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GRAVITY SURVEY IN ROSS ISLAND, ANTARCTICA

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Abstract: Gravity surveys have been carried out in Ross Island every summer since 1982/83 in order to investigate the subsurface structure of the active volcano in Antarctica, Mount Erebus. The Bouguer anomaly has been calculated at each station. The pattern of anomaly distribution on this island can be summarized that the anomaly is high in the whole island except the western and southwestern coasts, where anomalies are about zero or negative, and that a higher anomaly exists in the summit area of Mount Erebus. The structure of Mount Erebus might be classified as a type similar to the Kilauea Volcano of Hawaii Island or the Osima Volcano of Japan.

1. Introduction

Mount Erebus (77.5°S, 167.0°E, 3794 m) in Ross Island, discovered for the first time by J. Ross in 1841, has been one of the active volcanoes in Antarctica. It is reported that sometimes Mount Erebus repeated eruptions and this is a very rare volcano because of its lava lake, which was also seen in the 1986/87 summer season. On account of this character, Mount Erebus is one of the most interesting volcanoes for investigation.

An international cooperative project named IMESS (International Mount Erebus Seismic Study) has been promoted by Japan, the United States and New Zealand during a period from the 1980/81 season to the 1985/86 season. The main purpose of this project is to investigate the seismic activity, and thus the mechanism of eruption, by means of a radio-telemetry seismic network. It is also very important to know about the subsurface structure of the volcano. Gravity surveys will give information about the density structure of Ross Island.

Gravity surveys that started in the austral summer of 1982/83 have been carried out every summer season by using LaCoste & Romberg gravity meters, G-type. The locations of the gravity stations are shown in Fig. 1. The absolute gravity base station 59676C, the bench mark at Earth Sciences Laboratory of McMurdo Station, was chosen as the reference point for the relative measurements of gravity. All the measurements started from the reference point and ended there to correct instrumental drift of the gravimeter. The location of 59676C is 77°51.0′S, 166°40.4′E and 43.18 m in elevation above mean sea level, and its gravity value in the IGSN71 (International Gravity Standardization Net 1971) is 982969.771 mgal. The results in the 1982/83

