Bulletin of Glacier Research 6 (1988) 33−39

Bedrock and ice surface profiles in the Shirase Glacier basin determined by the ground-based radio-echo sounding

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(Received December 17, 1987 ; Revised manuscript received January 25, 1988)

Abstract

Profiles of bedrock and ice surface along several routes in the Shirase Glacier basin were determined by the ground-based radio-echo soundings. The routes consisted of the flow line of the Shirase Glacier, the 2200 m contour line between Mizuho Station and Yamato Mountains, and the routine traverse route between Syowa Station and Mizuho Station, all over a distance of about 1200 km. The radio-echo sounder was of a 60 MHz designed and constructed by the National Institute of Polar Research to be carried on an oversnow vehicle. Results of measurements show that the elevation of bedrock is approximately at sea-level from the coast near Syowa Station to the inland near Mizuho Station, while that in the upstream area of the Shirase Glacier is gradually increasing up to about 1500 m at a point 400 km inland, where the ice thickness reaches 2000 m. A deep subglacial trench was found near the outlet of the Shirase Gracier in the measurements along the 2000 m contour route. Comparison of profiles of the bedrock and the ice surface along the Shirase Glacier flow line revealed that surface undulations correspond to irregular features of the bedrock. To supplement the data for the depth of bedrock in some regions where no radio-echo obtained from the bed, measurements of the gravity anomaly were used to determine the ice thickness.

1. Introduction

A 5-year project on glaciology, named glaciological programme in East Queen Maud Land, started in 1982 and has been carried out to obtain more extensive informations for the ice dynamics in the Shirase Glacier drainage basin, and to recover ice cores at Mizuho Station. It is needed to know the ice thickness and velocity over a wide area of a glacier basin for the dynamical study. For obtaining informations of ice thickness in the area, both a 60 MHz ground-based radio-echo sounder and a 179 MHz airborne radio-echo sounder were designed and constructed at the National Institute of Polar Research (Wada and Mae, 1981). Although an intensive long-term surveys were carried out on the ice thickness by the use of these radio-echo sounders since 1982, this paper presents a preliminary results of the ice thickness obtained by the 60 MHz ground-based radio-echo sounder in the Shirase Glacier basin in 1982 and 1983. Also given in the paper is the bedrock topography estimated by gravimetric method in some areas where no radio-echo were obtained from the bed. More extensive reports on the ice thickness will be prepared for the folio series to be published as an integrated report of programme in East Queen Maud Land.

2. Echo sounding equipment

The 60 MHz ground-based radio-echo souder was designed and constructed at the National Institute of Polar Research. The instrument consisted of a transmitter, a receiver with an oscilloscope as an indicator and a pair of 3-element Yagi antennas. Since details of its original form was already reported by Wada and others (1981), only a brief summary of the major technical characteristics are presented in Table 1.

Table 1. Technical characteristics of 60 MHz ground-based radio-echo sounder in 1982.

1. Transmitter	
Carrier frequency	60 MHz
Pulse energy duration	0.3 μs
Rise time	0.15 μs
Peak power	1 kW
Pulse repetition interval	1 kHz
Total power consumption	DC 24 V, 4 A
RF gain	39 dB
2. Receiver	
Central frequency	60 MHz
Band width	5 MHz
Noise figure	3 dB
Receiver sensitivity	−102 dBm
Input attenuation	0 to 70 dB in 10 dB steps
3. Aerials	
3-element Yagi antenna	
Absolute power gain	8 dB
4. Indicator	
Oscilloscope and 35-mm continuous recording camera	

3. Survey routes of radio-echo sounding and operations

Figure 1 shows a map of the East Queen Maud Land with all the survey routes of the ground-based radio-echo sounding completed to date. The solid lines indicate the routes on which continuous records were obtained on the ice thickness from a running oversnow vehicle of the 23 rd Japanese Antarctic Research Expedition (JARE 23) in 1982−1983. The dotted lines are those on which the sounding was carried out at every points 2−20 km intervals. Operations of the radio-echo sounder were made on the moving oversnow vehicle for the continuous record. The antennas were set up on a sledge facing each other at a distance of about 2.5 m. Reflected waves were displayed on an oscilloscope, exhibiting a time-intensity curve (A-scope), which is photographed at 1 km intervals. Continuous records on 35-mm films (z-scope) were also obtained on the running oversnow vehicle.

