MORPHOLOGY OF THE NORTHERN CHILE SUBDUCTION USING LOCAL DATA

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RESUMEN: La subducción en el norte de Chile es analizada con sismos locales obtenidos en dos experimentos realizados en torno a Iquique-1991 (21°S) y Antofagasta-1988 (24°S). La inversión simultánea de hipocentros y estructura permitió obtener modelos bi-dimensionales de la litósfera oceánica, del manto superior y de la corteza continental en ambas regiones. Los mecanismos focales obtenidos permitieron estudiar el contacto sismogénico interplaca y la distribución de esfuerzos intraplaca, que sugiere una zona sísmica doble a 100 km de profundidad con esfuerzos compresionales más profundos que los tensionales.

KEY WORDS: Subduction, northern Chile, seismogenic interplate contact, inverted double seismic zone.

INTRODUCTION

Considering that northern Chile is one of the more active seismic zones of the circum Pacific belt, and that the last great event occurred there at the end of the last century (1877,M_W=8.7), two local microearthquake field experiments were carried out in the northern Chile seismic gap. The first experiment was located in the southern edge of the estimated 1877 rupture zone in 1988 near Antofagasta, and the second one was located in the middle of that rupture zone in 1991, near Iquique (Fig. 1). About 200 reliable microearthquakes were located in each experiment, and they were the data base for the simultaneous 2-D inversion of hypocenters and velocity structure of the oceanic and continental lithosphere, and the upper-mantle in both regions. With the resulting 2D velocity model, the morphology of the subduction was better defined around the Iquique and Antofagasta regions. The analysis of the local event focal mechanisms allows us to study the seismogenic interplate contact zone, and the distribution of stresses in the down-going part of the slab which shows an inverted double seismic zone.

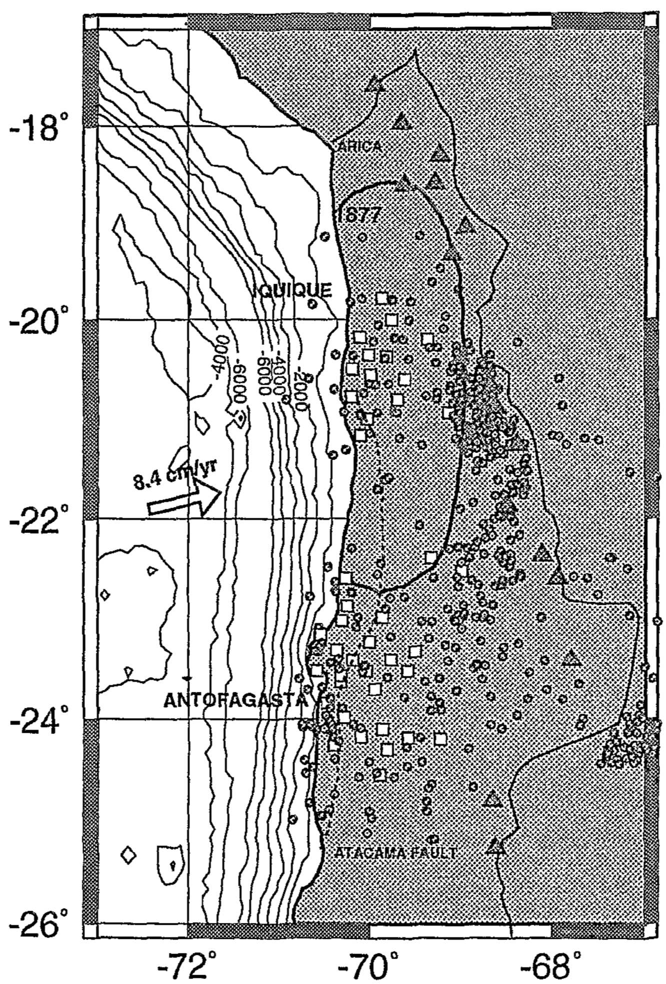

Figure 1.- Distribution of seismic stations (squares) and events (circles). Black triangles represent the active volcanoes. The open-ellipse shows the 1877 estimated rupture area.

