MAPPING OF THE P WAVE VELOCITY STRUCTURE BENEATH THE ECUADORIAN ANDES

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Introduction

The Andean chain forms an elongated structure about 7500 km-long located along the Western South American margin, with considerable latitudinal variations in width. Our zone of interest, located in Ecuador at the northern termination of the Central Andes segment [Jordan et al., 1983], is a downsized 220 km-wide structure of the 800 km-wide broad structure in Central Bolivia. The main morphological expressions of this reduction are : (1) between the Western and Eastern Cordilleras, the disappearance of the Bolivian Altiplano (220 km wide), replaced by the Ecuadorian Interandean depression (20 km wide), (2) the reducted width of the Cordillera with a great change from 400 km at 20°S (Bolivia) to 140 km at 1°S (Ecuador), and (3) the contraction of the Subandean zone from a 180 km width in Bolivia to 60 km in Ecuador. These variations, described by Winter [1990], are the consequence of the complex process of mountain building in the Central Andes. A better knowledge of the velocity structure will help to constrain and understand this process. Dorbath et al. [1993] performed a tomographic inversion of seismic data for the Bolivian Central Andes and mapped lateral variations of velocity. They found a clear relation between surface structures and the lithospheric velocity structure: lower velocity beneath the Altiplano Plateau, and higher velocity beneath the eastern flank of the Eastern Cordillera. Farther South, at 24.5°S latitude, in the same Central Andes domain, Whitman [1994] mapped variations of the Moho depth beneath the eastern margin of the Andes and found a decrease of its depth from the plateau to the eastern flank. A similar result is also found by Dorbath et al. [1993] in Bolivia.
The aim of this study is to map the velocity structure and the depth of the Moho of a segment of the Andes and to complete the above mentioned previous studies by producing a velocity model at the Northern termination of the Central Andes in Ecuador. In this study, travel time residuals of P-waves recorded by a local network in Ecuador, are inverted to obtain a velocity structure beneath the station array. Teleseismic data have been added to the inversion, to stabilize the velocity at depth. Finally, the velocity structure is associated with surface geomorphological units. We find that there is an apparent continuity in the velocity structure along the Central Andes : in Ecuador, the Cordillera margins have higher velocity than the Interandean depression, and the Moho depth increases beneath them, as observed farther South from previous studies.

Data and Method

Data used in this study are arrival time of P and S waves of earthquakes at local and teleseismic distances. Local data come from events recorded between 1990 and 1993 by an array of a total of 43 seismic stations from the National Seismic Network run by the Instituto Geofisico of the EPN. From the initial set of 2432 local events located using HYPO78, a final set of 1294 events was used for inversion. These selected events have at least 3S arrival times, and after relocation the root mean square residual (RMS) is less than 1.0 s and the condition number less than 100. P arrival times from 273 regional events, reported by the ISC bulletin between 1971 and 1987, was also used for inversion. Located in Ecuador, these events are recorded by WWSSN seismic stations in South America. All the selected teleseismic events have RMS than less 1.0 s after relocation. Finally a total set of 14684 P arrival times and 7472 S arrival times were used for inversion, where P and S wave velocities and hypocenters are determined simultaneously [Aki and Lee, 1976 ; Roecker, 1982 ; Roecker et al., 1987 ; Abers and Roecker, 1991]. In using this technique, we tried to explain as much residual as possible by first relocating events and calculating station corrections, and then by perturbing the velocity structure. Because of the paucity of published geophysical data in this region (e.g., S wave attenuation, apparent velocity) to corroborate our results, we consider as reliable results those which are associated with large geomorphological structures of the region.

Results

One-Dimensional structures

The starting velocity model has been adapted from Ocola et al. (1977), Flüh et al. (1981) and Leeds (1977). Because of the important contrast of velocity at the Moho transition, it is important to set the Moho depth. The previous authors found its depth varying from 43 to 66 km. Dorbath et al. [1993] found a depth of 50 km beneath the Eastern Cordillera in Central Andes. From all these data, we assumed a Moho depth of 50 km.

Results from the one dimensional inversion show both P and S wave velocity monotonically increasing with depth, without obvious low velocity zone (LVZ). However, an important velocity decrease is observed in layer 5, where the initial 6.40 km/s velocity is down to 6.21 km/s. The same pattern, although much more pronounced, is observed in Vanuatu [Prévot et al., 1991] where a clear LVZ appears on the one dimensional profile. By analogy with the Vanuatu study, we suspect the presence of a low velocity body in layer 5 of the three-dimensional structures.

