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24. Gravity Surveys of the Mount Melbourne and the Rennick-Lillie Glacier Areas, North Victoria Land, Antarctica

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INTRODUCTION

Gravimetry as one of the classical geophysical methods is an important tool in studying the deeper structures of the lithoshere, in particular in Antarctica, where the outcropping rock surface is very difficult to access. Earlier gravity surveys had been performed in North Victoria Land around the Mount Melbourne area during GANOVEX IV (DÜRBAUM et al. 1989) and GANOVEX V (REDFIELD et al. in press a, FRITSCH & KEWITSCH in press). During the latter expedition an additional zone close to the north coast between Rennick and Matusevich Glacier was surveyed (REDFIELD et al. in press b). Between these two areas exist some older data, which were collected, however, without information on ice thicknesses (TINGEY unpubl. manuscript). Finally, gravity data are available along a long inland traverse measured some thirty years ago during the International Geophysical Year (CRARY 1963). These data seem to have a good control on ice thickness again, as they were supplemented by seismic reflection measurements.

Contrary to the north area, a steep gradient in the Bouguer map shows up in the south giving rise to speculations on thickening of the crust towards the continent. The values decrease by approximately 250 mGal from the coast to the Polar Plateau. The break-in-slope towards the continent is not yet clearly determined. The objective of the present work was the continuation of these studies, specially to densify the data and amplify the area surveyed in order to be able to give a better structural interpretation and to perform quantitative modeling.

During GANOVEX VI three separate areas were surveyed. This paper is dealing with two of them (Fig. 1), the third one is described by REDFIELD et al. (this vol.).

PROBLEMS OF GRAVIMETRY IN ANTARCTICA

Gravity measurements in a highly mountainous region and particularly under Antarctic conditions are a difficult task. Besides the logistic problems the main difficulty arises from the existence of an ice and snow cover in most parts. The main objective of a gravity survey is to gain information on deeper structures in the earth's interior. Both, the topography of the terrain surface and the depth and topography of the interface between ice and rock considerably influence the values measured, as the specific densities of ice and rock are rather different. A good control of these surfaces is therefore indispensable. At a scale of 1 : 250,000 of the only available maps, the topographic reduction can not reach a very high precision. The greatest error, however, undoubtedly results from the insufficient information on lateral changes in ice thickness.

Another source of error stems from the great differences in altitude in the area, which can reach 3,000 m or more. Thereby, the contributions of the standard reductions Free Air and Bouguer slab can reach some hundreds of mGals. The absolute altitudes are under good control by GPS but as there is little information available on the vertical gravity gradient (besides the theoretical one) and on true rock densities - parameters entering into these reductions - considerable additional errors can result (REITMAYR & THIERBACH 1991).

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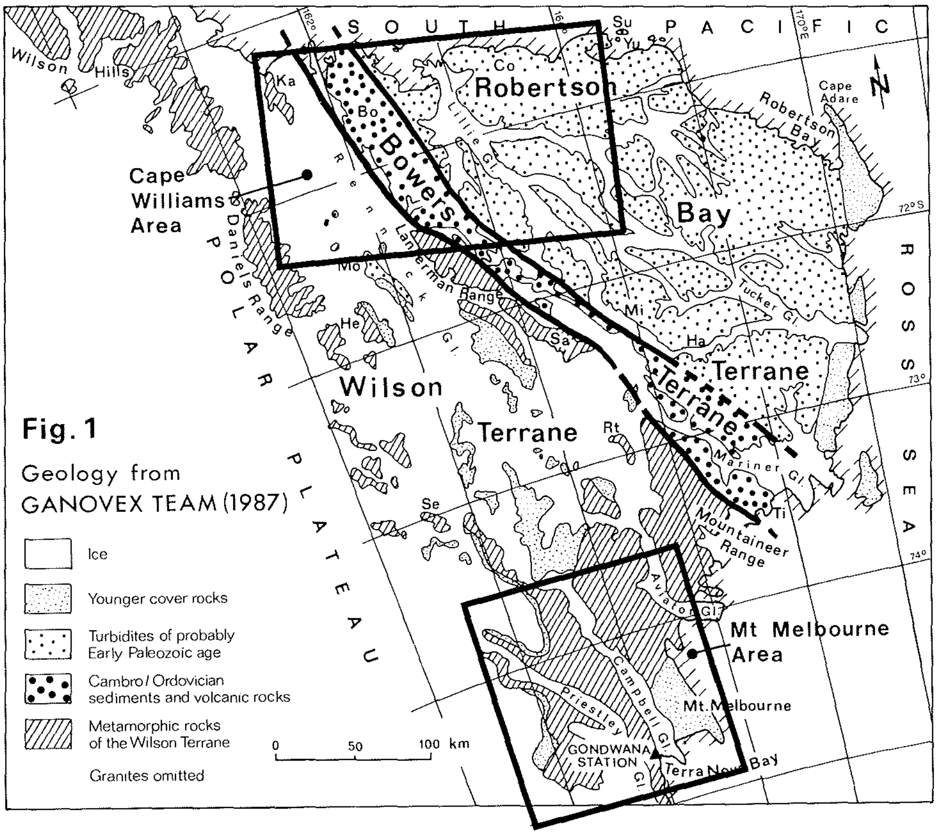

