Shear Wave Velocity Structure of the Lithosphere Beneath the Eastern Caribbean Revealed by Ambient Noise Tomography

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Abstract

We investigate shear-wave velocity structure of the Eastern Caribbean lithosphere using continuous seismic records from broadband stations deployed around the area. We construct cross-correlation functions of ambient noise for two time periods, 2003-2005 and 2011-2013, based on data availability. Phase velocities of fundamental-mode Rayleigh waves are measured from the daily-stacked cross-correlation functions using a phase-matched-filter based method, and they are further projected on a set of 2°x2° grids, as suggested by checkerboard tests. The grid phase velocity dispersion data are inverted for 1D shear velocity profiles. The 3D velocity model indicates that the mean shear velocity in the lithospheric mantle is lower than the global average. Similar results have been reported beneath other large igneous provinces. Meanwhile, the lithosphere-asthenosphere boundary is located at depths between ~50 km and ~75 km, which is thinner than a normal oceanic lithosphere with an age of ~126-150 Ma. We speculate that low velocities in the lithosphere are associated with its composition together with a slightly elevated thermal state. Significant amount melts are likely produced beneath the thickened oceanic crust during the formation of the Caribbean Large Igneous Province (CLIP). Meanwhile the plume head has also eroded the Caribbean lithosphere. In a later stage after the magmatic event, the melts crystalized and formed pyroxenite, which possesses a low seismic velocity but a high density, resulting in a thin lithosphere with a reduced wavespeed. A thick buoyant crust overlying on a thin denser lithospheric mantle may explain the subduction configuration in the eastern Caribbean.

