SEISMICITY AND STATE OF STRESS IN THE CENTRAL ANDES: BOLIVIAN OROCLINE REGION

R. Ayala(1,2) and G. Wittlinger(1)

1 EOPG, 5 rue Descartes, Strasbourg, FRANCE
2 OBSERVATORIO SAN CALIXTO, C.P. 12656, La Paz, BOLIVIA

ABSTRACT

The central Andean seismicity recorded from July 1988 to November 1994 by the Bolivian network and some other neighbours stations was located using a 3-D velocity model. The highest concentration of crustal events is located near the bending of the Bolivian orocline. A cluster of intermediate events is also located beneath the Peru-Bolivia border region. The stress orientations for shallow intraplate events is characterised by a principal ENE horizontal compression in the forearc region and Subandean Ranges. This direction is parallel to the direction of the Nazca-South American plate convergence. The western High Andes are caracterized by a principal N-S horizontal tensional stress. The Nazca plate is dominated by a tensional stress oriented parallel to the down dip direction of the slab.

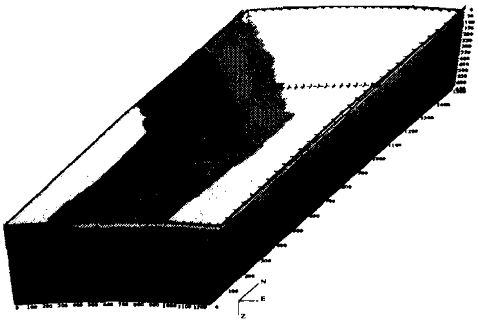
KEY WORDS: 3-D velocity model, earthquake location, seismicity, stress regime

INTRODUCTION

The Central Andes region presents a very important shallow seismicity related to compressional tectonic induced by the convergence of the Nazca and South America plates along the forearc, and in the both sides of the Andes Cordillera, and a extensional tectonic in the High Andes (Assumpçao, 1992; Mercier *et al.*, 1992).

The Central Andes subduction zone has two different geometries: a subhorizontal segment beneath Central Peru and a subducted slab dipping approximately 30°E beneath southern Peru-Bolivia-northern Chile region related to extensional stresses (Cahill & Isacks, 1992). The upper-part of the slab present a interplate coupling zone defined by a change of compresional to tensional stress field.

The two main objectives of this study are first the location of the seismicity recorded by the Bolivian network and not reported by the regional and international bulletins and second the determination of the state of stress in the Central Andes region as deduced from focal mechanism solutions.



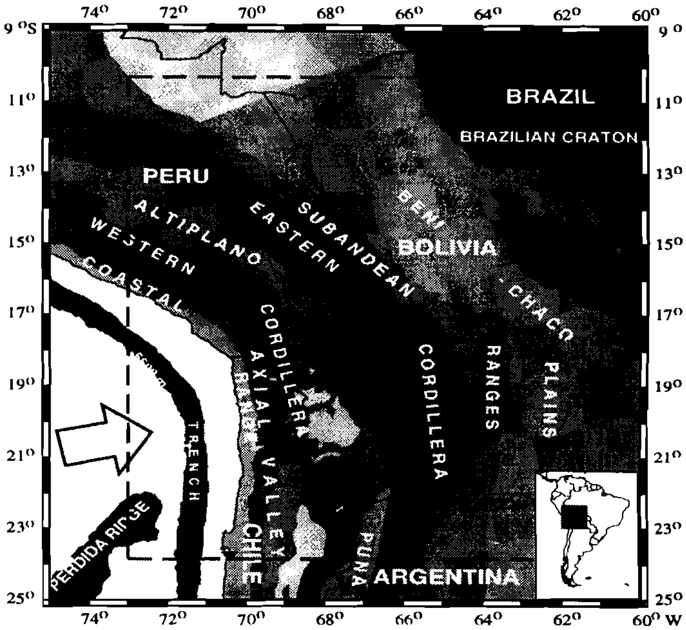


Fig. 1. Map showing the studied area and the limits of the main morphostructural units in Central Andes region. Triangles show the seismological stations used for earthquake location; large arrow indicates the direction of the Nazca-South American plate convergence (DeMetz *et al.*, 1990). The 3-D velocity model used to earthquake location is a cubic volume of 1500 km in north-south direction by 1280 km in east-west direction and down to 650 km depth.

SEISMICITY PATTERNS

Seismic data recorded from July 1988 to November 1994 by the seismic network of Bolivia and some neighbours seismological stations were used (fig. 1). Earthquakes were located using finite differences computations for traveltimes and a fully non linear approach for the inversion (Wittlinger *et al.*, 1993). A preliminary 3-D velocity model for this region was gathered using published geological data, velocity models deduced from seismic refraction (Schmitz, 1993) and from local seismic tomography (Dorbath & Granet, 1996). The shape of the Nazca plate was modelised like a continuous slab (Cahill & Isacks, 1992) with a velocity 2.0% faster that the surrounding mantle velocity (Dorbath *et al.*, 1995).