The total distance of the survey routes of the

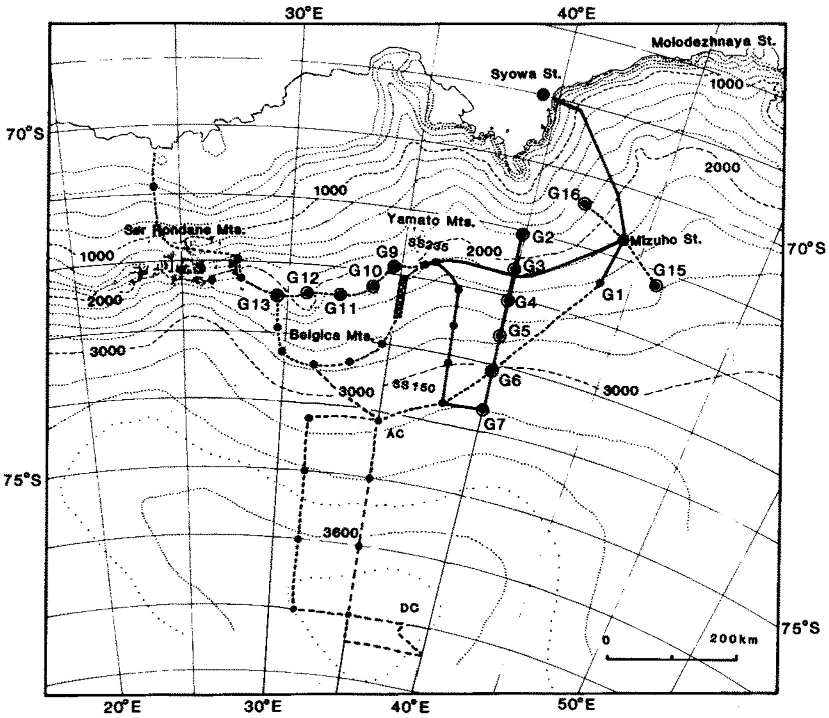

Fig. 1. Survey routes for ground-based radio-echo sounding in East Queen Maud Land, 1982−1987. Solid lines indicate routes on which continuous records of ice thickness were obtained at every 2−20 km.

sounding is about 5000 km, but clear records were not necessarily obtained on all the routes.

4. Reduction method

Profiles of the ice surface, the bedrock elevation and the ice thickness along each traverse route were constructed from the ice thickness data obtained from the film records taken at 1 km intervals, with reference to the surface elevation measured by satellite doppler positioning system (JMR-4A) and barometers. To calculate ice thickness from readings of echo times, a standard electromagnetic wave velocity of propagation of 169 m/μs was adopted (Robin *et al.*, 1969). It should be noted that corrections for a higher velocity in the surface firn are most relevant in the thin ice as, for example, in the area downstream of the Shirase Glacier and in the coast region.

Position and elevation of the measuring sites of radio echo sounding at approximately 1 km distance were determined mainly by the navigational data ; the distance and azimuth between neighbouring sites with occasional operations of a doppler positioning system, and by the use of barometric altimeters. All the data obtained in traverse operations in 1982–1983 are summarized in a JARE data report (Nishio *et al.*, 1986).

5. Results

5. 1. Ice surface and bedrock profiles

Vertical section profiles of ice surface and bedrock along various routes as shown in Fig. 1 are shown in Figures 2–6. Fig. 5 shows a longitudinal profile from the upper part of the downstream of Shirase Glacier to the upstream along the estimated main flow line of the glacier. A deep subglacial trench exists in the outlet of Shirase Glacier (Mae and Yoshida, 1986) and the elevation of bedrock is approximately at sea-level up to 70 km inland from the coast. Then further inland, approximately from 140 km, the bedrock elevation gradually increases up to 1500 m above sea-level and the ice thickness reaches about 2000 m.