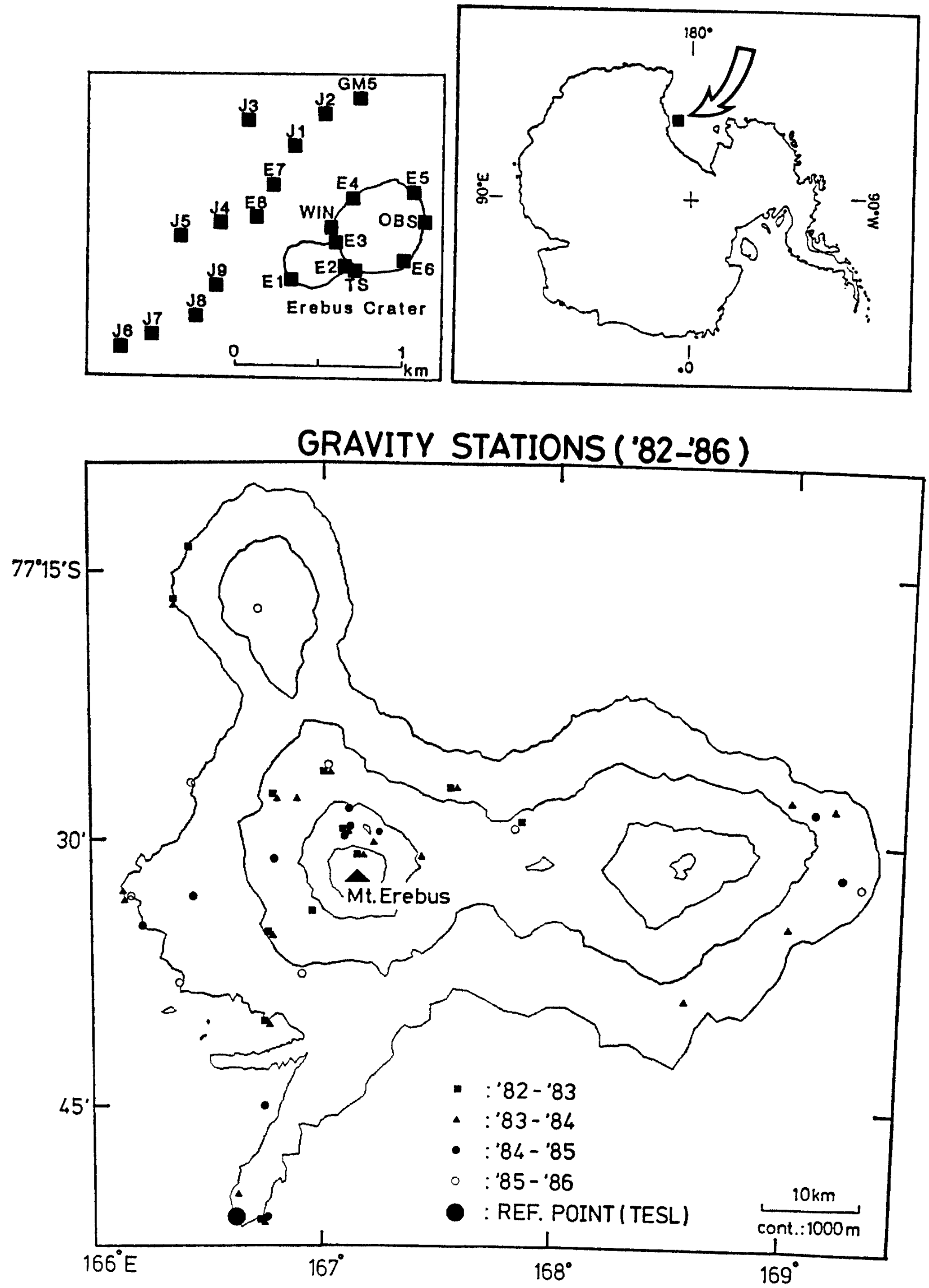


Fig. 1. Locations of gravity stations in Ross Island, Antarctica.

season were reported by KAMINUMA *et al.* (1984). In this paper, we will present new results from the surveys conducted in the 1983/84 and 1984/85 summer seasons as well as recalculated results of the 1982/83 surveys.

2. Estimation of Observation Error

The accuracy of the locations of the observation stations is directly related to the accuracy of the gravity survey. The climate and the general conditions for land surveys in Antarctica are so severe that there are not many points whose altitude is precisely determined. KAMINUMA *et al.* (1984) discussed the estimated error in altitude at the observation points.

In the case of observation points in the summit area (see small frame in Fig. 1), the accuracy of altitude at each point was better than 1 m because it was determined on the 1: 5000 topographic map of "Mt. Erebus, Antarctica" which was published by Department of Lands and Survey, New Zealand, with a contour interval of 5 m. This uncertainty of elevation corresponds to an error in gravity value of about 0.2 mgal in the Bouguer anomaly value.

For other observation points in Ross Island, the altitude of each station was determined by means of a barometric altimeter; the accuracy was estimated to be within about 10 m after applying corrections for the altimeter. Therefore, the estimated error in gravity values is up to 2 mgal for these points. The same procedure was taken for all measurements.

3. Terrain Correction

The values of terrain corrections are very important in order to get a precise Bouguer gravity anomaly map. This is particularly important for gravity surveys conducted in mountain areas because Bouguer corrections are made by assuming an infinite plate whose thickness is equal to the elevation of the observation point, so the mass at the convex place higher than the observation point is not considered and the mass at the concave place is overestimated. For Japan, a digital terrain data file published by the Geographical Survey Institute, in which altitude data are given at each grid point of small meshes (7.5″ in latitude and 11.25″ in longitude, 230×280 m), is available and the algorithm to get precise terrain corrections by using this data file has been successfully developed by NOZAKI (1981) and YAMAMOTO *et al.* (1982).

