Three dimensional P and S wave velocity models in central Chile and western Argentina (31°-34°S) from local data: No tear between the flat and steep segments of the Nazca plate

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INTRODUCTION

Between 27° and 32.5°S, in Central Chile – Western Argentina, the Nazca plate subducts beneath the South American plate and becomes horizontal or flat a depth of 100 km. The northern limit of this horizontal geometry is not well determined even with local seismicity, whereas its southern extension is clearly limited around 32.5°S, where the Juan Fernández Ridge (JFR) is also subducting along-strike N80°E (Gutscher et al, 2000); to the east, its limit can be established precisely by local seismicity (Pardo et al., 2003) and anisotropy (Anderson et al., 2004). Moreover, in this region, the Quaternary volcanism activity stopped 10 My ago probably because of the setting of the horizontal geometry. Nowadays, the JFR subduction is the best candidate to explain the flat geometry, as the results of negative buoyancy forces due to variations in temperature and rock composition by respect to the older 45-Ma supported Nazca oceanic plate, but its small width (~80 km) by respect to Nazca Ridge in Peru for example, makes doubt that it can be the only factor to maintain the flattening process (Kopp et al., 2004). By the way, there are controversies which argue that flat geometries are not real but results from artefacts in seismicity location (Muñoz, 2005).

In order to better constrain the subduction earthquake location and the lithospheric structures, local seismic events were recorded during three months at short and regional distances by a seismic network of 29 broadband stations, as part of the CHARSME project (Pardo et al., 2003). More than 7000 events were detected and analysed.

In this study, we locate precisely the local seismicity in three-dimensional velocity models obtained by tomography of P and S-wave travel time and confirm the flat geometry around 125±25 km depth over a distance of about 400 km to the east also the JFR related seismicity at that depth. We show that, in the transition zone (32°-33°S), the Nazca slab gradually goes from a flat to a steep geometry, without tearing. The P and S velocity models give information on crustal thickness and the likely presence of crustal material into the continental mantle which will favour the crustal thickening assumption in Western Argentina.

DATA

Field Experiment

CHARSME (Chile Argentina Seismicity Measurement Experiment) is a joint project between the Tierra

Sólida team of the University of Chile and UMR Géosciences Azur –IRD. As part of this project, a network of 29 broadband seismic stations was deployed in central Chile (14 stations) and Western Argentina (15 stations) during three months (Nov. 2002 – Feb. 2003), between 31° -34°S and 72°-67°W (Figure 1). The northerner stations were installed in the flat slab region and were very useful to enhance the location of earthquakes in that area. Each seismic station was equipped with a CMG-40T broadband seismometer (except three of them with CMG-3T seismometer) and GPS clocks. More than 7000 events were detected, but only ~5700 events of magnitude by 2 and 6 were recorded at more than five stations.

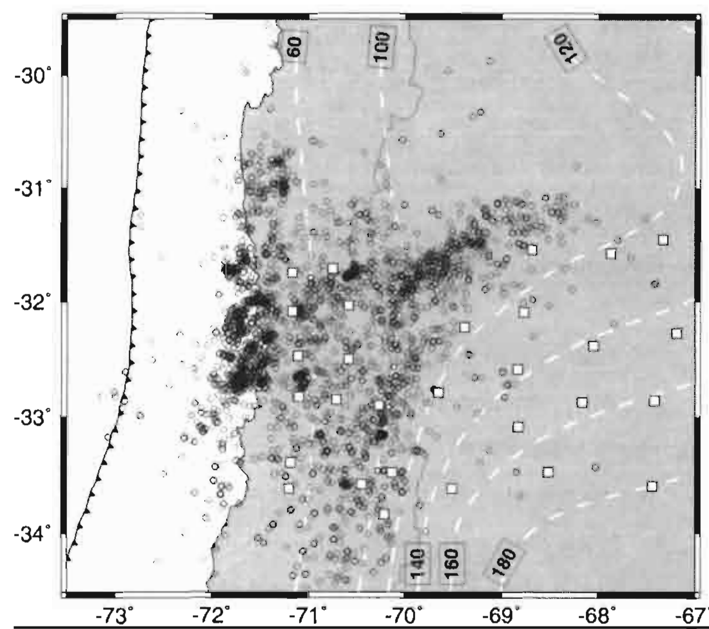

Figure 1: The three-month seismicity (open circles) recorded by the CHARSME seismic network (white squares) and located using P and S three dimensional velocity models. Iso-depth contours in km (white dotted lines) are from Pardo et al. (2003). The Chile – Argentina border is shown (thin dark line)

Data processing

P and S first arrivals were picked manually in order to minimize the error in hypocenter location. Using mine blasts recorded at the CHARSME network stations, a one-dimensional homogeneous layer model for the region was determined (Pardo et al., 2003). This model was used to make a preliminary location of the three-month seismic events. Focal mechanisms were determined using P-wave polarity and stress tensors were calculated by inverting sets of focal mechanism according to their location. Then, we performed a joint inversion between three-dimensional velocity structures and hypocenter relocation, by using the TLR algorithm (Latorre et al., 2004) with an inversion grid step of 20x20x10 km^3.

