MORPHOLOGICAL FEATURE OF THE ICE SHEET IN MIZUHO PLATEAU

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Abstract: The morphological feature of the ice sheet in Mizuho Plateau, East Antarctica, was described by the use of data of elevation and maximum slope of the surface and thickness of the ice sheet obtained by oversnow traverses of the Japanese Antarctic Research Expeditions. A surface topographical map of Mizuho Plateau was also given. The upper boundary of the katabatic wind region was estimated at about 3100 m from the distribution of the gradient of the ice sheet surface by applying BALL's theory (1960) to the data. The mean thickness of the ice sheet in Mizuho Plateau was 1650 m, while the maximum was 3870 m. Local trends of the bedrock surface were observed using cross-sectional profiles of the ice sheet. Mizuho Plateau was divided into subdivisional drainage basins of the ice sheet. It was estimated that the Shirase drainage basin, the largest one in this province, had an extent of 20×10^4 km^2 in area, and stored ice amounting to 32×10^{13} t in weight.

1. Introduction

The morphological feature of an ice sheet provides the basic condition for movement of the ice sheet and for other glaciological and meteorological phenomena taking place around it. This paper describes the morphological feature of the ice sheet in Mizuho Plateau to give the basic condition of the field where a number of glaciological and meteorological researches of the Glaciological Research Program in Mizuho Plateau were carried out.

As an initial process, all the data obtained by the 10th, 11th, 14th and 15th Japanese Antarctic Research Expeditions (JARE-10, -11, -14 and -15), were compiled, together with those by JARE-5 and -9. They were straightened and corrected under a common principle, then plotted in a sheet to make a topographical map of Mizuho Plateau. Section 2 outlines briefly the principles and methods of surveys, whereas Section 3 describes the morphological feature of the ice sheet in Mizuho Plateau from various viewpoints.

2. Surveys of the Ice Sheet

2.1. Position and elevation of stations

Astronomic surveys for determining the geodetic position of stations were conducted by sun shot at 41 stations on the inland traverse routes of JARE-5, -9, -10, -11, -14 and -15, 5300 km in total length, during the period of 1961–1975 (FUJIWARA, 1964; FUJIWARA *et al.*, 1971; SHIMIZU *et al.*, 1972; NARUSE and YOKOYAMA, 1975; WATANABE *et al.*, 1977). The positions of all other stations were interpolated between two successive astronomic stations using navigation records.

Altimetry of the ice sheet surface was carried out either by "traverse survey" or "barometric survey" by the use of stations on the traverse routes.

A traverse survey was carried out from Syowa Station to Mizuho Camp, through Routes S, H and Z, via S30, H200 and S122, in 1973 (NARUSE and YOKOYAMA, 1975). Elevations of the stations on the routes were taken as the base of barometric altimetry for stations on all other routes.

A triangulation chain was set up from A001 (a south nunatak of the Yamato Mountains) to A164(S240) along the parallel of 72°S in 1969, and a traverse survey line from W00 (a south peak of the Sandercock Nunataks) southwestward to W55 in 1970 (NARUSE *et al.,* 1972). An elevation difference of two neighboring stations on these routes was strictly determined by the triangulation and traverse survey, while some complicated procedure was necessary, as described below, to figure out the absolute elevation of the station.

The single-altimeter method was employed for altimetry of all other stations: reading of an elevation difference between two neighboring stations by four altimeters (American Paulin Altimeter MM-1 and MT-5) was averaged, and the result was corrected only for air temperature. For a closed circuit track which was initiated and terminated at a station (junction station) on the base route (Route S-H-Z), the error of closure of elevation at the junction station was uniformly distributed over the track subjected to the barometric method. For an open track, barometric results were simply superposed upon the corrected elevation of a junction station.

All the data of the surface elevation of the ice sheet made by JARE-5, -9,

-10, -11, -14 and -15 during the period of 1961–1975, were corrected according to the way described above (SHIMIZU, 1977). The highest point in this area was the Fuji Divide, which had an elevation of 3761 m above sea level.