Unfortunately, the terrain of Ross Island is not yet well determined. The most detailed topographic map has been published by the U. S. Geological Survey. It has a scale of 1 to 250000 and a contour interval of 200 m. Figure 2 shows the contour lines read from this map (NAGAO, personal communication) and the corresponding three-dimensional topographic map. Here, as a preliminary study (KAMINUMA *et al.*, 1984), we adopted Talwani's three-dimensional method (TALWANI and EWING, 1960) to calculate the terrain corrections. The actual topography is approximated by multilayered disks with a constant thickness (200 m) bounded by contour lines (see Fig. 3) and contributions to the observation point P from each disk are calculated. Figure 4 shows the spacial distribution of the terrain correction values calculated at 1.5′ (latitudinal direction)×6′ (longitudinal direction) grid points by Talwani's method. The correction values are normalized by a unit density. Therefore, the actual correction values are derived from multiplying these values by the assumed density. As expected, the large corrections are necessary to the observation points at high eleva-

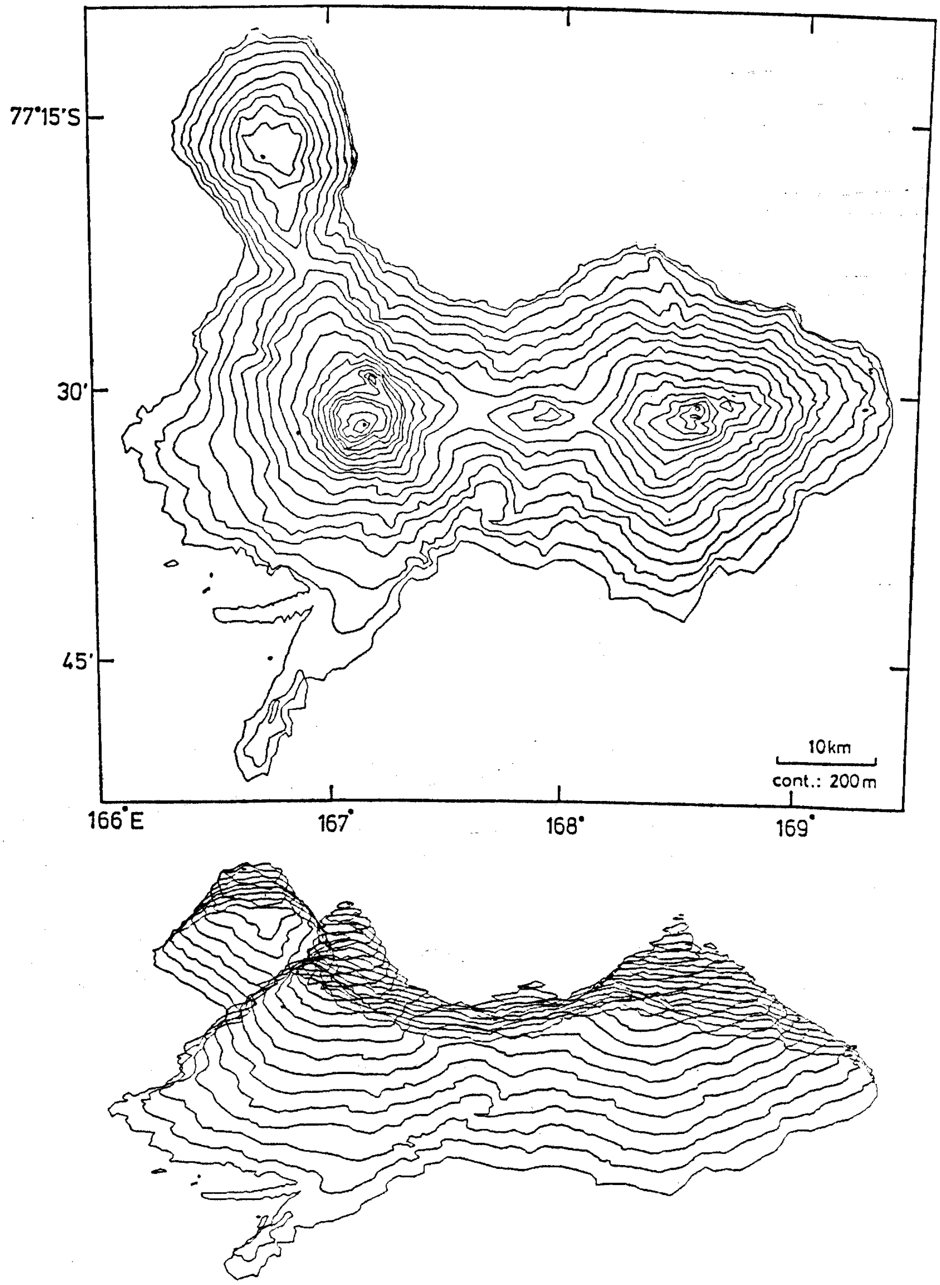


Fig. 2. Topographic map of Ross Island with a contour interval of 200 m based on the detailed topographic map with a scale of 1 to 25000 (upper) and the corresponding three-dimensional topographic map (lower).

tion.

