Tomographic Imaging of P and S wave velocity structure beneath Venezuela from local arrival times

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Abstract. The wave velocity structure of the crust and upper mantel of the Venezuela region have been measured by applying *Dapeng Zhao et al., (1992)* seismic body wave tomographic method. We have iteratively used the pseudobending technique and Snell´s law algorithm for tridimensional ray tracing and then we solved the large observation equation system using the LSQR algorithm. In order to study P and S wave tomographic images, this method is applied to 43293 arrival time from 10219 shallow and intermediate-depth earthquakes recorded in 72 stations at the Venezuelan national seismological network from 2007 to 2011. We have conducted several inversions to determine the best damping parameter. The resolved lateral velocity variations appear to be well correlated with Bouguer anomaly map. Large velocity variations amounting 7% for P and 8% for S wave were revealed in the upper crust. High velocity (high-V) zone exists under Paria Cluster that we have interpreted as the subducting Pacific plate, under northern Guayana shield that may correspond to Santa Rosalia complex and below the Bocono fault system at the triangular Maracaibo block. Low velocity zones were determined at The Eastern Venezuela Basin.

Keywords: **Seismic tomography, seismic velocity, Venezuela, Pacific plate, seismicity, depth.**

INTRODUCTION

Seismic tomography is one of the most important techniques to enclose and stablish limits to physical properties distribution that affects seismic waves propagation, such as: elastic properties, inelasticity, density and anisotropy parameters. Tomographic models frequently play a critical role in surface analysis, lithology, temperature, cracks and fluid content. In this study we applied the inversion technique developed by *Dapeng Zhao et al., (1992)* to characterize the velocity structure beneath Venezuela. In order to determinate internal wave velocity anomalies beneath Venezuela, were collected 32897 P wave arrival times and 10306 S wave arrival times from a total of 10219 earthquakes for the region between longitude 58°-74°W and latitude 6°-14°N (Fig.1). Several authors have applied a wide range of seismic tomographic techniques in order to study the velocity structure under Venezuelan. *Bezada, et al., (2010)* determine that the steep subduction of the Caribbean occurs ∼500 km landward from the trench, implying an initial stage of shallow subduction as far to the east as the Lake Maracaibo-Mérida Andes region. *Miller et al., (2009),* imaged the subducting oceanic part of the South American plate beneath the Antilles arc and suggest shear tearing of the oceanic lithosphere away from the buoyant continental South American plate offshore of northeastern Venezuela. An important low velocity zone was imaged by *Bosch, (1997)* below the junction of the Bocono and the Santa Rosalia fault systems. From a high density data we did image at 40 km the northern boundary of the Guayana shield cratonic root and the Pacific plate steep subduction slab.

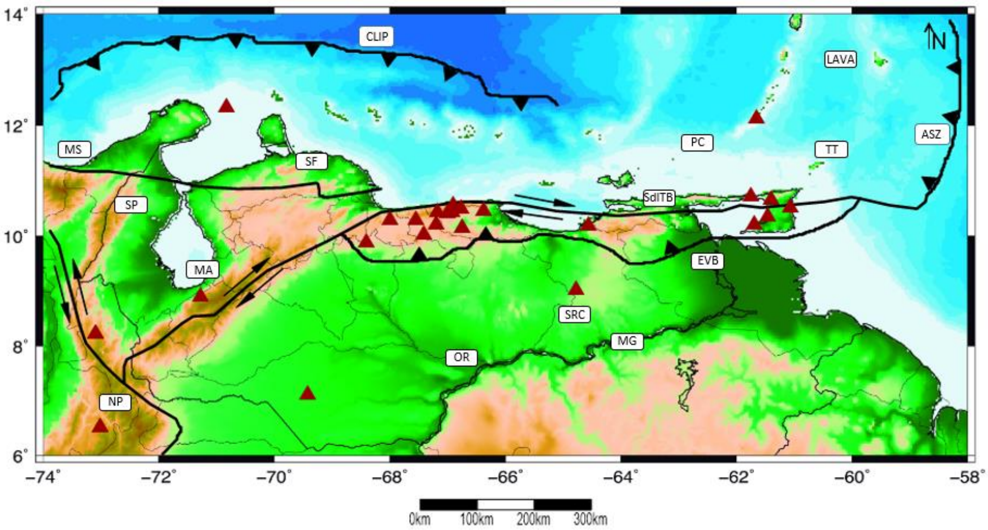

FIGURE 1. Map showing location of study area, seismic stations (red triangles), major tectonics features and regions of interest. Black arrows shows the Caribbean plate relative motion to the South America plate. LAVA, Leeward Antilles volcanic arc; CLIP, Caribbean Large Igneous Province ; OR, Orinoco River; PC, Paria cluster; MA, Mérida Andes; SP, Perijá Range; MS, Santa Marta Massif; SF, Falcón Range; GS, Guayana Shield; EVB, Eastern Venezuela Basin; NP, Pamplona nest; TT, Trinidad and Tobago; ASZ, Antilles subduction zone; SdlTB Interior Serrania Belt.

