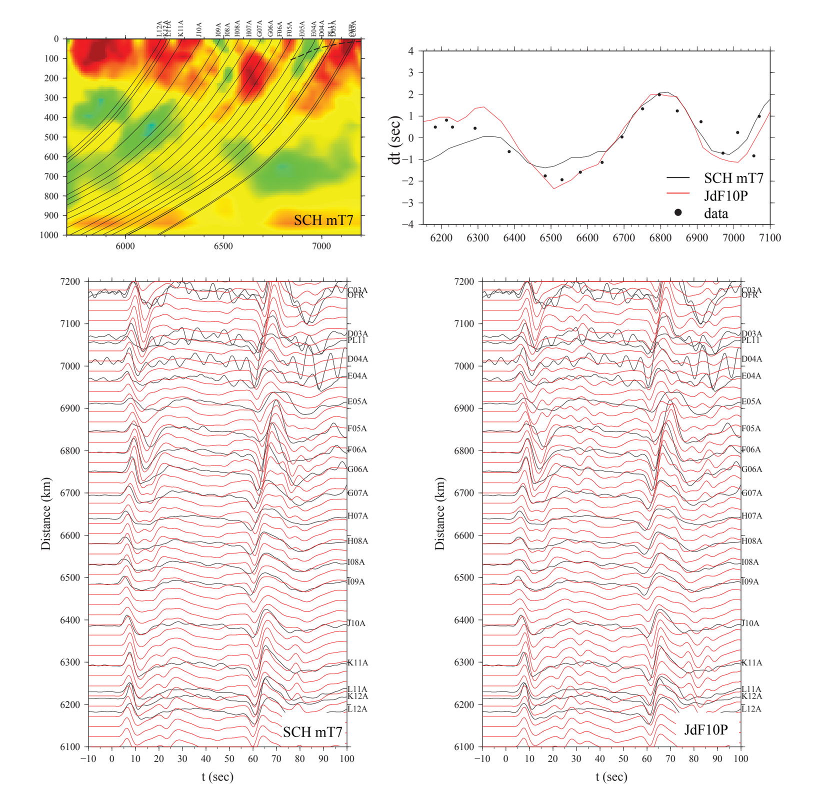

Fig 13. Comparison of data and synthetics for profile S1 with ray paths and travel time residuals plotted on the top. For S waves of SCH-mT7, we assume the ratio R=ΔVs/ΔVp= 2.0. The R ratio is 1.2 and 2.3 for the Juan de Fuca slab and DNTS for model JdF10P, respectively.

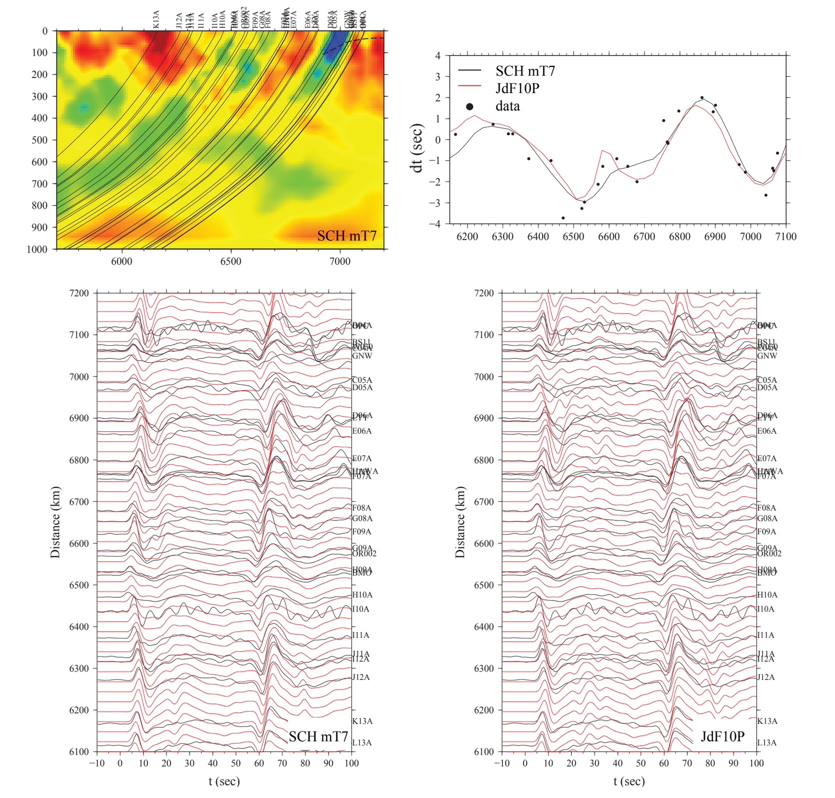

Fig 14. Comparison of data and synthetics for profile S2 with ray paths and travel time residuals plotted on the top. The Juan de Fuca slab has the same structure of Pe2. R ratios here are the same as Fig. 13.

