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GRAVITY MAPPING AROUND THE JAPANESE ANTARCTIC STATIONS

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Abstract: Free-air and Bouguer gravity anomaly maps around the Japanese Antarctic stations have been newly compiled. The area concerned is located approximately from 60°S to 80°S and from 20°E to 50°E. Data sources are, the land gravity measurements by Japan and other countries, the surface ship measurements by Japan, and the satellite altimetric gravity anomaly. The accuracy of these maps, especially in the coastal areas, has been extremely improved because of the use of the most updated surface ship gravity data in the calibration of the satellite altimetric gravity.

Using the gravity maps obtained, and taking the distribution of the ice sheets over the land into consideration, the present status of isostatic balance was examined. The results show that isostatic compensation beneath the continental and oceanic areas seems to be very well, although there exist some anomalous features which may reflect the local crustal structures.

1. Introduction

To study the subsurface structure or the tectonics, it is important to obtain a detailed gravity map. From this point of view, some gravity maps have been published of and around Antarctica (SEGAWA *et al.*, 1984b, 1986c). These maps fully employed satellite altimetric data, so that, the coverage in the oceanic region has been extremely improved. However, along the coastal areas, the satellite altimeter suffers various errors, for example, scattering from the iceberg or land area. Moreover, calculation of the gravity value from the altimetric geoid is also difficult in those areas, because of the lack of data in the land area. Therefore, there remains some uncertainty in the previous maps along the coastal areas.

On the other hand, surface ship gravity measurements have been continued around the Japanese Antarctic stations by Japanese Antarctic Research Expedition (JARE) since 1980. For this purpose, the newly designed NIPR-ORI sea gravimeter has been employed (SEGAWA *et al.*, 1984a, 1986a), and gravity data in the coastal area has been accumulating year by year.

The surface ship gravity data has been successfully connected to the gravity point at Syowa Station (69°0.3′S, 39°35.3′E) which has been used as the base station for all land gravity measurements conducted by JARE. Therefore, it is ingenious to combine the satellite, surface ship and land gravity data together to obtain a gravity map. The purpose of this paper is to compose the most reliable gravity map using the data mentioned above, and then discuss the subsurface structures from the map obtained.

2. Mapping of Gravity Anomalies

2.1. Data sources

For the mapping of gravity anomalies, gravity data from four different sources was used. They are as follows:

(1) Land gravity measurements conducted by JARE.
(2) Land gravity data published by GRUSHINSKY *et al.* (1972).
(3) Surface ship gravity data measured during JARE-22, -23, -27 and -28.
(4) Satellite altimetric gravity derived from GEOS-3 and SEASAT-1 altimeter.

These are summarized in Table 1, and their distributions are shown in Fig. 1.

Table 1. List of the data sources used in compilation.

Type[1]	Number of data used	Instrument	References
1	1531	LaCoste & Romberg (G)	YANAI and KAKINUMA (1971) YOSHIDA and YOSHIMURA (1972) ABE (1975) KAMINUMA and NAGAO (1984)
2	231	?	GRUSHINSKY *et al.* (1972)
3	3391	NIPR-ORI	KASUGA *et al.* (1983)
3	21853	NIPR-ORI[2]	Newly processed for this study
4	8473[3]	satellite altimeter	SEGAWA and MATSUMOTO (1987)

[1] See text.
[2] Sensor and data acquisition system were modified.
[3] Given at $10' \times 10'$ grids.

In addition to the gravity data, topographic data are necessary to calculate Bouguer gravity anomalies. For this, we digitized and used the 1/10,000,000 topographic map (Karta Kornnogo Rel'efa Antarktidy), the Surface of the Antarctic Ice Sheet and the Bedrock Surface of Antarctica (DREWRY, 1983) for the land areas, and the General Bathymetric Charts of the Oceans (GEBCO) for the sea areas.

2.2. Data compilation

Since different types of data were employed in this study, we first had to adjust the discrepancies among the data, especially because the satellite altimetric gravities have somewhat different meaning compared with other types of data (SEGAWA *et al.*, 1986b). It means, in a practical manner, there remains the possibility of discrepancies between altimetric and other gravity data in the long wavelength components. Fortunately, the surface ship gravity data listed above were well calibrated, and we found discrepancies of only a few mgals in magnitude at ship track crossover points. Therefore, we calibrated the altimetric gravity from the surface ship gravity data.

