ESTIMATION OF THE CRUSTAL STRUCTURE AND THE BEDROCK TOPOGRAPHY BY THE GRAVITATIONAL METHOD AROUND SYOWA STATION, EAST ANTARCTICA

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Abstract: Gravity survey was carried out at 303 stations in Lützow-Holm Bay and in the Mizuho Plateau during the wintering in 1981. Using the gravity data, the crustal structure in the Lützow-Holm Bay region and the bedrock topography in the Mizuho Plateau have been revealed in this study. The results are as follows: 1) In Lützow-Holm Bay, the thickness of the crust increases from northwest to southeast. 2) In the Mizuho Plateau, at least two subglacial valleys exist near Mizuho Station, whose strike is estimated to be consistent with the flow direction of the ice sheet. 3) In the Yamato Mountains region, the crustal thickness is larger than that in the Lützow-Holm Bay region by about 3.8 km estimated from the result of simple Bouguer anomaly difference. And the difference of the crustal thickness between Syowa and Mizuho Stations is less than 2 km.

1. Introduction

Since the International Geophysical Year of 1957, the gravity surveys have been conducted to obtain one of the most important and basic geophysical data for the crustal structure of the Antarctic continent. The gravity base point at Syowa Station was established by the 6th Japanese Antarctic Research Expedition (JARE-6), using a pendulum gravity meter of Geographical Survey Institute (GSI) type (HARADA *et al.*, 1963) and the value has been used as a reference for all gravity surveys around Syowa Station by JARE. The value is now converted to be 982525.6 mgal according to the Japan Gravity Standardization Net 1975 (JGSN75: SUZUKI, 1976).

In the previous works, ABE *et al.* (1978) compiled gravity data obtained by the over-snow traverses for the glaciological surveys in the Mizuho Plateau, and drew the maps of both free air and simple Bouguer anomalies in the Mizuho Plateau. KAMINUMA and MIZOUE (1978) introduced "reduced gravity anomaly", by which they estimated a large scale structure of the Antarctic continent. KAMINUMA *et al.*

(1980) carried out a gravity survey in the ice-free area of Cape Ryûgû as well as around Syowa Station.

JARE-22 made gravity measurements in Lützow-Holm Bay and in the Mizuho Plateau during the period from April to December 1981, using a LaCoste-Romberg gravimeter model G (G-183). The details of gravity observation and reduction are given in KAMINUMA and NAGAO (1984).

2. Data Analysis

The gravity measuring area in the case of JARE-22 was divided into three parts: The first area was an ice-free area in Lützow-Holm Bay, where simple Bouguer anomalies were calculated using an infinite plane model, assuming a constant density of the bedrock to be 2.67 g/cm^3. The second area was on the sea ice in Lützow-Holm Bay, where simple Bouguer anomalies were calculated assuming a density contrast between the bedrock and the sea water to be 1.64 g/cm^3. Water depth of gravity measurement point was measured by echo sounding at the same time (MORIWAKI and YOSHIDA, 1983). The third one was in the Mizuho Plateau. The density contrast between the bedrock and the ice sheet was assumed to be 1.77 g/cm^3, because the results of core drilling on the ice sheet in the Mizuho Plateau show that it undergoes a change from snow to ice with a density of 0.9 g/cm^3 at the depth of about 50 m from the surface of the ice sheet.

Using these data, the crustal structure has been estimated from the simple Bouguer anomaly on the sea ice and in the ice-free areas of Lützow-Holm Bay. Since the ice thickness at more than half of gravity stations was unknown in the Mizuho Plateau, Bouguer anomaly could not be obtained. Therefore, a reduced gravity anomaly was used to estimate the bedrock topography (KAMINUMA and MIZOUE, 1978; KAMINUMA, 1979). A reduced gravity anomaly is physically equivalent to the free air anomaly reduced to a point on the surface of the ice sheet extending at a constant elevation h. The reduced gravity anomaly is considered to express the bedrock topography better than the usual free air anomaly and is expressed by the following equation,

