# A DOUBLE-LAYERED SEISMIC ZONE IN ARICA, NORTHERN CHILE

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## INTRODUCTION

A global view shows that seismicity along subduction zones usually delineates a single well-defined surface, with earthquakes distributed in depth from the surface down to several hundred kilometres. Since about two decades the existence of double seismic zones (DSZ) along localised segments of some subduction zones has been recognised. However only few of them have been studied in detail: beneath Honshu [e.g., Kawakatsu, 1986], beneath Central and East Aleutians [e.g., Engdahl and Scholz, 1977; Abers, 1996] and beneath the Kuril-Kamchatka arc [e.g., Gorvatov et al., 1994; Kao and Chen, 1995]. They are characterised by a double-planed distribution of earthquakes, vertically separated by 20 to 40 km, at depths between 70 and 150 km. The upper plane seems to be just below the top surfaces of the subducting slab, and the lower plane is consequently within the subducted mantle. With the development of high quality global networks and the consequent improvements of waveform modelling, several DSZ have been identified during the past years. Most of them are defined by very few events spanning along hundreds of kilometres along the strike of the trench, and it is therefore almost impossible to asses the continuity or the segmentation of the phenomena. On the other hand, even if an unusual focal mechanism has been determined at intermediate depth in a subduction zone, it is also important to separate the double-layered seismic zones independently from stress-segmented criteria [Fujita and Kanamori, 1981]. In this work we present the results obtained using locally recorded events in the northern edge of the northern Chile seismic gap, along the Arica elbow.

## DATA AND METHODS

The data used consisted of two sets: (1) from a telemetric short-period seismic network of 9 stations that has been operating since December 1994 as a joint research project among the U. of Chile, the U. of Tarapacá, the IPG, Strasbourg, France and the IRD, France and (2) from a dense temporary seismic network (Figure 1), deployed from the coastline to the Altiplano from June to August, 1996. The second dataset contains ~1000 microseismic events while the first has about 3900 events.

The set of body-wave arrival times of microearthquakes recorded was used for preliminary hypocentral determination using a modified version of the HYPOINVERSE program. The crustal P-wave velocity model was the same flat layered model used by Delouis et al. [1996]. Each event is located with different trial depths (between 0 and 250 km, with an increment of 10 km), in order to minimise the effect of dependence of the final hypocentral determination with the initial trial solution. From the initial dataset, a subset of the best constrained hypocenters was selected to be used in a joint inversion for hypocentral locations and 3D body-wave velocity structure. The analysis of the hypocentral locations when 1D or 3D velocity models are used shows that, within the coverage of the network the epicentral differences reach maximum values < 2-3 km, and the average variations in depth are < 5 km. The improved ray geometry permits to determine single-event focal mechanisms using individual first motion polarity for some reliable events along the subducting plate. The polarity of each station was tested in laboratory and by comparing observed with expected first motion for teleseismic events.

## RESULTS

Three cross sections along the average direction of the convergence of the Nazca plate beneath South America (N77°E) are shown in Figure 2; the half-width of the P1 to P3 profiles is 20 km. Some selected focal mechanisms are presented on Figure 3 (corresponding to the P2 profile, but with a half-width of 40 km) in a vertical back hemispheric projection along the convergence direction of the Nazca plate. Most earthquakes below 100 km depth lie in a single zone, about 10 km thick, that is almost planar down a depth of 150 km, dipping ~30° to the east. A second parallel planar zone 20-25 km beneath (perpendicular distance between both layers) is observed with fewer events and an average thickness of ~10 km (Figures 2 and 3). Fault plane solutions for these intermediate depth events vary significantly, even between nearby events, (for example events 9 and 10 in the shallowest layer, and events 20 and 21 in the deepest layer). Moreover, focal mechanisms of events located at approximately the same depth and the same distance from the trench can present opposite polarities observed in almost all the stations (for example events 12 and 14 in the shallowest layer, and events 21 and 22 in the deepest layer).