METHOD

Model Parameterization

When the depth distribution of grid nodes is known, the depth of the discontinuity at any position within the study area can be calculated by linearly interpolating the depths at the four grids surrounding that position. The principal distinction between inversion techniques is the parameterization of the velocity model *(Thurber and Aki, 1987)*. Poor parameterization would reduce the ability to exploit information on the Earth's heterogeneous structure *(Zhao at al., 1992).* For this research we have divided the medium under study into three layers separated by two seismic velocity discontinuities (SVDs). We set a tridimensional grid nodes for each layer to represent the velocity structure. Our starting velocity model correspond to the same velocity model used by the Venezuelan Seismological Research Foundation (FUNVISIS) for locate seismological events.

Three-dimensional Ray Tracing

The principle for the algorithm used in this tomography is that an initial ray path is perturbed using geometric representation of the ray equation, and the travel time along the path is minimized in a piecewise fashion *(Zhao et al., 1992).* The algorithm applies iteratively a pseudobending technique and the Snell´s Law in order to find continuous points and discontinuous points respectively. This steps are repeated until the ray path converge to its true location.

Inversion

First, we conducted several inversion varying damping coefficient to determine the best value for travel time data inversion. We built a trade-off curve for P and S wave. Then we calculated the ray paths using iteratively the ray tracing technique proposed by *Dapeng Zhao (1992)* as described above. As soon as ray path were calculated we can set up a system of observation equations which relates arrival time residuals to the unknown source and medium parameters. The mathematical formulation has been discussed in detail by *Aki and Lee (1976), Thurber (1983) and Zhao (1991).* Finally, to solve the large problem of observation equations, we used a conjugate gradient type solver, the LSQR algorithm of *Paige and Saunders (1989)*.

Resolution analysis

To evaluate the result reliability we carried out a checkboard resolution test (CRT). We assigned negative and positive velocity perturbations to the grid nodes at the same interval to make a checkboard. Therefore, just seeing at the image of the synthetic inversion one can understand where the resolution is good and where is poor.

Data selection

For this study we have used the data recorded at 49 stations at the Venezuelan National Seismological Network administrated by FUNVISIS, 21 stations at the Colombian National Seismological Network administrated by the Colombian Geological Service and 6 stations at the Seismic Research Center of the University of The West Indies-Trinidad & Tobago. Location of stations is shown in figure 1. Data used is from events occurred between January 2007 and December 2011. Most of the network is composed by permanent band wide satellite stations. A few of them were nonpermanent and were integrated by three components short period sensors with a sample rate of 100 samples per second. Seismological stations are distributed along the greatest seismic activity zones: Central-Eastern region, Central-North region, North oriental region, Andes region and a remote station at Isla Las Aves. From seismic record 10219 local earthquakes were selected, 54% of these events have a focal depth over 30 km and 46% have a focal depth under 30 km. After relocation we used only events that obtained a root mean square (RMS) under 0.15 s. 85.4% of FUNVISIS data has a RMS between 0.3 and 0.5 s. As a result were collected 32897 P wave arrival times and 10306 S wave arrival times for the final inversion.

RESULT

We adopt the velocity model shown in table 1. The medium under study has been divided into three layers separated by two SVDs. We take initial seismic velocity to be 5,7 km/s and 6,3 for P wave at discontinuities located at 9,5 km and 35 km respectively. The velocity relation for internal waves is (Vp/Vs) 1,74. The grid mesh configuration is 40,5x80x20 km (latitude x longitude x depth). Grid separation is the same for P and S wave until 180 km. From the total of 3872 grid points were calculated 1435 for P wave and 737 for S wave at 8 layers. From the trade-off curve best damping parameter is 10 for P wave inversion and 7 for S wave inversion. Applying the velocity model described, a convergent solution was obtained after 149 iterations for those nodes were ray path number (hit count) was up to 10. For P wave inversion the total model rms is 0,04% and for S wave is 0,05%. Total rms travel time residual is 0.556 s and 0.669 s for P and S wave respectively. Checkerboard resolution test shows good P and S wave velocity resolution in layers at depth from 20 km to 100 km, especially nearby regions located at northwestern (Paria Cluster) and at southeast (Merida Andes) of Venezuela. In the upper crust, tomographic images obtained shows an important high velocity zone that exists nearby the region located northward San Sebastian – El Pilar fault system. An arc shaped anomaly appears at south of Orinoco River and a high velocity alignment can be observed at Maracaibo block left corner. An important low velocity zone appears at the Eastern part of the study area.

TABLE 1. Initial Velocity Model.