$$g_{\mathrm{redu}} = \Delta g_0 - 2\pi G \rho_{\mathrm{I}} (H-h) \,,$$

where g_{redu} is the reduced gravity anomaly, Δg_0 the free air anomaly, G the universal constant of gravity, ρ_{I} the density of ice, H the elevation of the gravity station, and h the reduced height, respectively. The ice thickness at some gravity stations along the over-snow traverse route from Syowa Station to Mizuho Station was determined by means of an ice radar (NARUSE and YOKOYAMA, 1975). At such stations, simple Bouguer anomaly was calculated with a model of the infinite plane.

3. Results and Discussions

Figure 1 shows the simple Bouguer anomaly on the sea ice and in the ice-free areas of Lützow-Holm Bay. Ice-free areas at the edge of the continent are shown by closed dotted lines. The gravity values of each area are given as an averaged simple Bouguer anomaly with a standard deviation in mgal, the number in parentheses

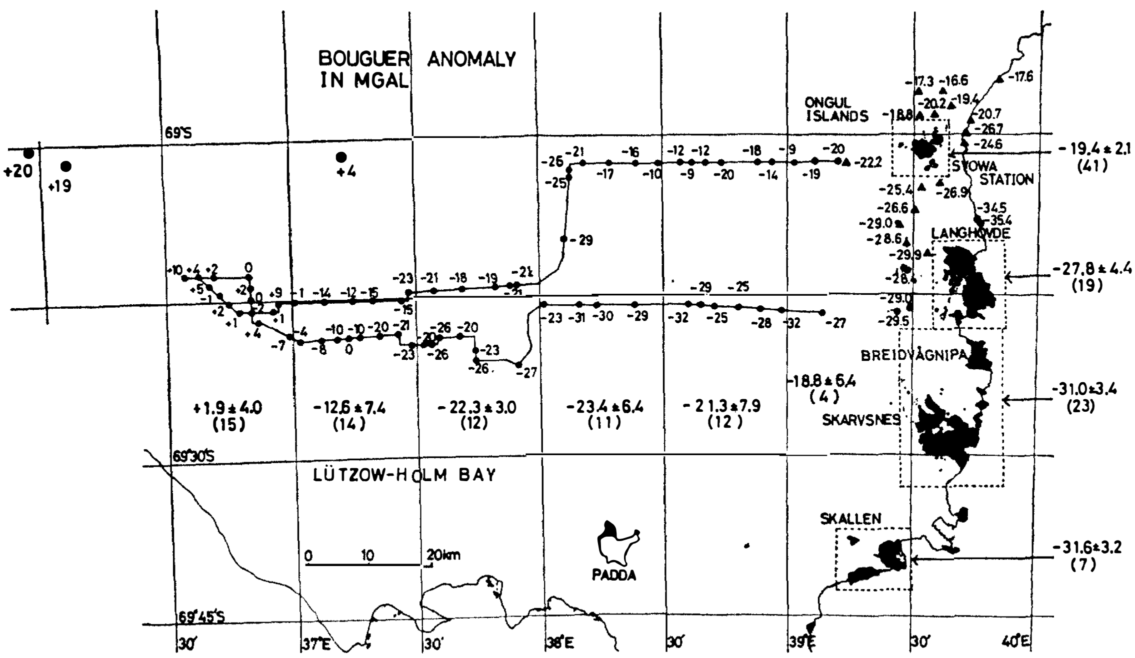

Fig. 1. Simple Bouguer anomalies on the sea ice and in the ice-free areas of Lützow-Holm Bay. The three data indicated by large solid circles were obtained by O*URA* *(1965). The areas enclosed by dotted lines show the ice-free areas. The values indicated by small solid circles on solid lines are the data on the sea ice. Solid triangles and solid circles are the measurement at triangulation points on islands and other small exposed areas, respectively.*

being the number of gravity stations in the area. Simple Bouguer anomaly values on the sea ice have been averaged within the area of 0.5° in latitude by 0.5° in longitude, and are also shown in the figure. OURA (1965) measured gravity using a Worden gravity meter and water depth with a wire at three stations in the northwestern part of Lützow-Holm Bay, as shown by larger solid circles in this figure.