Fig.1: Geologic map of North Victoria Land from GANOVEX TEAM (1987). The two survey areas are outlined.

Abb. 1: Geologische Karte von Nordvictorialand (nach GANOVEX TEAM 1987) mit der Lage der Arbeitsgebiete.

MEASUREMENTS

The absolut gravity connection for the Gondwana area is well established now, as the Italian colleagues realized an absolute gravity measurement of high precision at their Terra Nova Station at the beginning of 1991. We repeatedly tied in the gravity base point of Gondwana. The connection to the northern area was established by tie measurement with this base point and a base point at Kavrayskyi Hills used during GANOVEX V (REDFIELD et al. in press b)

The field work was realized with helicopter support. In a few cases skidoos were used. Very unfavourable weather conditions and logistic problems hampered productivity. Most of the data points are located along profiles.

In the southern area there are essentially three profiles (Fig. 1 and 2), one along the Tinker Glacier, another along the Campbell Glacier and a third one from Gondwana Station crossing lower Priestley Glacier up to the Polar Plateau (Fig. 3). A total of 35 new data points could be added to the 149 already measured in the Mount Melbourne area by former GANOVEX expeditions.

In the northern area, 76 new gravity points could be surveyed. The distribution there is more regular. A long profile runs from Cape Williams on the coast to the USARP Mountains, crossing the lower Lillie Glacier, the Bowers Mountains and the Rennick Glacier, passing Anderson Pyramid (Fig. 1 and 4).