TWO-DIMENSIONAL, P-WAVE VELOCITY STRUCTURE

The set of arrival times recorded by the two local microseismic experiments performed in northern Chile are used to simultaneously determine the hypocentral locations and the local seismic velocity structure around the Iquique and Antofagasta regions. A detailed description of the inversion is found in Comte et al. [1993]. The northern Chile margin is parametrized in metablocks, where the size of the blocks is governed by the ability of the data to resolve the structures. The initial velocity models were obtained from the refraction profiles perfomed in northern Chile by Wigger et al. [1991; 1993]. P-wave velocities of the upper-mantle below the continental lithosphere were not well resolved. However, they converged consistently to about 8.4 ± 0.2 km/s in both experiments (Fig. 2). The P-wave velocity of the continental lithospheric metablocks are in good agreement with that determined by the refraction studies. The inversion of the data collected near Iquique shows an average P-wave velocity of 8.1 ± 0.1 km/s within the slab. It was not possible to resolve more details in the oceanic lithosphere near Iquique, mainly because the majority of the events occurred at a depth of about 100 km. Near Antofagasta there is evidence in the slab of subducted oceanic crust with a thickness of approximately 10 km, with a P-wave velocity of 7.4±0.1 km/s, which is observed down to a depth of about 60 km. The subducted oceanic crust overlies an oceanic upper-mantle with a P-wave velocity of 7.8±0.1 km/s. The thickness and the velocity of the subcrustal zone indicates that it is made up of untransformed basaltic oceanic crust subducted with the underlying lithospheric mantle, and that the transformation of basalt to eclogite does not take place in the subducting slab at least down to depths of about 60 km. In the Antofagasta experiment, a low-velocity zone under the continental lithosphere was also observed. This low-velocity zone and the subducted oceanic crust agree with the low-velocity layer observed in seismic refraction studies..