Because the altimetric gravity data are given in $10' \times 10'$ grids, weighted mean values in the same grids were calculated from surface ship gravity data. Then we assumed the discrepancies between altimetric gravity and surface ship gravity might be represented by a quadratic formula, leading to an error model as follows.

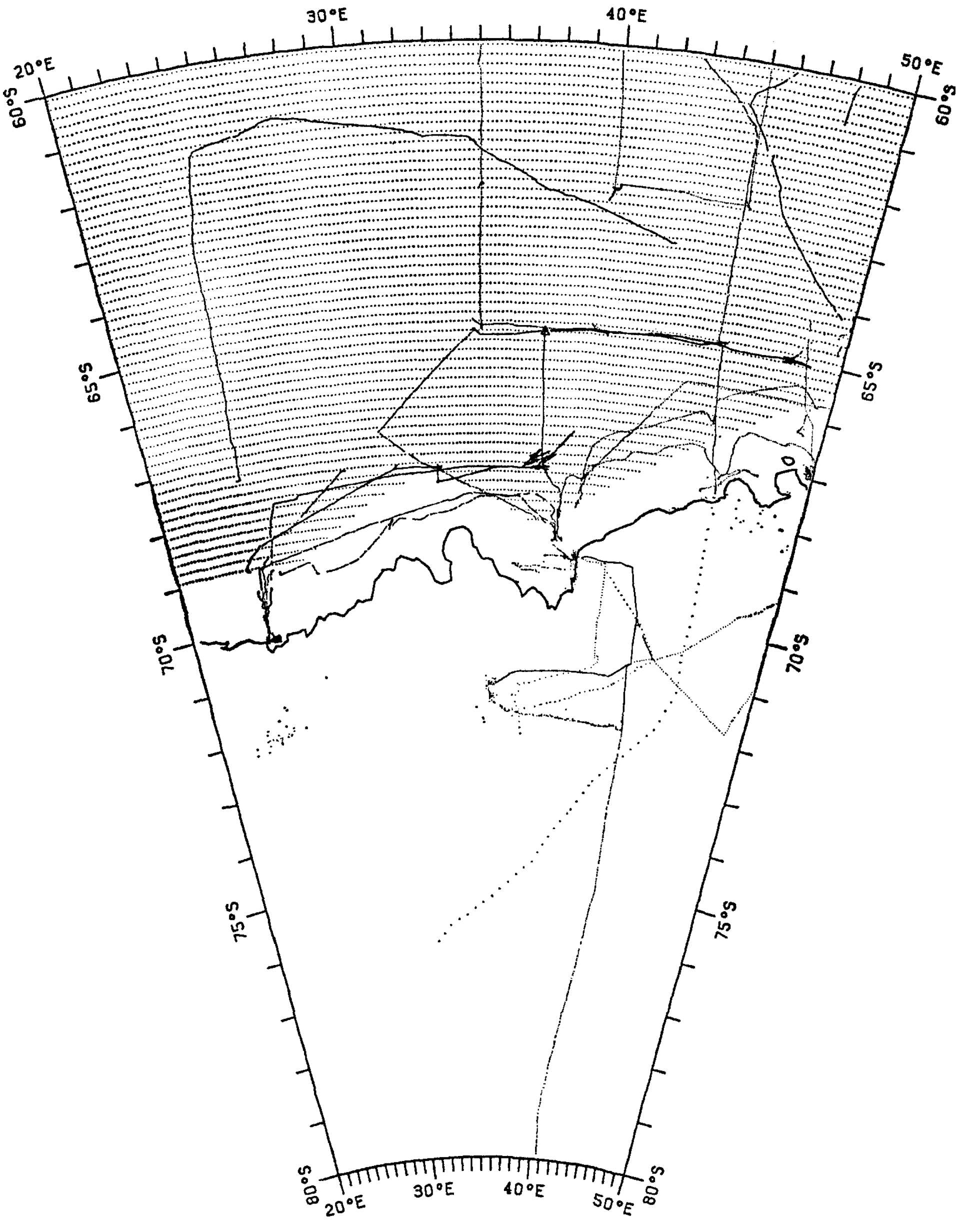

Fig. 1. Distribution of the gravity data used in this study.

$$G_{sat}(\varphi, \lambda) = G_{sea}(\varphi, \lambda) + A\varphi^2 + B\lambda^2 + C\varphi\lambda + D\varphi + E\lambda + F + v(\varphi, \lambda), \quad (1)$$

where

$G_{sat}(\varphi, \lambda)$:	altimetric gravity
$G_{sea}(\varphi, \lambda)$:	surface ship gravity
A to F:	coefficients of error model
$v(\varphi, \lambda)$:	residual.

