THE GRAVITY FIELD OF THE CONTINENT-OCEAN TRANSITION AT THE WESTERN CONTINENTAL MARGIN OF SOUTH AMERICA

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KEY WORDS: Offshore gravity, Free-air and Bouguer anomalies, subduction zone, Chile trench

INTRODUCTION

Under the framework of the interdisciplinary research project CINCA (Crustal Investigations Off- and Onshore Nazca/Central Andes) gravity surveys of the international MIGRA group with participants from Chile, Argentina and Germany has been extended to the Pacific ocean. In summer 1995 MIGRA took part in the "CINCA" offshore experiment SO - 104 of the german research vessel "Sonne" between the latitudes 20° S to 24° S. The offshore gravity data are connected with the onland survey to draw a complete gravity picture of this ocean-continent transition. Some 6.000 new gravity observations onland in an Andean Geotraverse covering N-Chile, SW Bolivia and NW-Argentina between 64°- 71° W and 20° - 29° S has been put to the data base which already existed when MIGRA started in 1982 (Götze et al., 1994 and Götze et al. 1995). MIGRA is a Spanish acronym for "Mediciones Internacionales de **GR**avedad en los Andes".

MEASUREMENTS AND DATA ACCURACY

Gravity data at sea were collected along continous survey lines (some 8.000 km). The average density of observational sites amounts of about 15 observations per km. The gravity survey of cruise SO - 104 was tied to the Chilean National Gravity network of the "Departamento Geofísico, Universidad de Chile, Santiago" at reference stations in Valparaiso, Antofagasta and Iquique. The drift of the KSS31/32 onboard gravity sensor was very low and amounts to -0.048 mGal/day or - 1.44 mGal/month, respectively. The overall drift of the gravity meter was determined to be 0.47 mGal per 92 days.

Further information about the accuracy of the offshore survey provide so called "misties". Misties are crossover errors if the gravity readings of two crossing lines are compared. Assuming this accuracy depends mainly on the gravity sensor several methods have been invented to minimize crossover errors (e.g. Prince and Forsyth, 1984). It has also been argued that misties are frequently caused by bad positioning (Fritsch and Roeser, 1986). Anyway, statistical treatments of misties at intersections of survey lines reveals the precision of the offshore gravity measurements including auxiliary physical quantities. On the 1st leg of cruise S0-104 about 44 intersections have been obtained. Some 80 % of gravity misties were less than 1 mGal and about 80 % of the water depth misties were less than 9 m. These data show the high precision of both gravity and waterdepth measurements on cruise So 104/1. The 2nd leg of the survey was characterized by a more complicated topology of crossing profiles due to the wide angle reflection experiments which required gravity measurements at the same line for three times. Therefore, a more sophisticated algorithm has been used to estimate crossover errors.