2.2. Maximum slope of the ice sheet surface

Inclinations of the horizon of the ice sheet in eight magnetic directions were measured by a theodolite, Wild T-2, at the stations of Routes S, A, I, J, X, Y and Z, to figure out the shape of the ice sheet surface in more detail. Generally, the maximum inclination of the horizon of the ice sheet surface was less than 30 minutes, and the axis of direction of the maximum uphill slope did not necessarily coincide with that of the maximum downhill slope.

Compiling the results of Sections 2.1 and 2.2., and referring to the other map (AKADEMII NAUK SSSR, 1966) as to the general tendency of contour lines in the outer range of Mizuho Plateau, a topographical map of Mizuho Plateau was made as given in Fig. A at the end of this volume.

2.3. Thickness of the ice sheet and elevation of the bedrock surface

The thickness of the ice sheet was measured by radio echo sounding along Routes S, A, B, C, D, H, W, X, Y and Z. The instrument used for the measurement was an SPRI (Scott Polar Research Institute) MK II Radio Echo Sounder with a 35 MHz transmitter and a receiver. Antennas for transmitting and receiving signals were properly selected out of a folded dipole of 0.7λ long, a 4-wire half-wave dipole, and a 3-element Yagi, depending upon the local conditions of the ice sheet. A common antenna for transmission and reception with a TX/RX switch was also properly used. An electromagnetic wave velocity of 171 m/μs in the ice sheet (CLOUGH and BENTLEY, 1970) was used to calculate the thickness of the ice sheet from the echo time. The thickness of the ice sheet was determined by the longest echo time, when multi-echoes were obtained.

Subtracting the ice thickness from the surface elevation of the ice sheet, the elevation of the bedrock surface was calculated. The thickest ice was found to be 3870 m at S176 where the bedrock elevation was 1759 m below sea level. The average thickness of the ice sheet in Mizuho Plateau was 1650 m approximately.

3. Morphological Feature of the Ice Sheet

3.1. Surface topography of the ice sheet

As indicated in Fig. 1, topographical observations in Mizuho Plateau revealed the existence of broad ridges of the ice sheet surface f-a, f-b, f-d and f-e, each drawn in a bold line (in a broken line where a ridge was not definite), and broad valleys g-h, i-j and m-n, in chain lines. Profiles of the ice sheet surface along each of the ridges and valleys are illustrated in Fig. 2, and their gradients are given in Table 1. Even by plotting the profiles at intervals of 100 m elevation, a clear