Using formula (1), the coefficients A to F were determined from 1093 grid data under the condition of $\sum v(\varphi, \lambda)^2$ is minimum.

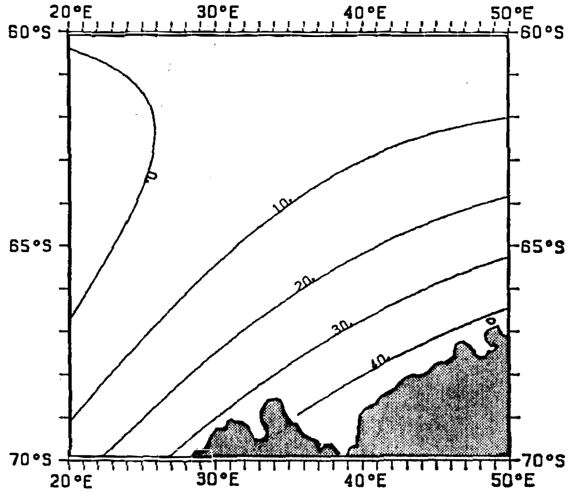

Fig. 2. Long wavelength error in the altimetric gravity estimated from the surface ship gravity. Unit: mgal.

Figure 2 shows the tendency of the error model. It clearly shows that the error increases toward the continent. Although it is not clear whether the error is due to the continental effect or other causes, the difference between surface ship gravity and altimetric gravity is 17.8 mgals in standard deviation after removing the error from altimetric gravity. This is almost the same as the results obtained in other areas (MATSUMOTO *et al.*, 1985).

Gravity data in the land area is extremely sparse and the satellite altimetric data covers only the offshore area. This particularly creates problem in the compilation. Hence we tried two approaches.

First, we divided the area into two, namely, the oceanic area and the continental area including the continental shelves. The boundary of the two areas was set to contain an overlap. In the continental area, land and surface ship gravity data were filtered to avoid small scale topographical perturbation. In this process, insignificant data was carefully rejected. Then, using a two dimensional interpolation method (BRIGGS, 1974), we calculated the values in the same grids as the altimetric gravities.

Second, at each grid point in the overlapping area, the weighted mean values were calculated from the gravity data in the both areas. In this process, the weight of the data in the oceanic and continental areas was linearly decreasing and increasing respectively towards the continent. Then gravity data in the both areas are smoothly connected at the boundary.

2.3. *Characteristics of free-air and Bouguer anomalies*

Through the process mentioned above, we obtained the free-air anomalies on the basis of $10' \times 10'$ grids. Figure 3 shows their features. Moreover, Bouguer anomalies were calculated from free-air anomalies with topographic data file, *i.e.*, topography of basement and surface height for land areas, and bathymetry of sea areas. Assumed densities are 2.67 g/cm^3 (crust), 1.03 g/cm^3 (sea water) and 0.90 g/cm^3 (ice), respectively. It should be noted that the ice thickness was taken into account in the calculation of the continental area. The Bouguer anomaly map obtained is shown in Fig 4.

These maps have the following characteristics compared with gravity anomaly maps published so far (SEGAWA *et al.*, 1984b, 1986c).