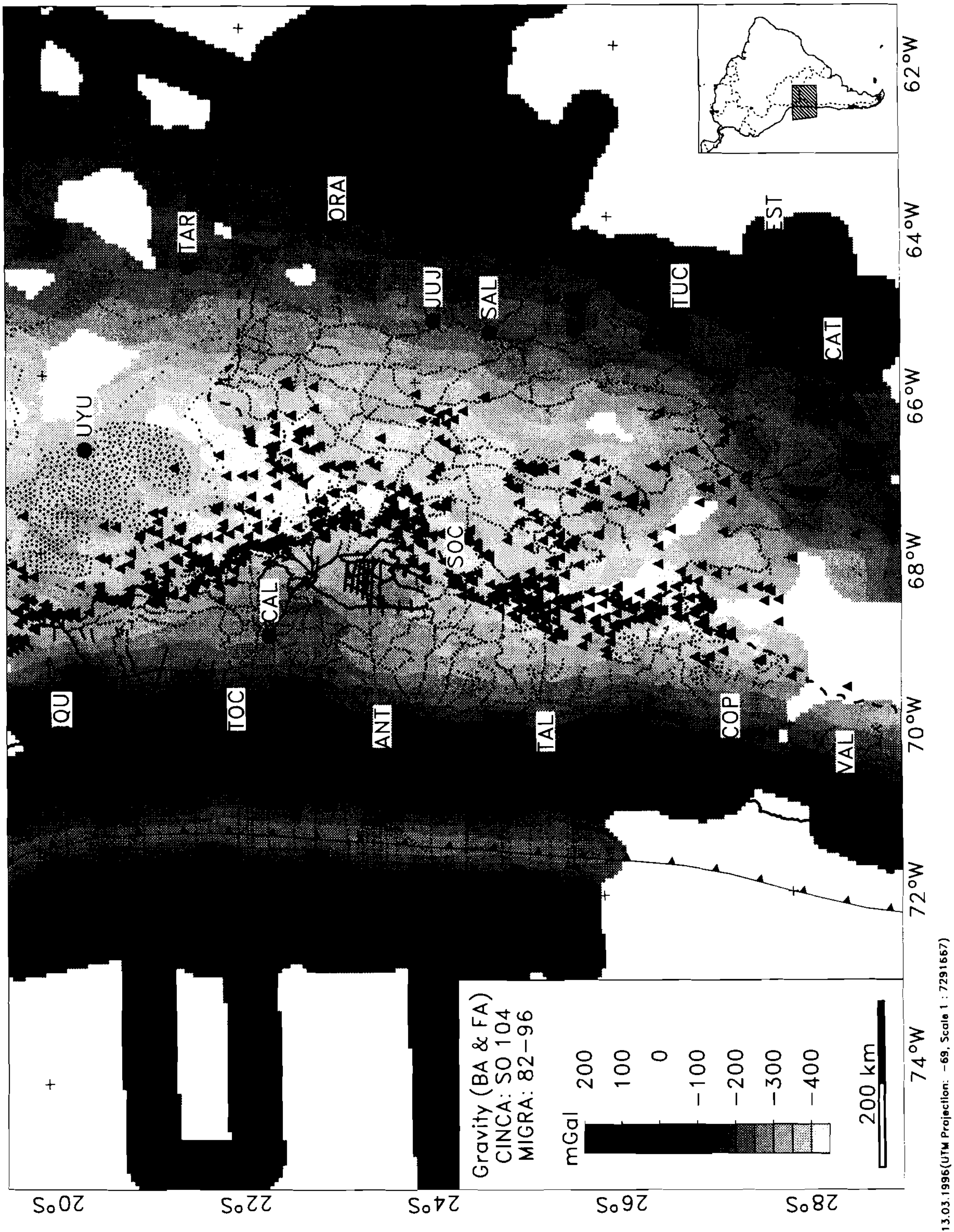

Figure 1: The gravity field of the Central Andes and offshore South America between 20° - 29° S. In the Pacific offshore area Free-air anomalies replace onland Bouguer anomalies Shading intervals: 50 mGal. Gravity database is shown together with volcanoes and other geographical features.

In total, the accuracy of the gravity survey is truly better than 1 mGal, and accuracy of water depth determinations are better than 10 m.

At the continent the investigated region covers a 900 km x 1.000 km area in the central part of the Andean orogenic system. It is an arid/semiarid zone, where elevations vary from sea level up to heights greater than 6.000 m at the Andean volcano summits. The young Andean orogen between 20° - 29° S comprises different structures which have evolved on a Precambrian-Paleozoic basement.The investigated area is characterized by its enormous topography and remoteness, by its aridity, low population density and limited infrastructure. Other difficulties limiting our field work were the lack of topographic maps and geodetic networks in some regions. The spacing of stations amounts to approximately 5 km along all passable tracks aside from some local areas with a higher station density . To complete this data base we included gravity observations from different sources. With the exception of some inaccessible regions in the "Eastern" and "Western Cordillera", the gravity coverage for the region is fairly uniform. All measurements are tied to the IGSN71 gravity datum at base stations in Oran/Argentina, Iquique/Chile and Tucumán/Argentina.

The large size of the area and the severe logistical problems did not always allow us to determine the drift of the gravity meters by repeating the measurements at each station. However, even when we used bad tracks, the drift of the LaCoste & Romberg instruments (model G) rarely exceeded 0.1 mGal per day. Only about 35% of the gravity sites could be tied directly to benchmarks, such as levelling lines or trigonometric heights, so we used altimeters for height determinations. To improve the quality of our barometric measurements, we calculated time-dependent drift corrections as it is usually done for gravity measurements, using as many benchmarks and repeated measurements as possible. Moreover, the profiles of several days were tied together in order to eliminate systematic errors. The scales of the barometers have been calibrated on levelling lines with an altitude difference of about 2000 m. Error estimations showed that even in the worst case the accuracy was better than 20 m, giving an error in the Bouguer anomaly of about 4 mGal, which is less than 1% of the overall magnitude of more than 450 mGal. For the terrain correction (up to 167 km around all stations), a method including calculations of the earth's curvature developed for gravity investigations in the Alps was used, after adapting it to the special situation in the Central Andes. Reduction density was 2.67 g/cm^3. For different morphological units we obtained the following typical values of topographic reduction: Longitudinal valley and Chaco region: 0.5 - 1 mGal, Coastal, Pre- and Western Cordillera, Altiplano/Puna and Subandean Belt: 1 - 10 mGal and steep coast

