Sea Gravity Measurement in the Antarctic Region on Board the Icebreaker FUJI in the 22nd Japanese Antarctic Research Expedition

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砕氷船「ふじ」による南極周辺での海上重力測定 (第22次南極地域観測隊夏隊)

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要旨: 第22次南極地域観測隊夏隊による砕氷船「ふじ」船上での海上重力測定は，1980年11月25日の東京出港から1981年４月20日の帰港までの全航海を通じ，実施することができた．途中，オーストラリアのフリマントル，南極・昭和基地，モーリシャスのポートルイス，シンガポールの各寄港中，ラコステＧ型重力計を用いて，海上重力計との比較測定も実施した．

得られた重力異常値をみると，東南極の大陸棚では，氷食地形を除き，全体としてアイソスタシーが成り立っている．また，グンネラス海堆では，その根もとに－70 mgal にも及ぶ負のフリーエア重力異常が観測され，地下深部に広範囲にわたり密度の大きな物質が存在することが推定される．

Abstract: Sea gravity measurements on board the icebreaker FUJI during the 22nd Japanese Antarctic Research Expedition conducted from November 1980 to April 1981 were very successful with almost no lack of measurements throughout the cruise.

Free air and Bouguer gravity anomalies obtained at the continental shelves of East Antarctica show that the crustal structures are isostatic as a whole, except for the glaciated shelves with steep troughs or canyons. The Gunnerus Bank protruding from the Antarctic Continent is associated with free air gravity lows of −70 mgal at the foot of both sides. Existence of these lows indicates that masses of the bathymetric high are isostatically compensated at a great depth.

1. Introduction

East Antarctica is an old continental mass which is inferred to have been separated from the Indian and the African continents in the Palaeozoic era. The Transantarctic Mountains is a conspicuous topographic feature distinguishing East Antarctica from West Antarctica and is an important tectonic zone in the evolution of Antarctica. Considering a close affinity with other old continents, the

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underground mineral resources anticipated in Antarctica cannot be overlooked. Gravity and geoid data provide the most fundamental information in surveying unexplored areas.

Although gravity data in the polar regions have been accumulated, they are still too sparse to obtain a feature of gravity distribution. The success of satellite altimetry was epoch-making not only for oceanography but also for gravimetry (TAPLEY *et al.*, 1979). However, the altimetry from the satellite cannot show its ability in the polar regions owing to poor orbital trackings and also to uncertain prediction of the orbit. If knowledge of gravity for the polar regions is lacking, we are unable to define an exact shape of the earth which is neccessary to predict orbits of artificial satellites.

Since 1957 the Japanese parties for antarctic research expedition were sent to Syowa Station almost every year. Gravity measurements on board an icebreaker during her round trip cruises were tried several times in the past, but the results were not satisfactory. The sea gravity measurements by the use of a newly designed sea gravity meter were carried out in the antarctic region during the 22nd Japanese Antarctic Research Expedition (JARE-22) from 1980 to 1981. They seem to be the first successful measurements in the antarctic region.

2. Outline of the Cruise

Figure 1 shows the navigation chart of the icebreaker FUJI. She left Tokyo on 25 November 1980, calling at Fremantle, Australia from 11 to 16 December, and reached the edge of the sea ice at 40 km north of Syowa Station on 2 January

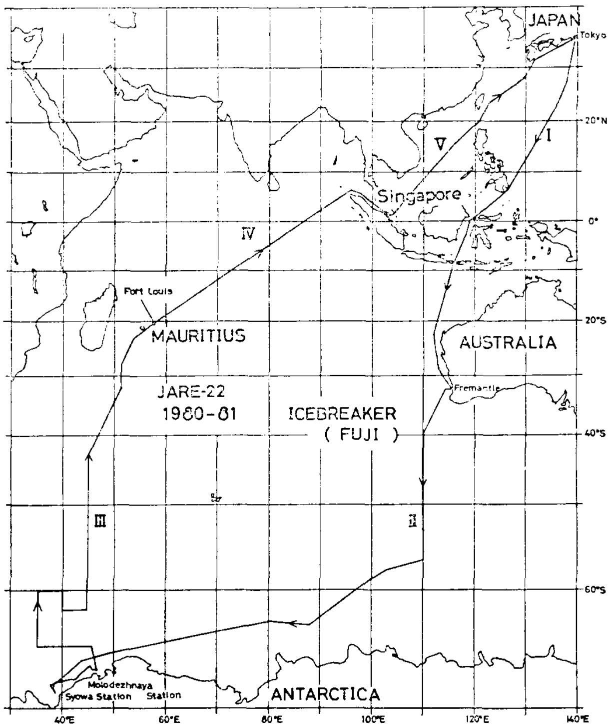

Fig. 1. Outline of cruise track of the icebreaker FUJI in 1980 to 1981 during JARE-22.