4. Results

As mentioned by Kaminuma *et al.* (1984), we do not, at present, have any information about the basement density, so we cannot decide the best value for density. Since the anomaly value at each station depends on assumed density, we have calculated

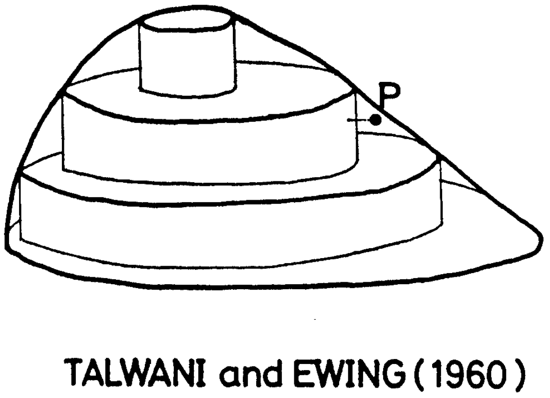


Fig. 3. Schematic representation of terrain correction using Talwani's three-dimensional method.

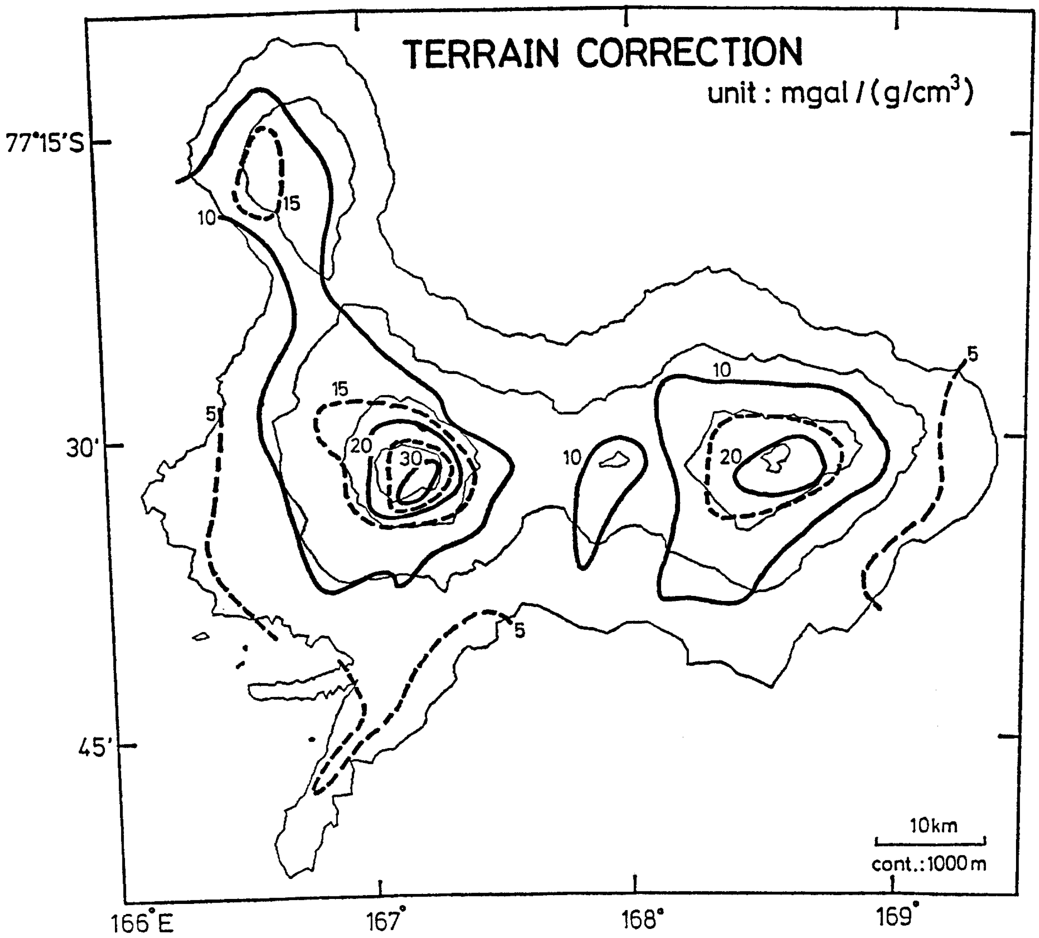
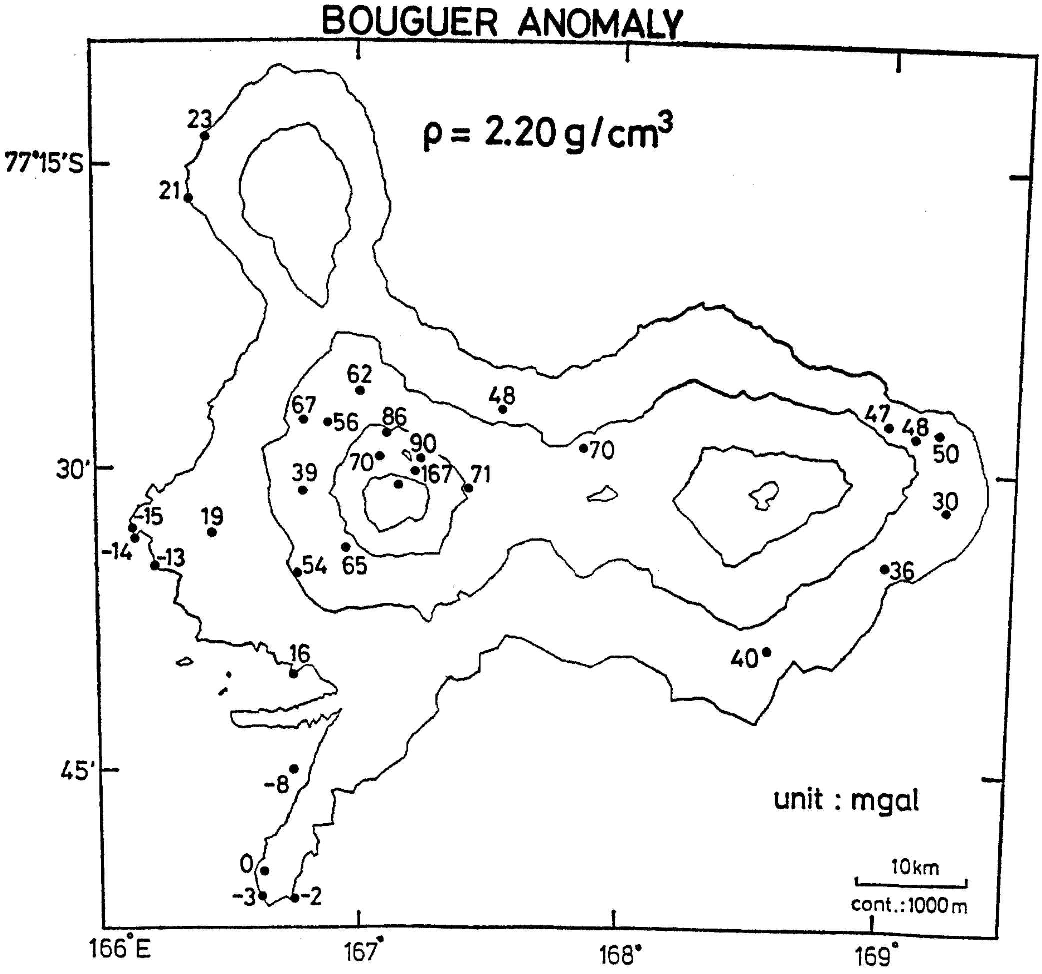


Fig. 4. Spacial distribution of the terrain correction values calculated by Talwani's three-dimensional method. Contour lines were drawn by using 1.5′ (latitudinal direction)×6′ (longitudinal direction) grid point value. Values are normalized by a unit density, unit being mgal/(g/cm³).

