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THE LITHOSPHERIC STRUCTURES OF THE CENTRAL ANDES (20° - 26°S) AS INFERRED FROM INTERPRETATION OF GEOPHYSICAL RESEARCH

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RESUMEN

Las anomalías geofísicas y las inhomogeneidades en la litósfera andina brindan una idea acerca de la dinámica, structura y desarollo de la placa andina cabalgante. Tanto las informaciones sísmicas y gravimétricas muestran que la corteza andina se encuentra espesada en hasta unos 60-70 km. Estudios integrados de balanceo tectónico y cortical muestran que en el retroarco un 90-95% del acortamiento reciente, debe ser atribuido al acortamiento tectónico ocurrido en los últimos 15 ma. Se desconoce aún en que medida el restante 5-10% se relaciona con espesamiento magmático y/o con un espesamiento cortical tectónico más antiguo. En base a los desultados recientes de la geofísica se concluye en la siguiente estructuración reológica grosera de la litósfera andina: area del antearco, frágil. Area del arco magmático: transición frágil/dúctil a escasa profundidad. Area del retroarco: ALTIPLANO, corteza superior frágil hasta los 10-20 km, por debajo dúctil. CORDILLERA ORIENTAL: corteza superior frágil hasta 20-30 km, por debajo dúctil. SIERRAS SUBANDINAS: horizontes de cizalla en los sedimentos, por debajo condiciones corticales normales, frágiles.

INTRODUCTION

In 1981, the Earth Science Instituts of Freie Universtät and Technische Universität of Berlin lauched a research programme called "Mobility of Active Continental Margins and more recently the Sonderforschungsbereich 267 (Special Research Programme) entitled "Deformation Processes in the Central Andes". The intention is to obtain more insight into the structures of the mentioned area by interdisciplinary approach which comprises a variety of mostly geophysical and geological studies [1]. These are concentrated on a segment of the southern Central Andes extending between 20° and 26°S from the Pacific Ocean to the eastern Andean foreland (Fig. 1). Research was made possible only through intensive assistance of our South American colleagues of the three countries involved.

It should be noted that the Global Geoscience Transect No. 6 "Central Andean Transect, Nazca Plate to Chaco Plains, Southwestern Pacific Ocean, Northern Chile and Northern Argentina" runs through the area under investigations [2]. It was elaborated in close cooperation with scientists from South America and Berlin, i.e. by those colleagues who also contributed to the presented paper.

PRESENT DATA BASES

Seismic refraction measurements were carried out since 1982 in N-Chile e.g. [3].The crustal structure of the Coastal Cordillera is very anomalous. Extremely unnomal are the arrival times of the first onset that indicate the existence of a rock velocity of about 7.2 km/s in the upper 20 km. Petrologic studies have revealed that the coastal Cordillera is made up of rocks that have been situated during Jurassic time at about 15 km depth and which are invaded by magmatic rocks of basic composition. This zone of anomalous high velocities is seen as the base of the continental crust of the upper plate. In eastern direction this high--velocity layer dips down to about 30 km beneath the Precordillera. Beneath the Western Cordillera this high velocity zone is in a depth of only 25 km. In the coastal region and the eastward adjacent areas a second and well pronounced discontinuity was found at 40-45 km depth, showing a velocity of about 8.2 km/s.