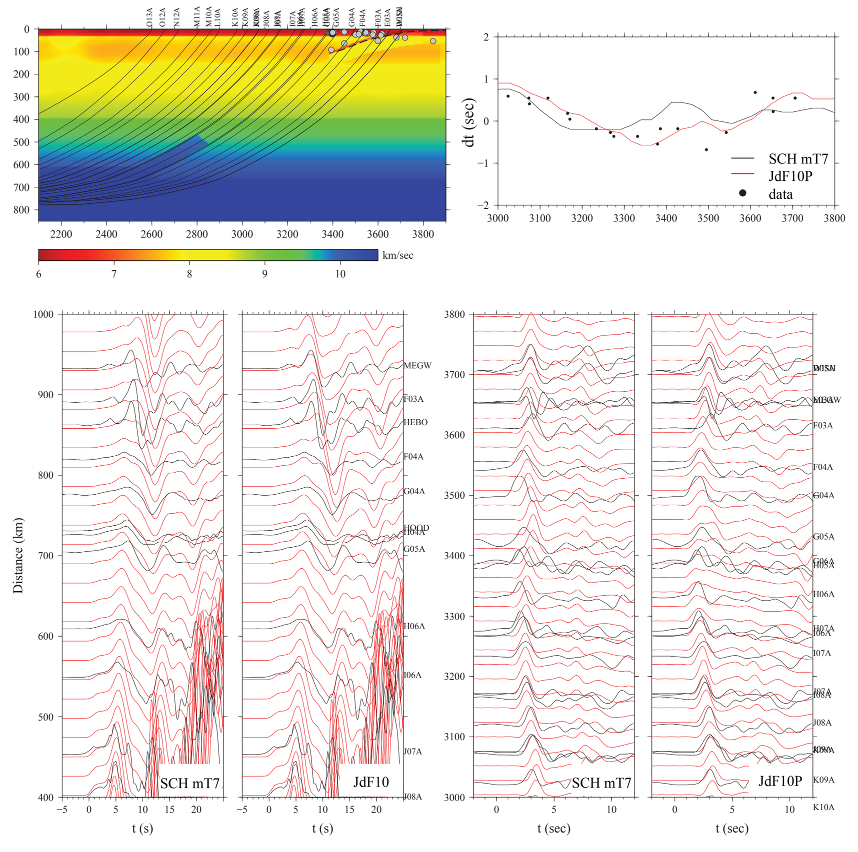

Fig 15. Comparison of data and synthetics for profile R2 (left) and Pw2 (right) with ray paths and travel time residuals plotted on the top. The Juan de Fuca slab is about 110 km deep.

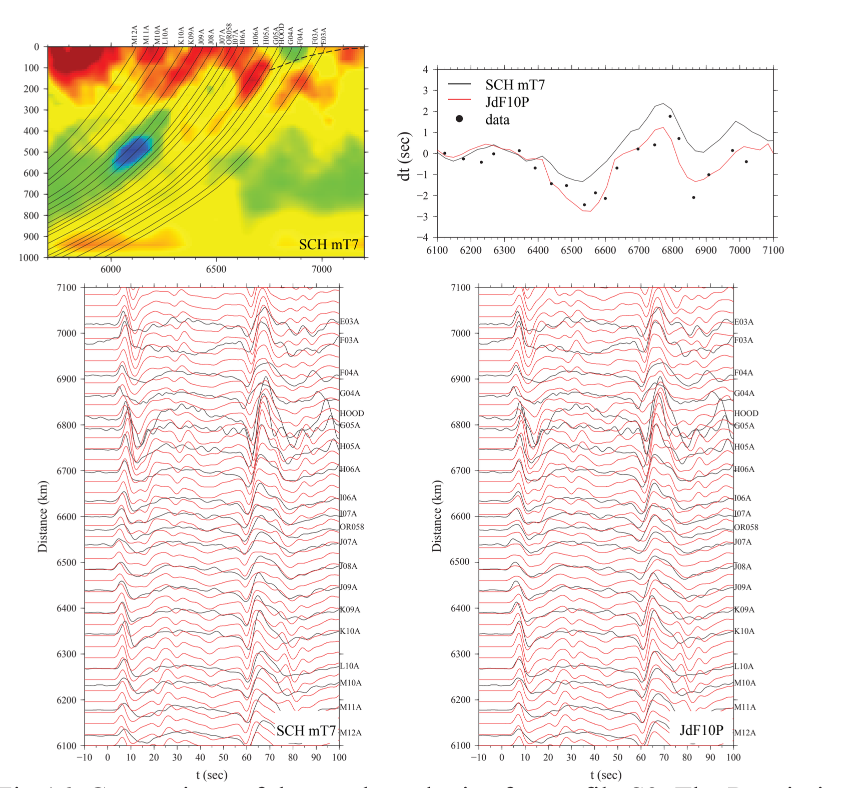

Fig 16. Comparison of data and synthetics for profile S3. The R ratio is 2.0 for the Juan de Fuca slab and 2.3 for the DNTS.