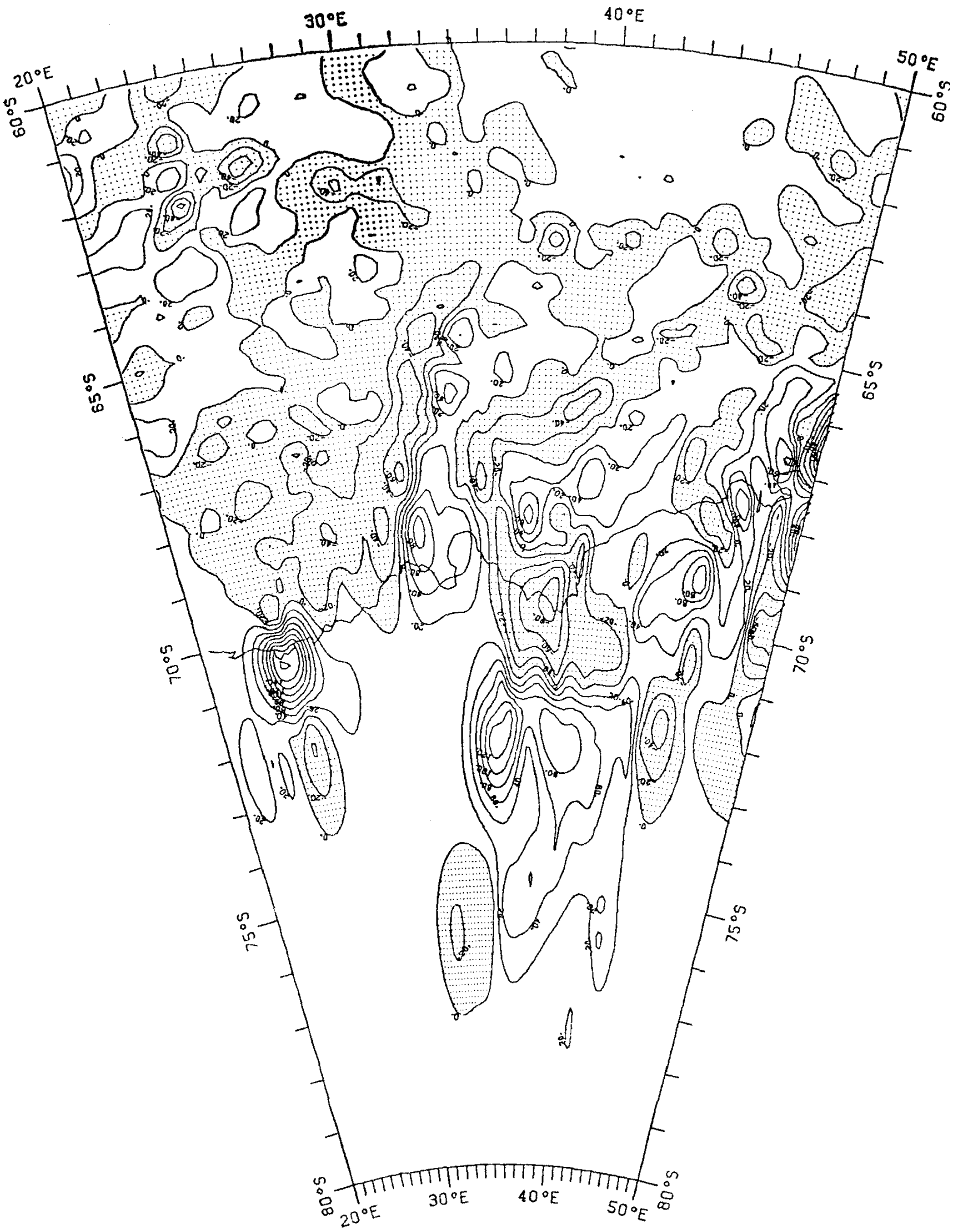

Fig. 3. Free-air anomaly. Dots represent negative area. Contour interval is 20 mgals.

(1) Accuracy in the continental shelves and the coastal areas is obviously improved.

(2) Dummy features due to the erroneous data in land area are eliminated.

3. Geophysical Interpretations

If we assume the cause of the Bouguer anomalies is due to the density contrast at the Moho discontinuity, we can easily estimate the crustal thickness. To remove the effects of small scale topography, a lowpass filter of 7×7 (approximately, $1°\times1°$)