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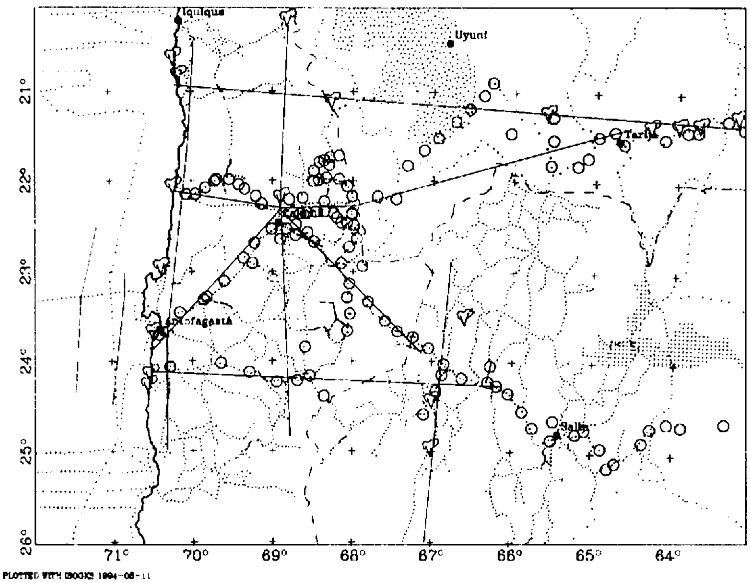
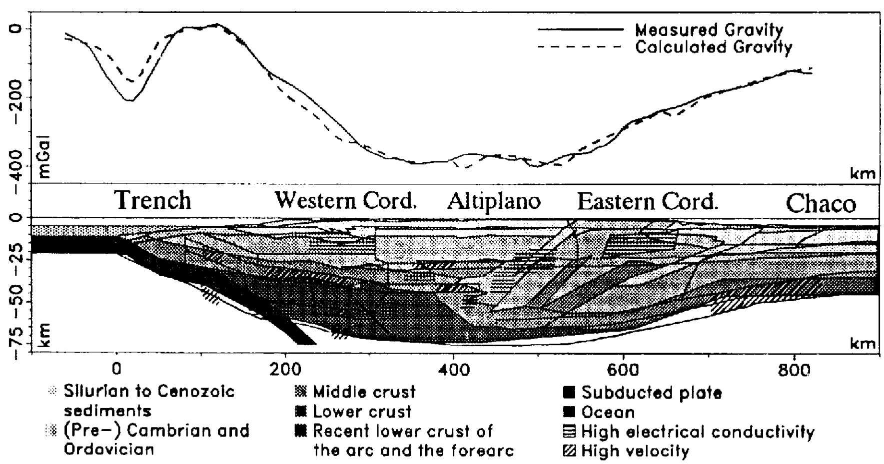


Fig. 1: Geophysical database (December 1993 update). Lines of seismic refraction and shotpoints; + = gravity stations; O = MT stations;



Contributions:
Structural model: Schmitz, 1994; Electrical Conductivity: Schwarz et al., 1994; Velocity: Wigger et al., 1994

Fig. 2: Geophysical cross-section Central Andes combining structural elements and geophysical modelling

This second crust/mantle boundary is interpreted as oceanic Moho of the downgoing Nazca plate. Beneath the Precordillera a deep and well expressed discontinuity could be detected at 60 - 70 km.

Between these two discontinuities there is a zone of strong heterogeneity, high and low velocities are interchanging, the average interval velocity is about 6 km/s. As petrologic interpretation several possibilities must be discussed: (1) remnants of the eroded continental margin between the coast and the trench, (2) relics of the continental mantle of the upper plate, (3) oceanic crustal material probably thickened by the compressional subducting process and (4) magmatic intrusivons from the oceanic lower plate.

Along two W-E profiles at 21.5° and 24° S the Western Cordillera of the Central Andes was traversed. The record sections of these lines demonstrate the heterogeneous structure of the crust beneath the Western Cordillera. Here as well an interchanging between high and low velocity zones is observed. In the Precordillera (Fig.1) late reflections are coming from a deph of about 70 km which is clearly recognisable. A rather different crustal structure is revealed in the backarc region. The crust/mantle boundary of the Brazilian Shield beneath the Andean foreland at 40 km depth dips down westwards to 60 km beneath the Eastern Cordillera and the eastern part of the Altiplano. Beneath the Eastern Cordillera there exists a clearly expressed intracrustal discontinuity at 20 - 25 km depth with a velocity increase to about 7.2 km/s.