## DISCUSSION

This work presents reliable data that show a double layered seismic zone in Arica, northern Chile located at depths between about 100 to 150 km, with compressional and tensional events at almost the same depth (Figure 3). The Arica DSZ can be observed mainly with microseismicity, therefore it is a phenomena that depends on the magnitude threshold used. Even though we are not able to define the genesis of the Arica

DSZ, there are some things that can be established: considering that the Arica DSZ is a localised phenomena in the northern Chile region, it seems to be independent of the age (84 My), the relative convergence rate (~8.3 cm/yr) and convergence direction (N77°E) of the subducting slab, because all of these parameters are almost the same along the whole northern Chile region. Moreover, the Arica elbow can not be responsible of the Arica DSZ, because no similar changes along the strike of the trench are observed in other well studied double seismic zones. In fact, it can be noted that the general patterns of the Arica DSZ are very similar with that observed in the Alaska Peninsula where no elbow is present [Abers, 1992, 1996]. Kao and Liu [1995] presented an interpretation for the seismogenesis of DSZ based on studies along the Kuril-Kamchatka and Japan subduction zones. Even that the general pattern of the stress distribution at intermediate depths is not so similar with that observed in the Arica DSZ, their hypothesis that microearthquakes in the upper portion of the top layer can be probably caused by conventional mechanisms such as dehydration of subducted materials and facies change from basalt to eclogite, whereas the lower layer could be associated with metastable phase transition, can not be rejected by our results. In the same way, the presence of melt-rich regions formed near of the mid-ocean ridges at the base of a thermal boundary layer, that occasionally crystallised into the plate without ascending to the surface proposed by Abers [1996] is still a viable alternative to explain the lower-zone seismicity.

## ACKNOWLEDGEMENTS

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**FIGURE 1.-** Spatial distribution of events and seismic stations.

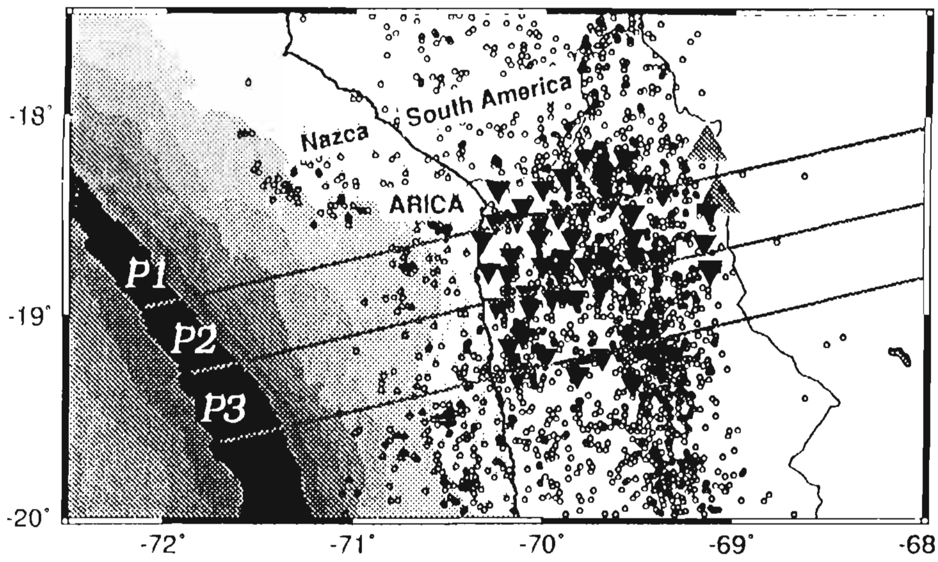
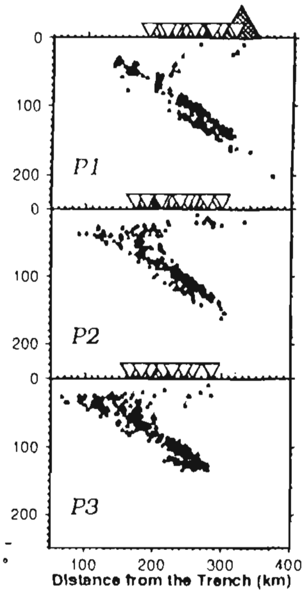


