3D Shear Velocity Structure of the Northwestern South America-Caribbean Subduction Zone from Ambient noise and Ballistic Rayleigh Wave tomography

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Abstract

Geology background The Caribbean plate (CAR) collided with and began subducting beneath northwestern South America (SA) at about 60-55 Ma. Since the onset of subduction, it has formed the Lara nappes and subsequently the Laramide-style uplifts of the Merida Andes, Sierra dela Perija and Santa Marta ranges, with maximum elevations > 5km. The triangular Maracaibo block, bounded by the Santa Marta-Bucaramanga, Bocono, and Oca-Ancon Faults, is currently escaping to the north relative to SA over both the subducting and nonsubducting CAR plate (Figure 1).

Motivations Although many petroleum related seismic studies have been done in this area, the details of subduction geometry of the CAR plate beneath the Maracaibo block remain unclear. The few deeper seismic investigations are either very large scale, very local, or only peripheral to this area (*Van der Hilst and Mann, 1994; Van Benthem et al, 2013; Bezada et al, 2010; Masy et al, 2011, 2015; Escalona et al, 2011; Mora et al, 2017; Mazuera et al 2019; Cornthwaite et al, 2021*). Previous geodetic studies suggest that this region has potential for a great (8+) earthquake (*Bilham & Mencin, 2013*). To investigate this complex region, we fielded a 65 element broadband seismic array to complement the 48 existing stations of the Colombian and Venezuelan national seismic networks. The array is collectively referred to as the CARMArray (Figure 1).

Results In this study, we jointly inverted ambient noise Rayleigh wave Z/H ratios, phase velocities in the 8-30s band and ballistic Rayleigh wave phase velocities in 30-80s band to construct a 3D S-wave velocity model in the area from 75°-65° west and 5°-12° north. Rayleigh wave Z/H ratios are sensitive to the shallow sedimentary structure, while the phase velocity data have good resolution of the crust and upper mantle. The Vs model shows strong low-velocity anomalies beneath the Barinas-Apure and Maracaibo Basins, the Paraguana Peninsula that are well correlated with surface geology. Sediment thickness beneath the Maracaibo basin reaches up to ~9 km depth, consistent with previous studies (*Kellogg & Bonini, 1982*). Crustal thickness beneath the Santa Marta uplift is 27-30 km, shallow for its nearly 4km elevation. From the trench to the southeast, Moho depth increases from 25-30 km near the coast to 40-45 km beneath the Maracaibo Basin, with the thickest crust, ~ 50 km, lying under the Merida Andes beneath the Bocono Fault. Crustal thickness decreases under the Venezuelan interior to ~45 km. From 50 to 150 km depth, the CAR plate show ~2% high Vs anomalies beneath the Santa Marta uplift and the Serrania de Perija range. Our slab image matches local seismicity very well, and is consistent with and complements images from teleseismic P-wave tomography (*Cornthwaite et al, 2021*).

Data and Study area

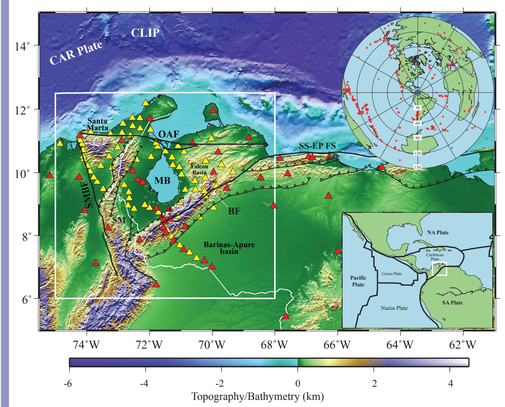


Figure 1. Map of study area with the main surface geology structure included. Red triangles represent 48 permanent stations in Columbian and Venezuelan national seismic networks, cyan triangles represent 65 broadband temporary stations, combined as the CARMArray. Due to the irregular distributions of seismic stations, the main resolution locates in the area bounded by white box. OAF: Oca-Ancon Faults; SMBF: Santa Marta-Bucaramanga Faults; MB: Maracaibo Basin; BF: Bocono Fault.

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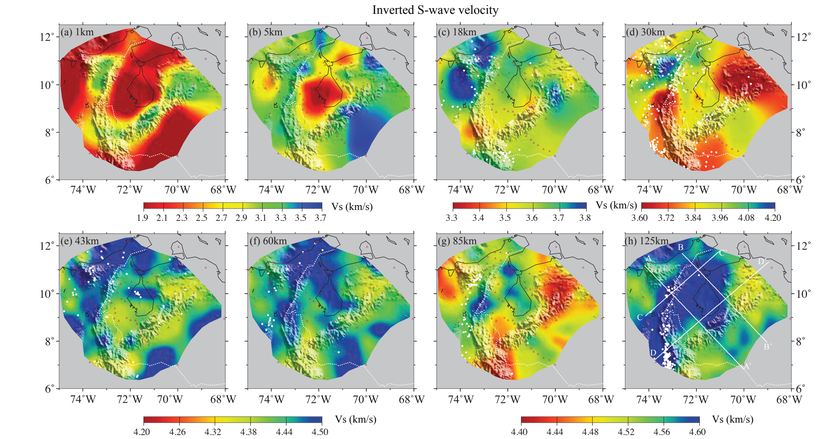


Figure2. Vs maps at the depths of (a) 1km, (b) 5km, (c) 18km, (d) 30km, (e) 43km, (f)60km, (g) 85km and (h) 125km.