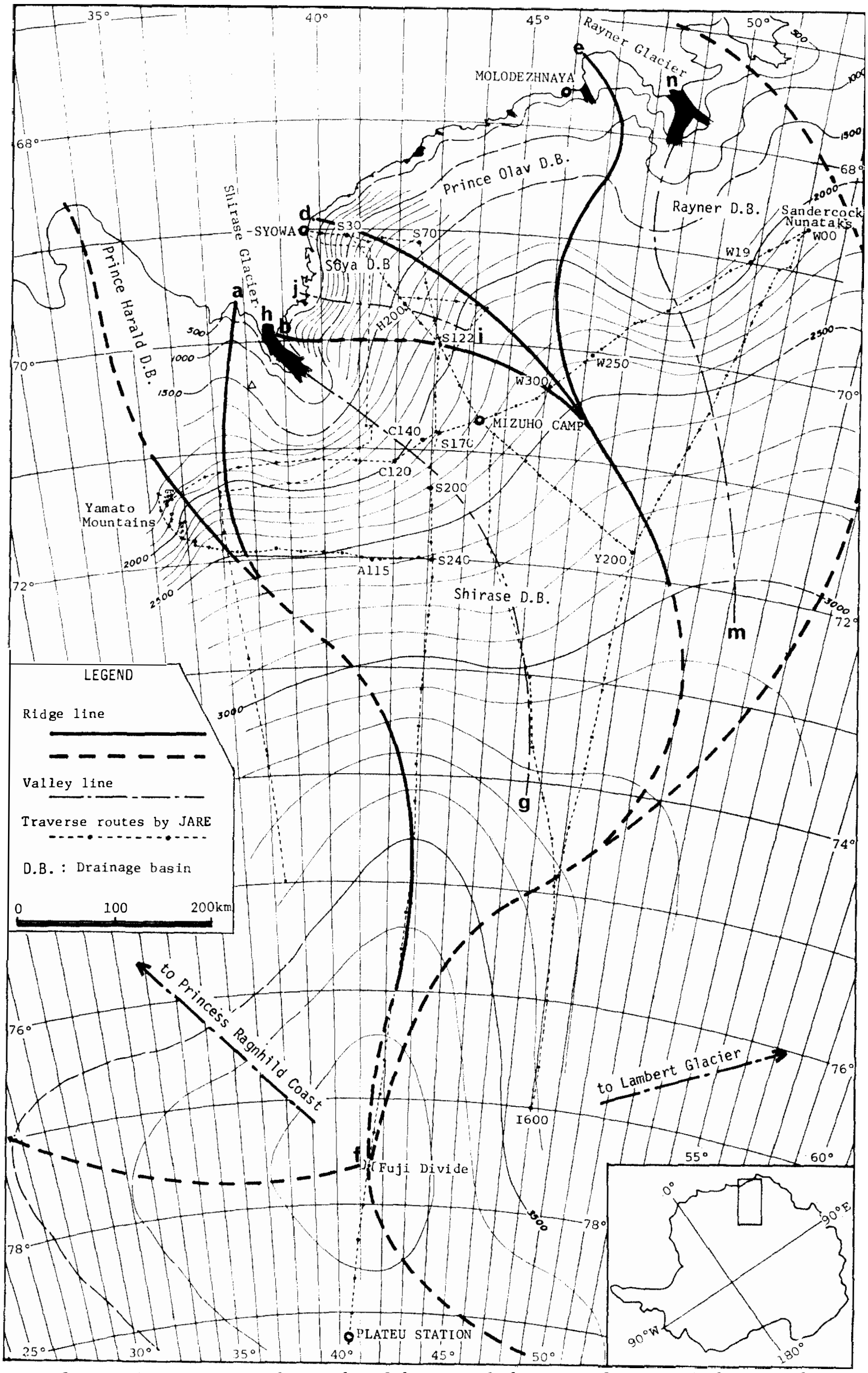

Fig. 1. Surface topography and subdivisional drainage basins of the ice sheet in Mizuho Plateau, in 1969–1974.