In the measurements on the sea ice, the sea water density of 1.03 g/cm^3 is substituted for the bedrock constant density of 2.67 g/cm^3 in calculation of the simple Bouguer anomaly. Usually, the effect of the existence of a sediment layer is not neglected when the sediment layer is thick. However, the thickness of the sediment layer near Syowa Station is estimated to be a few meters (MORIWAKI, personal communication). We have no other data for the thickness of the sediment layer in Lützow-Holm Bay. Therefore, the effect of the sediment layer is neglected in this gravity data reduction.

The simple Bouguer anomaly on the sea ice decreases from the central part of the bay to the western part. The anomaly in the ice-free area gradually increases from north to south. This fact may suggest that the crustal thickness increases from north to south at the edge of the continent, from west to east in Lützow-Holm Bay. This tendency is consistent with the value of simple Bouguer anomaly obtained by OURA (1965).

Figure 2 shows reduced gravity anomaly of the Mizuho Plateau at a reduced elevation of 4000 m. The data indicated by solid circles are the results of JARE-22,

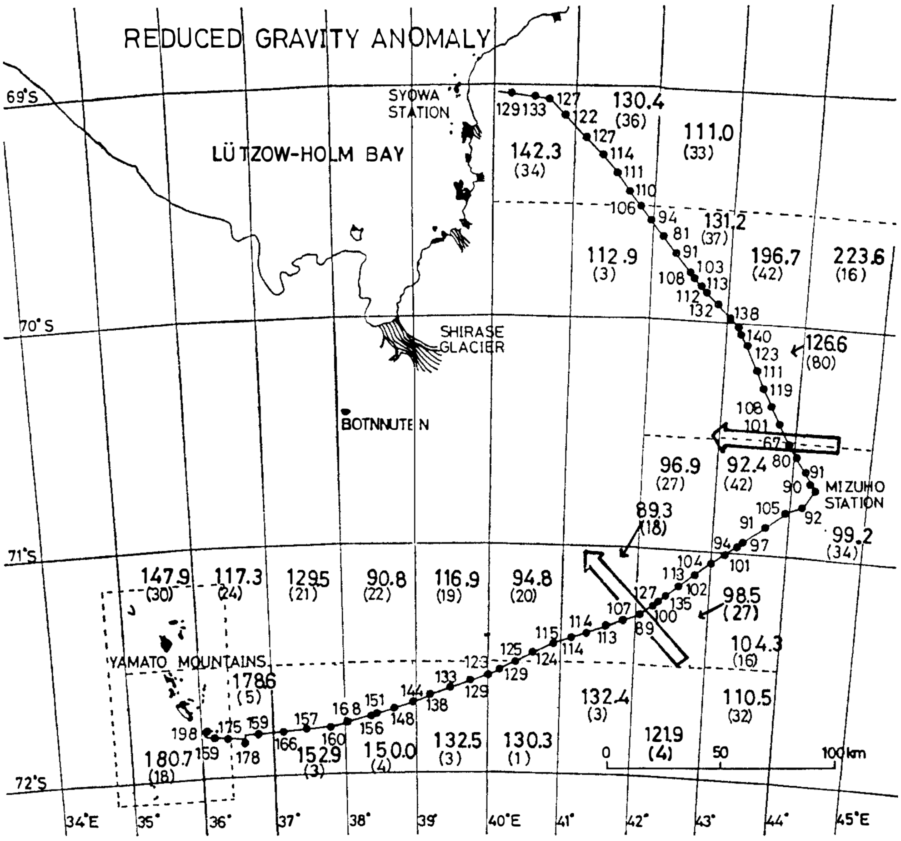

Fig. 2. The reduced gravity anomaly in the Mizuho Plateau. The values indicated by larger letters and the number in parentheses are the averaged reduced gravity anomalies and the number of stations in the area of 1° in longitude and 0.5° in latitude by KAMINUMA *(1979). Large open arrows are the locations of estimated subglacial valleys and their flow directions.*