A profile to the direction in the right angles to the Shirase Glacier flow line, is the one between Mizuho Station and Massif-A in Yamato Mountains shown in Fig. 4. The elevation of ice surface is uniformly at about 2200 m, and the bedrock profile shows nearly flat feature at about several hundreds meters above sea-level for more than 200 km from Mizuho with some small-scale irregularities. However, the bedrock elevation gradually rises in an area approximately 50 km from the massif-A in the Yamato Mountains. Along the route between Syowa and Mizuho Stations, the elevation of bedrock is at sea-level up to 100 km along the route and it arises to several hundreds

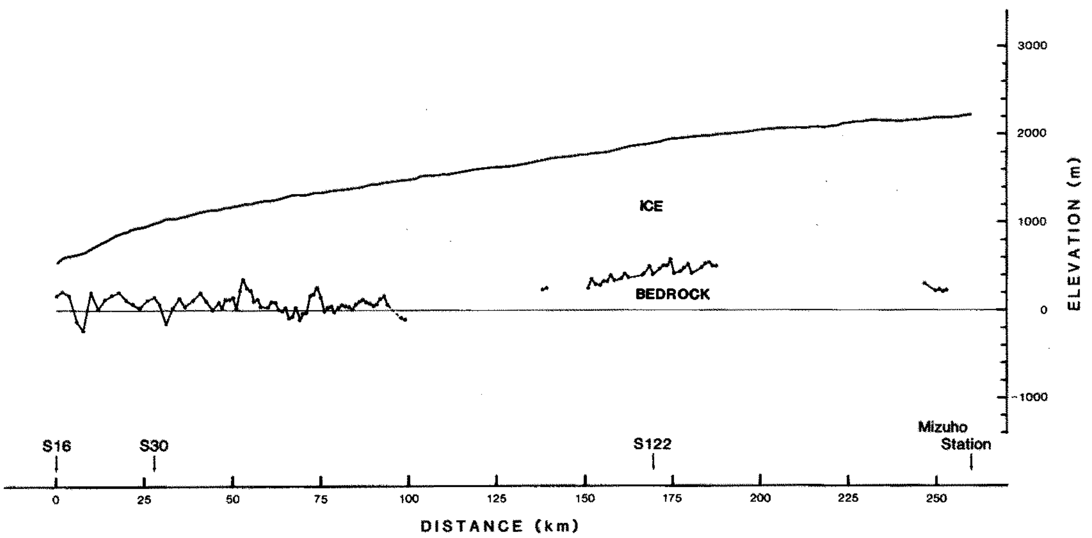

Fig. 2. Ice surface and bedrock profiles between Syowa Station and Mizuho Station.

meters which seem to continue to the vicinity of Mizuho Station as shown in Figs. 2 and 3.

5. 2. Special features

The most remarkable large-scale feature of the bedrock in the Shirase Glacier basin, is the comparatively flat and low level plateau below several hundred meters, which extends up to the latitude 72°S. In the further inland area, however, the bed rock exhibits a high plateau which reaches to approximately 1500 m in elevation

Another remarkable feature appeared in the profile of ice surface and bedrock topography is close correlations between the ice surface depressions and the bedrock irregularities. In Fig. 7, which is a reproduction of Fig. 5 with a exaggerated scale of the

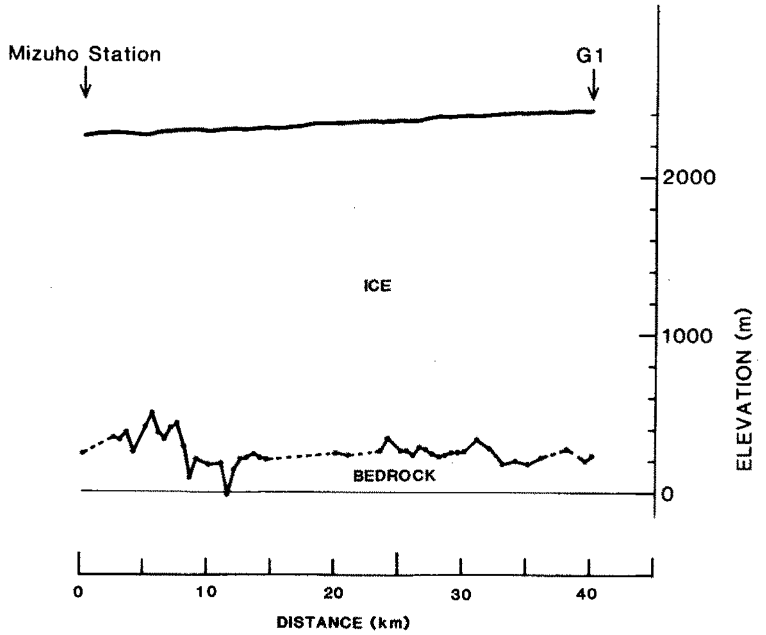

Fig. 3. Ice surface and bedrock profiles between Mizuho Station and G 1.

