A SEISMIC STUDY OF THE ALTIPLANO AND THE EASTERN CORDILLERA IN NORTHERN BOLIVIA: NEW CONSTRAINTS ON A LITHOSPHERIC MODEL

Catherine DORBATH [1,2], Michel GRANET [2], Georges POUPINET [3], Claude MARTINEZ [4]

(1) ORSTOM, 213 rue La Fayette, 75480 PARIS Cedex 10, FRANCE.
(2) EOPG, 5 rue René Descartes, 67084 STRASBOURG Cedex, FRANCE.
(3) LGIT IRIGM, BP 53X, 38041 GRENOBLE Cedex, FRANCE.
(4) Laboratoire de Géologie des Bassins, 34095 MONTPELLIER Cedex, FRANCE.

RESUME: Un profil de 34 stations sismologiques du réseau Lithoscope a été maintenu durant 4 mois en Bolivie, coupant l'Altiplano et la Cordillère Orientale depuis l'arc volcanique jusqu'à la zone sub-andine. Les téléséismes et les séismes locaux enregistrés ont été inversés séparément afin d'étudier la structure de la lithosphère et la géométrie de la subduction. Dans la région étudiée, qui correspond à la virgation des Andes, la zone de faille de la Cordillera Real controle les changements de structure très marqués jusque dans le manteau supérieur.

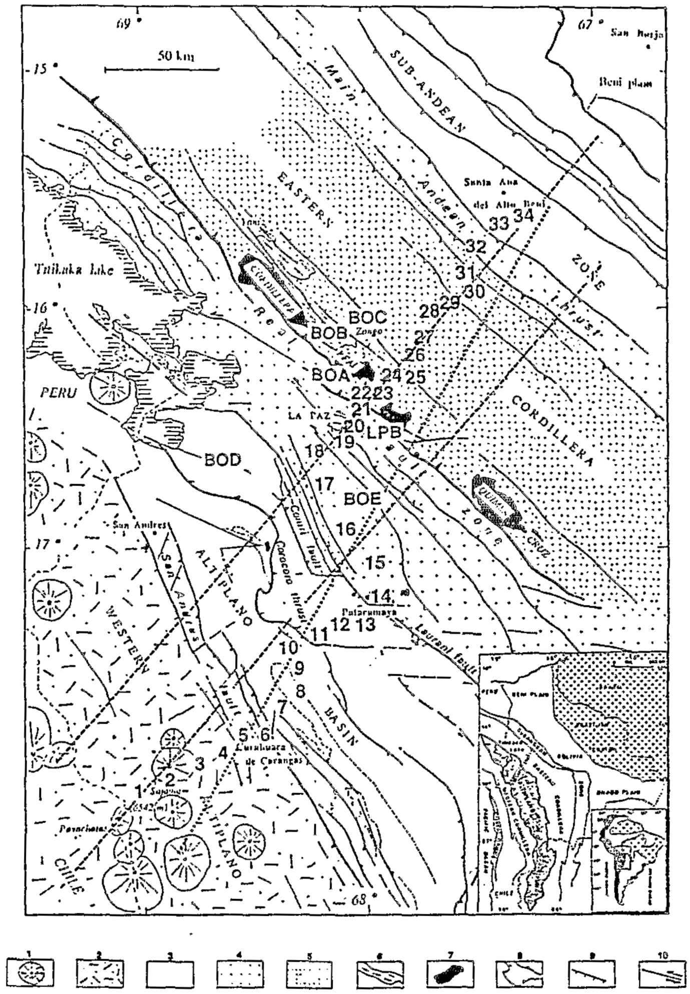
KEY WORDS: Andean Lithosphere, Altiplano, Tomography.

INTRODUCTION

The most significant geomorphological unit of the Central Andes is the Altiplano: it is, after Tibet, the largest high plateau in the world. The knowledge of its lithospheric structure is essential to the understanding of the mountain building in the Central Andes, which is undoubtedly a very complex process. Seismic tomography has proved to be a powerful tool in studying velocity structures, especially in active regions. In order to improve our knowledge of the deep structure beneath the Central Andes, we performed a seismic field experiment in northern Bolivia in 1989-1990. Thirtyfour vertical short period seismic stations of the French "Lithoscope" network were installed during a period of 4 months along a 320 km long profile, from the Volcanic Arc to the sub-Andean zone, crossing the Altiplano and the Eastern Cordillera in a direction approximately perpendicular to the main structural trend of the Andean chain. Among the 500 recorded earthquakes, we inverted separately the phases generated by 57 teleseismic events and 64 local events to study the lithospheric structures and the geometry of the subducted Nazca plate.

STRUCTURAL SETTING

Figure 1



The geological setting of the region under study, after Martinez (Dorbath et al.,1993), is presented on Figure 1. The bold numbers show the location of the temporary seismic stations, the permanent Bolivian stations are represented by their code names. The dotted line shows the location of the cross-section through the teleseismic inversion model presented on Figure 2a. The dashed lines show the locations of the northern and southern cross-sections through the local earthquake inversion model presented on Figure 2b.