At shallow depth (Figure 2a and 2b), low velocity anomalies correlate well with surface geology. Sediment thickness can reach to ~9km depth beneath the Lake Maracaibo.

High Vs velocity (~3.8 km/s) beneath Santa Marta indicate the existing of subducted Caribbean Large Igneous Province (CLIP)

Crust thickness beneath Santa Marta is ~30km, shallow for its nearly 4km elevation.

From 50km to 125km depth, the CAR plate shows high velocity anomalies beneath the Santa Marta and the Serrania de Perija range and extented to Maracaibo Block.

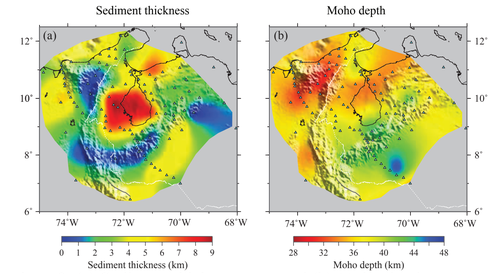


Figure3. (a) Sediment thickness map and (b) Moho depth map.

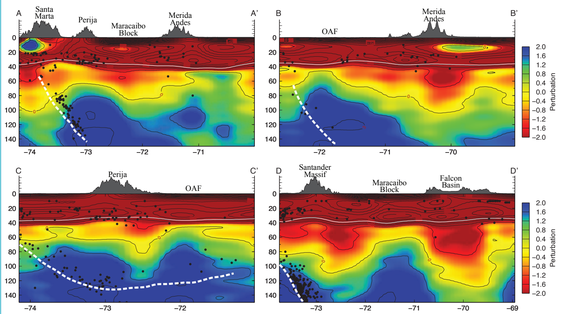


Figure4. Vs perturbation profiles at lines AA', BB', CC' and DD', reference model is AK135 1D Vs model. Black dots are local seismicities, white dashed lines are slab intermediate surface from teleseismic body wave tomography (*Cornthwaite et al., 2021).*

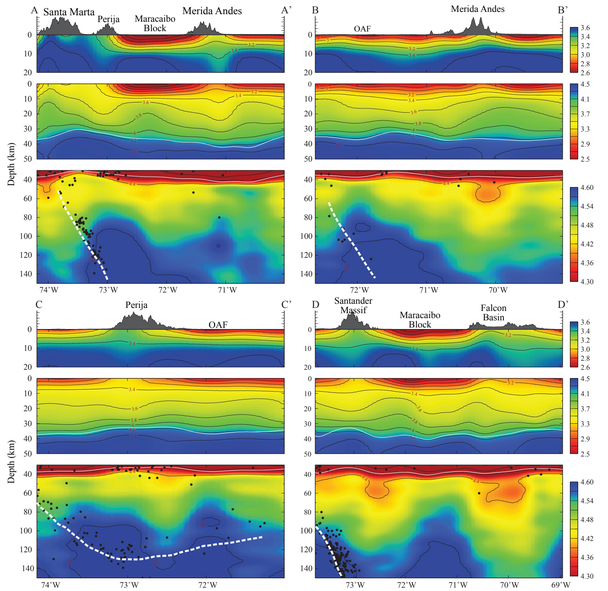


Figure5. Sedimentary (top), crustal (middle) and upper mantle (bottom) shear velocity structures profiles beneath lines AA', BB',CC' and DD', locations are shown in Figure 1.

Method

1. We measured ambient noise Rayleigh wave phase velocities and Z/H ratio in the 8-30s band, mainly following (*Li et al., 2016 and Bensen et al., 2007*).
2. We used two-plane-wave method to extract Rayleigh wave phase velocities from ballistic data in 30-80s band (*Forsyth & Li, 2008 and Yang et al., 2008*).
3. A Monte Carlo joint inversion method was used to construct a 3D velocity structure of the study area.

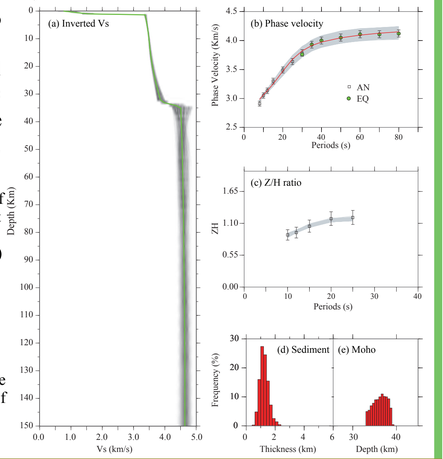


Figure 6. An example of outcomes from the joint inversion. (a) Inverted 1D velocity profiles. (b) Observed Rayleigh wave phase velocity (circles and squares) vs predictions of accepted models. (c) Same with (b) except for Z/H ratios. (d) and (e) are the posterior distributions of the sediment thickness and Moho depth.

Conclusions

1. First time high-resolution 3D Vs model of the study area, range from 0km to 150km, including sediment structures, crustal structures and lithospheric structures.
2. Imaged the slab geometry in the transiton zone from flat slab subduction to normal subduction and is consistent with and complements images from teleseismic P-wave tomography (*Cornthwaite et al., 2021 G3*).
3. A clear image of slab tear beneath the Sierra de la Perija range at the depth between 80km and 120km.
4. Weak lithospheric structure beneath the Merida Andes and Falcon basin, that may related to collisions between the CAR oceanic lithosphere and SA continental lithosphere.

References

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