Table 1. Gravity measurements on quays and the fast ice for the calibration of the sea gravity meter. The calibration was made by a LaCoste & Romberg gravity meter (model G) for land use. These measurements were tied to gravity values of gravity base stations at Tokyo and Syowa Station (JGSN 75), and also at Singapore (IGSN 71).

Place	Latitude	Longitude	Gravity value (mgal)	Free air anomaly (mgal)	On the quay: Q or on the ice sheet: I
Tokyo	35°38.9′N	139°46.3′E	979773.5	− 14.6	Q
Fremantle	32° 3.0′S	115°44.6′E	979402.5	− 85.1	Q
Antarctica	68°47.8′S	38°49.9′E	982518	− 19	I
Port Louis	20° 9.4′S	57°29.9′E	978909.5	+264.3	Q
Singapore	1°15.8′N	103°50.7′E	978065.5	+ 31.1	Q

1981. On the way back from Syowa Station FUJI visited Molodezhnaya Station of USSR and left the station on 17 February. The next port of call was Port Louis, Mauritius where she stayed from 11 to 17 March, and then visited Singapore to stay from 1 to 8 April. The date when she returned to Tokyo was 20 April.

On the round trip cruise of FUJI we conducted gravity measurements by the use of the sea gravity meter named "NIPRORI" (SEGAWA *et al.*, 1981). This meter was newly designed and manufactured for the purpose of installing on board icebreakers. The meter has a servo accelerometer as a gravity sensor which is characterized by its accuracy up to 10^{-6} G (G:earth gravity) and its toughness against shocks more than ± 10 G.

We measured gravity at the quays of Fremantle, Port Louis, Singapore, and Tokyo by means of a LaCoste & Romberg land gravity meter (model G) to calibrate the sea gravity meter. We attempted to measure gravity on the fast ice 10 meters apart from the icebreaker. This point was located 40 km north of Syowa Station. Thickness of the ice sheet was about 100 cm. Gravity values measured by the LaCoste & Romberg gravity meter are listed in Table 1. Their uncertainty of reading was less than ± 30 μgal except the value of ± 5 mgal on the fast ice which resulted from considerable vibrations. At Tokyo and Singapore we brought the LaCoste & Romberg gravity meter to the gravity base stations to calibrate the gravity meter. We brought it also to the gravity base station at Syowa Station and made a calibration.

Detailed procedures of the sea gravity measurements and the calibration can be referred to *e.g.* KASUGA *et al.* (1982). As the result of the calibration of the sea gravity meter, we were able to reduce ambiguities of the sea gravity measurements. Consequently, the error of the measurements is thought to be less than 8.5 mgal throughout the cruise.

Profiles of gravity anomalies and bathymetry are shown in Figs. 2 and 3. In each figure, the profiles show bathymetry in meters, free air gravity anomaly in mgal, and simple Bouguer gravity anomaly in mgal from the lower to the upper, respectively. The abscissa of each figure shows the length of ship's track. Verti-