The insert shows the morphostructural zoning of the Central Andes. From the Pacific Ocean to the Brazilian craton (area marked with crosses), the main units are: the coastal range, the axial valley, the Western Cordillera, the Altiplano-Puna region (shaded area), the Eastern Cordillera and the sub-Andean zone. Crossing the Altiplano and the Eastern Cordillera, between 15° and 18° S and 67° and 69°W, the dotted line represents the approximate location of the seismic study described in this paper. The rectangle in the insert shows the location of the Central Andes in South America.

The numbers of the legend refer to the different geological and tectonical units:
1: Quaternary volcanoes. 2: Cenozoic volcano-sedimentary cover. 3: Meso-Cenozoic Altiplano Basin and Paleozoic-Mesozoic Cenozoic sub-Andes. 4: Siluro-Devonian borders of the Eastern Cordillera. 5: Ordovician axial zone of the Eastern Cordillera 6: Hercynian plutons. 7: Andean plutons. 8: Thrust fault. 9: Normal fault. 10: Strike-slip fault.

DATA PROCESSING

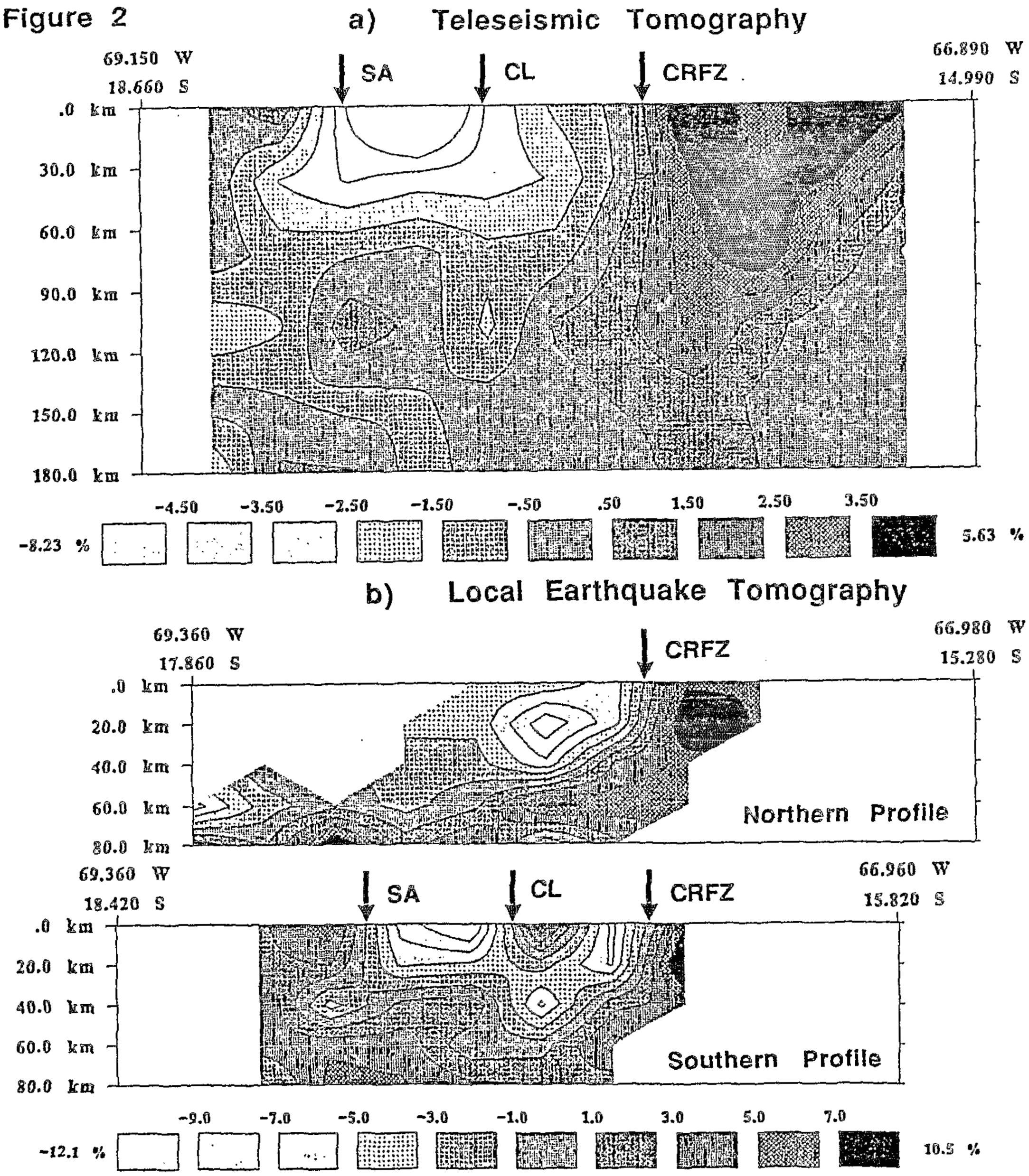
Teleseismic Tomography (TT): The data set contains 595 observations, nearly equally divided into P and PKP-phases. Relative residuals have been computed taking as a reference the station 10 which is situated in the central part of the Altiplano far from any major structural change. These residuals have a maximum amplitude reaching 3 s for P-phases and they show a strong azimuthal dependence. A noticeable sudden increase is observed, clearly associated with the fault system bordering the Eastern Cordillera to the west, the Cordillera Real fault system (CRFZ). The technique used here to invert the relative residuals follows the method developped by Aki et al. (1977), and involves the partition of the volume under investigation into layers, which are themselves divided into blocks. The starting P-velocity model is a smoothed version of velocity models obtained by previous geophysical studies. Several tests have been performed to check the reliability of this inversion: change of the geometry of the blocks, checkerboard resolution test... The final reduction of the variance obtained is 72%.