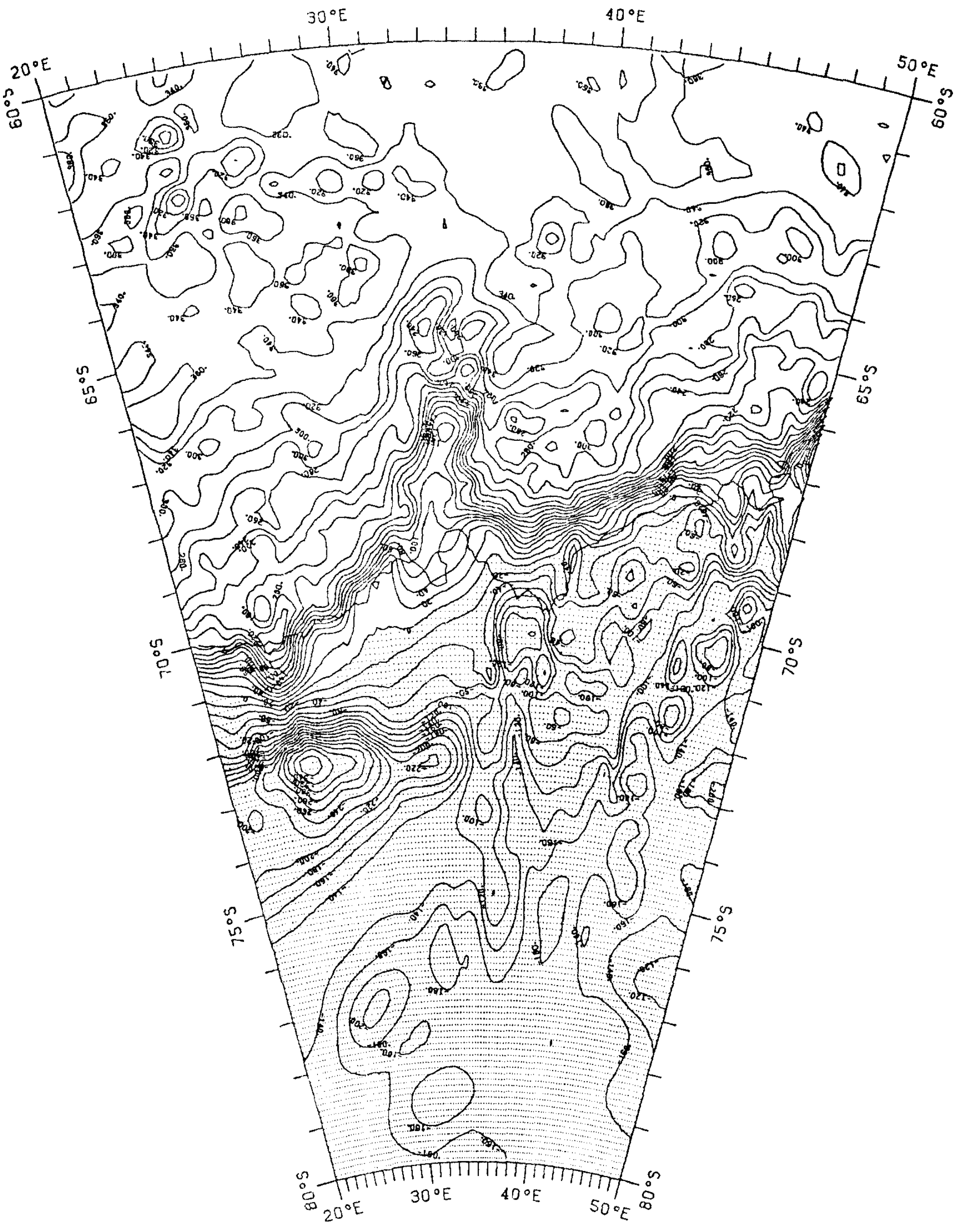

Fig. 4. Bouguer anomaly. Dots represent negative area. Contour interval is 20 mgals.

boxcar type was applied to the Bouguer anomalies obtained, then the crustal thickness was estimated by using the sin x/x method (TOMODA and AKI, 1955). In this process, we assumed that a density contrast between the upper mantle (3.30 g/cm^3) and the crust (2.67 g/cm^3) was 0.63 g/cm^3 and the mean crustal thickness was 25 km. Figure 5 shows the relative crustal thickness.

On the other hand, if we assume the isostatic compensation to be complete in the area concerned, relative thickness of compensation can be estimated from the topographic data independently as shown in Fig. 6. Here again, the same lowpass filter mentioned above was applied to, and the same values of densities were assumed.