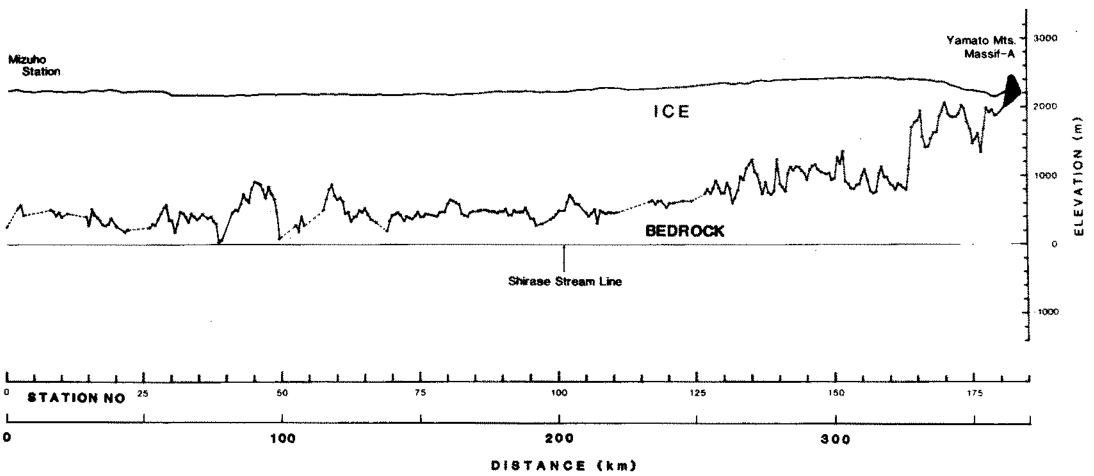

Fig. 4. Ice surface and bedrock profiles between Mizuho Station and Massif-A in the Yamato Mountains, which cross the Shirase Glacier stream line at about 2200 m in surface contour.

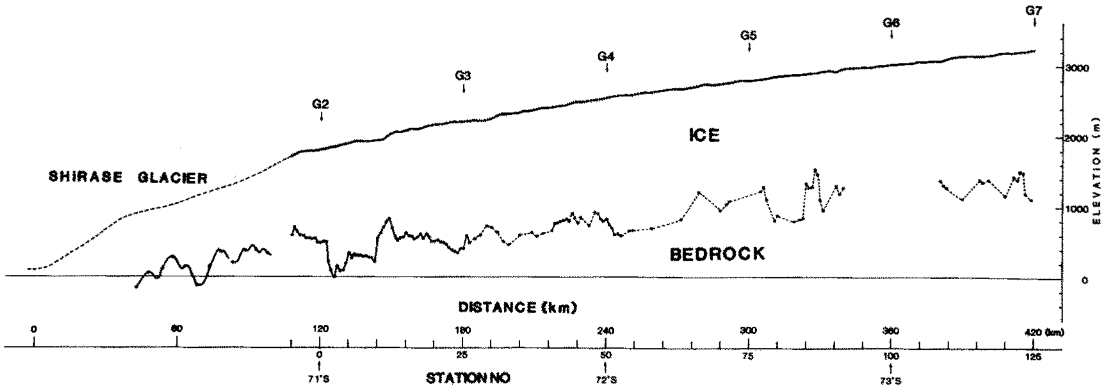

Fig. 5. Ice surface and bedrock profiles from the upper gorge of the Shirase Gracier to the further inland along flow line (40°E). The bedrock profile below G 2 of the Shirase Glacier is constructed from the airborne radio-echo sounding (Wada and Mae, 1981).

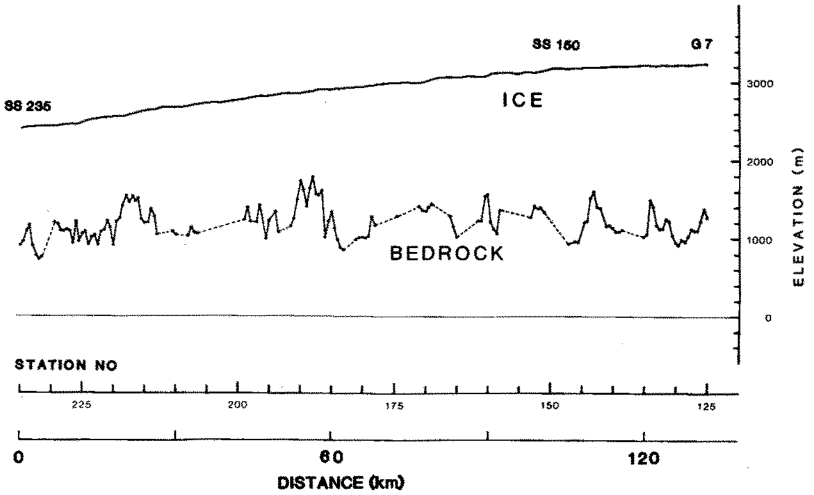

Fig. 6. Ice surface and bedrock profiles from station of SS235 to G 7 through station of SS150 along the longitude of 37.5° E.