**FIGURE 2.-**



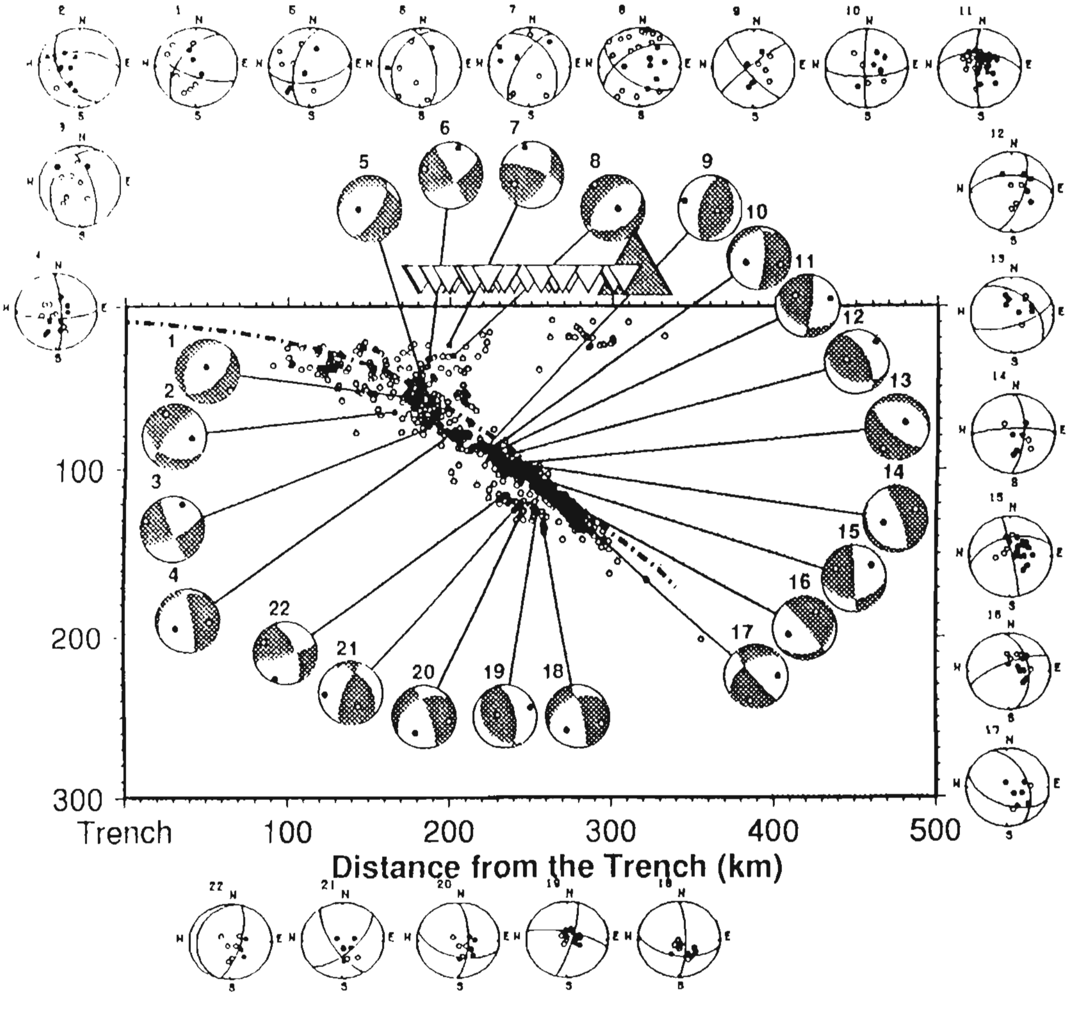


**FIGURE 3.-** Cross-section of reliable 3D hypocenters determined along the ±40 km wide P2 profile (Figure 1). Focal mechanism solutions projected on the vertical lower hemisphere are also shown. The lower hemispheric projection of each mechanism, with the first motion polarities is also shown. Projections of the seismic stations (inverted triangles) and active volcanoes ( triangles) are also presented.