RESULTS AND DISCUSSION

Seismicity

The seismicity pattern obtained during the three months of CHARSME field experiment is globally representative of the region. In this study, we consider only subduction earthquakes, even if shallow seismicity is important (in particular, south of 33°S). At 31°-32°S, the earthquakes are distributed continuously from the west to the east, preferably along a track which is assumed to be the Juan Fernandez Ridge. If we examine the focal mechanisms obtained by the polarity of local P-wave of the CHARSME dataset, there are mainly thrust faults on the seismogenic zone between Nazca and South American plates (< 60 km of depth); at greater depths, normal faults are dominant because of the slab pull. On the flat segment, the focal mechanisms are mainly normal but the stress tensors indicate a NNW-SSE extension regime perpendicular to direction of the slab convergence (77°) and with a plunge of ~11±4°, which favours a gradually transition between the flat segment to the down-going "normal"one. In addition, the almost horizontal slab dips also to the west with a slope of ~5° as already noted by Régnier et al., (1994) using another dataset of local earthquakes. This slop might reveal a bulge produced by the deformation of Nazca plate before down-dipping eastward into the mantle, with a steeper angle. South of 32°S, the EW dipping angle decreases smoothly till reaching a value in conformity with a steep angle which confirms once more the absence of tear into the Nazca slab.

On the flat segment, the hypocenters are mainly concentrated along a band of ~80 km width and ~20 km thick which corresponds to the JFR. Northern to 32.5°S, we observe two bands of seismicity located between 70 and 100 km depth, separated by a seismic gap of ~23 km width (this pattern is not seen southern to 33°S) and might be related to dehydration of the oceanic lithosphere. Double layer seismicity has already been observed in different places around the world, in particular in Japan and also in northern Chile (Comte et al., 1999; Rietbrock and Waldhauser, 2004).

Three-dimensional velocity models

We performed a P and S wave velocity tomography, where velocity structures and hypocenters are determined independently. The resolution is good between 25 and 125 km depth. We associate the continental crust/mantle boundary to a P velocity of ~8 km/s, which gives an average crustal thickness of 60±5 km in the region. In the continental mantle, above the flat slab segment, we observe low velocity anomalies which might be associated with continental crustal material related with the crustal thickening in the region.

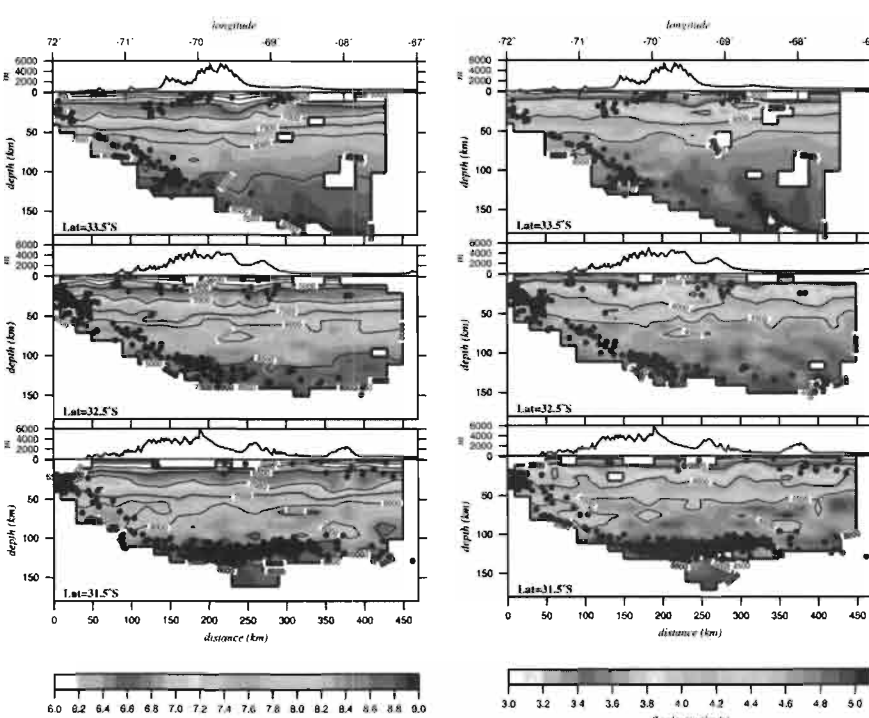

Figure 2: E-W cross sections of P-wave (left) and S-wave (right) velocity tomography. The seismicity is represented by black dots. A topography profile is shown on top of each cross section. The continental crust/mantle boundary corresponds to P-wave velocity of 8 km/s. At the bottom, P and S velocity models show crustal material into the continental mantle.

We obtained a three dimensional Vp/Vs ratio model. Although there are evidences of high Vp/Vs ratio anomalies, probably related with fluid circulation, dehydration processes, and also to the down-going slab, little work needs to be done before concluding. In that perspective, jointly with Vp/Vs ratio, P and S wave three dimensional models, an attenuation tomography will be performed to identify thermal structures, as a mantle wedge.

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