elevation, it is shown that variations of the surface slope are related to the bedrock feature, in particular, that the steep surface slopes tend to occur over local peaks on the bedrock.

5. 3. Bedrock elevation deduced from gravimetric method

In Fig. 2, we have lack of data of bedrock echos on some distance along the route between Syowa Station and Mizuho Station. In order to obtain the bed rock elevation in such a region of no radio-echo we used results of the free air gravity anomaly measured simultaneously on the route. For this purpose, the relationship between the free air gravity anomaly and the bedrock elevation is adopted (Bentley, 1964). In actual practice, we have plotted data of free air gravity anomaly of the bedrock elevation obtained by radio-echo sounding between Syowa Station and Mizuho Station. The best linear fit by least-square analysis gives a slope of 8.6 m/mgal as shown in Fig. 8, and we can deduce the following for converting the gravity anomalies to the bedrock elevation,

$$h-x=8.6 \cdot \Delta g_0-104 \text{ (m)}$$

where h is the elevation of ice surface, x the ice thickness and Δg_0 the free air gravity anomaly. The standard deviation of observed bedrock elevation from the fitted line in Fig. 8 is 70 m. Now, the bedrock elevation is interporated among the radio-echo

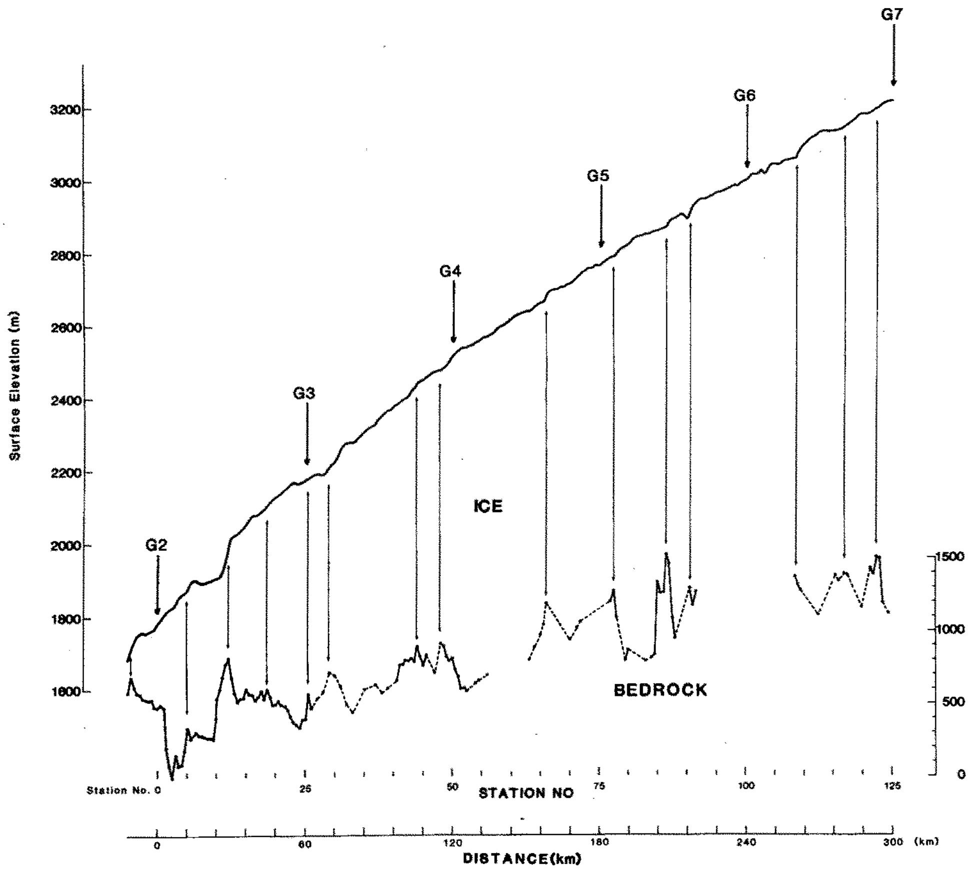

Fig. 7. Datailed ice surface and bedrock profiles along the Shirase slopes tend to occur on local peaks of the bedrock.