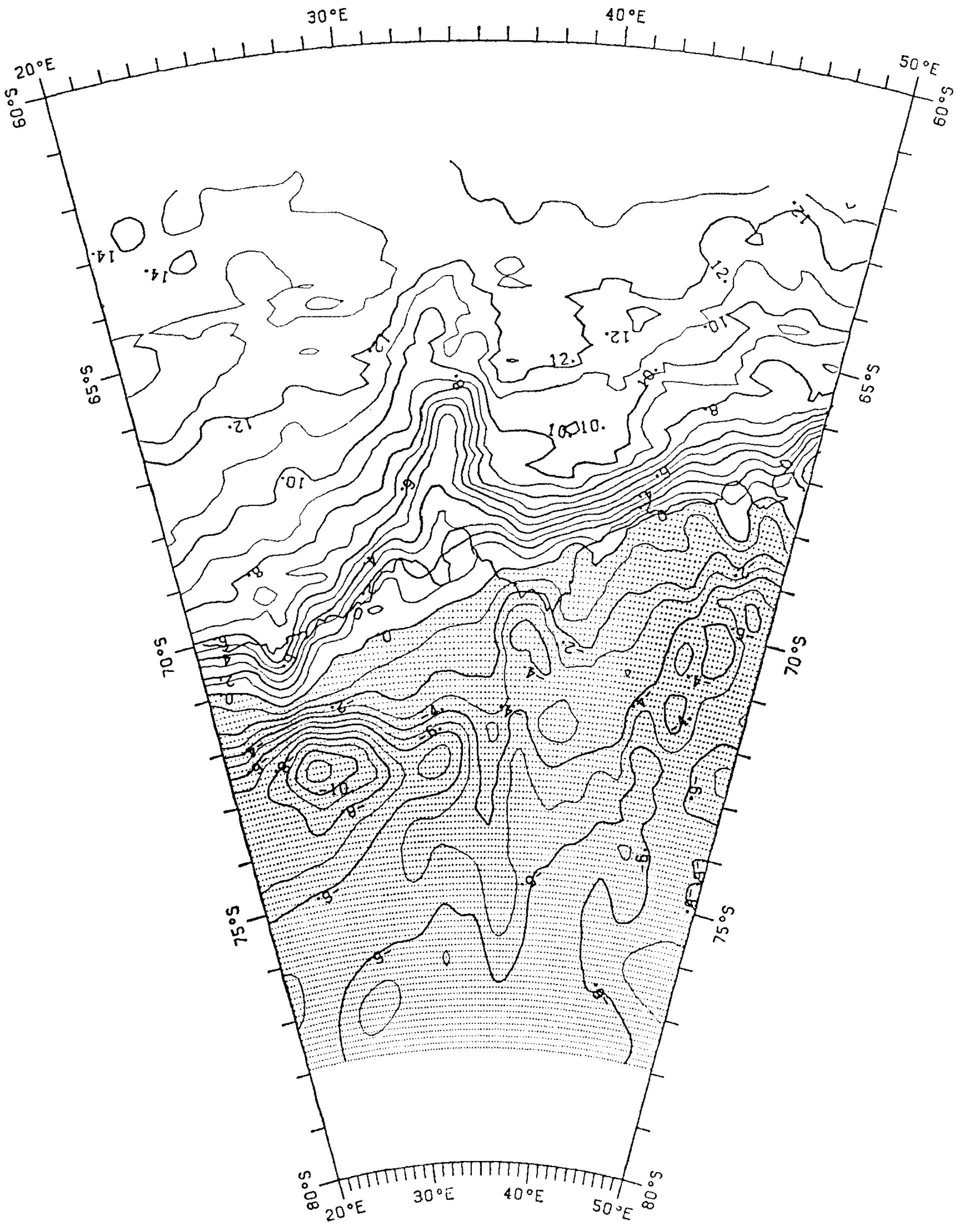

Fig. 5. Relative thickness of the crust estimated from the Bouguer anomaly. Mean crustal thickness of 25 km is assumed. Dots represent the area where the crust is deeper than 25 km. Contour interval is 1 km.

It is clearly seen that Figs. 5 and 6 are very similar suggesting isostatic compensation in general.

For further discussion, the difference of the crustal thickness between Figs. 5 and 6 was calculated (see Fig. 7). According to the different premises, positive areas in Fig. 7, where the Moho discontinuity obtained from gravity anomaly boundary is shallower than the depth of isostatic compensation, may be interpreted as follows:

(1) If regional isostatic compensation is assumed, excess masses due to the local crustal structure should exist in the areas.