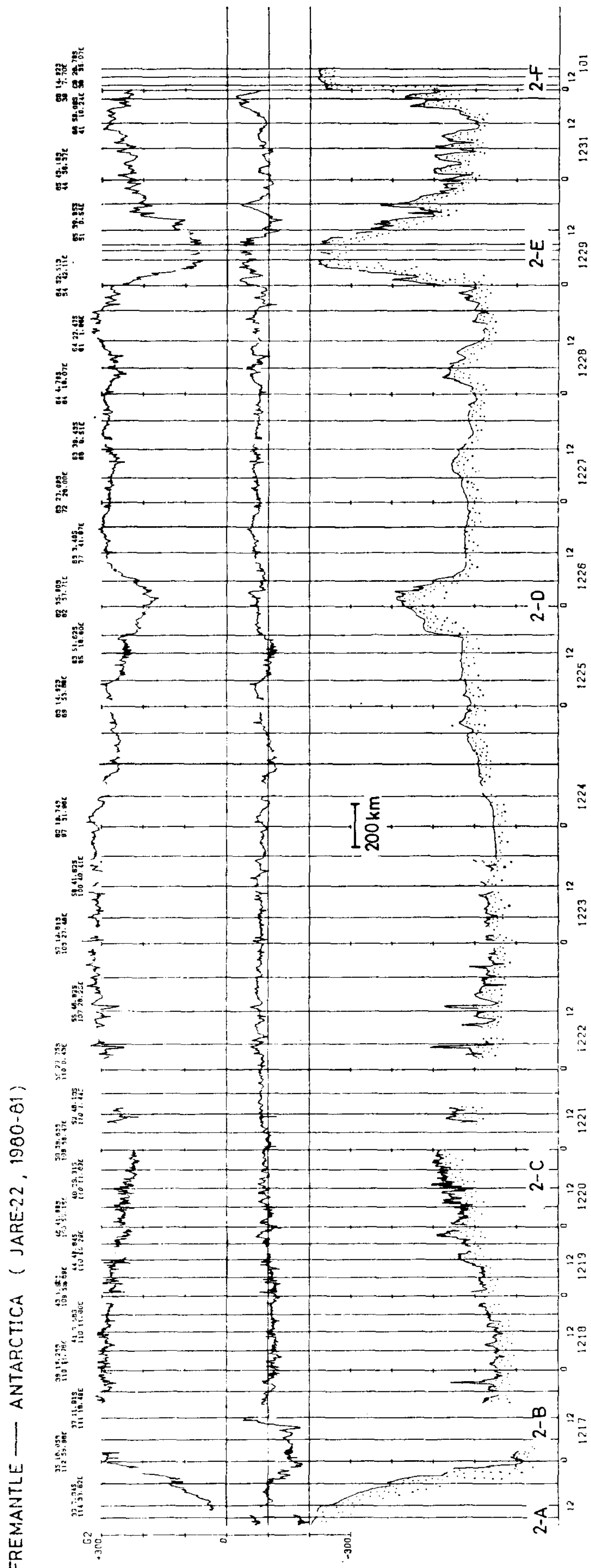

Fig. 2. Measurements in the leg from Fremantle to Syowa Station. 2-A: continental shelf of Australia, 2-B: Diamantina Fracture Zone, 2-C: Southeast Indian Ridge, 2-D: Gaussberg Plateau, 2-E: continental shelf off the Enderby Land, and 2-F: continental shelf in Lützow-Holm Bay of Antarctica.

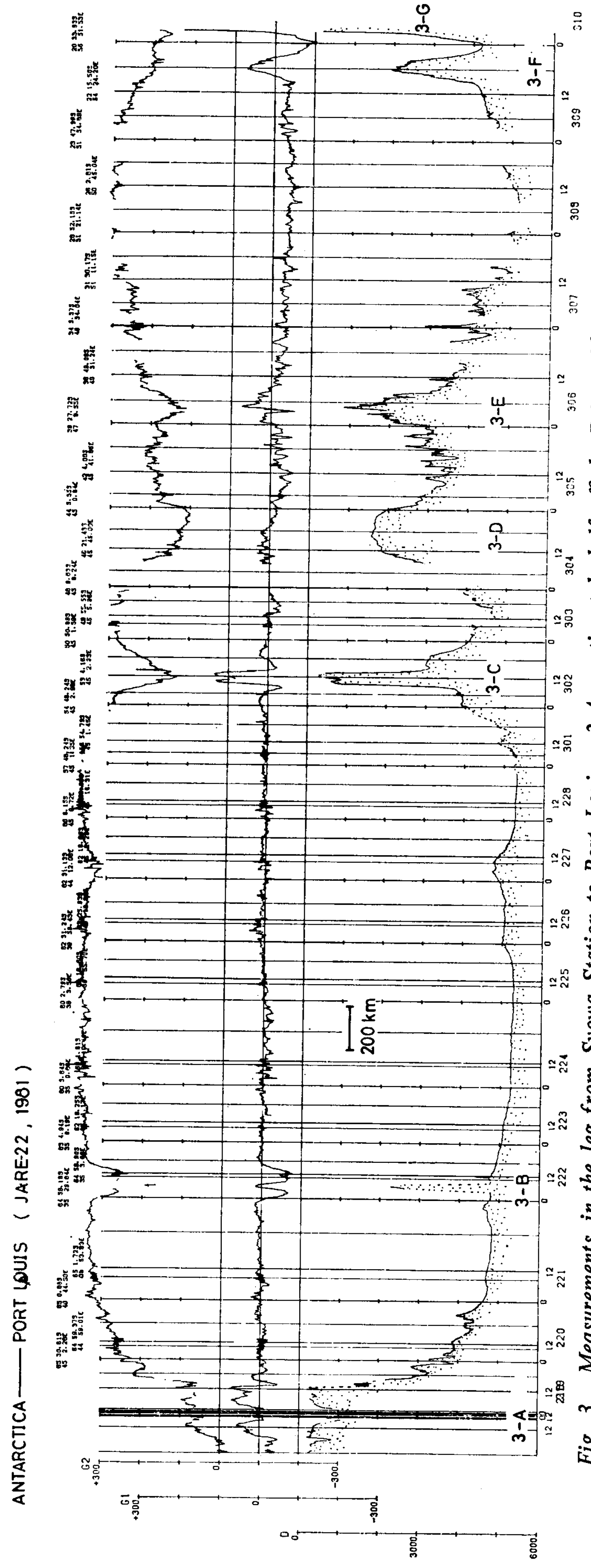

Fig. 3. Measurements in the leg from Syowa Station to Port Louis. 3-A: continental shelf off the Prince Olav Coast. A dip of the topography at 3-A indicates Casey Bay, 3-B: Gunnerus Bank, 3-C: Lena Bank, 3-D: Crozet Plateau, 3-E: the Southwest Indian Ridge, 3-F: near the Reunion Island, and 3-G: near the Mauritius Island.