The Three-Dimensional Structures

The Ecuadorian Andes topography shows a very contrasted figure which probably reflects complex subsurface tectonics, with a complex associated velocity structure. This region is poorly known, so we are searching only for major velocity structures that can be related to the surface topography. To address this problem, a relatively coarse block model is used in the inversion process. Each layer is divided in 60x60 km blocks. The best azimuthal orientation for the grid is N30E, parallel to the Andes north of 1°S. In this direction, the reduction in variance is maximum, and thus a correlation exists between the geometry of surface structures and the underneath velocity structure. As we are searching for large structures, we are limiting our investigation to the first iteration of the inversion process. We assume that if any major structure exists, it must come up immediately in the inverse study and details will be absorbed into the averaging of the block velocity. As a consequence of this coarse study, the reduction in variance is a low 16% .

Discussion

Shallow structure (0-10 km ; Figures 1a and 1b)

The only well resolved blocks (resolution > 75%) are those just beneath the seismic array of stations. A common pattern for these first two layers is observed : blocks located beneath the eastern margin of the Cordillera have higher velocity than those located right below the Interandean depression. The lack of resolution beneath the western margin Cordillera prevents us from comparing velocities beneath these two margins. On the other hand, smaller blocks in our model could provide a better picture of the velocity structure but numerous details will appear at the same time and other geophysical data (e.g., refraction data, gravity) are needed to constrain the interpretation of these features, which do not exist.

Lower crust structure (10-50 km ; Figures 1c, 1d, and 1e)

As we investigate deeper into the crust, the three layers between 10 and 50 km depth show more blocks with resolution greater than 75%. Layer 3 (10-20 km) shows very little lateral velocity variation and is considered as an homogenous layer (Figure 1c).

In layers 4 and 5 remarkable high velocity blocks are bordering the western flank of the Cordillera, in a direction parallel to the Andes (Figures 1d and 1e). Beneath the Andes, velocity is everywhere lower. Unfortunately, a lack of resolution prevents us to determine the velocity structure beneath the eastern flank of the Cordillera.

As mentioned above, the one-dimensional velocity profile shows a sensible decrease of velocity in layer 5. In the three-dimensional solution, a particularly low velocity block (6.05 km/s) is found in layer 5.

Upper Mantle (50-75 km ; Figure 1f)

Most of the local data are located above 50 km depth and in using only local data, we are unable to have a resolution >75% at this depth. So, teleseismic ISC data have been added to the local data to improve the resolution of the layer beneath 50 km depth. The initial poorly resolved velocity structure is still preserved but resolution is now largely improved. In other words, the addition of ISC data is just improving the velocity image deduced from the local data.

Except for a relatively low velocity zone located along strike the Andes, most of blocks have velocity greater than 8 km/s indicating a transition from the lower crust to the upper mantle and the hypothesis of an average 50 km Moho depth is consistent with these results. A simple explanation to account for the low velocities found in layer 6, is to consider a down dip Moho wiggle, occurring beneath the Cordillera. Unfortunately velocities in layer 7 (75-150 km, figure 1g) are very instable because only the teleseismic events account for determining this structure and it is impossible to determine how deep is the bottom of the Moho wiggle.

Conclusion

The aim of this study was to investigate if major velocity structures were apparent beneath the Ecuador Andes. Because of the paucity of geophysical studies in this region, we restrain our study to the big structures, which can be related to the surface topography. Generally the crustal velocity beneath the Andes is lower than the velocity found on the margins of the Cordillera (Figure 1g). The volcanic activity along strike the chain inducing a thermal anomaly, could be a factor to explain this relative low crustal velocity. In the lower crust, a permanent nest of seismicity is occurring inside a particularly low velocity zone (6 km/s) at crustal basement (Figure 1e). The most interesting features found in this study are (1) the probable down dip wiggle of the Moho along strike the Ecuadorian Andes, and (2) remarkable high velocity blocks bordering the western flank of the Cordillera, in a direction parallel to the Andes (Figures 1d and 1e), while velocity is lower beneath the Cordillera, as observed farther South from previous studies. We thus find that there is an apparent continuity in the velocity structure along the Central Andes.