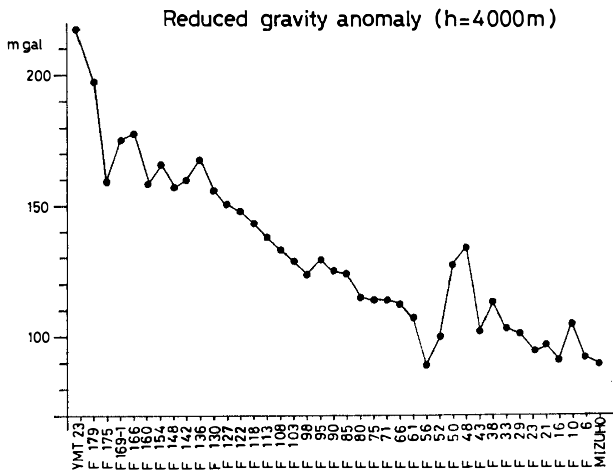

Fig. 3. The reduced gravity anomaly between Mizuho Station and the Yamato Mountains. The points on the abscissa show the station name of over-snow traverse by JARE-22.

and others indicated by larger letters are the reduced gravity anomaly obtained by KAMINUMA (1979), which is the average in the area 0.5° in latitude by 1° in longitude, and the number in parentheses is the total number of gravity stations within a grid. The enclosed dotted area in Fig. 2 is the Yamato Mountains region, where 20 gravity stations were established in the ice-free area by KAMINUMA and NAGAO (1984) as mentioned in the latter part of this section.

Figure 3 shows a profile of the reduced gravity anomaly along the over-snow traverse route between Mizuho Station and the Yamato Mountains. The reduced gravity anomalies of Figs. 2 and 3 are considered to indicate a general feature of the bedrock topography in the Mizuho Plateau. A relatively low value of 89 mgal is found at F56 in Fig. 3. This point is located southwest of Mizuho Station and another point of a lower value of 67 mgal in reduced gravity anomaly is located in the northwest as shown in Fig. 2 where the both values are placed within the open arrows. From the results in Figs. 2 and 3, it is possible to estimate at least two subglacial valleys in the southwestern side and the northwestern side of Mizuho Station, as shown with large open arrows in Fig. 2. The directions of these subglacial valleys are estimated by the result of the ice sheet flow observation by SHIBUYA and ITO (1983), indicating that the ice sheet flowed down toward the Shirase Glacier in the Mizuho Plateau. KAMINUMA (1979) also suggested the existence of a branch flow of the

