The Geometry and Seismic Properties of the Subducting Cocos Plate in Mexico

YoungHee Kim, Robert W. Clayton, and Jennifer M. Jackson

1 Abstract

The subducted Cocos plate beneath central Mexico as imaged with receiver functions (RFs) from the MASE (Mexican- American Subduction Experiment) array tectonically underplates the continental crust for a distance of approximately 300 km from the trench. The receiver functions are modeled with a 2D finite-difference code, and the results confirm the need for a low-velocity zone (lower than normal oceanic crustal velocities), corresponding to a thin serpentinitized layer on the top of the subducting slab, to reproduce the impedance contrasts. This zone appears to absorb nearly all of the energy above the upper plate and the oceanic crust. By inverting RF amplitudes of the converted phases and their time separations, we present a new method to infer the detailed maps of the seismic properties of the slab, upper plate, and oceanic crust. A prominent low-velocity zone (LVZ) is inferred above the upper plate and oceanic crust. High Poisson’s ratio and Vs/Vp ratio due to anomalously low S-wave velocity at the upper oceanic crust in the depth range of 0.5-3 km is observed in the upper plate. The high Poisson’s ratio and relatively high Vp/Vs ratio above the LVZ may indicate the presence of water and hydration minerals or high pore pressure. The average of high water content within the slab explains the flat slab geometry without strong coupling of two plates. This may also explain why small slab earthquakes occur in the subducting plate and the overlying oceanic crust rather than in the overriding plate. Similar analyses will be performed utilizing the data from the VEOX (Veracruz-Oaxaca Seismic Line) array across the latitudes of Tehuantepec in southern Mexico to compare the subduction process with the same slab, but where the dip angle is steeper. The thick dashed line indicates the continental Moho, which extends from TMVB to the coast near Gulf of Mexico. The abbreviations are Ctl, Chrysotile; Tlc, Talc; Atg, Antigorite; Lz, Lizardite; Gb, Gabbro (fresh, unmetamorphosed); Pyx, Pyroxenite; Harz, Harzburgite.

2 Data

Maps on the left show the location of our study and two seismic arrays (gray triangles for MASE and red triangles for VEOX). Iso-depth contours of the subducted Cocos plate beneath the North American plate (Pardo and Suárez, 1995) are shown in the map. Map on the right shows the distribution of teleseismic events used in the study (gray dots for MASE and red dots for VEOX). Dotted lines are distance of 30˚ and 40˚ away from the center of the study area. Migrated RF image showing the slab and Moho geometry in central Mexico. The top plot shows the migrated image using Pms and Pfs phases. The thick dashed line indicates the continental Moho, which extends from TMVB to the coast near Gulf of Mexico. The abbreviations shown in the image are Ocm = oceanic Moho, Cm = continental Moho. Note that the green (dotted and dashed) lines are the multiples from the crustal interface (Pds and Pms) and the dipping slab can be located by changes in the depth of the seismic multiple changes. The bottom left plot shows RFs for one teleseismic event along the flat slab portion of the slab. The blue, white, and orange colors overlay denote the continental crust, slab, and oceanic lithosphere, respectively. The bottom middle plot illustrates the corresponding model. The bottom right plot shows the compressional-wave velocity model determined from the finite-difference modeling.

3 MASE: Geometry of the Cocos plate

Seismic and mineralogical properties of the oceanic crust of the MASE array north of the TMVB. The plots on the 1st and 2nd columns show variations in the (normalized) impedances, Vp/Vs and Poisson’s ratios at upper and lower oceanic crust. The plot on the 3rd column shows calculated Vp/Vs ratio versus S-wave velocity (Vs) at a depth of 30 km and a range of likely temperatures (500 - 800˚C) at this depth for candidate hydrated phases (gray lines) and rock types (black diamonds). The points for randomly oriented talc and c-axis oriented talc are from Mainprice et al. (2008), and those for different rock types from Christensen and Salisbury (1975). The data points for the upper oceanic crust are highly varying in Vp and Moho geometry, whereas those for the lower oceanic crust are tightly bounded (average of 1.72). The abbreviations are Ctl, Chrysotile; Tlc, Talc; Atg, Antigorite; Lz, Lizardite; Gb, Gabbro (fresh, unmetamorphosed); Pyx, Pyroxenite; Harz, Harzburgite.

5 VEOX: RF image showing controversial structure dipping from the Gulf of Mexico

Preliminary RF results for the VEOX array (uninterpreted display on the left and interpreted display on the right). The RFs obtained from the events located SE from VEOX are used. Amplitudes are relative to incident P-wave. Red and blue colors correspond to velocity increase and decrease with depth, respectively. Strong azimuthal variations of Moho are observed especially in the mid- and end-section of the figure. This is partly due to the fact that the trench-normal plane of the slab is modeled in a right-lateral strike-slip tectonic setting. The slab along the east and west limbs of the Pacific coast are not clearly imaged due to poor station quality, and we observe a well-defined dipping interface indicated as a cyan dotted line.