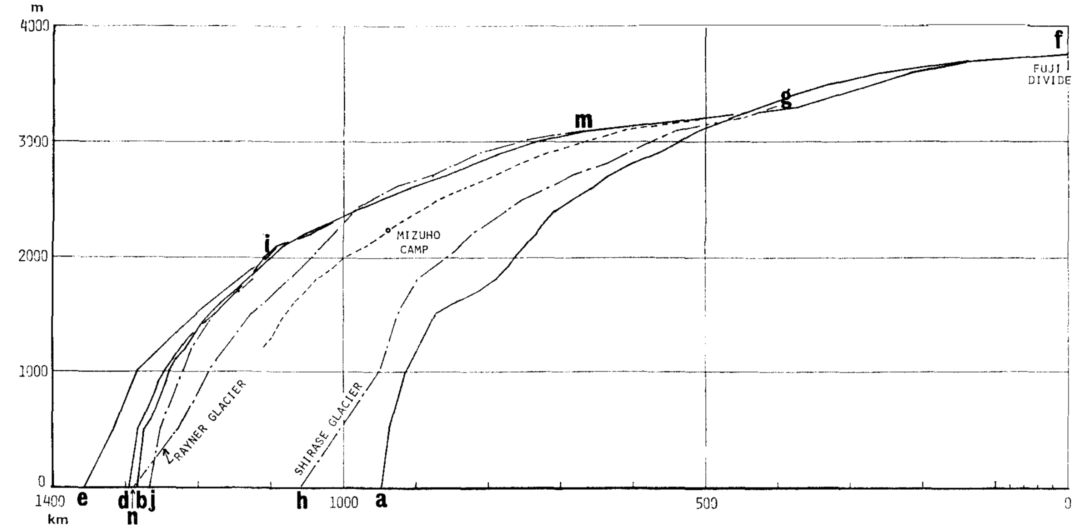

Fig. 2. Vertical profiles of the ice sheet surface along ridge and valley, in 1969–1974 (Points f, a, b, d, e, g, h, i, j, m and n correspond to those in Fig. 1).

Table 1. Gradient of the ice sheet surface in Mizuho Plateau.

Ice sheet surface \ Elevation range		0-500 m	500-1000 m	1000-2100 m	2100-3100 m	3100-3300 m	3300-3700 m	3700-3775 m
Ridge	f-b	50×10^{-3}	16×10^{-3}	6.9×10^{-3}	2.4×10^{-3}	0.7×10^{-3}	1.7×10^{-3}	0.5×10^{-3}
	f-d	41	14	7.0	2.2			
	f-e	13	16	5.4	2.2			
Valley	i-j	31	16	8.3	2.2			
	m-n	†7.8	13	6.9 (up to 2400 m)	disappeared			
Ice sheet surface \ Elevation range		**0-1000 m**	**1000-1500 m**	**1500-1800 m**	**1800-2400 m**	**2400-3100 m**	**3100-3700 m**	
Ridge	f-a	31×10^{-3}	12×10^{-3}	3.8×10^{-3}	7.1×10^{-3}	3.5×10^{-3}	1.6×10^{-3}	
Valley	g-h	*9.3	19	6.1		2.9	1.5	

(* Shirase Glacier, † Rayner Glacier)

change of the gradient could be observed at 500 m, 1000 m, 2100 m, 3100 m, 3300 m and 3700 m in elevation along each of the ridges f-b, f-d and f-e, and valleys i-j and m-n, as well as at 1000 m, 1500 m, 1800 m, 2400 m, 3100 m and 3700 m in elevation along both the ridge f-a and the valley g-h. As the cross-sectional profiles of these ridges and valleys could be divided into two groups in shape as seen in Fig. 2, Table 1 was divided into two parts except for the highest elevation range where the ridges and valleys were converging into the Fuji Divide.

The gradient of the ice sheet surface and their geographical distribution would strongly affect the climatic condition of the province, especially for generation of katabatic wind. A characteristic feature of the surface topography of the ice sheet in Mizuho Plateau was that the gradient of the surface was relatively constant with a value less than 1.7×10^{-3} in the region where the elevation was more than 3100 m, while in the rigion lower than that the gradient of the surface varied widely, $2.2-50\times10^{-3}$, depending upon the location with a general tendency that the closer a location is to the coast, the steeper is the ice sheet surface. Therefore, the contour line of 3100 m could be the upper boundary of the katabatic wind region (BALL, 1960). If so, Mizuho Camp is located in the katabatic wind region.

3.2. *Profiles of the ice sheet along the traverse routes*

Profiles of the ice sheet along the traverse routes in Mizuho Plateau are given in Figs. 3, 4, 5, 6 and 7. The routes of the oversnow traverses were generally neither parallel nor perpendicular to the surface contour lines of the ice sheet, but oblique commonly and crossing valleys and ridges occasionally. Therefore, one must be careful in distinguishing between the information given by Fig. 2 and that by Figs. 3 to 7: the former represents the vertical profiles of the ice sheet surface along the ridges and valleys, while the latter merely shows the profiles along the traverse routes. It is difficult to make a topographical map of the bedrock surface in Mizuho Plateau only from the ice thickness data along the traverse routes, as the relief of the bedrock was much strong even in a narrow range, while that of the ice sheet surface could be figured out therefrom, as its