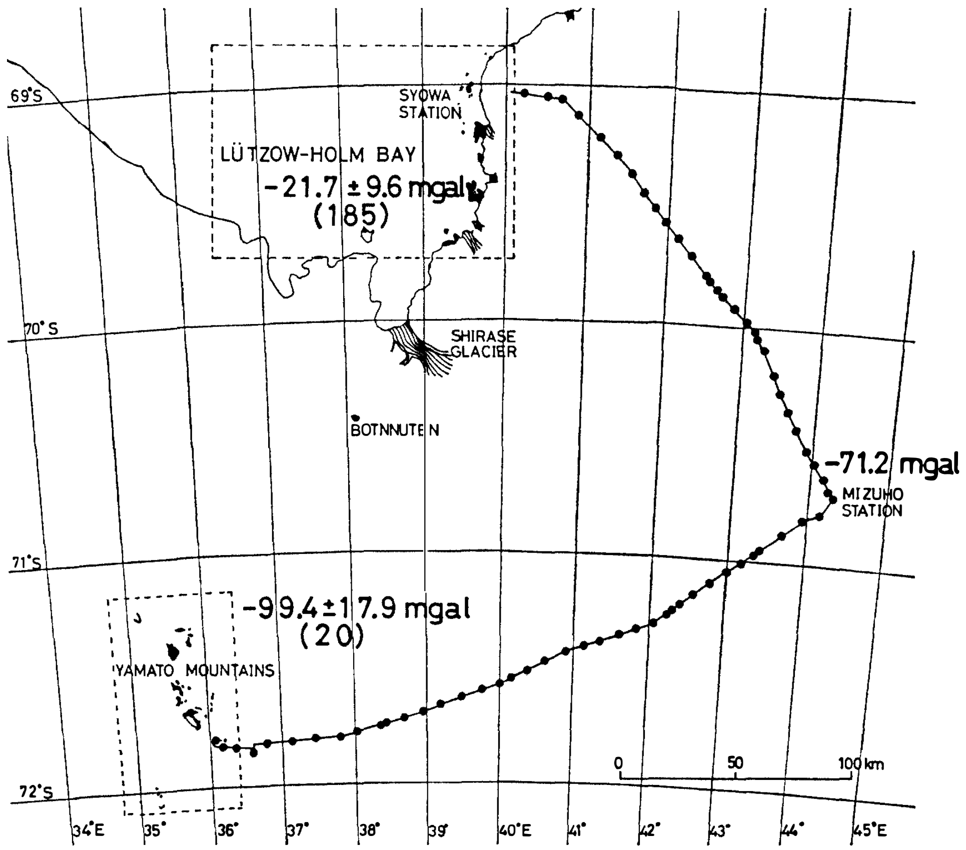

Fig. 4. Averaged simple Bouguer anomalies in the Lützow-Holm Bay region and the Yamato Mountains region, and simple Bouguer anomaly at Mizuho Station. The number in parentheses is the number of stations in each enclosed area by dotted line.

Shirase Glacier in the same area of F56.

Figure 4 shows an averaged value of simple Bouguer anomalies in the Lützow-Holm Bay region, including all the data on the sea ice and in the ice-free areas, the simple Bouguer anomaly at Mizuho Station and an averaged value in the ice-free area of the Yamato Mountains region. The simple Bouguer anomaly in the Lützow-Holm Bay region is -21.7 ± 9.6 mgal which is an average of the values at 185 stations and that in the Yamato Mountains region is -99.4 ± 17.9 mgal, an average over 20 stations. The Bouguer anomaly difference depends generally on the difference of the crustal thickness, if the crustal structures in the both regions are assumed to be the same. In this case the difference of the crustal thickness is expressed by the following equation if an infinite plane model is employed,

$$DH = \Delta g / 2\pi \Delta\rho G ,$$

where DH is the difference in crustal thickness, Δg the difference of simple Bouguer anomaly, $\Delta\rho$ the density contrast between the crust and the mantle, and G the universal constant of gravity, respectively. If a density contrast between the crust and the mantle is assumed to be 0.5 g/cm^3, the simple Bouguer anomaly difference (Δg) of 77.7 mgal is equivalent to the difference of the crustal thickness of 3.8 km when the above equation is followed. The crustal thickness of the Yamato Mountains region is larger than that of the Lützow-Holm Bay region. The ice thickness under Mizuho Station is 2100 m from the result of the ice radar observation (NISHIO, personal communication). From this ice thickness it is estimated that the simple Bouguer anomaly at Mizuho Station is -71.2 mgal. This leads to a difference of 49.5 mgal