cal lines mark intervals of every six hours, where the corresponding times are given with every twelve hours in GMT. Numbers attached to the bottom of the figure indicate month and day; for example, 1229 reads 29th December. Detailed ship's tracks in the antarctic region are drawn in Fig. 4. The bathymetric map in this figure is after ATLAS OKEANOV, VOENNO-MORSKOY FLOT, SSSR (1977).

Figure 2 shows the profiles in the leg from Fremantle to Syowa Station. Ship's track of this leg is indicated by II in Fig. 1. The total length of this track was about 7200 km. 2-A of Fig. 2 indicates the continental shelf of Australia. 2-B corresponds to the Diamantina Fracture Zone where there is a negative free air anomaly of about −50 mgal. Between this fracture zone and the Southeast Indian Ridge indicated by 2-C, there continues a negative free air anomaly of −10 mgal. Free air anomaly is normal at the ridge and increases gradually from south of the ridge towards Antarctica. 2-D indicates the Gaussberg Plateau whose free air anomaly is about +30 mgal to +40 mgal. 2-E corresponds to a continental shelf off the Enderby Land, and 2-F to a continental shelf of Lützow-Holm Bay of Antarctica.

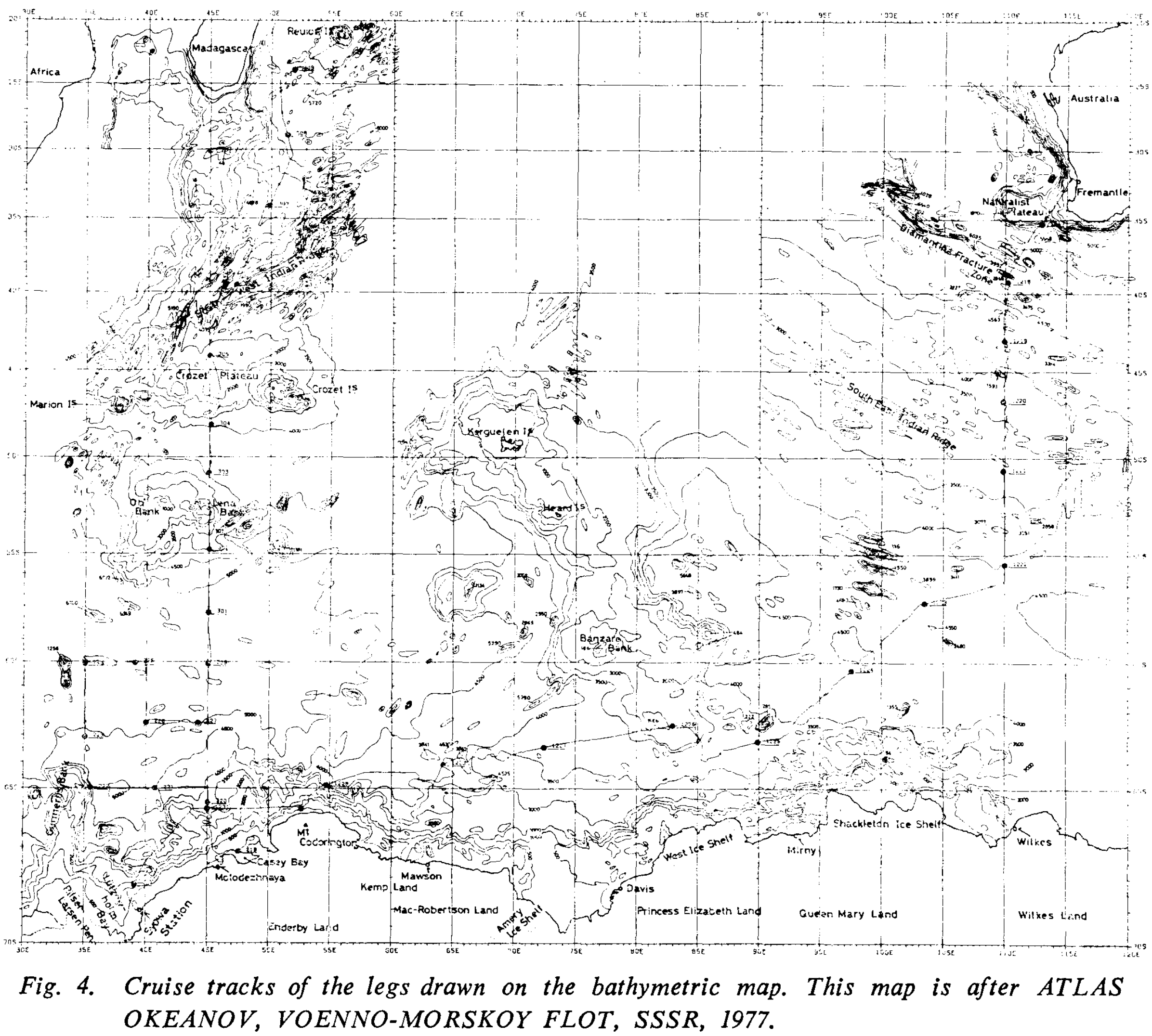

Fig. 4. Cruise tracks of the legs drawn on the bathymetric map. This map is after ATLAS OKEANOV, VOENNO-MORSKOY FLOT, SSSR, 1977.

Profiles in the leg from Antarctica to Port Louis are shown in Fig. 3. Ship's track of this leg whose length was about 6300 km is indicated by III in Fig. 1.

In Fig. 3, 3-A corresponds to a continental shelf of Antarctica. A dip of bathymetry at the center of 3-A indicates Casey Bay. Free air anomaly in the bay is normal, but it increases up to 50 mgal on the shelf. 3-B corresponds to the Gunnerus Bank, off the Riiser-Larsen Peninsula. This bank is a rise continuing from the Riiser-Larsen Peninsula. The icebreaker changed her course from west to north on the slope of the bank and did not pass over the top where free air anomaly might be maximum. This is the reason why the free air maximum is only +10 mgal whereas the minimum is as low as −70 mgal. 3-C indicates the Lena Bank, which has a positive peak of +130 mgal in the free air anomaly accompanied by gravity lows of −30 mgal. 3-D corresponds to the Crozet Plateau, where no significant free air anomalies are found. 