Bouguer anomalies for differently assumed densities. Figures 5, 6 and 7 show anomaly maps for densities of 2.20, 2.40 and 2.67 g/cm³, respectively. As shown in these figures, the pattern of the Bouguer anomaly in the island is not changed essentially by the assumed densities. We do not have so much information about the average



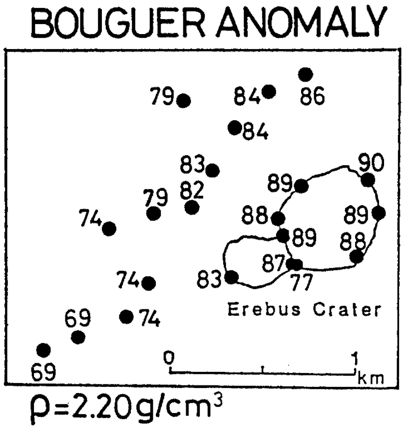
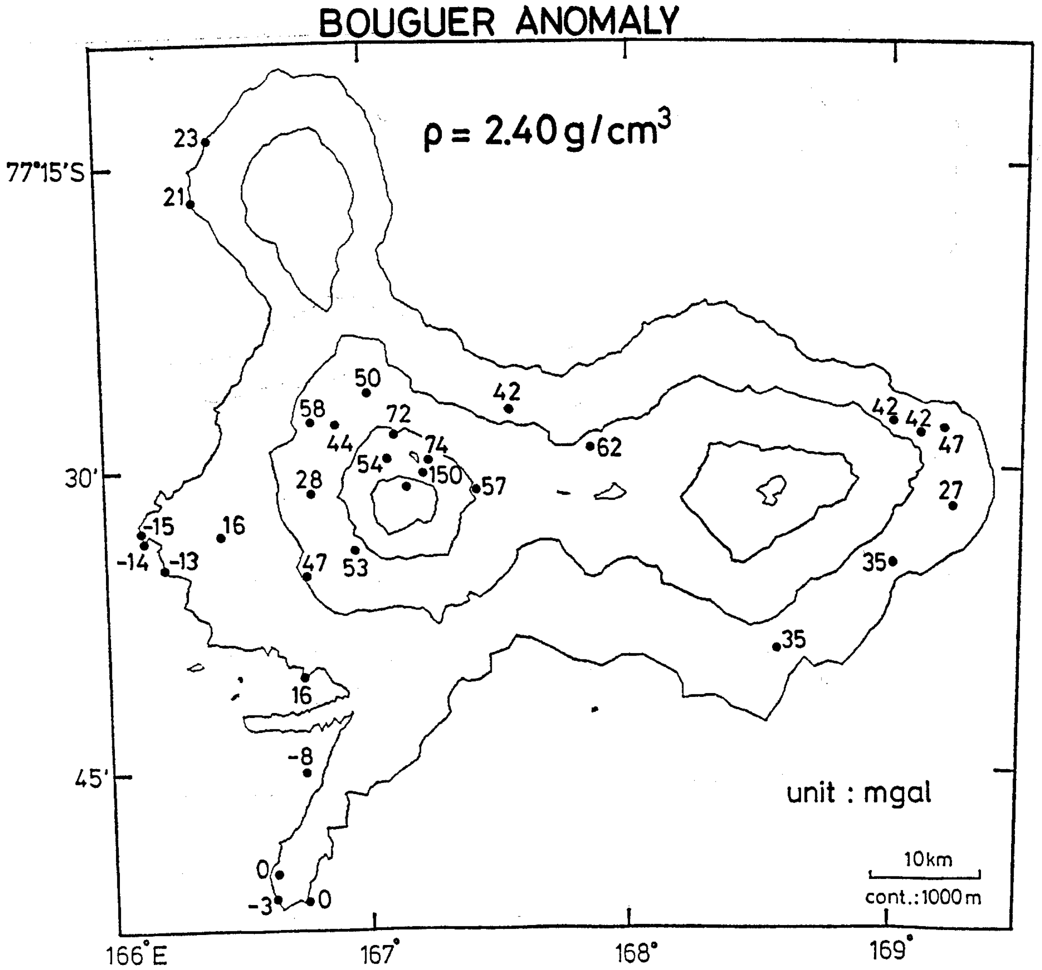


Fig. 5. Bouguer anomaly map of Ross Island and the summit area of Mount Erebus with assumed density of 2.20 g/cm³.

density of this island that we discuss only about the pattern of the Bouguer anomaly in this section. The whole island except for the western and southwestern coasts shows relatively high anomalies. The western foot of Mount Erebus can be noted as a negative anomaly and the southwestern part as nearly zero.