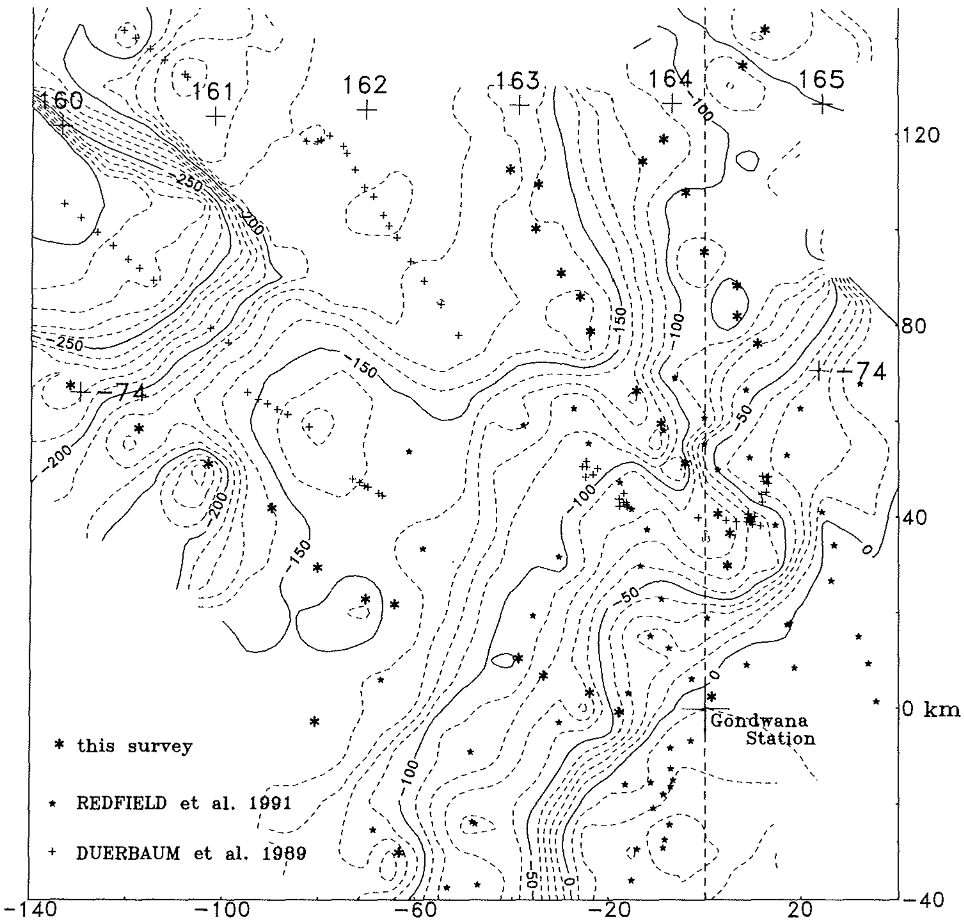

Fig. 2: Complete, ice and topography corrected Bouguer Map of the Mt. Melbourne area. The points measured during this survey are marked by bold asterisks. The Gondwana Station is situated at the origin of the coordinate system.

Abb.2: Bouguer-Karte des Mt. Melbourne Gebiets nach Terrain und Eiskorrekturen. Eigene Meßpunkte sind markiert durch große Sterne. Die Gondwana Station ist als Nullpunkt des Koordinatensystems gewählt.

The gravity measurements proved to be the most simple part of the survey. The instrument used, LaCoste & Romberg No. 865, worked very reliably and showed little drift even under the rough Antarctic conditions, thus reaching a reading accuracy of a few hundredths of mGal.

The determination of the coordinates was performed using the NAVSTAR Global Positioning System (GPS). The availibilty of the NAVSTAR satelites is now quiet satisfactory. There are only short epochs of the day during which observation possiblities are not sufficient. Using a simultaneous registration at a base station we determined the relative positions with high precision which in gravimetry is particularly important for the altitude. The GPS satellite signals were registered with Trimble receivers (Series 4000) for 20 to 30 minutes at each point thus permitting an preciseness in the determination of altitude better than one meter in most cases. Preliminary post processing could be performed in the base camps. Additional to the GPS measurements conventional barometric altimetry (Thommen instruments) was performed.

A certain difficulty arises from the fact that GPS delivers coordinates in an ellipsoidic coordinate system (WGS84),

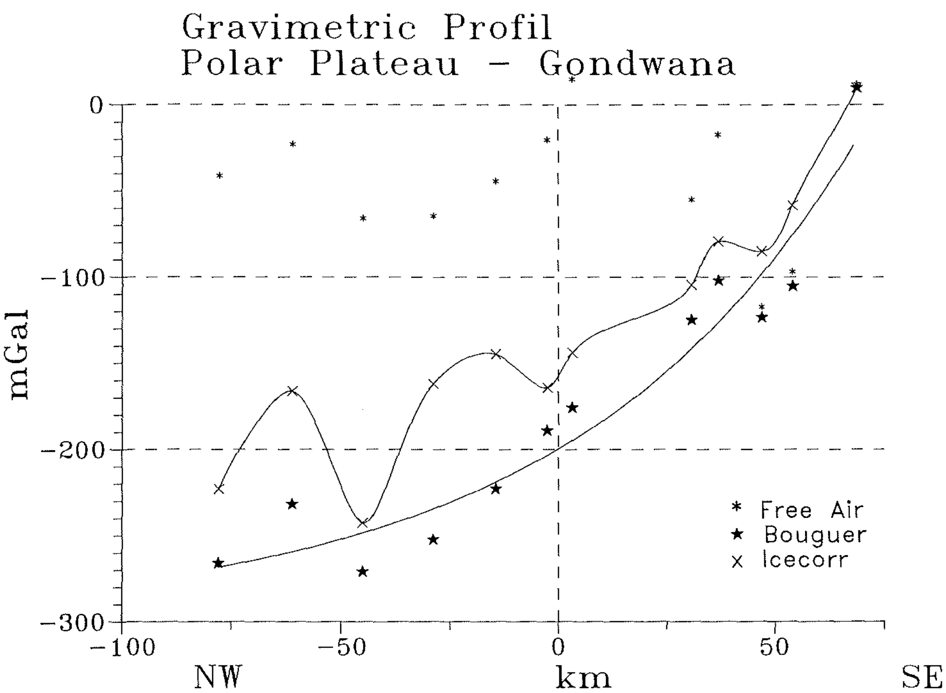

Fig. 3: South profile from Gondwana Station (right side), crossing lower Priestley Glacier and Skinner Ridge to the Polar Plateau (left). Small asterisks = free air, bold asterisks = Bouguer, crosses = ice and topography corrected Bouguer values. A flattening in the slope of the curve towards the plateau is cleqarly indicated.