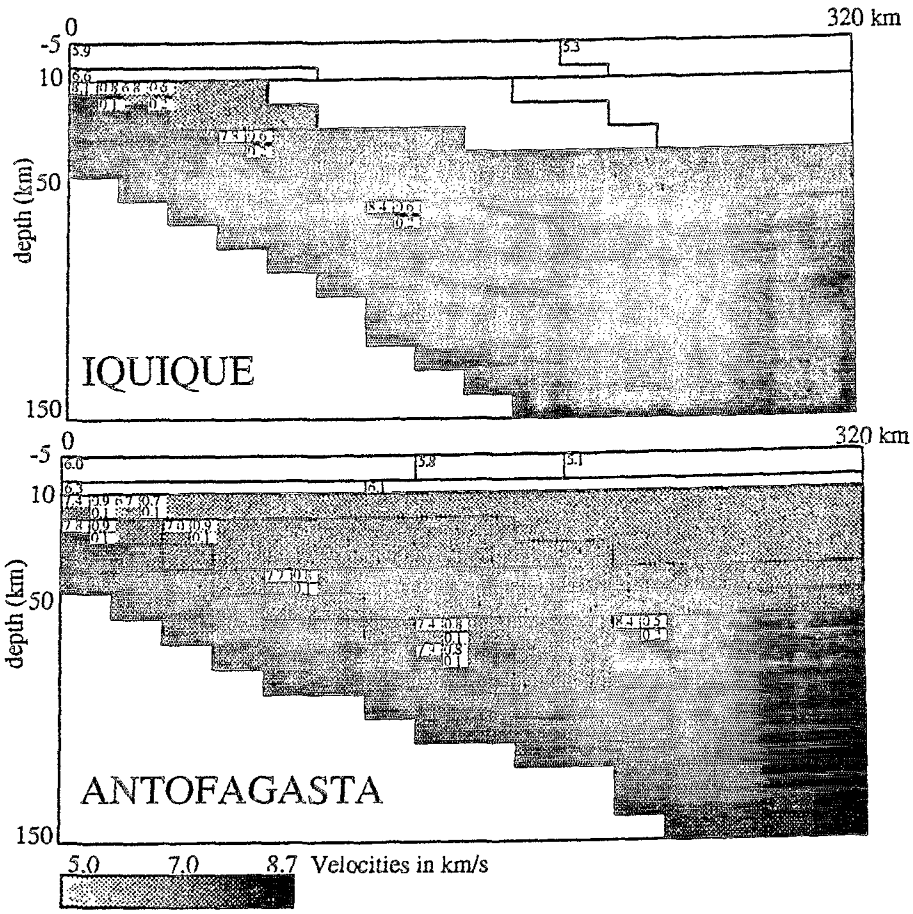

Figure 2.- 2D P-wave velocity model obtained for Iquique and Antofagasta. The first two layers were not included in the inversion. The white metablocks are unresolved by the inversion. In the left-upper corner of each metablock, the velocity (km/s), the resolution and the values error in km/s (below the resolution) are presented. In Antofagasta a low-velocity layer in the upper part of the slab is interpreted as oceanic crust.

SEISMOGENIC INTERPLATE CONTACT

The seismically coupled zone is the depth range of the plate interface that is capable of producing large underthrusting earthquakes [Tichelaar and Ruff, 1991]. However, the determination of that depth is difficult in northern Chile because of the lack of geodetic measures of coseismic ruptures. Tichelaar and Ruff [1991] studied the Chilean subduction zone using thrust earthquakes with magnitudes greater than 6.0 recorded teleseismically. Comte and Suárez [1993] discuss the difficulties involved in measuring the depth of the seismogenic interplate contact, and the different values obtained from teleseismic recording earthquakes in comparison with those obtained with locally-recorded data using permanent and temporary networks in Chile. We observed that the depth of the seismogenic coupling extends to approximately 50 km along northern and central Chile without showing appreciable variations along strike, and the landward extent of the coupled zone has a width of about 40 to 60 km. There is also a change from high-angle reverse faulting to down-dip tensional events. This could be an alternative method to determine the maximum depth of the seismogenic coupling. The mechanical idea is that near and below the interplate surface, where unstable sliding occurs, the subducted slab is under compression. The compressive regime causes not only thrusting along the plate interface, but also intraplate, reverse faulting events within the slab. At a certain depth, the slab becomes completely decoupled from the upper plate and begins to sink due to its negative bouyancy. Thus, the transition from compressive to tensional behavior would reflect the mechanical conditions in the shallow part of the subducted slab and may help to map indirectly the depth of the seismogenic coupling. In the three regions, where a good local data exists to control this change, Iquique, Antofagasta and central Chile, this transitional depth lies consistently at a depth of about 70 km.

AN INVERTED DOUBLE SEISMIC ZONE IN NORTHERN CHILE

The epicentral distribution of the seismicity observed in Iquique during 1991 is similar to that observed in Antofagasta in 1988, in the sense that the seismic activity is mainly concentrated to the east, in the downgoing slab. A nucleation of intraplate events is observed in both experiments at about 100 km depth, the focal mechanisms of the nucleations show that these intraplate events present a variety of tensional and reverse faulting events. The down-dip tensional events are shallower than the compressional micro-earthquakes, suggesting a double-planed seismic zone in northern Chile (Fig. 3).

The Iquique intraplate nucleation shows that the tensional events ranges from 88 to 108 km depth, and the compressional events show depths varying from 106 to 126 km. In the case of Antofagasta, the tensional events have depths from 80 to 108 km, and the compressional ones are located between 104 to 122 km depths. The error in depth for these events is estimated to be about 3 km for both experiments, therefore, instead of the two sheets of tensional and compressional events are very close in depth, the lower errors obtained from 2-D velocity model resulting from the inversion, permits us to conclude that there is a double seismic zone in northern Chile with the polarity inverted relative to that observed in other subduction zones in the world, such as those found in the Aleutians, Tonga and Honshu.

The only intermediate-depth earthquakes reported teleseismically which shows a compressional mechanism in northern Chile, is the reverse faulting earthquake occurred on January 17, 1977 [Araujo and Suárez, 1993]. The focal depth of this event is 152 km, and clearly is located beneath the sheet of tensional events which lie at an average depth of 110 km. Kono et al. [1985] also identified this earthquake as an intermediate-depth event and suggested the presence of a double seismic zone. However, due to their lack of good hypocentral depth control, they incorrectly assumed that the sheet of down-dip tensional events was beneath this reverse-faulting earthquake as in other subduction zones of the western Pacific.