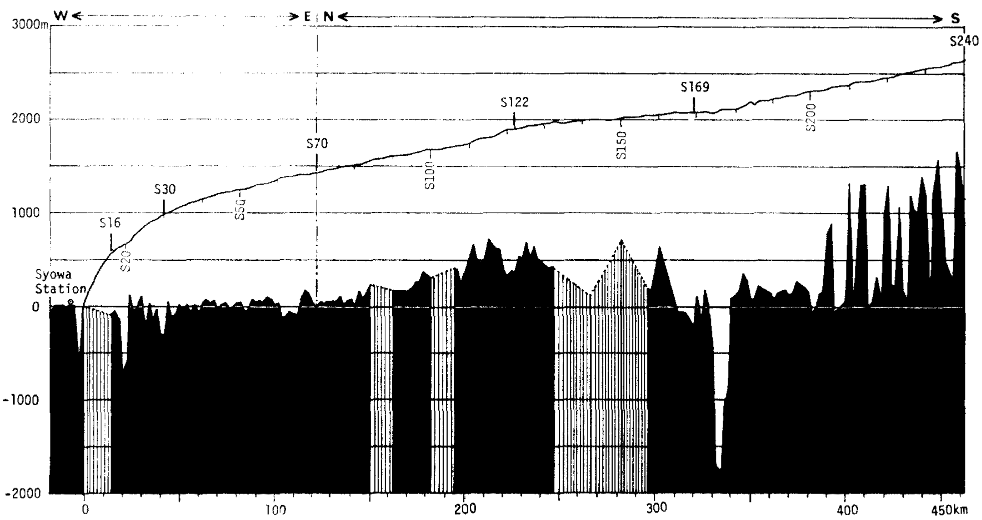

Fig. 3. Vertical cross-section of the ice sheet along Route S, from the coast to S240, Mizuho Plateau, in 1969–1974 (In the hatched area measurement of ice thickness is lacking. Vertical magnification to the horizontal is ×50).

relief was extremely broad in general. However, one can figure out some local characteristics of the bedrock relief, the existence and distribution of particular types of the bedrock relief, together with an outline of the local ice sheet, from Figs. 3 to 7.

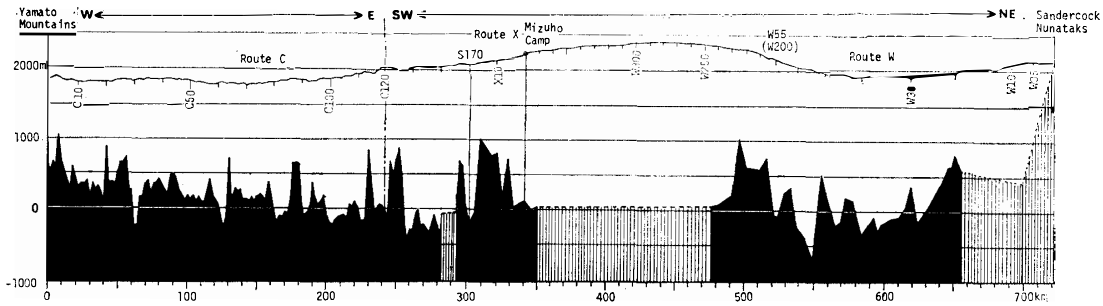

Fig. 4. Vertical cross-section of the ice sheet along Routes W, X and C, from Sandercock Nunataks to the Yamato Mountains, Mizuho Plateau, in 1969–1974 (In the hatched area measurement of ice thickness is lacking. Vertical magnification to the horizontal is ×50).