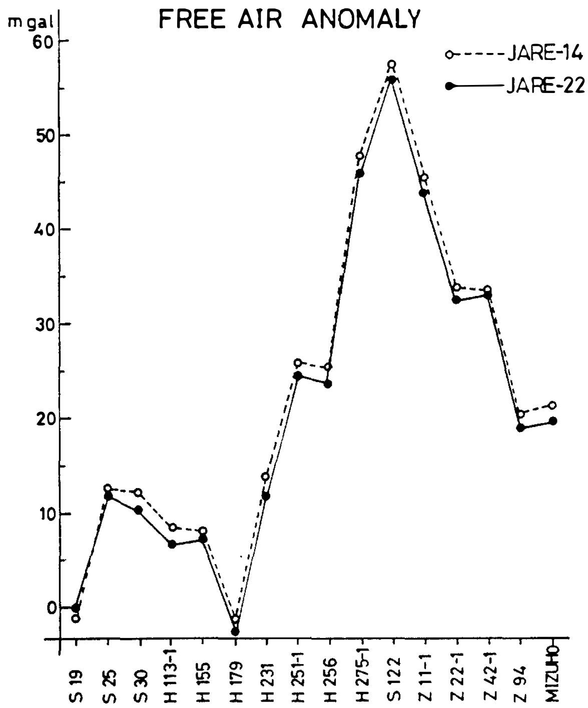

Fig. 5. Free air anomalies between Syowa and Mizuho Stations along the snow traverse route by JARE-14 and -22.

in comparison with that of the Lützow-Holm Bay region. This difference suggests that the difference of the crustal thickness between the above two areas is about 2 km. Explosion seismic experiments between Syowa and Mizuho Stations were carried out during JARE-21 and -22 (IKAMI *et al.*, 1984). The experiments showed that the crustal thickness along the measurement line was about 40 km. Supposing the crustal thickness under Mizuho Station is 40 km, those of the Lützow-Holm Bay region and the Yamato Mountains region are about 38 and 42 km, respectively.

ABE (1975), and KAMINUMA and NAGAO (1984) measured gravity at 17 same points on the traverse route from Syowa Station to Mizuho Station. ABE made the measurements in 1973, and KAMINUMA and NAGAO in 1981. There is an 8 year interval between the two measurements. Figure 5 shows free air anomalies measured at the "same" points observed by ABE in 1973 and KAMINUMA and NAGAO in 1981. The "same" means that the measurement was made at the same flag which had been established along the traverse route. Geographical latitude, longitude and altitude of the pole, however, may be changed by the ice sheet movement. SHIBUYA and ITO (1983) showed that the flow velocity of the ice sheet along the route between Syowa and Mizuho Stations ranged from 15 to 70 m/y. Each value of free air anomalies from the two measurements at the same station is coincident within a difference of 1.5 mgal for all of the stations. The correspondence of the two gravity measurements seems to show good accuracy of the two measurements even if the measurement points were moved by the ice sheet flow. This correspondence between the two measurements also shows that the measurements were successful in spite of the harsh measuring conditions such as low temperature, strong wind, and transportation of the gravity meter by an over-snow vehicle, which sometimes gives strong vibration and shock to the gravity meter.

4. Summary

The thickness of the continental crust gradually increases from northwest to southeast in Lützow-Holm Bay. In the Mizuho Plateau, at least two subglacial valleys exist near the station, and the strike of the valleys may be consistent with the direction of the ice sheet flow. These subglacial valleys may continue as far as the Shirase Glacier. The crustal thickness of the Yamato Mountains region is larger than that of the Lützow-Holm Bay region by 3.8 km. Using the same method, the difference between the Syowa Station area and the Mizuho Station area has proved to be less than 2 km.

Acknowledgments

The authors thank Prof. Y. YOSHIDA, leader of JARE-22, National Institute of Polar Research, and all members of JARE-22 for their kind assistance rendered for the field work. The authors also thank Dr. J. SEGAWA of the Ocean Research Institute, University of Tokyo, and Mr. K. ITO of Regional Observation Center for Earthquake Prediction, Kyoto University, for their critical reading of this manuscript.

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(Received March 26, 1984; Revised manuscript received May 8, 1984)