6 VEOX: Projected seismology along different sections

Seismicity along the line 6-7, and 7 continues along the structure. By analyzing the data from the SSN, the slab geometry in 3D as well as variations in seismic and mineralogical properties within the slab dip for VEOX. Preliminary results on the RFs show that a thin seismic layer (dotted thin line) is observed near the top of the slab, but not as strong as the one we have seen from Kim et al. (2009). Thus, we expect to observe considerable change in the impedance of the layer due to the change in the water content and/or different mineral assemblages or the thickness of the layer itself. By analyzing the data from the SSN, the slab geometry in 3D as well as variations in seismic and mineralogical properties are observed especially in the mid- and end-section of the figure. This is partly due to the fact that the trench-normal plane of the slab is modeled in a right-lateral strike-slip tectonic setting. The slab along the east and west limbs of the Pacific coast are not clearly imaged due to poor station quality, and we observe a well-defined dipping interface indicated as a cyan dotted line.

Migrated RF image showing the slab and Moho geometry in central Mexico. The top plot shows the migrated image using Pms and Pfs phases. The thick dashed line indicates the continental Moho, which extends from TMVB to the coast near Gulf of Mexico. The abbreviations shown in the image are Ocm = oceanic Moho, Cm = continental Moho. Note that the green (dotted and dashed) lines are the multiples from the crustal interface (Pds and Pms) and the dipping slab can be located by changes in the depth of the seismic multiple changes. The bottom left plot shows RFs for one teleseismic event along the flat slab portion of the slab. The blue, white, and orange colors overlay denote the continental crust, slab, and oceanic lithosphere, respectively. The bottom middle plot illustrates the corresponding model. The bottom right plot shows the compressional-wave velocity model determined from the finite-difference modeling.

4 MASE: Seismological and mineralogical properties of the Cocos plate

Geological setting of the Cocos plate in the MASE array. The plots on the 1st and 2nd columns show variations in the (normalized) impedances, Vp/Vs and Poisson’s ratios at upper and lower oceanic crust. The plot on the 3rd column shows calculated Vp/Vs ratio versus S-wave velocity (Vs) at a depth of 30 km and a range of likely temperatures (500 - 800˚C) at this depth for candidate hydrated phases (gray lines) and rock types (black diamonds). The points for randomly oriented talc and c-axis oriented talc are from Mainprice et al. (2008), and those for different rock types from Christensen and Salisbury (1975). The data points for the upper oceanic crust are highly varying in Vp and Moho geometry, whereas those for the lower oceanic crust are tightly bounded (average of 1.72). The abbreviations are Ctl, Chrysotile; Tlc, Talc; Atg, Antigorite; Lz, Lizardite; Gb, Gabbro (fresh, unmetamorphosed); Pyx, Pyroxenite; Harz, Harzburgite. Earthquakes from SSN (National Seismic Network of Mexico) and VEOX are projected into 8 different profiles (see map on the top left). Line 1 to 8 are roughly perpendicular to the Middle America Trench (MAT), line 5 and 6 parallel to the VEOX array. Note that earthquakes recorded from the VEOX are relocated by the double-difference location method. Also, the dotted line indicates the dipping structure from the Gulf of Mexico that we have seen from the RF image (section 5). We observe that the seismicity along the line 5 to 8 is influenced by this anomalous structure. In particular, the structure truncates the seismicity along the line 5 at a depth of 120-130 km, and then the seismicity along the line 6, 7, and 8 continues along the structure.

7 Future Work

• Kirschknöre migration/inversion using teleseismic earthquakes will be used to image the subduction structure down to the mantle transition zone. The noise in the RFs and/or spectral separation from the 3D structure can be suppressed by stacking to produce a better image than the RF image.

• RF amplitude inversion technique proposed by Kim et al. (2009) will be used to investigate the variations in seismic and mineralogical properties within the slab for VEOX. Our preliminary result on the RFs shows that a thin seismic layer (dotted thin line) is observed near the top of the slab, but not as strong as the one seen from Kim et al. (2009). Thus, we expect to observe considerable change in the impedance of the layer (due to the change in the water content and/or different mineral assemblages or the thickness of the layer itself).

• By analyzing the data from the SSN, the slab geometry in 3D as well as variations in seismic and mineralogical properties in 2D along the Middle American Trench in Mexico, we will need to incorporate other means such as seismology and reflection results to build the 3D model.

References


email: ykim, clay, jackson@geophysics.caltech.edu