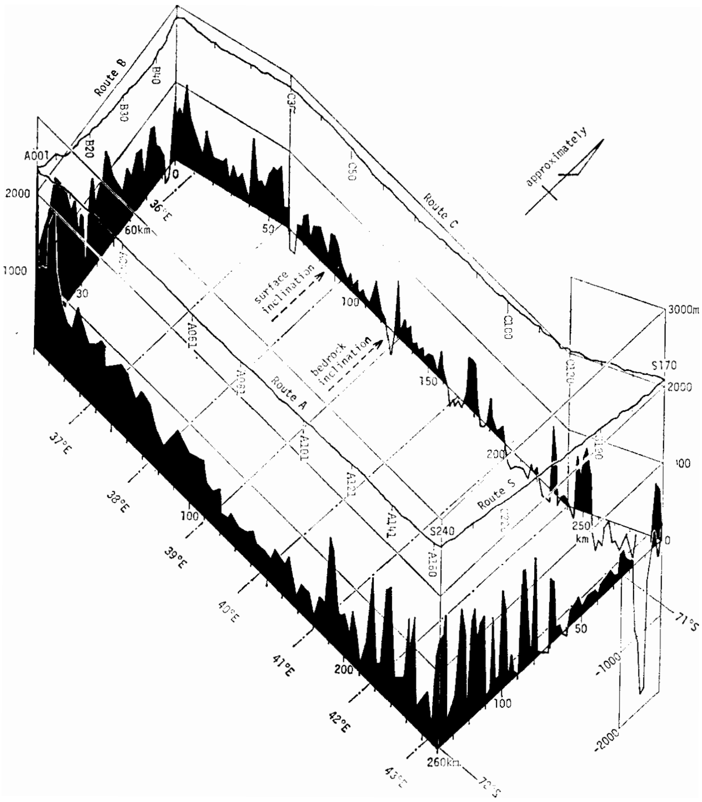

Fig. 5. Isometric drawing of the ice sheet in the region of a circuit track of Routes S-A-B-C, Mizuho Plateau, in 1969–1974 (Vertical magnification to the horizontal is ×36).

From Fig. 3, a general tendency of the bedrock relief along Route S from the coast to S240 can be seen. The bedrock surface from the coast eastward to S70 is fairly flat at sea level with a couple of depressions of several hundreds metres (the elevation is magnified by 50 times the horizontal distance in Figs. 3 and 4); the bedrock surface from S70 southward to S200 is hilly with a very deep depression, 1759 m below sea level with a width of 14 m between S172 and S179, and the bedrock surface from S200 southward to S240 is mountainous.

Fig. 4 reveals that the bedrock relief along Routes W, X and C from Sandercock Nunataks to the north part of the Yamato Mountains is fairly mountainous, although no measurement was made at most of the stations between Sandercock Nunataks and W18, and all the stations between W250 and W365, because of instrumental troubles. From the surface topography of the ice sheet, the existence of a fairly high mountainous region of the bedrock was presumed between W250 and W365. Supplementary surveys are definitely necessary.

Figs. 5, 6 and 7 are isometrical drawings of the ice sheet and bedrock where

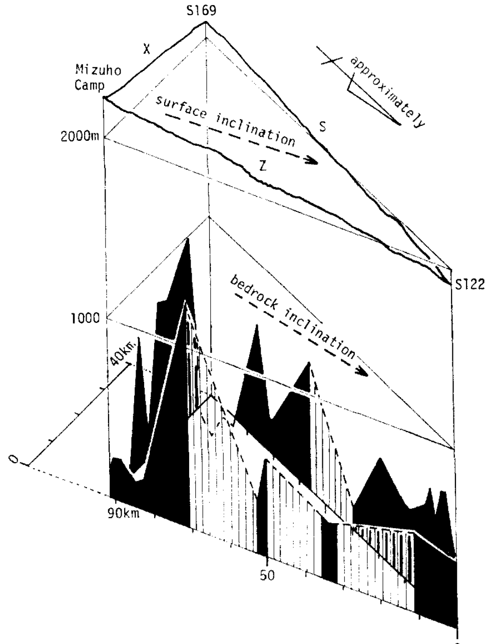

Fig. 6. Isometric drawing of the ice sheet in the region of a circuit track of Routes Z-X-S, Mizuho Plateau, in 1969-1974 (In the hatched area measurement of ice thickness is lacking. Vertical magnification to the horizontal is ×45~51, depending upon the direction).