Abb. 3: Südliches Inlandprofil von der Gondwana Station (rechts) über unteren Priestley-Gletscher und Skinner Ridge bis zum polaren Plateau (links). Kleine Sterne = Freiluft-Meßwerte, große Sterne = Bouguer-Werte, Kreuze = Eis- und Terrain-korrigierte Bouguer-Werte. Deutlich ist die Abflachung der Profilkurve in Richtung Polarplateau zu erkennen.

whereas in gravimetry it is customary to refer on geoid heights. Because of missing data in Antarctica, geoid undulations are not as well known as in other parts of the earth. Comparing the measured barometric height with the GPS heights supplies us some information on these undulations. For the final evaluation, however, the latest published geoid model OSU86F was used, which is generated by spherical functions up to the 360th degree TORGE 1989.

The third measurement at each point was the ice thickness determination by Radar echo sounding electromagnetics. The portable instrument developed by the BGR working group has once more proved to function well under polar conditions. Applying different orientations and separations between transmitter and receiver we tried to get as much information about ice thickesses and their lateral changes as possible.

DATA PROCESSING

Besides the conventional gravity corrections additional peculiarities of the Antarctic environment have to be considered. The final Bouguer anomaly - also named complete Bouguer anomaly - is computed according to:

Bouguer anomaly = value measured + corrections

of tide, latitude, instrumental drift, free air, Bouguer slab, topography, ice thickness one-dimensional, lateral changes of ice thickness.

The most tedious labour of the whole processing is the topographic correction. The area surrounding each point