3-E corresponds to the Southwest Indian Ridge where the free air anomalies show steep changes, but in general they are nagative on the flank of the ridge and positive in the axis. 3-E and 3-F indicate profiles near Reunion Island and Mauritius Island, respectively. There are large positive free air anomalies near these islands. The free air anomaly at Mauritius amounts to +260 mgal as seen in Table 1.

3. Discussion

Detailed profiles of some interesting areas in the antarctic region are given in Figs. 5 to 10.

Figure 5 shows the Gaussberg Plateau where a notable change of free air anomaly cannot be seen in spite of nearly 1500 m rise of bathymetry. This plateau is a southern part of the much larger plateau which continues to Kerguelen Island.

A rise of bathymetry at the center of Fig. 6 is a continental shelf, though it looks like a plateau. The profile was obtained when the icebreaker passed off the Enderby Land. A continental shelf in Lützow-Holm Bay is shown on the right side of the figure.

Figure 7 shows a continental shelf off the Prince Olav Coast where there is Casey Bay at the center. As illustrated in Figs. 6 and 7, most continental shelves do not have remarkable changes of free air anomalies, although they are characterized by significant topographic highs. On the other hand, small scale changes of free air anomalies with the amplitude of some tens of mgal and the length of about ten km are recognized in good correspondence to valleys or peaks on the shelves.

Figure 8 shows the Gunnerus Bank which is a rise continuing from the Riiser-Larsen Peninsula. This bank has large negative free air anomalies as low as −70 mgal at its foot which makes contrast with normal anomaly at the top and flatness of bathymetry arround it.

Figure 9 shows the Lena Bank which has a positive peak of free air anomaly of +130 mgal at the center of the rise and gravity lows of −30 mgal at its both sides. A topographic sink which can be recognized at the top of this bank is