The recorded crustal earthquakes (fig. 2) are located in the northern part of the Bolivian foreland region, in the Altiplano near La Paz, and in the southern Peru-western Bolivia region. A more sparse crustal seismicity is also observed in south-western Bolivia. The highest concentration of crustal seismicity is located in the Western Cordillera and in the Subanden Ranges near the bending of the Bolivian orocline. The deeper earthquakes (fig. 3) related to the subducted slab show a continuous distribution, and indicate a deep slab beneath northern Bolivia (region of the great earthquake from June 9, 1994). A cluster of seismicity is located beneath Peru-Bolivia border region from 70 to 150 km depth.

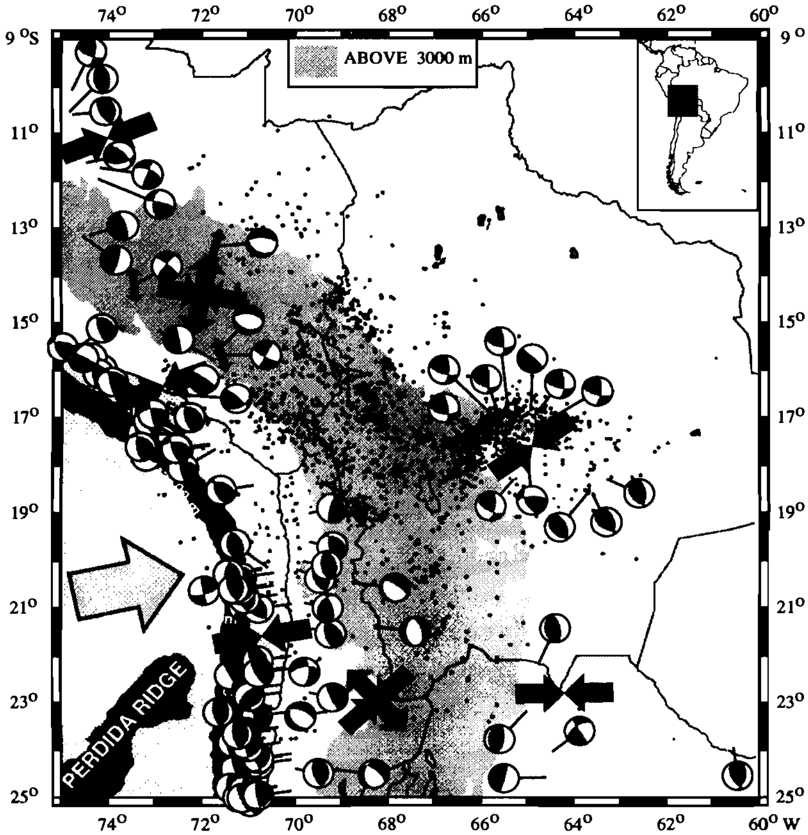


Fig. 2. Map showing the located shallow seismicity (less than 70 km depth). Balloons stand for lower-hemispheric projection of focal mechanism solutions. Convergence arrows stand for principal compressive horizontal stress direction (σ_1); big divergence arrows for principal tensional horizontal stress direction (σ_3) obtained from the inversion of focal mechanism solutions. The T-axes direction of tensional events for the High Andes is given by small divergence arrows.