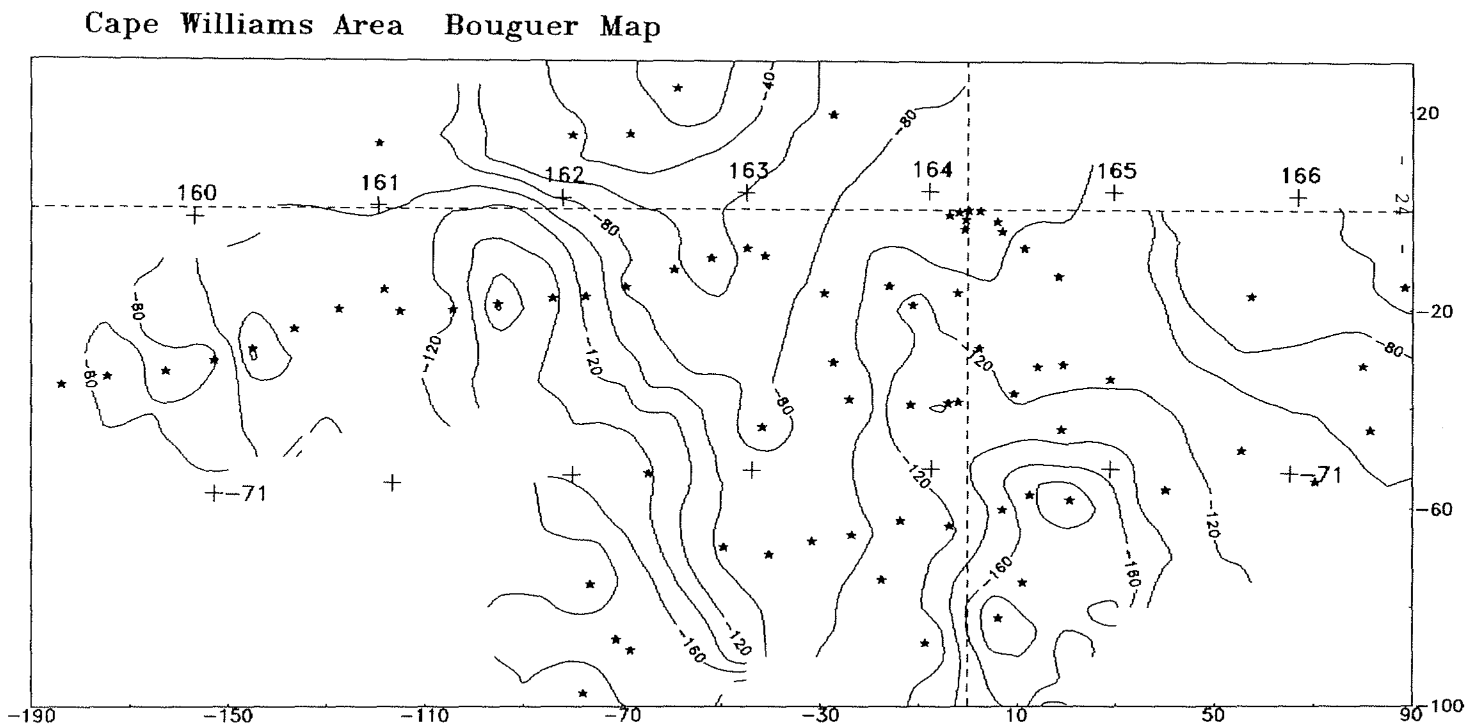

Fig. 4: Complete, ice and topography corrected Bouguer map of the area between Rennick Glacier and Yule Bay. Asterisks marke points measured. Origin of the coordinate system is camp Cape Williams. The Rennick Glacier is situated approximately around longitude 161°E and the Lillie Glacier around 163°E.

Abb.4: Bouguer Karte des Gebiets zwischen Rennick-Gletscher und Yule-Bucht nach Terrain- und Eiskorrekturen. Sterne bezeichnen die Meßpunkte. Als Nullpunkt des Koordinaten Systems ist das Lager bei Cape Williams gewählt. Der Rennick-Gletscher liegt etwa bei 161° östlicher Länge, der Lillie-Gletscher bei 163° E.

has to be digitized in an appropriate manner. The method used is BERIOZKIN's method using hyperbolic functions, published in the textbook of MIRONOV (1977). Up to 96 points were digitized for the correction of each point measured. The input of data and computation of the topographic correction was accomplished with the help of the commercial spreadsheet program LOTUS 123 (REITMAYR & THIERBACH 1991).

For the calculation of the effects of lateral changes in ice thickness plausible two-dimensional models were assumed. The computer program used for the final evaluation is an amplification of a Fortran program developed for gravity work in the BGR.

RESULTS

The complete Bouguer map of the Mt. Melbourne area is shown in Fig. 2. A general tendency of decreasing values with distance from the coast (towards NW) is clearly visible, as also demonstrated in Fig. 3 by the southernmost profile. However, many local anomalies disturb this picture, for instance the bulging isolines some 50 km north of the Gondwana station. This is the zone of the Campbell Glacier, where we had great problems to measure realistic ice thicknesses. The depths obtained appear to be by far too shallow. A plausible explanation for this could be the existence of ash horizons within the glacier (coming from the nearby Mt. Melbourne vulcano) which detain the radar signals to penetrate down to the bedrock. In any case, the Bouguer values in this zone have to be used with care.

First quantitative modeling of representative profiles of the free air anomaly shows, as expected, that by far the greatest influences come from the superficial details of topography and ice cover, i.e. the input of the measured altitudes as well as the measured ice thicknesses into the models already fits most of the details. There remains, however, still a long wave length decrease in gravitational attraction towards the continent. This can be explained plausibly by a thickening of the crust by an order of magnitude of 10 km, indicating the transition from oceanic to continental crust. In South Victoria Land where the observed horizontal gravity gradients in comparable areas are reported to be stronger, apparently higher amounts of the thickening are indicated too (ROBINSON & SPLETTSTOESSER 1984).

The Bouguer map of the northern area is presented in Fig. 4. The two major glaciers in the north region, Lillie and Rennick Glacier, are apparently causing conspicous gravity lows. It is known, that sea water below the glaciers penetrates deeply into the continent. The mass deficit due to the much lower density of water (compared to crystalline rock) and probably existing sediments below it could explain the minima observed, at least over parts close to the coast. Preliminary numeric modeling indicates the existence of sedimentary troughs of some thousand meters thickness, obviously also deep inland where the glaciers are surely no longer floating on water.

Comparing the two maps of the Rennick-Lillie and the Mt. Melbourne areas a rather different pattern is indicated: a general gravity gradient does not show up on a regional scale in the northern area. From these different attitudes we can clearly see the different tectonic settings of the two areas: the south area as part the tectonically active rift systems of the Ross Sea, and the north area as a passive rift margin.

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