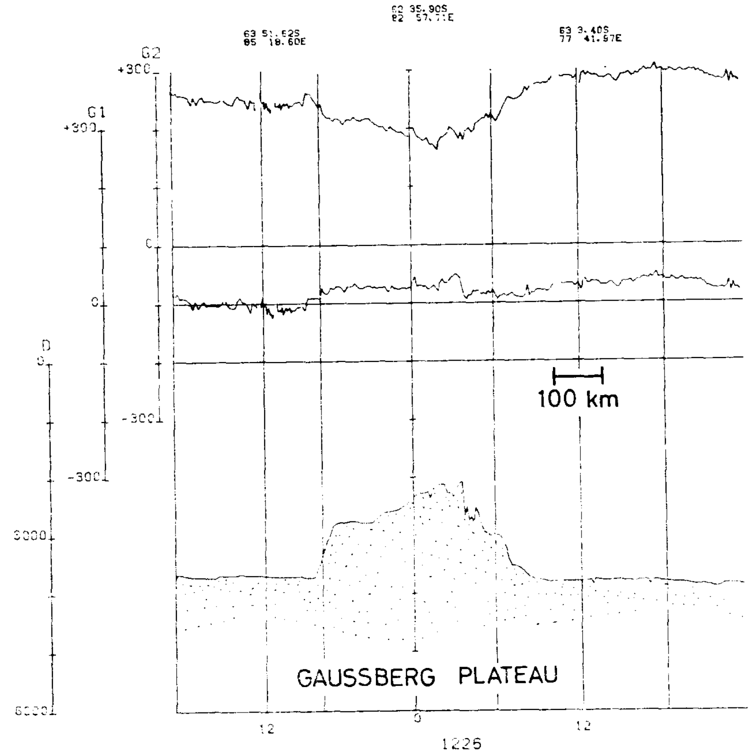

Fig. 5. Measurements across the Gaussberg Plateau.

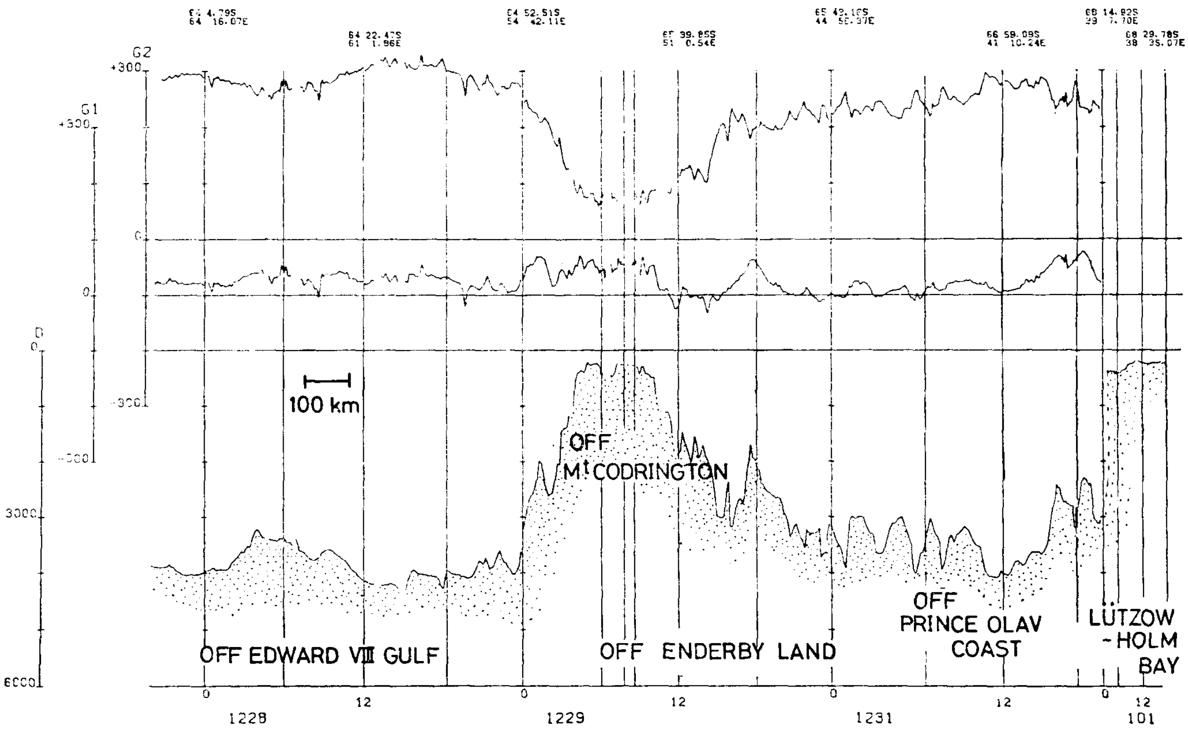

Fig. 6. Measurements off the Enderby Land.