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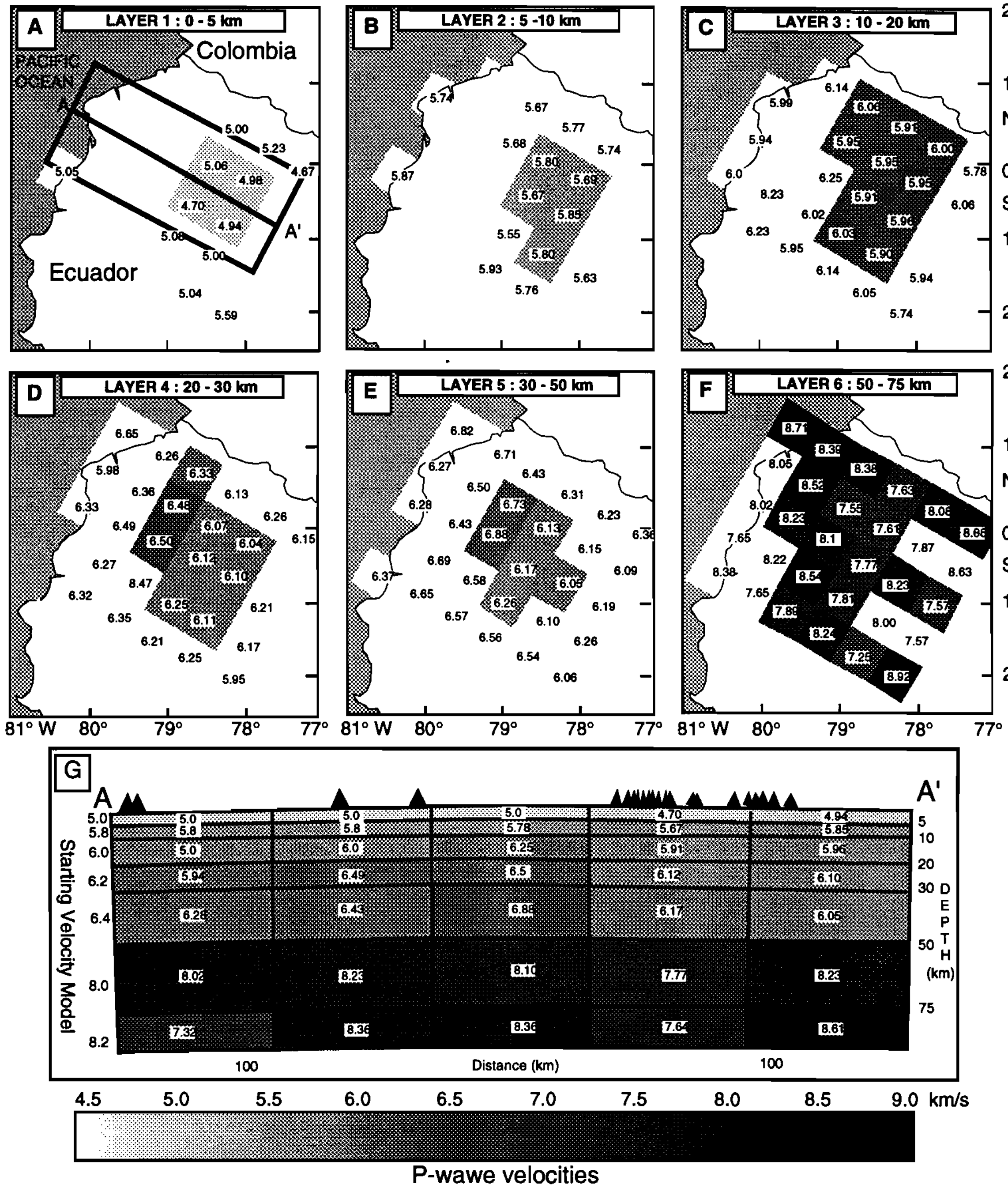

Fig. 1: (A-F) Maps of the block velocity solutions for 6 layers, down to 75 km depth. The uniform colored areas represent solutions with resolution higher than 75%. The dashed colored areas represent solutions with resolution higher than 75%. Numbers inside blocks indicate the mean velocity of each block. Blocks without colors were rejected from inversion. (G) Color codes as for figures 1a-f. Solid triangles represent the stations of the local array. A large number of these stations are located along the Andes Cordillera, therefore the packed stations at the top of the cross section is a good means to locate the Cordillera on the figure. The color velocity scale at the bottom of the figure applies for all maps and the cross section.