The **gravity field** of the southern Central Andes was investigated with regard to the isostatic state and crustal density structure of the orogeny. Both Bouguer and isostatic anomalies were correlated with mean topographic hights. Statistical analysis were applied to in order to determine the degree to which quantitative conclusions could be drawn with reference to the main scope of this paper. Additionally the balance of topographic surplus and deficit masses was estimated for the ares under investigation. In case of gravity database came from recent field data acquisition in the Central Andes e.g.[4]. All gravity data analysed in this paper are tied to the IGSN-71 gravity datum and terrain-corrected as well. Bouguer anomaly was evaluated using the sea level datum and a standard density of 2.67 kg/m^3 for mass correction. Analysis of andean topography bases on the mean elevation data set of [5]. West of the South American coast line an elongated minimum of -200 mGal follows the 71.5 °W

Medians of	Central Andes
Mean height Mean Bouguer anomaly Mean isostatic anomaly	3.021 m -262 mGal 14.5 mgal
Gravimetric mass deficit per km^2 Topographic mass per km^2	6.43 * 10^{12} kg/km^2 7.18 * 10^{12} kg/km^2

Table 1: Height, gravity data medians and mass calculations from gravity and topographic surplus by applying Gauss' Theorem.

meridian and marks those anomalies caused by the Peru-Chile trench. Onshore, we obtain a significant asymetry of the Bouguer gravity field with stronger horizontal gradients in the west (2.4 mGal/km) than in the east (1.2 mGal/km). A belt of positive anomalies of as much as 70 mGal occurs at the coast marking th Jurassic magmatic arc of the coastal range. The effects of the younger magmatic arcs and sedimentary basins of mid- and upper Cretaceous are completely superimposed by the strong decrease of the regional gravity field. However, a relative gravity high south and south-west of Calama (Chile) indicates an anomalous density distribution in the crust of the Chilean Precordillera and the preandean depression zone, continuing in SE direction to the Argentinean Puna. The absolute minimum is observed as about -450 mGal in the Altiplano - Puna area, thus giving a total range of 510 mGal. Towards the east in the area of the Western Chaco near 64° W, the field decreases to normal gravity values of old Precambrian crust.

For compiling frequency distributions of both gravity and heights, a grid size of 5 km 5 km was chosen. Maximum occurrence of heights of 3.000 to 4.000 m underlines the role of the Altiplano/Puna-Plateau within the Andes. Statistics is shown in Fig. 3 and Table 1 for the Bouguer anomaly and a Vening-Meinesz isostatic anomaly. Frequency distribution of mean Bouguer anomalies show in both cases a shape similar to the mirror image of topographic frequency distribution. In the Andes anomaly values around -350 mGal prevail. Mean isostatic anomalies have quite different frequency distributions with a much smaller range of values. As can be expected from the principle of isostasy, isostatic anomalies close to cero dominate, however, clearly shifted to positive values (14.5 mGal)

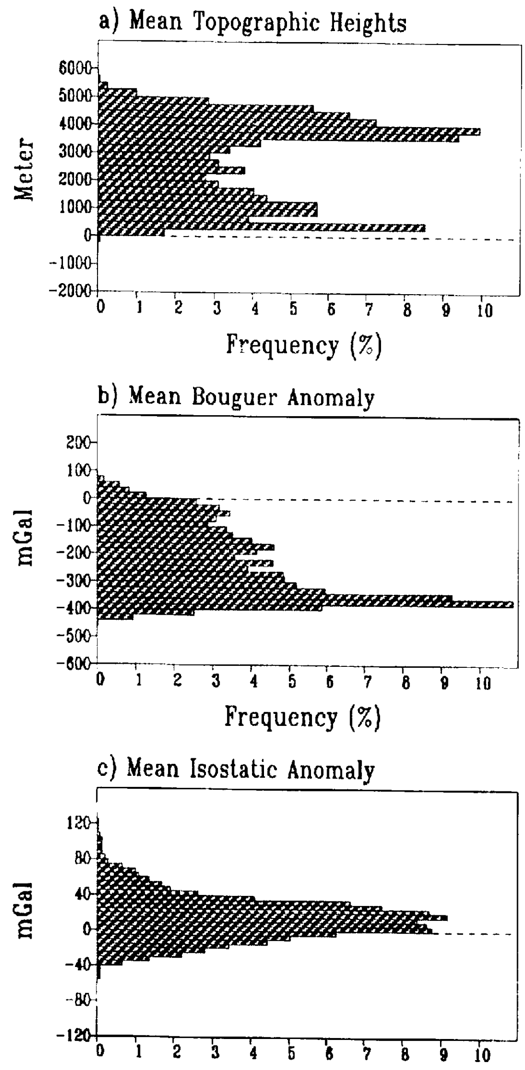


Fig. 3: Statistics of gravity anomalies and topography of the Central Andes between 20° - 26° S. Mean of isostatic anomaly indicates a small mass surplus of topographic masses