Layer	Depth, Km	P Wave Velocity, Km/s
Upper Crust	0	5,7
SVD (1)	9,5	6,3
SVD (2)	35	8,3
Semi _space	100	8,5

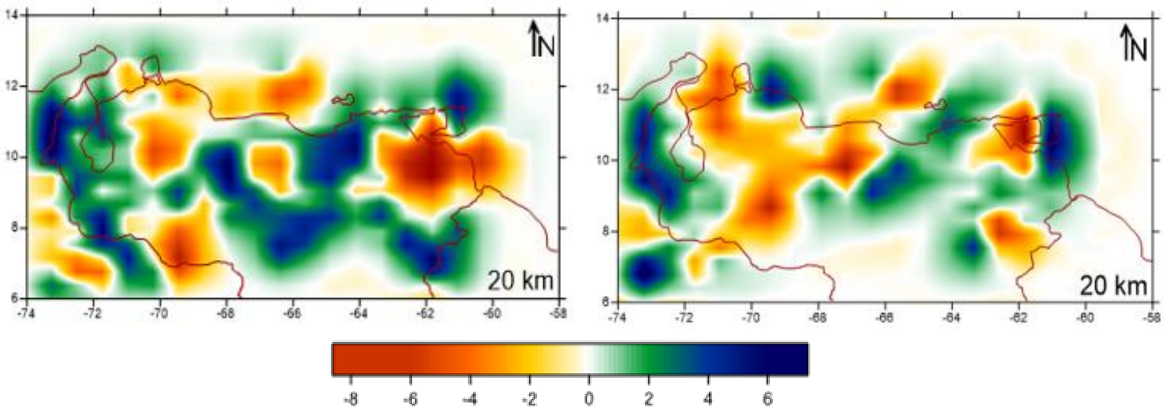

FIGURE 2. P (left) and S (right) wave velocity perturbations (in percent) at 20 km depth. Blue and Red colors denotes fast and low velocity respectively. The velocity scale is shown in the bottom.

CONCLUSION

The tomographic images obtained beneath Venezuela shows large and prominent high velocity zone at northwestern (Paria Cluster). As observed in vertical cross sections (C-C'), this high velocity anomaly dips westward in the upper mantel, extending to a depth of about 160 km, with a steep angle close to 65°. In addition, within this region most depth hypocenters are located in a narrow band between 63° and 62° W. We have interpreted this anomaly as the Pacific plate subducting slab (fig.3). This high velocity anomaly founds its limit at 10.5° where its value drops dramatically in the Venezuelan east coast strike fault system *(SdlTD).* The inversion results shows another arc shaped high velocity anomaly with an arm that extents to the central part located between 10° and 12° N. This high velocity zone under northern

Guayana shield *(MG)* may correspond to Santa Rosalia complex *(SRC).* The anomaly distribution suggest that the cratonic root extents at least as north as the Orinoco River *(OR)* (fig 2). At the northeast boundary is located the Eastern Venezuela Basin *(EVB).* The result shows a large wide spread low velocity zone within this region (fig.2). The inversion result appears to be well correlated with data obtained by other researchers for Bouguer anomaly at Merida Andes and Paria Cluster and for internal waves velocity propagation at the Guayana Shield.

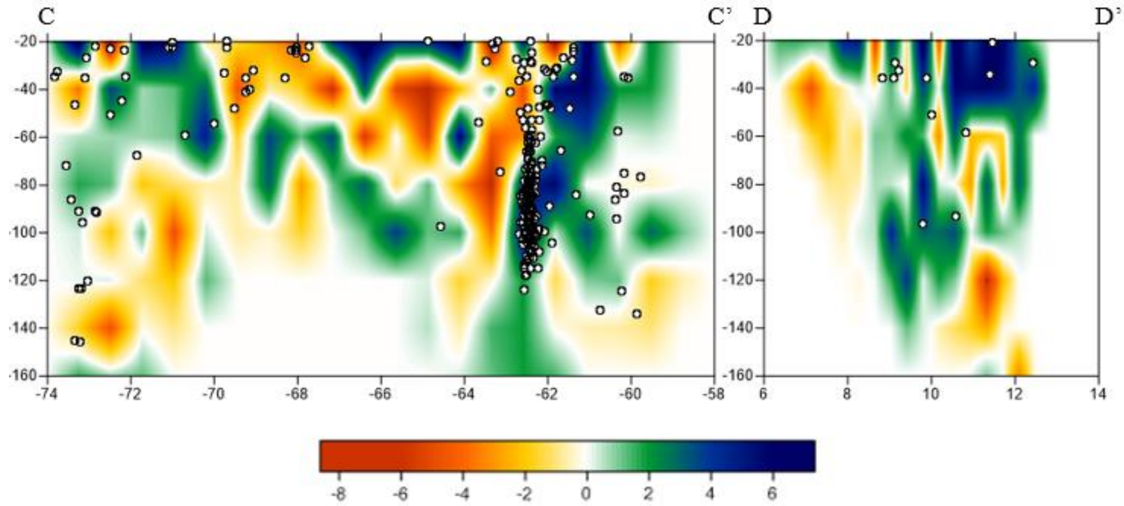

FIGURE 3. Cross sections P wave velocity perturbations (in percent). Blue and Red colors denotes fast and low velocity respectively. The velocity scale is shown in the bottom.

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