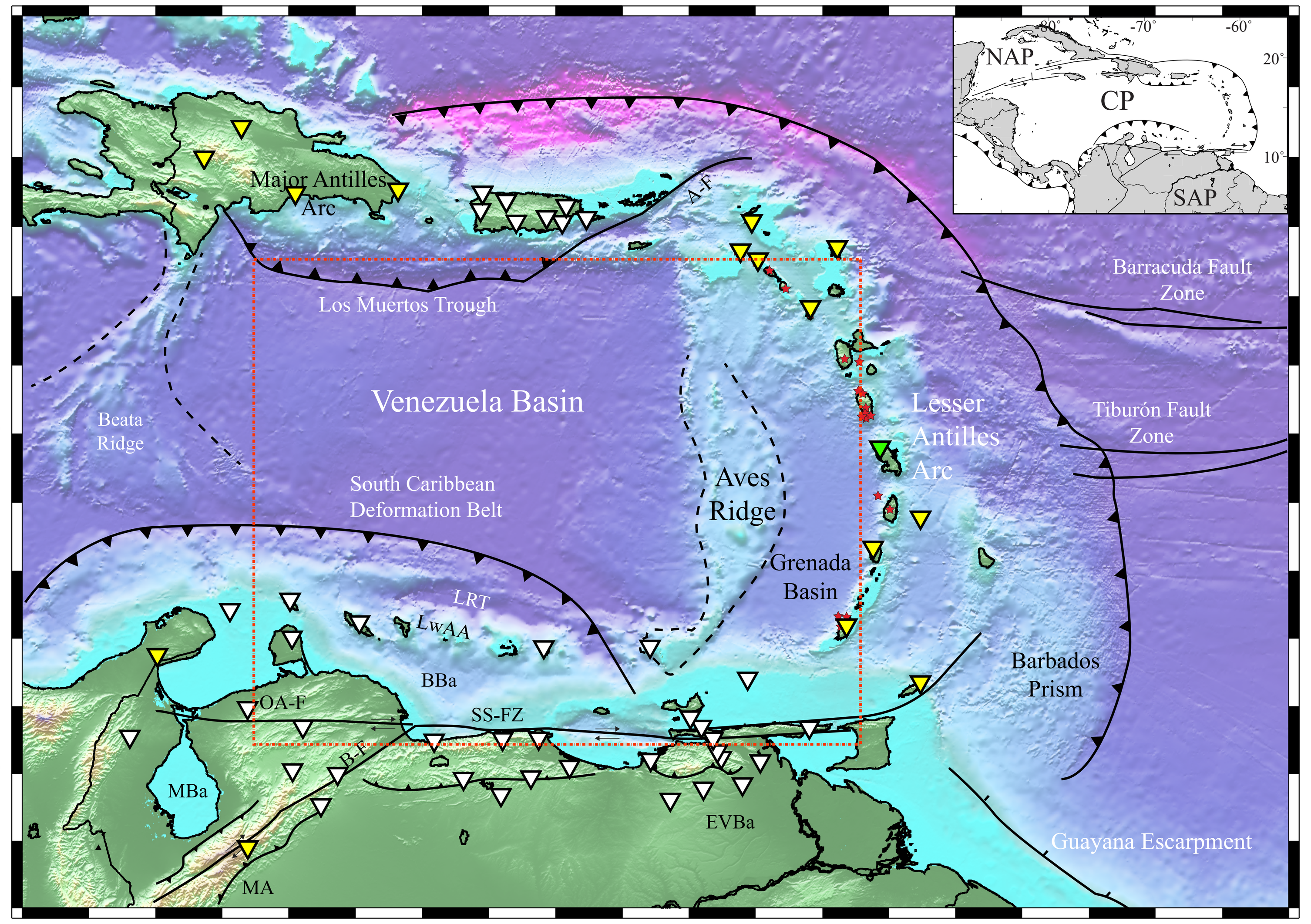


Fig 1: Map showing the broadband stations (triangles) and the principal plate boundary fault systems (solid black lines) of the eastern Caribbean. White and yellow triangles indicate stations being active in the periods of 2003-2005 and 2011-2013, respectively. Station G.FDF shown in green was active in both periods. The dashed red and black lines delineate the CLIP, the Beta and the Aves ridges, respectively. Red stars indicate volcanoes with recent activity (Bouysse et al., 1990). Box indicates the area with good data coverage and model resolution.

Introduction

The Caribbean Large Igneous Province (CLIP) is a late Cretaceous LIP emplaced onto an oceanic crust (the Caribbean Plate; CP; Fig. 1) that sits between the North American plate (NAP) and South American plate (SAP). Both have been studied with a variety of techniques that have come to the conclusion that its current tectonic setting derives from a complex geodynamic evolution. A key stage of this development is the influence over the lithosphere of two magmatic events, occurred *circa* 90 and 76 Ma, possibly related to plume-like activity (Sinton et al., 1998). Even though there is a large amount of information regarding the geochemistry (e.g. Sinton et al., 1998), neotectonics (e.g. Audemard, et al., 2005) and seismic stratigraphy (e.g. Mauffret and Leroy, 1997) of the Caribbean, there is scarce information regarding the lithospheric structure of the CP and the relationship to its history. Our goal is to image the upper lithospheric section of the eastern Caribbean and estimate its shear wave velocity (Vs) structure using this method. The results presented here are consistent with previous studies on LIPs while delivering new constrains on the Caribbean plate structure and geodynamics.