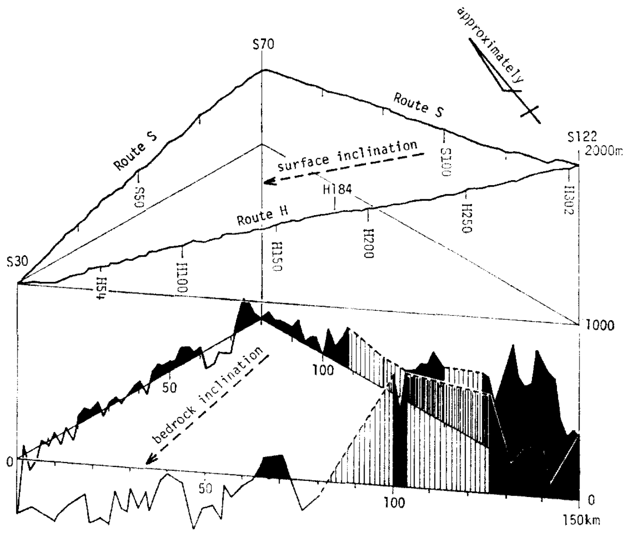

Fig. 7. Isometric drawing of the ice sheet in the region of a circuit track of Routes S-S-H, Mizuho Plateau, in 1969-1974 (In the hatched area measurement of ice thickness is lacking. Vertical magnification to the horizontal is ×48~51, depending upon the direction).

an oversnow traverse was made in a closed circuit track for each. Some ideas of the general feature of the ice sheet and the bedrock in a horizontal extent could be obtained from these figures, although the track of the traverse was occasionally modified to a straight line in the figures, and the elevation was magnified by 36–50 times of the horizontal distance depending upon the case.

Fig. 5 reveals the following:

1) Existence of a mountainous area of the bedrock around S240, as pointed out in Fig. 3, is very clear; it extends up to S200 northward along Route S, and to A115 westward along Route A, at least.

2) A big trough of the bedrock may exist across Route S, between S172 and S179, and Route C, between C142 and C146. At the moment, no definite evidence is available to prove the existence of a trough there, because ice thickness data between C142 and C146 were not obtained because of instrumental troubles, while a big depression of the bedrock between S172 and S179 seems to suggest a section of a trough. If a big trough exists there, however, the width and the depth of it could be of the order of 10 km and 1700 m respectively, leading to the Shirase Glacier. Further extensive surveys are strongly called for this subject.

3) Existence of the Yamato Mountains is reflected on the bedrock topography, *i.e.* the bedrock surface rises westward to the Yamato Mountains.

4) Also, the bedrock surface descends northward which makes the ice sheet flow northward, in this region.

Fig. 6 clearly indicates that both the surfaces of the ice sheet and the bedrock incline northwestward. This fact would imply that the ice sheet in this area flows northwestward.

In Fig. 7, it can be seen that:

1) The south boundary of the hilly region of the bedrock, pointed out in Fig. 3, is around S70 along Route S and H200 along Route H.

2) The general bedrock surface in this area inclines evidently toward the Sôya Coast in the west-southwestward, although the ice sheet surface inclined northwestward.

3.3. Subdivisional drainage basins in Mizuho Plateau

Mizuho Plateau was divided into several subdivisional drainage basins of the ice sheet by the ridges of the surface, as shown in Fig. 1, on an assumption that ice flowed in the direction of the general surface slope (GIOVINETTO, 1964) which was supported by an actual measurement of the ice sheet flow across the triangulation chain established along Route A (NARUSE, 1978). (The ridge line occasionally crosses the contour lines obliquely in Fig. 1. This is caused by insufficient altimetry data. In such a case, an indecisive ridge line was given by a broken line.)