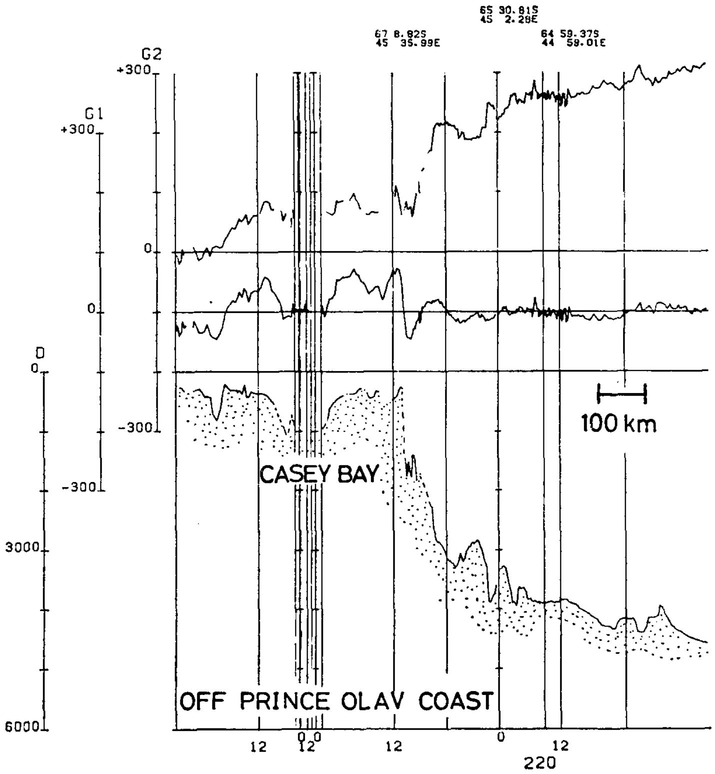

Fig. 7. Measurements off the Prince Olav Coast.

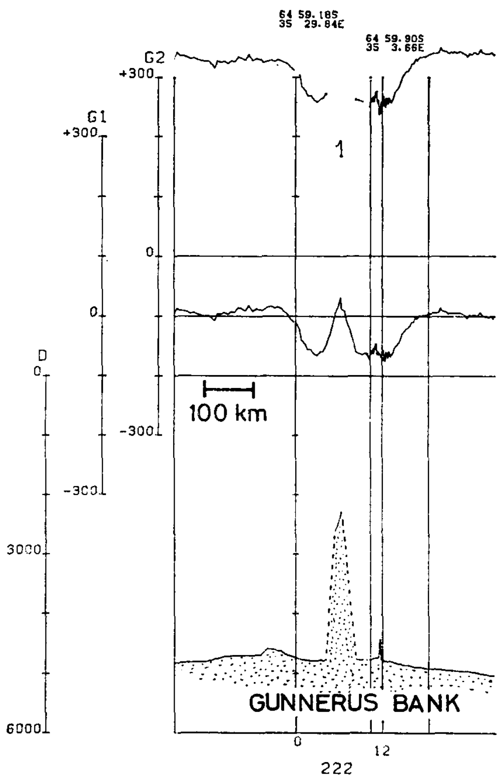

Fig. 8. Measurements across the Gunnerus Bank.

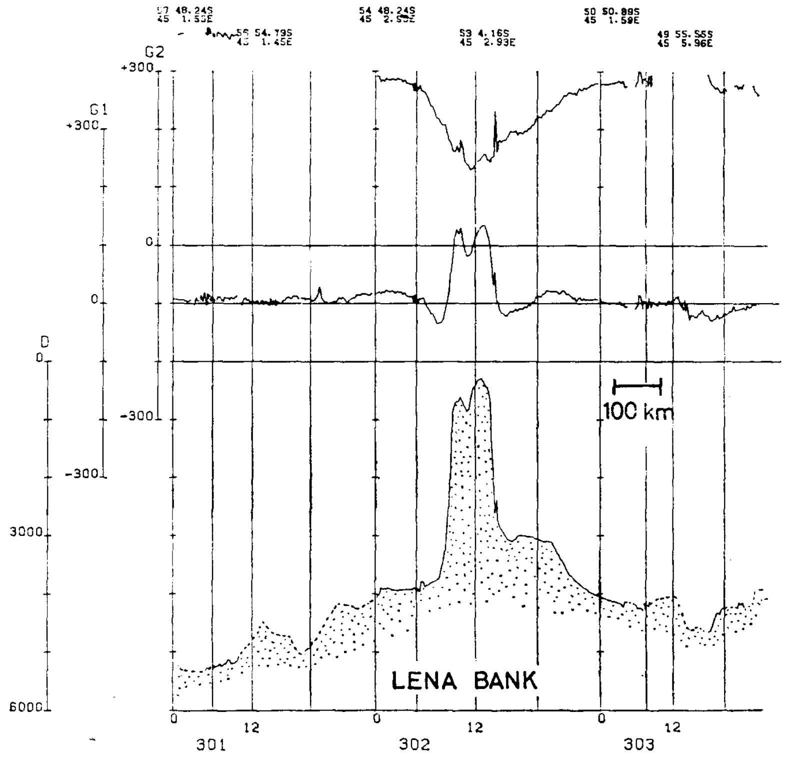

Fig. 9. Measurements across the Lena Bank.