Although the station distribution is too sparse to discuss the detailed structure,



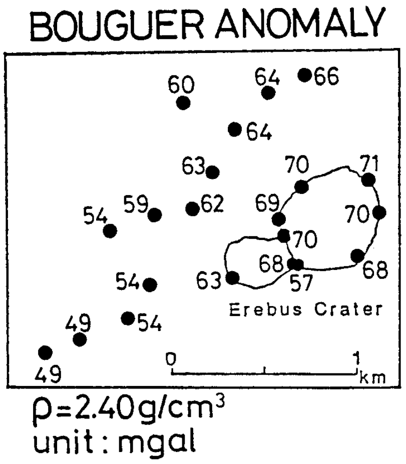
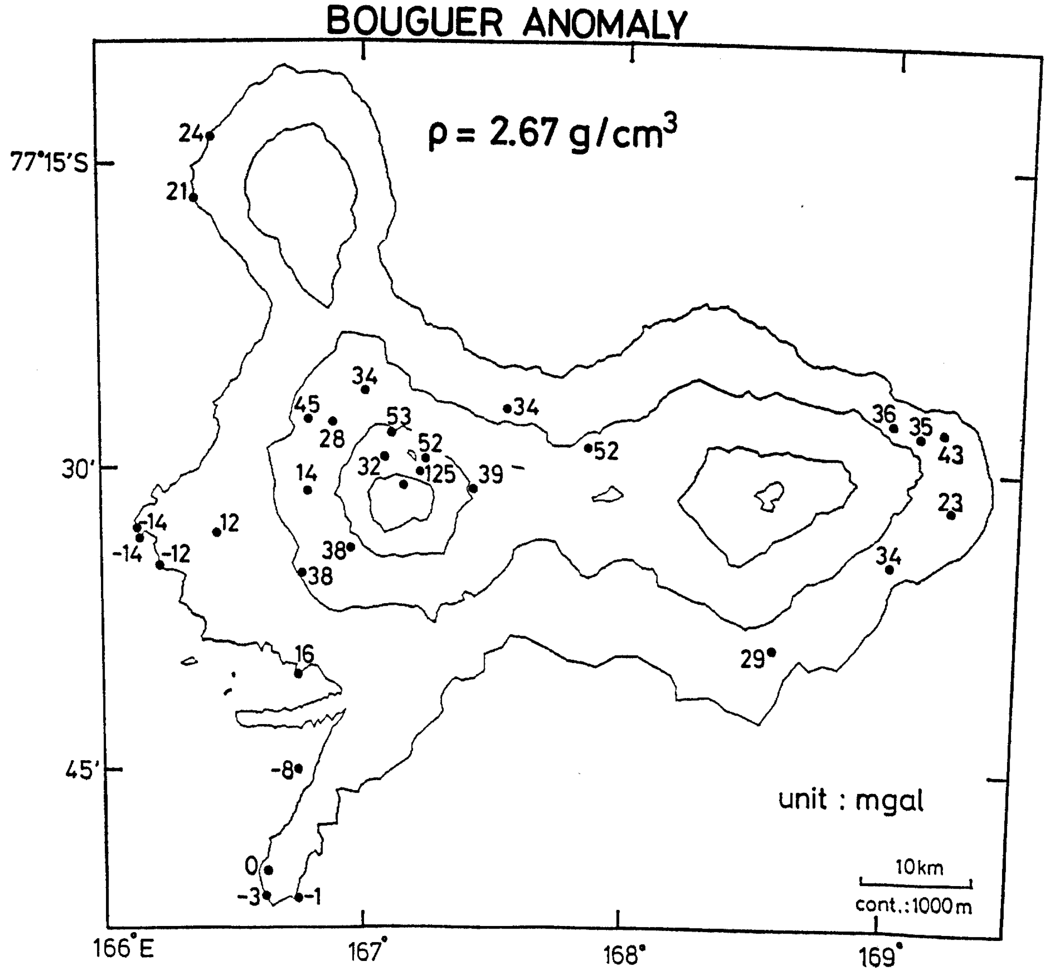


