A 3-D MODEL FOR THE CENTRAL ANDES BASED ON JOINT INTERPRETATION OF SEISMICS AND GRAVITY

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INTRODUCTION

Here we present the results of intensive wide angle seismic refraction and gravity research in the southern Central Andes (20°- 28° S) during the 80's and early 90's. The gross crustal structures could be determined covering the principal morphostructural units of the Andes between 21° and 25° S (e.g. Wigger et al., 1994). In 1994 (PISCO 94 - Proyecto de Investigación Sismológica de la Cordillera Occidental) and 1995 (CINCA 95 - Crustal Investigations Off- and On-shore Nazca Central Andes) seismic investigations focussed on the arc and forearc structures in order to provide more detailed insight in the crustal structure of this region (see also posters Lessel, Schmitz and Giese and Patzwahl et al., this issue). The structural and velocity informations obtained by the seismic refraction is available along N-S and W-E trending profiles covering the the central region of the 3D-gravity model.

From 1993 to 1996 the MIGRA group with participants from Chile, Argentina and Germany has surveyed some 3.000 new gravity observations in an Andean Geotraverse covering N-Chile and NW-Argentina between 64°- 71° W and 20° - 29° S. MIGRA is a Spanish acronym for "Mediciones Internacionales de GRavedad en los Andes". Including reprocessed older data of Freie Universität Berlin, South American universities, oil and mining industry, there is now a data base of about 15.000 gravity values available, which can be used together with other geophysical and geological information for an interdisciplinary interpretation of the structure and evolution of the Central Andes (Götze et al., 1994). The data base which includes point data and data grids of free-air-, and "complete Bouguer anomalies", isostatic-residual anomalies, were frequently described by Götze et al. (1995) and Götze (1996).

FOREARC CRUSTAL STRUCTURES FROM SEISMIC REFRACTION DATA

In the Coastal Cordillera between 21° and 24° S, upper crustal P-wave velocities vary between 6.0 and 6.7 km/s. The top of the lower crust is located between 7 and 12 km depth, reaching down to 20 - 22 km, proven by prograde phases with velocities up to 7.2 km/s. The prominent discontinuity at 40 km depth (V_p = 8.2 km/s) is interpreted as Moho of the subducted Nazca Plate with an average velocity of 6.6 - 6.7 km/s (Wigger et al., 1994). Upper crustal as well as lower crustal structures can be followed into the Precordillera with the upper crust increasing to 20 km thickness and the lower crust extending down to about 40 - 45 km depth. Three distinct discontinuities with velocities from 7.3 - 8.0 km/s, separated by low velocity layers, are located between 50 and 70 km depth. P_n observations from the Isla Santa Maria shot point can be correlated to the deepermost discontinuity. The average velocity down to 65-70 km depth decreases to 6.3 km/s. The upper crust as well as deeper crustal units can be followed into the Western Cordillera; however, the average crustal velocity decreases to 5.9 - 6.0 km/s. The most striking feature in the record sections of the Western Cordillera, a discontinuity at 20 km depth (Vp = 6.4 km/s) beneath Ollagüe, is interpreted from structural point of view as the top of the lower crust, although the crustal units below are characterised by partly reduced velocities. Locally limited high-velocity discontinuities in this crustal unit are observed down to approximately 45 - 50 km depth. Assuming this depth range as the base of the lower crust, a 25-30 km thick lower crust results with low average velocities of only 6.0 - 6.2 km/s. Fan observations between the Precordillera and the Western Cordillera give indications for a deep reflector (Vp = 8.2 km/s) which is interpreted as the eclogitized top of the subducted Nazca Plate.