Engdahl and Scholtz [1977] explained the presence of double-planed seismic zones as a result from the flexure suffered by the subducted slab as it unbends beneath the shallow interplate contact. This hypothesis does not explain our observations because the polarity of the expected stress sheets would be opposite to what is observed in northern Chile. Araujo and Suárez [1993] suggested that the presence of this anomalous double-planed seismic zone is the result of the sudden downward flexure of the slab where a drastic change in the radius of curvature of the downgoing plate occurs. However, we observed the double seismic zone in northern Chile in two regions with different dipping. The dip angle observed around Iquique is about 30°, and around Antofagasta is about 20°, therefore the northern Chile double-seismic zone probably is not controlled by the geometry of the slab.

The question arises: Why is there an inverted double seismic zone in northern Chile, and why it is mainly observed with local data? The double seismic zone in northern Chile is observed beneath the volcanic Andean belt in the Iquique and Antofagasta regions. Therefore, it is probably associated with the process involved with the generation of magmas and the production of arc volcanos. Recently, Kirby and Hacker [1993] present new evidence suggesting a phenomenon associated with the earthquakes that occur at depth of 90-150 km in the subducting lithosphere. In summary, they argue that the oceanic plates has a laminated structure, with a thin crust on the top composed by basaltic minerals, and a thicker mantle of peridotite minerals beneath. The subducting crust is densified to eclogite due to the pressurization during the plate descent. However, the peridotite in the upper mantle does not change because it is stable to greater pressures. Their numerical results suggest that this volume change produces a surface stretching deformation in the transformed crustal layer and a smaller compressional deformation near the top of the underlying mantle. This explain apparently the inverted double seismic zone observed in northern Chile, and also the fact that it is observed mainly with events of smaller magnitude.

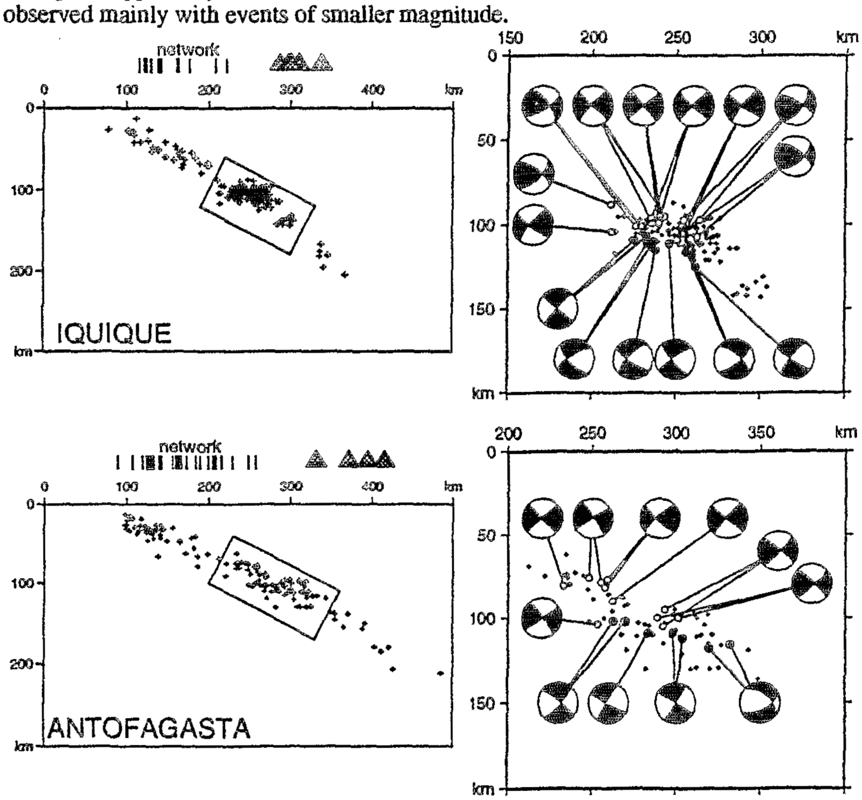

Figure 3.- Cross-sections along the N77°E directions in Iquique and Antofagasta regions. The focal mechanisms solutions of the events that are within the boxes are projected on a side-looking, lower hemispheric projection where dark quadrants indicate compression and the white ones dilations.

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