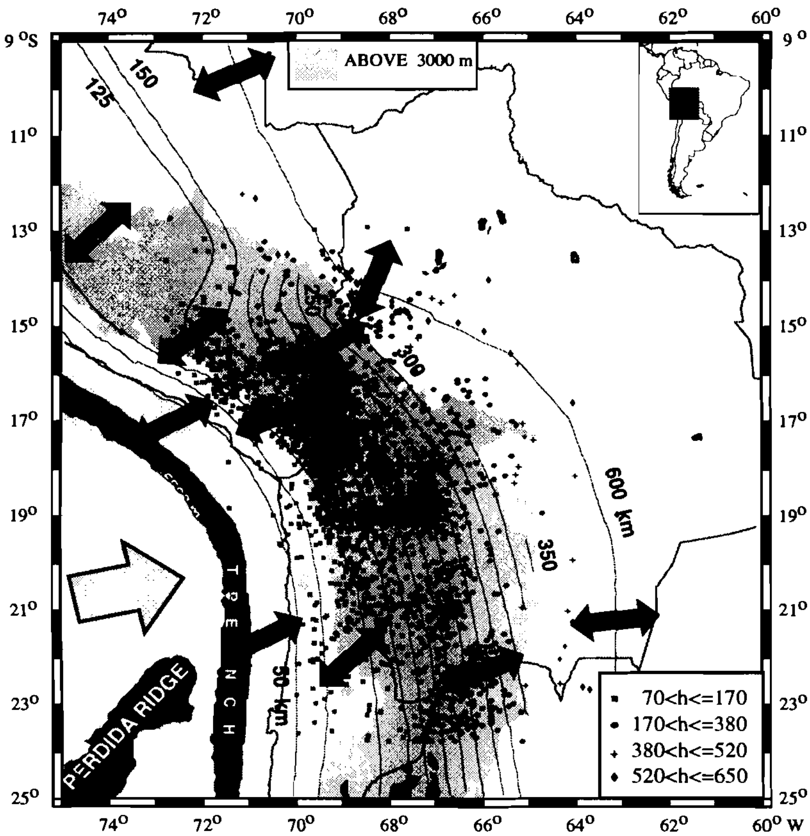


Fig. 3. Map showing the located intermediate and deep seismicity (from 70 to 640 km depth); depth contours of the Wadati-Benioff zone are from Cahill & Isacks (1992). Divergence arrows indicate principal tensional stress direction (σ_3) obtained from the inversion of focal mechanism solutions.

STATE OF STRESS

The focal mechanism solutions for 111 shallow intraplate events and 294 subduction zone events were compilated from the literature. Other 18 focal mechanisms for shallow earthquakes include also our data. The focal mechanisms were grouped by geographic region and depth range and inverted for the orientation and relative magnitude of the stress using the method developed by Rivera & Cisternas (1990).

In the forearc region and in the Subandean Ranges the stress pattern is characterised by a ENE horizontal compressional stress (σ_1) and a vertical σ_3 (fig. 2). A horizontal tensional stress (σ_3) oriented N-S (in the north-west) and NW-SE (in the south-west) and a horizontal σ_1 characterise the western High Andes.

The stress pattern for the tensional events of the subduction zone (fig. 3) is characterised by a principal ENE tensional stress (σ_3) in the down dip direction of the Nazca plate and a vertical σ_1.

CONCLUSIONS

There is an evidence of a correlation of the crustal seismicity with the direction of the main morphostructural units. The crustal seismicity near to the "bending of Santa Cruz" is related with the compressive forces induced by the Nazca-South American plate convergence. The Subanden Ranges and forearc region are under a triaxial compressional stress regime. Southward of the Subandean Ranges from 20°S, the principal compressional stress direction change of NE-SW to E-W following the trend of the Cordillera The western side of Andean Cordillera is under a shearing stress regime. The stress orientations calculated agreement with the stress orientations deduced from a field study of fault kinematics (Mercier *et al.*, 1992) and with the regional stress field (Assumpçao, 1992). The seismogenic interplate contact zone is about 60 km depth. The slab is dominated by a triaxial extension stress regime with a principal extensional stress direction parallel to downdip direction of the Nazca plate.

REFERENCES

Assumpçao, M., 1992. The Regional Intraplate Stress Field in South America, *J. Geophys. Res.*, **97**, 11889-11903.
Cahill, T. & B. L. Isacks, 1992. Seismicity and Shape of the subduction of the Nazca Plate, *J. Geophys. Res.*, **97**, 17503-17529.
DeMetz, C., R. G. Argus, & S. Stein, 1990. Current plate motion, *Geophys. J. Int.*, **101**, 425-478.
Dorbath C. & Granet, M., 1996. Local earthquake tomography of the Altiplano and the Eastern Cordillera of northern Bolivia, *Tectonophys* (accepted).
Dorbath C., Paul, A. and Lithoscophe Andean Group, Tomography of the Andean Lithosphere at 20°S: Preliminary results of the Lithoscophe experiment (soumitted to EPI Letters section, 1995).
Mercier, J. L., M. Sébrier, A. Lavenu, J. Cabrera, O. Bellier, J-F., Dumont and J. Macharé, 1992. Changes in the tectonic regime above a subduction zone of Andean type: The Andes of Peru and Bolivia during the Pliocene-Pleistocene, *J. Geophys. Res.*, **97**, 11945-11982.
Rivera, L. & Cisternas, A., 1990, Stress Tensor and Fault plane solutions for a population of earthquakes, *Bull. Seismol. Soc. Am.*, **80**, 600-614.
Schmitz, M., 1993. Kollision strukturen in den zentralen Andean: Ergebnisse refraktion seismischer Messungen und Modellierung Krustaler Deformationen, 1993, Inaugural - Dissertelion zur Erlangung des Doktorgrades am Fach bereich Geowissenschaften der Frein Universital Berlin.
Wittlinger, G., Herquel, G. & Nakache, T., 1993. Earthquake location in strongly heterogeneous media, *Geophys. J. Int.*, **115**, 759-777.