GRAVITY ANOMALIES

Onshore the Bouguer anomaly drops down to a regional minimum of about - 450 mGal in the area of the recent volcanic arc, related to crustal thickening by isostatic compensation (For more details refer to abstract: Götze, Schmidt, Kirchner, Kösters, Araneda and Lopez, this issue). The gravity effect of the isostatic compensation root was eliminated from the Bouguer gravity and the resulting anomaly serves as a residual field. The most interesting features of this field are: (1) Positive values in the area of the Jurassic forearc with isolated complexes parallel to the coastline. They are regionally caused by the presence of the dense subducting plate (gravity effect of more than 50 mGal; density contrast: 0.05 g/cm^3) and locally by uplifted jurassic batholiths intruded into the volcanic "La Negra" formation. (2) The NNW-SSE striking positive anomaly from Calama (CAL) by the Salar de Atacama to southern Puna which can be explained by a highly metamorphic and high-density Paleozoic/Precambrian structure, which is oblique to the N-S orientation of the recent volcanic belt. (3) Local minima along the recent volcanic arc point to partly molten material at depths of 15 - 20 km. (4) Minima following a line from Ollagüe (OLL) to Calama (CAL) along 69° W, are caused by the Eocene volcanic arc with low-density volcanic material in the upper crust.

3D MODELLING

A large scaled 3D density model was constructed to investigate the regional structure and density composition of the Andean lithosphere (Figure 1a). The model comprises the new results of seismic refraction and summarizes discussions with colleagues from geology and petrology. Based on various 2D raytracing models seismic cross sections extending from the trench to the magmatic arc were used to design major elements of the Andean crust and mantle transition between 21° through 24° S. Further parts of the density model are the downgoing Nazca plate according to results of Cahill and Isacks (1992) and continental lithosphere together with the Brasilian shield in the east, which is not shown here. As a preliminary study the velocities of seismic models were directly converted into densities by using e.g. the Nafe & Drake relationship or similar density/velocity relations by Wollard. Initial model geometry was slightly modified by the application of interactive computer graphics to verify regional trends implied by the Bouguer gravity field. Although we used various non-linear inversion algorithms to optimize the model density we also tried to follow well established density/velocity relations from laboratory and literature. Due to unknown conditions of high temperature/pressure and the presence of fluids at the crust-mantle interface of the Central Andes we learned from modelling that we have to distinguish a ‘gravity’ Moho which is characterized by a density contrast of less or equal 0.3 g/ccm from the "seismic" Moho which is not very clear.

In order to interprete long wavelengths of the gravity field we also calculated the potential (geoid) of the 3D density model by forward modelling and compared it with the observed geoid (OSU01A). Andean topography and ist corresponding Airy root (including effects of compensated topography of the entire earth) contribute approx. 18 m to the geoid of the area. Instead of Airy or Vening-Meinesz isostasy we used the 3D model to calculate the gravity and/or geoid contribution of the Andean lithosphere respectively, because usual isostatically equilibrated state is not necessarily representative at an active continental margin. Density inhomogeneities from deeper parts of the mantle also contribute to the observed geoid undulations. Even undulations caused by the core-mantle boundary result in potential signals that dominate the geoid in the Central Andes.