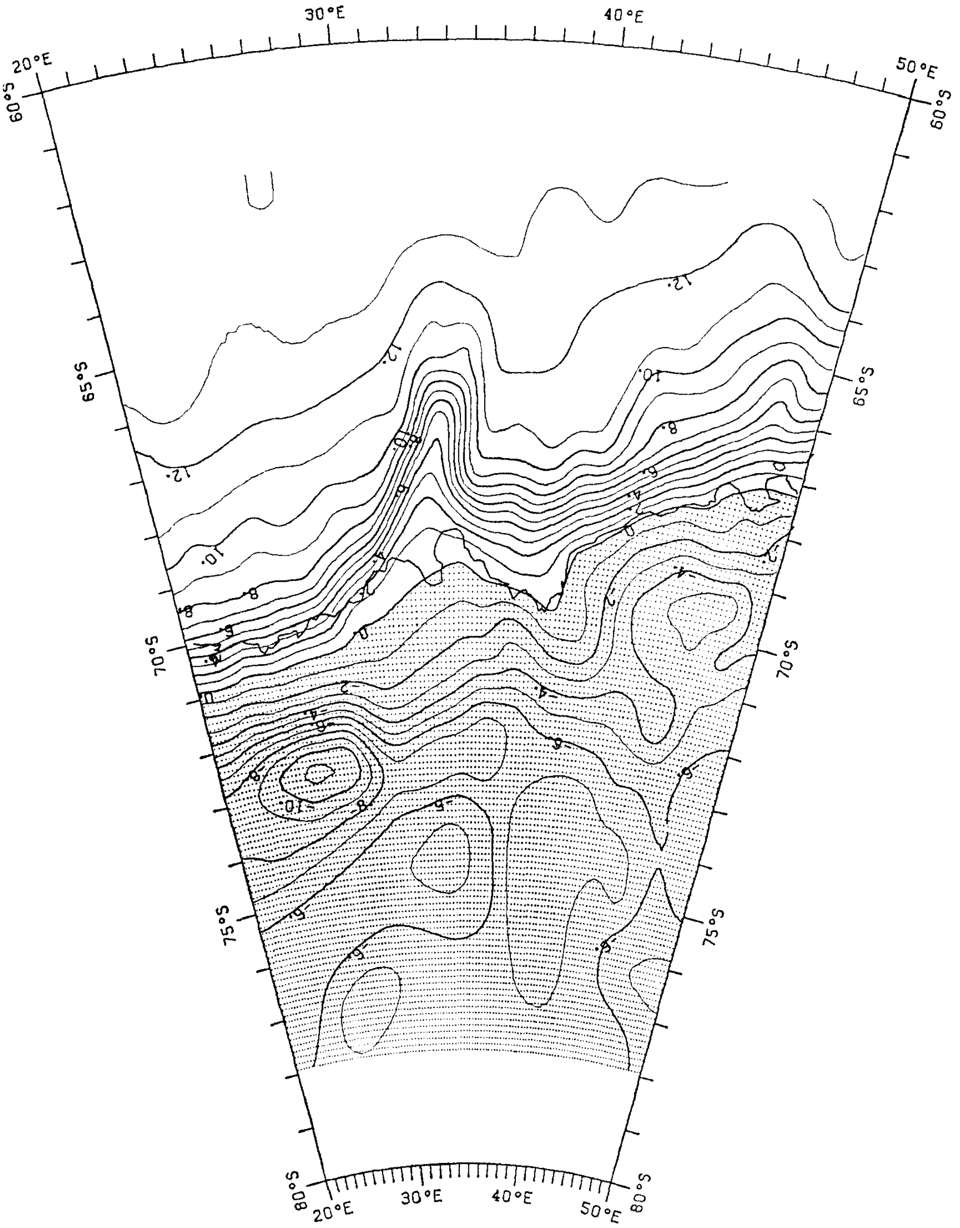

Fig. 6. Relative thickness of the crust estimated from the isostatic compensation. Dotted area is deeper than the mean crustal depth. Contour interval is 1 km.

(2) If density uniformity in the crust is assumed, regional isostatic compensation might be insufficient, and consequently, tends to sink.

At this stage, because we have little information concerning geological or topographical structure, it is difficult to conclude which assumption could be acceptable. However, the existence of the same scale local mass anomalies as alternate distributions of positive and negative in Fig. 7 is plausible, and so, the first assumption is considered to be more appealing.