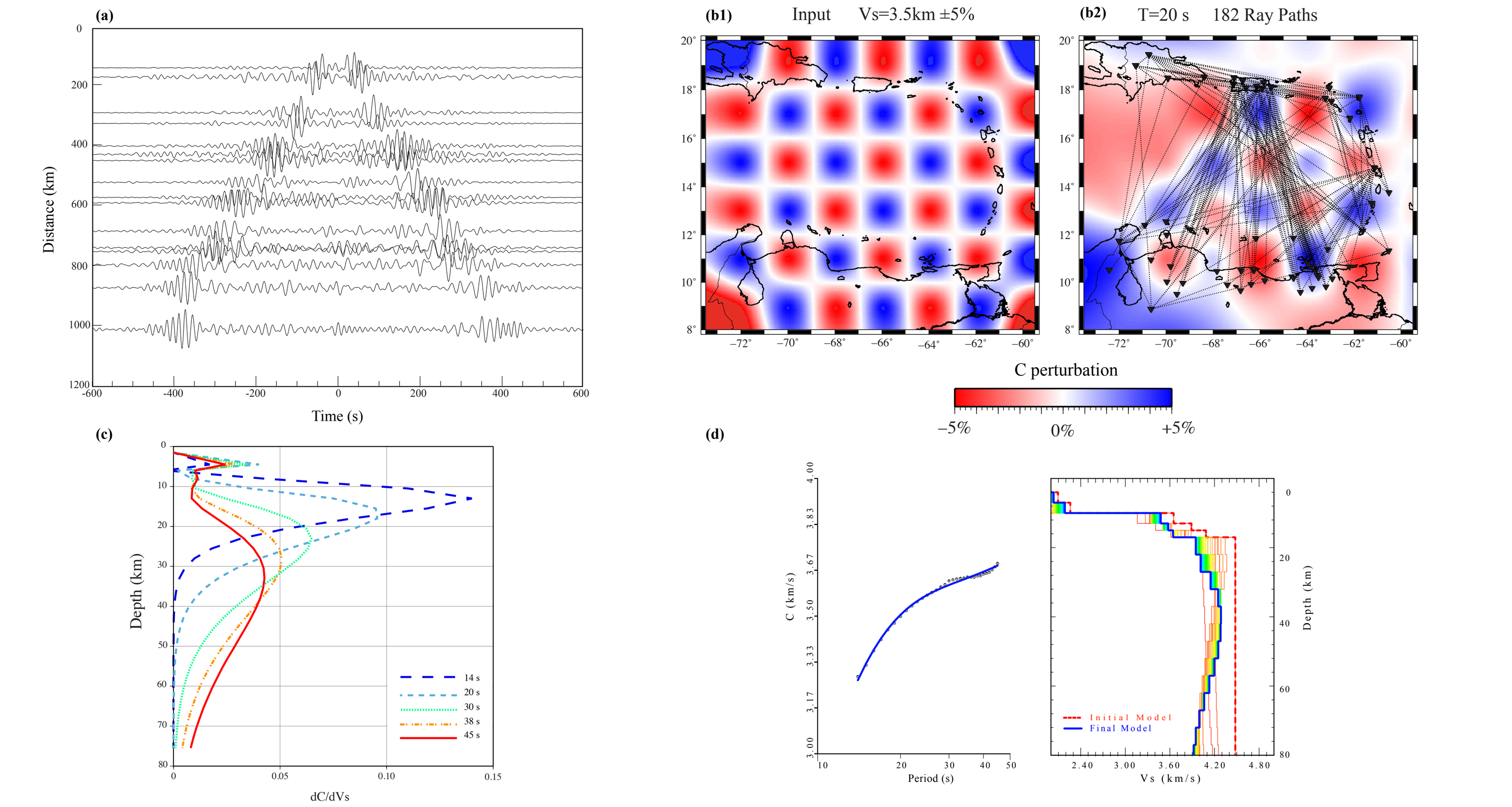
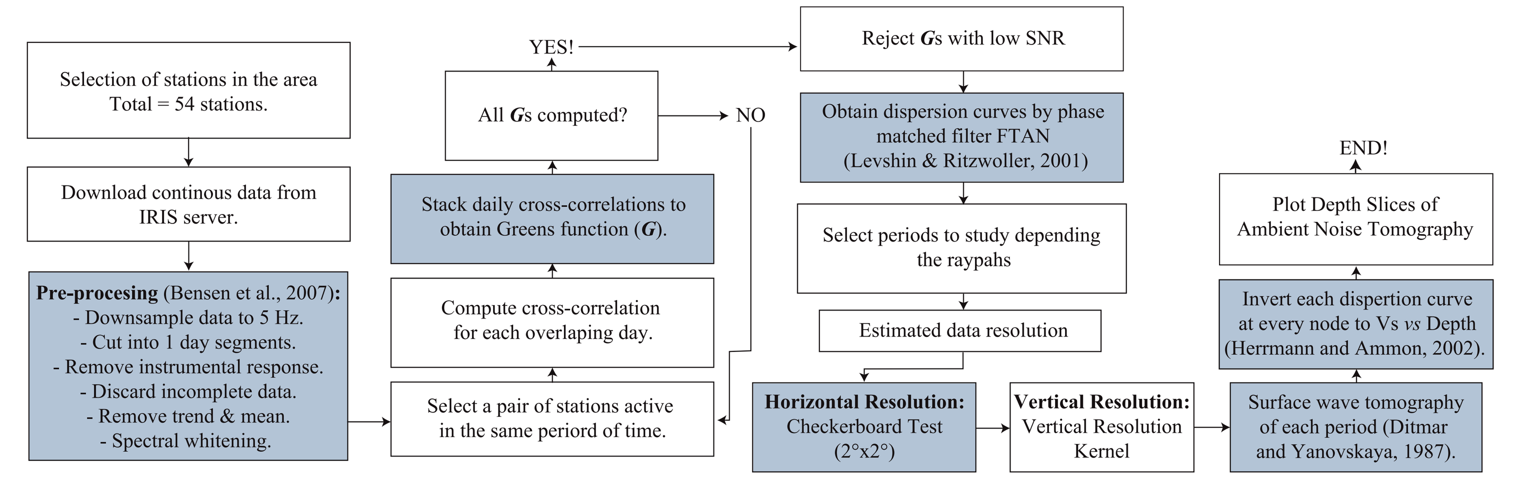