The Shirase drainage basin, the principal one in Mizuho Plateau, has an areal extension of 20×10^4 km^2, providing the Shirase Glacier with the outlet. The mean thickness of the ice sheet in this area was estimated as 1840 m (SHIMIZU, 1977), and the mean density as 0.88 g/cm^3 from the deep core analyses at Mizuho Camp (NARITA, in preparation for printing). Using these data, the amount of the ice stored in the Shirase drainage basin was estimated to total approximately 37×10^4 km^3 in volume and 32×10^{13} t in weight.

As for the Sôya drainage basin, it had an extent of 2.2×10^4 km^2 in area, providing the outlet of the Sôya Coast which has a number of small glaciers. The mean thickness and the mean density of the ice sheet were presumed as 1290 m and 0.90 g/cm^3 respectively in this area, and the amount of the ice sheet as 2.8×10^4 km^3 in volume and 2.6×10^{13} t in weight.

As the Japanese Antarctic Research Expedition carried out scientific researches in the Rayner drainage basin only once (besides, a radio echo sounder was out of order for the most of time along Route Y), a discussion on that area is very limited. However, a depression of the ice sheet surface in the Rayner drainage basin was the most evident in Mizuho Plateau, as shown in Fig. 1, and the average thickness of ice along Route W was 1885 m.

Drainage basins of the ice sheet could be classified into two types, the converging and the diverging type. In a converging drainage basin, flow lines of the ice sheet converge into a big glacier at the outlet, resulting in a stream flow type of discharge, while in a diverging drainage basin, they diverge and result in a sheet flow type of discharge, generally with small glaciers at the outlet (MELLOR, 1959a, b, 1961). The Shirase and Rayner drainage basins belong to the former, and the Sôya, Prince Harald and Prince Olav drainage basins to the latter.

4. Conclusion

The morphological feature of the ice sheet in Mizuho Plateau was described by analyzing the compiled data of the surface elevation and thickness of the ice sheet obtained by the Japanese Antarctic Research Expedition.

The upper boundary of the katabatic wind region was estimated at about 3100 m in elevation, from the gradient of the ice sheet surface, applying the BALL's theory (1960). The mean thickness of the ice sheet was 1650 m, and the maximum 3870 m. Local trends of the bedrock surface were observed by the aid of cross-sectional profiles of the ice sheet in several locations. Mizuho Plateau was divided into several subdivisional drainage basins of the ice sheet, on an assumption that ice flows along the general slope of the ice sheet surface. The drainage basins were classified into two types, the converging and the diverging type; namely the former provides a stream flow type of discharge of ice at the outlet, while the latter a sheet flow type. It was estimated that the Shirase drainage basin (converging type) had an extent of 20×10^4 km^2 in area and stored ice of

32×10^{13} t in weight, while the Sôya drainage basin (diverging type) had an extent of 2.2×10^4 km^2 in area and stored ice of 2.6×10^{13} t in weight. As a general tendency in the province of Mizuho Plateau, the dimensions of the diverging drainage basins (the Sôya, Prince Harald and Prince Olav drainage basins) were much smaller than those of the converging ones (the Shirase and Rayner drainage basins).

As for the measurement of thickness of the ice sheet, radio echo sounding was conducted intermittently with an interval of 2–5 km along the traverse routes, and the deepest echo was simply taken as the one reflected from the bedrock surface when multi-echoes were obtained. We have to recognize that some fundamental problems were left in the operation of sounding and analysis of multi-echoes (BERRY, 1975; GUDMANDSEN, 1975; OSWALD, 1975; ROBIN, 1975).

In this research program, traverse routes were set up so as to obtain information uniformly in Mizuho Plateau as the primary step. However, the sophistication of instruments and elaboration of research operations and analyses are needed, especially on the measurement of thickness of the ice sheet. And more intensive and extensive research projects are necessary on particular subjects, *e.g.*, the existence of a large trough of the bed rock in the vicinity of S170, and the existence of a mountainous region of the bed rock in the vicinity of S240, and others, for completion of the primary stage and for development of further stages of the Research Program.

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