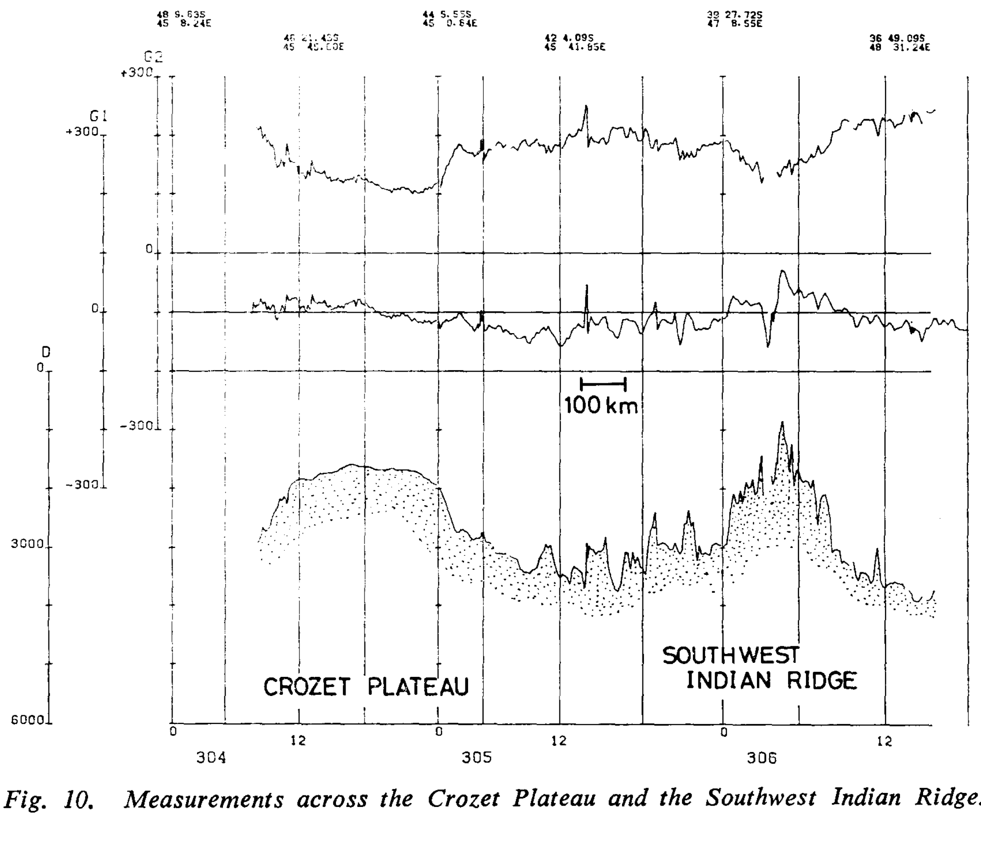

Fig. 10. Measurements across the Crozet Plateau and the Southwest Indian Ridge.

reflected clearly on the free air anomaly. This may be an evidence of a double structure of the bank divided by a certain structural belt like an elongated volcanic crater.

Figure 10 shows the Crozet Plateau and the Southwest Indian Ridge. The Crozet Plateau has no significant free air anomalies. The Southwest Indian Redge is considerably fractured and free air anomalies have a good correlation to the notches which are seen in the bathymetric profiles. In the median rift valley of the ridge there is a steep dip of free air anomaly to as low as −70 mgal.

4. Conclusion

Free air anomalies are not affected by plateaus or shelves in the antarctic region, and as a consequence there are large changes of Bouguer anomalies. This is because the surveyed regions of Antarctica are continental and almost isostatic at present. Small valleys or peaks formed by the erosion of water and glacier are not isostatic, hence making change of free air anomalies.

The Gunnerus Bank has large negative free air anomalies at both sides. Such gravity lows can also be seen at the sea mounts in the Pacific Ocean and are perhaps explained in terms of peculiarity of the upper mantle, that is, the existence of a low density zone for compensation at a great depth.

Compared with the banks or plateaus off Antarctica, Mauritius Island has a much larger positive free air anomaly up to +260 mgal. This is one of the evidences that Mauritius Island is made of the oceanic crust. It is significant that we have never seen such a case with respect to the topographic highs in East Antarctica.

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References

KASUGA, T., KAMINUMA, K. and SEGAWA, J. (1982): Gravity measurement on board the icebreaker FUJI during the Japanese Antarctic Research Expedition, 1980–1981. J. Geod. Soc. Jpn., **28**, 1–21.

SEGAWA, J., KAMINUMA, K. and KASUGA, T. (1981): A new surface ship gravity meter "NIPRORI-1" with a servo accelerometer. J. Geod. Soc. Jpn., **27**, 102–130.

TAPLEY, B. D., SCHUTZ, B. E., MARSH, J. G., TOWNSEND, W. F. and BORN, G. H. ed. (1979): Accuracy Assessment of the SEASAT Orbit and Altimeter Height Measurement. Austin, The University of Texas, Institute for Advanced Study in Orbital Mechanics, 120 p (IASOM TR79-5).

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