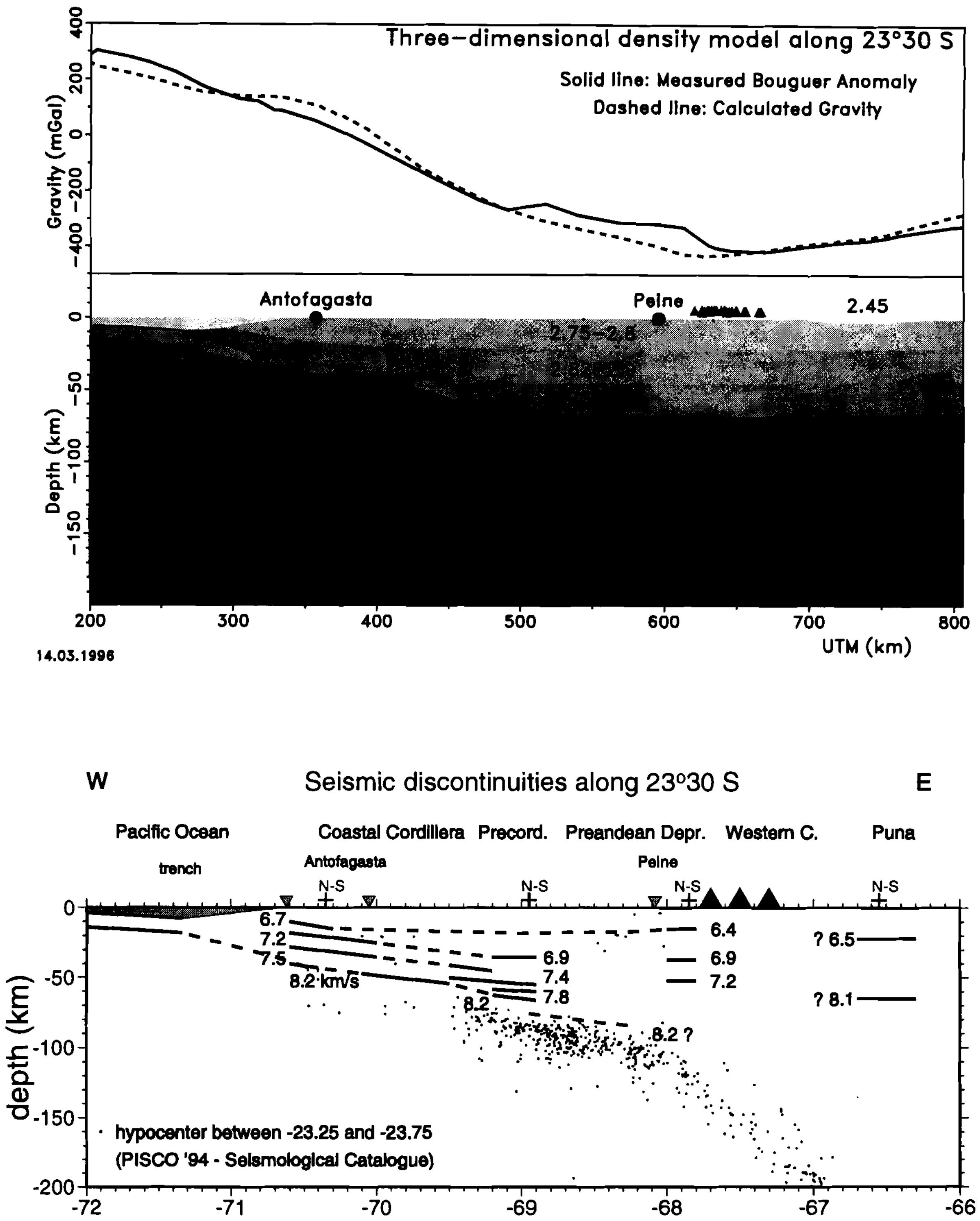

Figure 1: Cross sections with the density structure and modelled / measured gravity fields (a) and seismic discontinuities in northern Chile at lat. 23° 30' S. Crustal structures can be traced from the Coastal Cordillera with increasing thickness towards the Western Cordillera. The shape of the subducted Nazca plate can be inferred from Moho observations in the Coastal Cordillera and from locations of the earthquake hypocenters derived from the PISCO 94 - seismological catalogue (Asch, Rudloff and Graeber, pers. comm., 1995). Crosses indicate the position of corresponding N-S profiles; black triangles give the position of magmatic arc.

CONCLUSIONS

In the magmatic arc and Puna region of western Argentina the Bouguer anomaly and density modelling (-450 mGal) indicate a crustal thickness in the order of 70 km. There are no Moho observations in this region; the seismic waves are strongly attenuated with a reduction of the seismic velocities. Beneath the magmatic arc the electric resistivities decrease to values of 0.5 - 1 Ohmm at 20 km depth (Schwarz et al. 1994) indicating a zone of partial melting. The continental crust of the forearc has a thickness of 25 - 45 km without indications for a clear Moho. Between the subducting Nazca plate and the continental crust there is a wedge of material with low seismic velocities and with low densities, typical values for crustal material, which are interpreted as a mixture of hydrated upper mantle relicts and material eroded from the continental margin. Our 3D gravity model which is based on structural information of seismic refraction data in its central part unables us to extend these information even to regions where no seismics exists. The gravity field images structural anomalies which require further inverstigations.

This interdisciplinary modelling of results from both seismic refraction and gravity observations plays an important role in regional geodynamics of the Andean lithosphere and interdisciplinary interpretations. Seismic velocities and density distribution in the area of the Central Andes seem to be sensitive indicators which are linked to many processes contributing to the tectonic framework of the Nazca subduction zone.

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