Fig 2: Some steps of the method followed in this research: **(a)** Record section of the daily-stacked cross-correlations functions between some stations in region and station G.FDF (green triangle in Fig. 1) arranged by distance. **(b)** Ray paths coverage and Checkerboard test: (b1) Synthetic velocity structures grid with 2°x2° cells and ±5% velocity perturbation; and (b2) Results for T=14 s. **(c)** Depth sensitivity kernels for fundamental-mode Rayleigh wave phase velocities. Rayleigh waves at 14 s are most sensitive to the lower crust and uppermost mantle while at 45 s are sensitive up to 70 km. **(d)** Example of the linear step inversion of the mean Rayleigh wave phase velocity dispersion

Summary of Method



Results

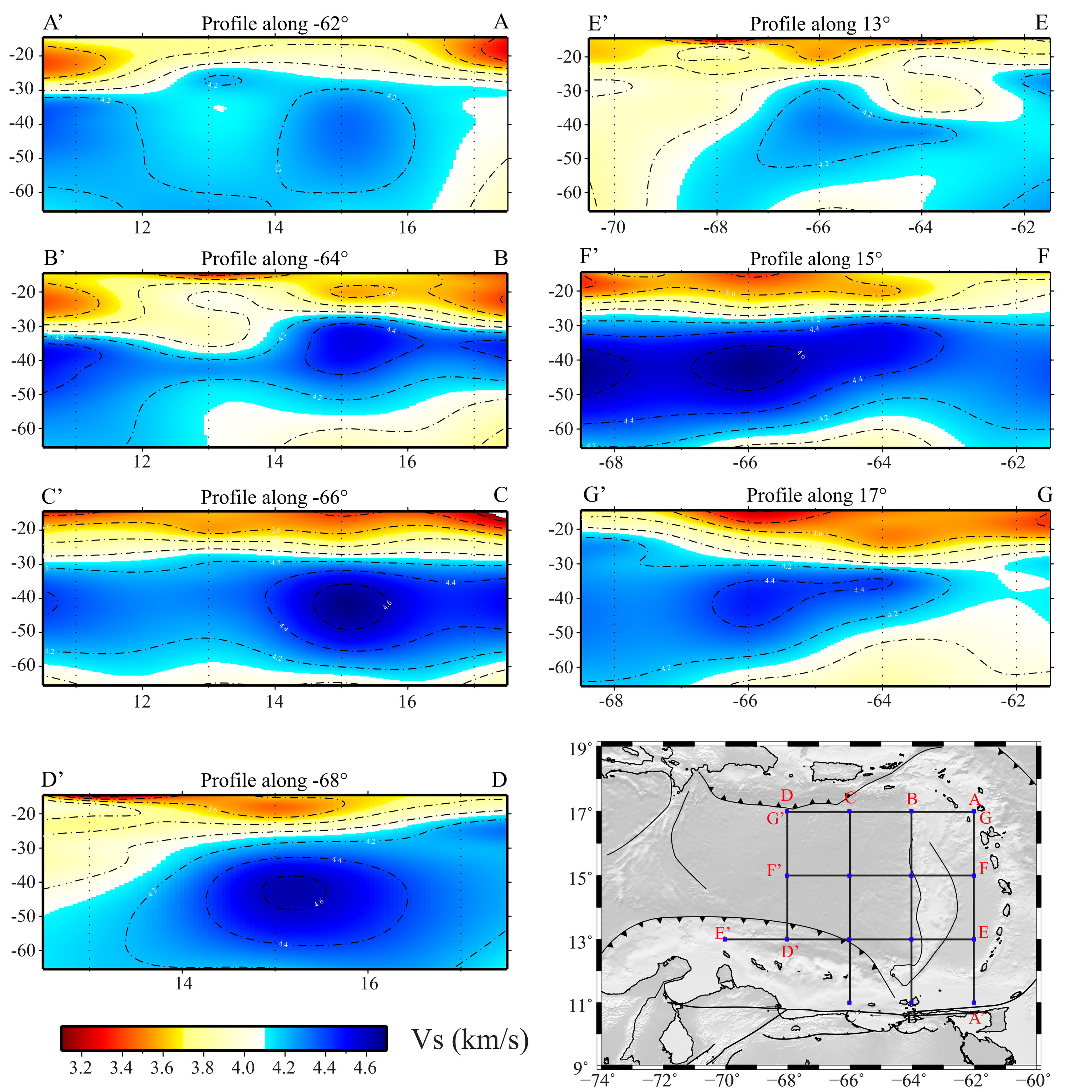


Fig 3: Depth profiles of the inverted shear wave velocity model. Profiles from A-A' to D-D' are in N-S direction, whereas profiles from E-E' to G-G' are in E-W direction. The location of the profiles is specified on the map in the lower left corner. All the profiles are in the same color scale. S wave values vary from 3.2 to 4.6 km/s. The mean Vs (~4.13 km/s) represents which denotes an anomaly of -7.8% in global terms. Lower values, from 3.2 to 4.0 km/s are confined to the shallower depth (crustal velocities), while the higher ones (> 4.1 km/s) appear from 30 to 60 km depth associated to upper mantle velocities.

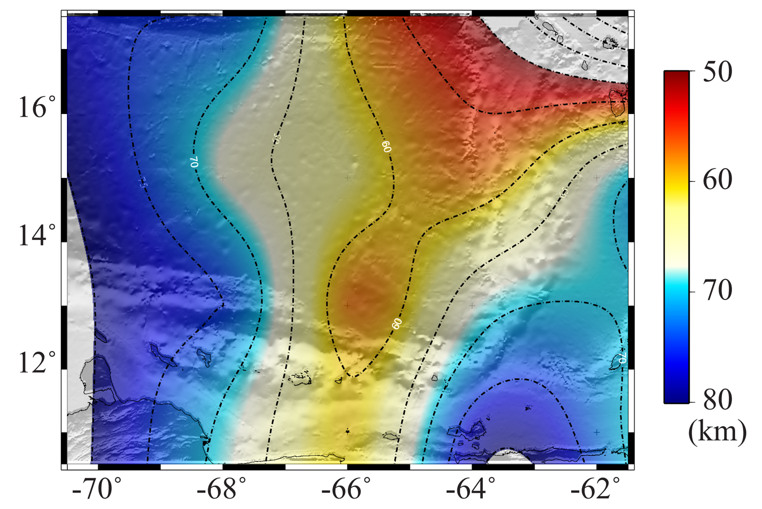


Fig. 4: Depth the LAB. It varies from 50 km in the northeastern to 60 km in the center and to more than 75 km depth to west and the southeast.

Conclusions

The joint use of stations arrays from different time periods has allowed us to image the broad mantle structure of the Easter Caribbean region. The prime results of our Ambient Noise Tomography revealed the following features of the upper mantle beneath the Venezuela Basin and the Aves Ridge:

- Shear wave velocities in the upper Caribbean mantle represent an anomaly of -7.8% in global terms. Similar results have been found in other LIP around the world (e.g. Deccan Traps, Paraná province, Ontong Java Plateau).
- A low velocity anomaly in the northeastern section of the area, found in both, the phase velocity maps and the shear wave velocity model, is most likely interconnected to the mantle wedge of the AOP-CP subduction zone.
- A deep (> 55 km) negative gradient of S wave velocities bellow a region of high velocities in the mantle is interpreted as the LAB. This frontier varies from 50 km in the northeast to 60 km in the Venezuela Basin, and becomes deeper than our resolution frame to the west and the southeast. We find this shallow LAB to be compatible with the Caribbean history.
- Low shear wave values and a thin lithosphere in the CP resolves in a moderately buoyant lithosphere that is hard to be subducted when in contact with other tectonic plates. Therefore, the mantel activity that led to the emplacement of the CLIP has had a major impact on the lithospheric structure on the CP and its fate, when been confronted with other tectonic plates.
- A high velocity region at 40 km depth bellow the thin crust region in the Venezuela Basin suggests that this area was less disturbed by the emplacement of the CLIP, but was affected by extension derived from this process.

Futher Work

- Improve the resolution of our tomography by adding more stations deployed in the area.
- Better constrain the vertical resolution of our data.
- Use Monte Carlo inversion to improve the Vs vs Depth model.

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