Discussion

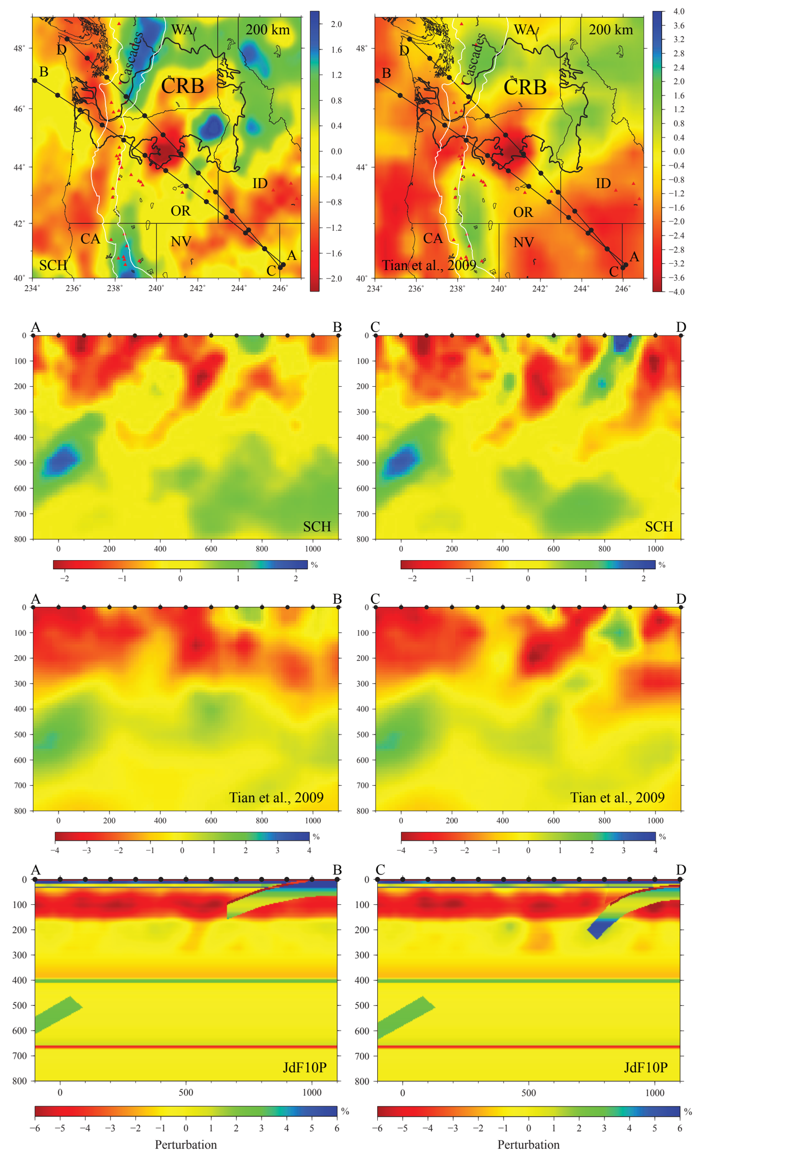

Fig 17. Comparison of velocity profiles along corridors AB and CD with respect to AK135 for Schmandt and Humphreys [2010], Tian et al. [2009] and JdF10P. The location of AB and CD are displayed with the tomography map at 200 km on the top. White lines mark the boundary of the Cascades and thick black lines denote the boundary of the Columbia River Basalts (CRB). Red triangles represent volcanoes in western US. The lower panels display the velocity images for P-waves (SCH), SH-waves (Tian), and at the bottom, our hybrid model JdF10. The SCH anomalies are not needed to match this data set below 300 km.

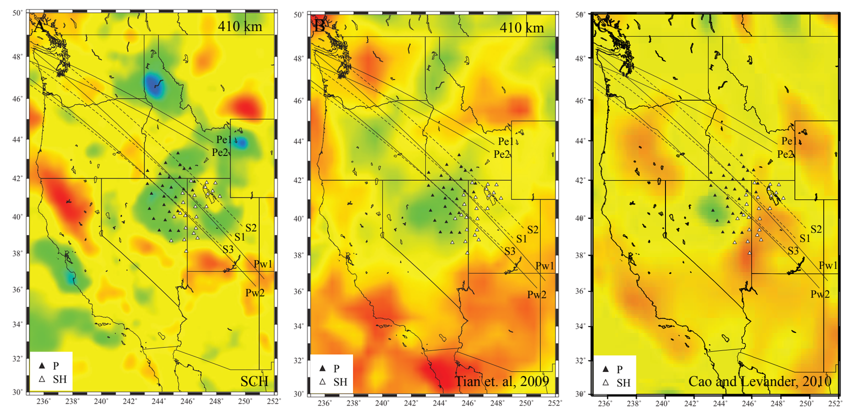

Fig 18. Right. Seismic stations with complex P (black triangles) and SH (white triangles) waveforms. The stations displaying complexity (red in Fig. 11) are migrated down to "410" along ray paths from these two events assuming mT7, and displayed relative to the seismic tomography from Schmandt and Humphreys [2010] (A), Tian et al. [2009] (B), and receiver function stacking [Cao and Levander , 2010] (C). Solid and dashed line are P and SH profiles we modeled in this study.

Acknowledgement

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