Magnetotelluric soundings in the southern Central Andes (CA) started in the early 80s resulting in two profiles crossing all structural units of the mountain belt (Fig. 1) and one running in strike of the W-Cordillera e.g. [6]. The Coastal Cordillera of northern Chile shows high electrical resistivities of about 5000 ohm m down to a depth of 40 km [7], while decreasing at greater depth to about 500 ohm m where velocities typical for the upper mantle were found by seismic refraction studies [3]. Lamella like conductors in strike of the coastal range may be interpreted by upper crustal fault zones providing pathways for fluids expelled from the downging slab. The question of why there is no dipping conductor under the Central Andes may be answered by almost no sediments offshore to be dragged beneath the continent. But as subduction erosion at the continental margin is most likely to occur the question given above cannot yet be answered sufficently.

The most striking zone of high electrical conductivity in the Central Andes was found at shallow depth beneath the W-Cordillera. Total conductance is greater than 25.000 Siemens in a zone where the gravity has local minima e.g. [4], seismic waves have reduced velocities e.g. [3] and are strongly attenuated and/or scattered. These observations were unified in a model of a partially molten middle and lower crust but the divergence in strike of the volcanic belt and the hight conductivity zone (HCZ) is not yet explained by the data.

A HCZ was also found beneath the Bolivian Altiplano at middle to lower crustal depth. It ascends from a depth of about 45 km at the eastern margin of the W-Cordillera to about 20 km at the western limit of the E-Cordillera. Its total conductance is of about 15.000 Siemens. The HCZ may be related to decollement type tectonics as being responsible for mountain building in the Eastern Andes although partial melts cannot be excluded in explaining its origin. In the E the Altiplano HCZ connects to a HCZ found within the western part of the Eastern Cordillera of southern Bolivia of which the total conductance can be calculated to at least 10.000 Siemens.

The Subandean and the unfolded foreland show a low resistive cover of only 5 to 10 ohm m with a maximum thickness of 6 to 7 km, corresponding to the sedimentary cover. MT data are highly anisotropic [7]. The electrical resistivity of the lithosphere below increases eastwards from 500 to 3000 ohm m. This may be explained with the more consolidating Brasilian craton, uneffected by the process of Andean mountain building though the upper mantle at a depth of 90 km becomes less resistive (about 10 ohm m).

CONCLUSIONS

The interpretation of intracrustal high velocity zones must be seen together with the compressional tectonics of the eastern part of the Andes (Fig. 2). Within the last 15 - 10 Ma the continental sedimentary series in the Subandean Range have been compressed from an original width of 280 km to 140 km e.g. [8] and [9]. Consequently the missing 140 km of continental crust must be located in the recent deeper crust beneath the Eastern Cordillera and the eastern Altiplano. The crust of the Eastern Cordillera sheared off at the crustal base and has been thrusted eastwards onto the basement of the western Subandean belt. By this process the "Subandean Thrust and Fold Belt" has been formed. This interpretation is proved by the intracrustal discontinuity at 20 - 25 km depth that forms the base of the allochthonous Eastern Cordillera crust. Consequently the recent lower crust beneath the Eastern Cordillera must be interpreted as normal crust of the Brazilian foreland.

The clearly expressed crust/mantle boundary beneath the Eastern Cordillera can be traced only up to the eastern part of the Altiplano. From the seismic point of view beneath the Altiplano the crust/mantle boundary appears to be undetectable. Here the deepest interface was found at about 40 km depth. This can be interpreted as base of the displaced Eastern Cordillera crust. Thus, with some caution it can be concluded that the crust/mantle boundary of the Brazilian shield extends only up to the eastern border of the Altiplano, a statement confirmed by tectonic balancing considerations. Beneath the western part of the Altiplano and the Western Cordillera it must be supposed that in the depth between 40 and 70 km processes are going on which dissolve the crust/mantle boundary as sharp, seismically detectable interface although density modelling points to that kind of interface structure.

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