Fig. 6. Bouguer anomaly map of Ross Island and the summit area of Mount Erebus with assumed density of 2.40 g/cm³.

there seems to be an abrupt change in the anomaly somewhere southwestern foot of Mount Erebus. If this is true, the material of the crust might change or a fault system might exist around here. We will have to make more surveys before discussing this problem more persuasively.

The summit area of Mount Erebus shows the highest anomaly. This feature



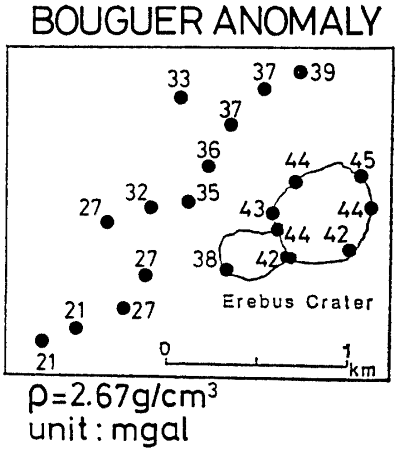


Fig. 7. Bouguer anomaly map of Ross Island and the summit area of Mount Erebus with assumed density of 2.67 g/cm³.

was pointed out in the preliminary work (KAMINUMA *et al.*, 1984). Now, with a greater density of observation near the summit, we are able to confirm the preliminary calculation. These results indicate that the structure of Mount Erebus is classified in the Kilauea-type caldera represented by the Kilauea Volcano of Hawaii Island (KINOSHITA *et al.*, 1974) and the Osima Volcano of Japan (YOKOYAMA, 1969). The high Bouguer anomaly observed around the summit area of a volcano characterizes this type of caldera and suggests the existence of the denser material inside the caldera accumulated by the repeating lava flows.

5. Conclusion

The Bouguer gravity anomalies of Ross Island were compiled from the results of recent gravity surveys. Although there is an ambiguity in absolute values of anomaly because of lack of information about the average density, the pattern of Bouguer anomalies is high in the whole island except the western and southwestern coasts, where low anomalies (zero or negative) are shown. High anomaly around the summit area is now confirmed from the new results. A more homogeneous distribution of gravity stations is needed for a more detailed study on the structure of the island area although it is difficult to establish more gravity stations in the icy mountain area. We need more precise information about the locations of stations in order to improve the accuracy of gravity values at each station within 1 mgal. The best technique for this may be GPS (Global Positioning System) if the system can be used more easily and at a lower cost.

Acknowledgments

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References

KAMINUMA, K., KOYAMA, E. and UEKI, S. (1984): A preliminary report of the gravity survey in Ross Island, Antarctica. Mem. Natl Inst. Polar Res., Spec. Issue, **33**, 41–46.

KINOSHITA, W. T., SWANSON, D. A. and JACKSON, D. B. (1974): The measurement of crustal deformation related to volcanic activity at Kilauea Volcano, Hawaii. Physical Volcanology, ed. by L. CIVETTA *et al.* Amsterdam, Elsevier, 87–115.

NOZAKI, K. (1981): Kyûmen chikei hosei no keisan puroguramu (A computer program for spherical terrain correction). Sokuchigaku Kaishi (J. Geod. Soc. Jpn.), **27**, 23–32.

TALWANI, M. and EWING, M. (1960): Rapid computation of gravitational attraction of three-dimension bodies of arbitary shape. Geophysics, **25**, 203–225.

YAMAMOTO, A., NOZAKI, K., FUKAO, Y., FURUMOTO, M., SHICHI, R. and EZAKA, T. (1982): Gravity survey in the Central Ranges, Honshu, Japan. J. Phys. Earth, **30**, 201–243.

YOKOYAMA, I. (1969): The subsurface structure of Oosima Volcano, Izu. J. Phys. Earth, **17**, 55–68.

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