Local Earthquake Tomography (LET): As a first step, we computed the location of events reporting more than 15 arrival times with a minimum of 2 S-waves. We then kept only the events that met restrictive criteria insuring a high quality of their location. The complete data set includes about 1600 arrival times consisting of 1200 P and 400 S arrivals. Most of the local events we located are related to the subduction zone. The seismicity defines, between 90 km and 225 km, a part of the slab deeping to the NNE with a low angle of about 30°. The plot of mean P-residuals along the profile shows a pattern similar to the teleseismic profile; particularly, a jump of 1 s is observed when crossing the CFRZ. The tomographic inversion used is that developped by Thurber (1983) for the iterative simultaneous inversion of P-wave arrival times data for a 3D velocity structure and hypocentral parameters, adapted by Eberhart-Phillips (1986) to include S-wave data. The parametrization of the region under study is achieved by assigning velocity values at fixed points on a 3D grid.The same initial velocity model was used as for TT. The possibility offered by LET to get velocity structures and not simply perturbations of velocity as with TT is very useful in order to improve the knowledge of geological units; it also will help to estimate the Moho depth. The stability of the solution has been tested by the usual methods. The reduction of the variance is 87% for P-waves.

RESULTS

The results of the two tomographic studies are presented for P-waves on Figure 2a and b as vertical cross sections (see Fig.1 for their respective positions). They present consistent results, moreover they show a close correlation with the geological and tectonical units. For the two data set, the figures show a similar simple model consisting of two well contrasted blocks separated by a discontinuity sub-vertical or slightly dipping to south-west, which at the surface coincides with the CRFZ. The Altiplano is characterised by low velocities in the crust; the origin of velocity perturbations in the upper-crust is reasonably accounted for by the depth variations of the sedimentary fill, with a maximum thickness of 12 to 20 km under the Altiplano Basin. The spatial consistency between the main fault systems and velocity changes is very precise, particularly on Fig. 2b: the two fault zones bordering the Altiplano Basin, San Andres (SA) and Coniri-Laurani (CL) faults, enclose the well marked slow anomaly connected with this basin. The velocity perturbations in the lower crust interpreted as variations of the Moho depth, as well as the geometry of the iso-velocity lines obtained by LET, show a Moho depth wich decreases from about 60 km below the Altiplano to 50 km below the Eastern Cordillera. The absence of low velocity anomaly below the crust does not support hypothesis of magma accretion at the bottom of the crust under the Altiplano. The high velocity zone under the Eastern Cordillera extends down to 120 km on Fig. 2a, to the bottom of the model on Fig. 2b; we interpret this zone as the Brazilian craton. The representation of the underthrusting of this craton is somewhat different on the teleseismic and local earthquake studies. Nonetheless, both results are not consistent with a thin-skinn underthrusting as proposed in previous models. In the region under study, corresponding to the change of trend of the Central Andes, the western limit of the underthrusting of the craton is clearly the CRFZ, which is interpreted as an old suture zone.

Figure 2



REFERENCES

AKI, K., CHRISTOFFERSSON, A. and HUSEBYE, 1977, Determination of the three-dimensional seismic structure of the lithosphere, J. Geophys. Res., 82, 277-296.

DORBATH, C., GRANET, M., POUPINET, G. and MARTINEZ, C., 1993, A teleseismic study of the Altiplano and the Eastern Cordillera in northern Bolivia: new constraints on a lithospheric model, J. Geophys. Res., to be published.

DORBATH, C. and GRANET, M., 1993, Local Earthquake Tomography of the Altiplano and the Eastern Cordillera in northern Bolivia, J. Geophys. Res., submitted.

EBERHART-PHILLIPS, D., 1986, Three-dimensional velocity structure in Northern California Coast Ranges from inversion of local earthquake arrival times, Bull. Seism. Am., 76, 1025-1052.

THURBER, C.H., 1983, Earthquake locations and three-dimensional crustal structure in the Coyote Lake area, central California, J. Geophys. Res., 88, 8226,8236.