GRAVITY ANOMALIES

Both on- and new offshore gravity data base were put together to shed new light on the gravity field at the continent - ocean transition zone at the western continental margin (Figure 1). In the western part of the investigated offshore area the oceanic basement of the downgoing Nazca plate causes positive Free-air anomalies with an average of about 20 mGal; water depth is about 4.500 m. The Peruvian-Chilean trench is characterized by strong negative gravity values which extend to a minimum of less than -250 mGal. In continuation towards the Chilean coast there is a broad zone of alternating positive and negative Free air gravity which vary in size and magnitude. It appears to be difficult to interpret these anomalies without any modelling which will be performed in the next months. However, the character of the gravity field over the continental slope appears to be complicated. It shows several domains with gravity highs and lows which may be interpreted in terms of morphology of the continental slope and density structures which could belong to already eroded parts of the Jurassic Forearc.

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. The effect of isostatic compensation of topography was calculated assuming the model of Vening-Meinesz with the following parameters: density contrast of the earth's mantle and crust dRHO = 0.35 g/cm^3, normal crustal thickness: 35 km and a flexural rigidity of 10^{23} Nm. 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 in the forearc region of the Central Andes: (1) Positive values in the area of the forearc with isolated complexes parallel to the coastline. They are regionally caused by the presence of the dense subducting plate (gravity effect of about 50 mGal; density contrast: 0.05 g/cm^3) and locally by uplifted jurassic batholiths intruded into the "Formación La Negra" and (2) the 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.

CONCLUSIONS

Both on- and offshore gravity data will play an important role in local investigations of applied geophysics and regional interdisciplinary interpretations.The Andean gravity field seems to be a sensitive indicator which is linked to many processes contributing to the tectonic framework of the Nazca subduction zone. In close cooperation with the Geological Survey of Chile (Santiago) we are going to complete the survey in the south-west and south part of the traverse (Fig.1) in early 1996 and fill the gaps that still exist due to extreme logistical problems. In 1997 we are planning to join an international seismic reflection program with participants from both Americas and Germany in the Altiplano of Bolivia.

ACKNOWLEDGEMENT

This paper presents results of the 1995 "CINCA" offshore experiment SO - 104 of the german research vessel "Sonne".Processing and interpretation of gravity data are part of a joint project of the gravity research group at Bundesanstalt für Geowissenschaften und Rohstoffe (Hannover) and the gravity research project D3 of the SFB 267 which is funded by the Deutsche Forschungsgemeinschaft (DFG) and Freie Universität Berlin. This paper contributes also to the IGCP 345.

REFERENCES

Fritsch, J. And H.A. Roeser 1988. On the accuracy of gravity measurements at sea. Geologisches Jahrbuch, E 42, 195 - 208.

Götze, H.-J., Lahmeyer, B., Schmidt, S. and Strunk, S. 1994. The Lithospheric Structure of the Central Andes (20°- 26° S) as inferred from Quantitative Interpretation of Regional Gravity. In: Tectonics of the Southern Central Andes (Eds.: Reutter, Scheuber, Wigger), pp. 7-21, Springer Verlag Heidelberg.

Götze, H.-J., M. Schmitz, P. Giese, S. Schmidt, P. Wigger, G. Schwarz, M. Araneda, G. Chong D. and J. Viramonte 1995. Las estructuras litosféricas de los Andes Cantrales australes basados en interpretaciones geofísicas. Revista Geológica de Chile, Vol. 22 No. 2, p. 179-192.

Prince, R.A. and Forsyth, D.W. 1984. A simple objective method for minimizing crossover errors in marine gravity data. Geophysics, 49 (7), 1070-1083.