It is worthy to mention about the absolute thickness of the crust. Figure 5 or

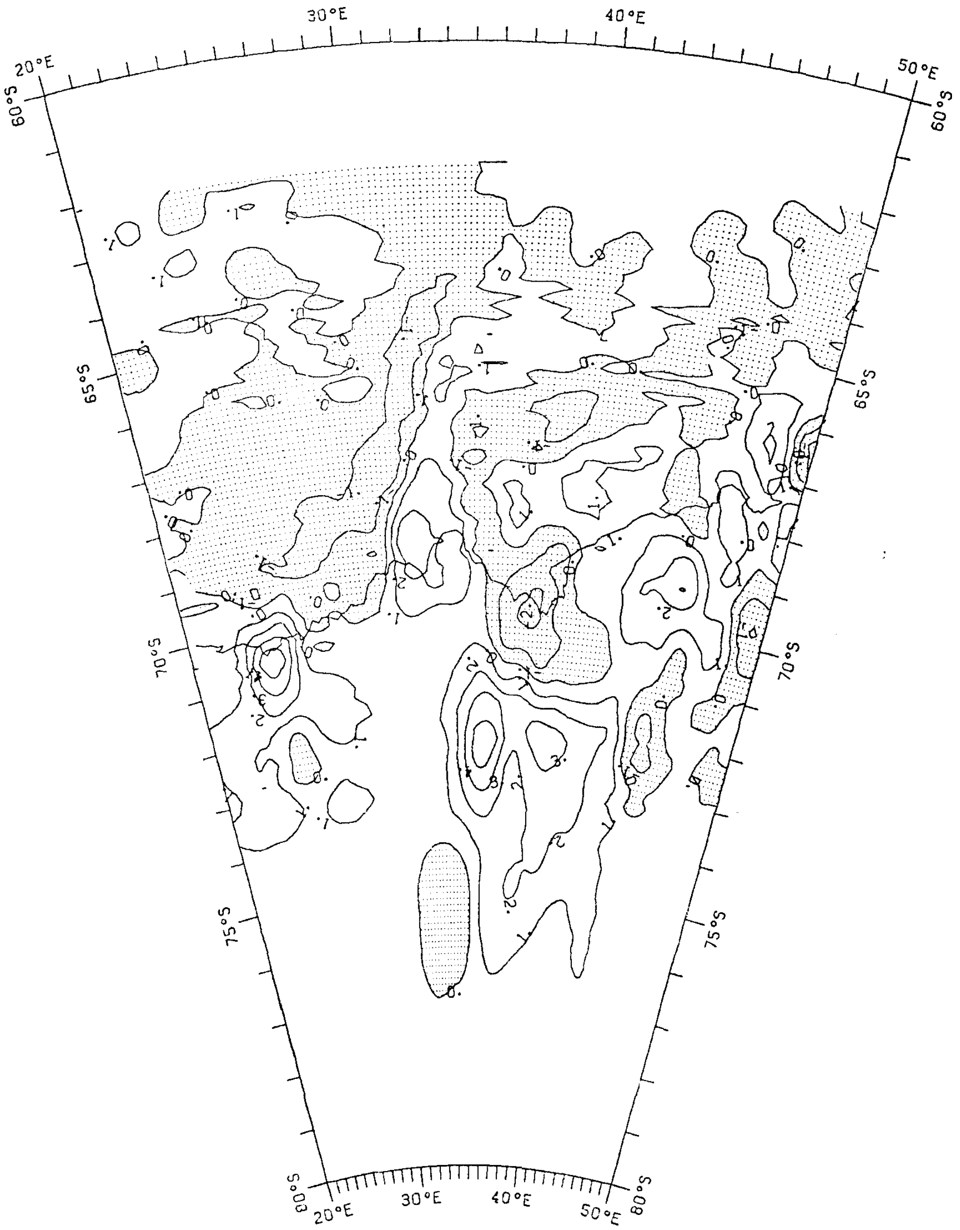

Fig. 7. Difference of the crustal thickness obtained from Fig. 5 subtracted by Fig. 6. Dots represent the area where the gravimetric boundary is deeper than the depth of isostatic compensation. Contour interval is 1 km.

Fig. 6 shows only the relative values from a thickness which was taken somewhat optionally. Therefore, some assumption or more information is needed to determine the absolute thickness.

The result of seismic soundings (IKAMI *et al.*, 1984) suggests the crustal thickness between Syowa and Mizuho Stations is about 40 km. If we use it as the thickness in the continental area, the depth of Moho from the mean sea level in the oceanic area becomes 20 km, which is unacceptable. The contradiction could be revised to modify the density contrast between the upper mantle and the crust to be 0.4 g/cm^3. In this case, the magnitude of crustal thickness would vary in Figs. 5 to 7. However, their contour patterns would be unchanged, and the previous discussions left as they had been.

4. Summary

Combining the satellite, surface ship and land gravity data, the most reliable gravity map around the Japanese Antarctic stations was obtained. In this map, the accuracies along the coastal areas have been extremely improved. However, gravity data distribution in the area is not enough, especially in the land area. Therefore, to make a more complete gravity map, we have to make more efforts to fill up the blank area of gravity data.

Using the newly compiled gravity data, isostatic balance in the area was also examined roughly. It shows that the isostatic compensation is achieved in general. However, there remains some anomalous features related to the local crustal structures. To study more detailed structure, besides the gravity measurements, it is also important to get more information about the topography including ice sheet thickness.

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