7 Further Constraints on Lateral Variations of Structure at the Base of the Pacific LLSVP Using Shear Diffracted Waves

Meng Cai and Barbara Romanowicz

Introduction

Large Low Shear Velocity Provinces (LLSVPs) are regions of reduced shear wave velocity in the lowermost ~500-1000 km of the mantle, which are located antipodally beneath the central Pacific and Africa and rooted in D". Their lateral boundaries are sharp as evidenced by the observation of complex local waveforms in seismic phases, and their density may be larger than in the surrounding structures. Ultra Low Velocity Zones (ULVZs) appear to correlate with edges of the Pacific LLSVPs as well as the locations of hotspots. The ULVZs are constrained by modeling to be several hundred kilometers in diameter and tens of kilometers in thickness. Cottaar and Romanowicz (2012) identified an intriguingly large ULVZ structure (called the preferred model) at the core-mantle boundary, at the northern border of the Pacific LLSVP and in the vicinity of Hawaii. Since this work was published, several recent earthquakes in different locations have illuminated this unusually large ULVZ structure and revealed quite similar waveform complexities. Owing to the strong sensitivity of the seismic data to the structure, we can model a simplified 3D ULVZ, providing further constraints on the geometry and location. The results of this study are aimed at confirming and better characterizing this unusual structure, as a first step towards searching for other possible structures of this type in the vicinity of the Pacific LLSVP.

Method and Data

Most recent seismological investigations of the lowermost mantle have used global datasets to analyze the travel time shift and amplitude variation of different seismic phases. We are using numerical forward modeling of the shear diffracted (Sdiff) phase observed at broadband stations from the USArray and other permanent networks in North America for large deep earthquakes (depth>200 km and 6<Mw<7) in the western Pacific region at distances of 80º-130º. In this study, we used the April 17th, 2014 event (depth 208.6 km, Mw 6.9) to illustrate the affect of the ULVZ in north-central Pacific on the Sdiff waveforms.

The modeling approach is to consider the variations with azimuth and epicentral distance of Sdiff travel time residuals computed with respect to the reference 1D Preliminary Reference Earth Model (PREM, Dziewonski and Anderson, 1981). We also compute corresponding waveforms for 3D synthetics using the Coupled Spectral Element Method (CSEM, Capdeville et al., 2003) to further interpret the waveforms of the main phase and post-cursor. This method is computationally effective for the study of D" with full 3D spectral element solution in a layer of limited thickness above the core-mantle boundary, coupled with 1D normal mode solution in the rest of the mantle and in the core.

We find that the focal mechanism provided by Centroid Mo-

Figure 2.7.1: The location of the event is indicated by a yellow star and the stations are indicated by blue triangles, the great circle paths are indicated by green lines from entrance to exit points of a lowermost mantle layer about 300 km thick from core-mantle boundary. Background is cluster analysis result of five tomographic models (Lekic et al., 2012). The numbers on the right indicate how many of the models agree that a particular location has shear velocity lower than average.

Figure 2.7.2: The comparison of tangential velocity waveforms from (a) observed data, (b) 1D PREM and (c) 3D CSEM at distances between 110º and 120º. The traces have been band-pass filtered between 10-20 s. The main Sdiff (blue) and post-cursor (yellow) are highlighted in (a) and (c) for the data and the waveforms calculated for the preferred model.

ment Tensor (CMT) catalog for this event may not be optimal in that it does not accurately predict the observed amplitude ratios between the main phase and the depth phase, so modifying the focal mechanism may be necessary before we attribute amplitude variations as a function of azimuth to the structure in the D" region. This requires analyzing records from different
locations and azimuths using a grid search method to get the best solution.

Results

Figure 2.7.1 presents the Sdiff paths to 217 available stations from the US transportable array and permanent stations in North America that sample the border of the northern Pacific LLSVP. Based on the CMT data for this event, we computed the 1D synthetics for the PREM model in Figure 2.7.2b and 3D synthetics using CSEM for a model in which we have added a ULVZ as shown in Figure 2.7.2c. The model explains the time shift of the main Sdiff phase well (about 15 s at the most) and also the relative arrival time of the post-cursor with respect to Sdiff (about 40 s at the most), as a function of azimuth. However, the synthetics are not able to reproduce the strong amplitude reduction in the Sdiff phase at certain azimuths between 46° and 60° (Figure 2.7.3a), nor the amplitude reduction in the post-cursor phase (Figure 2.7.3b).

In Figure 2.7.3b, the post-cursor is too weak at azimuths smaller than 48°, so these measurements are only possible for larger azimuths. The synthetics reproduce the trend of increasing amplitude of the post-cursor at large azimuths, but the amplitude is slightly under-estimated compared to observed data. In Figure 2.7.3c, the travel time in 3D synthetics matches the general trend of both the Sdiff and the post-cursor phases with observed data. Some scatter in the travel time of post-cursors between 46°-48° azimuths may be due to the difficulty of measuring the peak of post-cursors, including possible cycle slips.

On the other hand, Figure 2.7.4 indicates that after adjusting the focal mechanism, updated 3D synthetics have a clear Sdiff phase amplitude reduction as the azimuth increases, and a clear Sdiff phase amplitude reduction as the azimuth decreases, which can explain the trend in the observed data. This is also the case in 1D synthetics. However, the post-cursor synthetics at the large azimuth now have a slight time shift, which may be due to the uncertain geometry and location of the ULVZ.

Conclusions

The preferred model has been confirmed using the amplitude and travel time variations of the main Sdiff phase and time delayed post-cursor for an event not previously used in Cottaar and Romanowicz (2012), but there are still some features in the data that the preferred model cannot explain well. Adjusting the focal mechanism of the earthquake source can help improve the fits for the amplitude variation with azimuth, but may degrade the travel times of the post-cursors. There is potential for further constraining the shape and location of ULVZ by analyzing Sdiff phase data from new events in different locations, which can better cover the study area from all available directions.

References