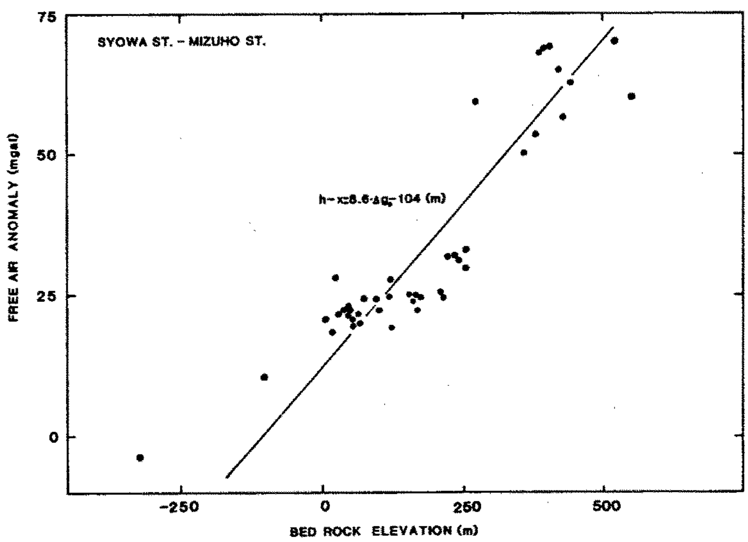

Fig. 8. Relationship between the free air anomaly and the bedrock elevation along the route between Syowa and Mizuho stations. h ; the elevation of ice surface, x ; ice thickness, Δg_0 ; free air anomaly.

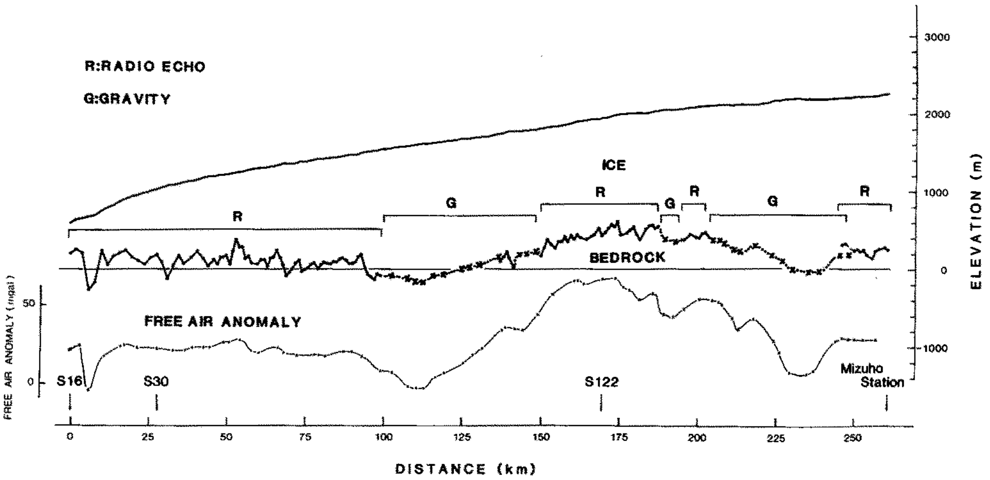

Fig. 9. Ice surface and bedrock profiles between Syowa and Mizuho Stations, obtained both by radio-echo sounding (indicated by R) and by free air gravity anomaly (G).

data using the gravity data as shown in Figure 9. A striking result is that there is a depression of the sea-level elevation near Mizuho Station. Detailed results on the areal profile of the bedrock elevation, the ice thickness and the ice surface elevation will be published in the folio-series of results of the program.

Acknowledgments

The authors coordialy acknowledge help and encouragement given to this project from Prof. T. Hoshiai, National Institute of Polar Research who was the leader of wintering party of JARE 23. We also wish to express our thanks to all members of the wintering party. This is countribution to the Glaciological Reseach Programme in East Queen Maud Land, Antarctica (Prof. A. Higashi. the program chairman). Financial support by the Ministry of Education, Culture and Science of the Japanese government is acknowledged.

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