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Ice flow characteristics derived from bedrock topography around Mizuho Station, East Antarctica

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Abstract

The surface and bedrock topography of an about 100 kilometer square area around Mizuho Station and along routes SZ and Y, in which one of the tributaries of the Shirase Glacier is located in East Queen Maud Land, East Antarctica, was obtained by an oversnow traverse using a radio echo sounder and a barometric altimeter. Bedrock topography along the routes showed an elevation of almost sea level with an undulation of several hundreds of meters.

The map of the surface and bedrock topography around Mizuho Station shows that the station is located on the slope of a broad ridge that trends to north-west-west (NWW), and that is placed between two hills of bedrock in the northward and the southward direction that are several hundreds meters higher than surrounding bed. As to relation between the surface and bedrock topography, the direction of ice flow around Mizuho Station is estimated to be between NWW and NW. Comparison of this ice flow with that of other polar glaciers revealed that it is an ice stream that is influenced by local bedrock topography.

1. Introduction

Since 1982 the Japanese Antarctic Research Expedition has been engaged in a glaciological project to study the flow of an ice sheet and the characteristics of snow and ice in a drainage area of the Shirase Glacier located in the area of East Queen Maud Land, East Antarctica. Data from the project has revealed the features of flow and the bedrock topography of a large part of the area examined thus far (Nishio *et al.* 1984, Nishio *et al.* 1986, Nakawo and Narita 1984, Fujii *et al.* 1986, Ageta *et al.* 1987).

One of goals of the project was to conduct 700-m deep drilling at Mizuho Station (70° 42′ S, 47° 17′ E), from which a 700-m length core was brought to Japan, and several analyses of physical and chemical characteristics of core were made with the goal to determine its age in the future.

After the drilling, the closure rate of the drilling hole and the ice temperature at certain depths were measured and ice flow at Mizuho Station was studied. The results showed that the rheological property of ice at Mizuho Station was softer than that of the ice obtained at Byrd Station and that of the Northern hemisphere ice caps (Naruse *et al.* 1987). The age of ice sheet at Mizuho Station will be also studied by a flow model based upon the rheological property of the ice. The model will be made using basic information obtained on the ice thickness along a flow line.

The present paper discusses the surface and bedrock topography along the flow line passing through Mizuho Station and presents a precise map of the surface and bedrock topography around the station in order to make a flow model. Furthermore after the relation between ice flow and surface topography related to bedrock topography was determined, the direction of ice flow around Mizuho Station was estimated.

2. Methods of observation

Surface elevation and thickness measurements were carried out in 1986 along 8 survey lines which were about 100 kilometers in total length. The area surveyed around Mizuho Station, which is the center of the area, was about 100 kilometers square. The observation point was positioned by measuring the distance indicated on the distance meter of an oversnow vehicle along the surveyed lines and by measuring the magnetic direction from the observation point to the 30 m meteorological tower of Mizuho Station. Surface elevation was measured by a Paulin barometric altimeter at every 500 m along the surveyed lines, and barometric changes were corrected by closing the measuring loop at Mizuho Station. These elevation data were compiled with those obtained at Mizuho Station, where a satellite positioning was used as the reference point.

Ice thickness was measured continuously along the survey lines by a radio echo sounder, which was equipped in a oversnow vehicle with two 3-element Yagi antennas for aerials on a sledge. The radio echo sounder were mainly operated at a frequency of 60 MHz (Wada *et al.* 1980).

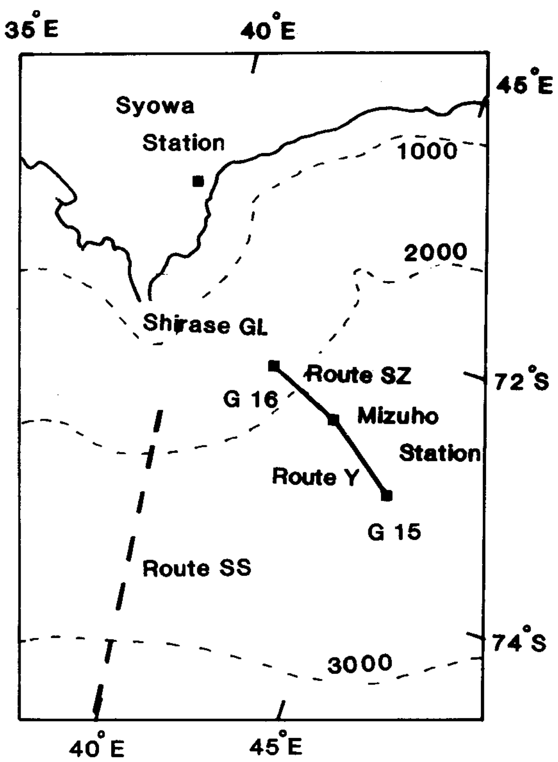

Fig. 1. Map of the surveyed area. Thick line through Mizuho Station shows routes SZ and Y. Thick dashed line shows route SS, which is a route along the main flow line of Shirase Glacier.

Data on a A-scope, which is the time-dominated data on an oscilloscope, were continuously recorded by a video tape recorder. Those data were transferred to the data of ice thickness by using 169 m/μsec of radio velocity within ice sheet (Ohmae *et al.* 1984, Robin *et al.* 1969). Bedrock elevation along the survey line was compiled by subtracting the ice thickness from the value of surface elevation.

In addition, measurements of the surface elevation and ice thickness along routes SZ (Mizuho Station to geodetic station G 16, which is situated north-east of Mizuho Station, 70° 23′ S, 42° 06′ E) and Y (to geodetic station G 15, south-west of Mizuho Station, 71° 11′ S, 45° 58′ E) were carried out as follows (Fig. 1): Surface elevation was measured by a Paulin altimeter at every 1 km and ice thickness was recorded by taking photographs of A-scope at every 1 km. All data were connected to the surface elevation of Mizuho Station, which was used as the reference point.

3. Results of measurements

along routes SZ and Y

The figure of the cross section obtained along the routes is shown in Fig. 2. Surface elevation of the downstream of G 16 was drawn by using the data digitized from the surface elevation of the Shirase Glacier drainage basin compiled by Moriwaki of the N.I.P.R.. And the dashed line of bedrock elevation shows the area where no data of ice thickness were available by radio echo sounding.

Surface elevation increased gradually from about 1800 m at G 16 to about 2600 m at G 15. While the surface elevation of the down stream of the flow decreased steeply to the outlet of the Shirase Glacier. But the height of bedrock elevation was almost the same near sea level along the routes, with an undulation of some hundreds of meters, especially near G 16.

around Mizuho Station

Maps of the ice sheet surface and bedrock topography around Mizuho Station are shown in Fig. 3 a,b. The characteristic features of the surface topography around Mizuho Station is a broad ridge, which runs from the south-east to the north-west of Mizuho Station, and a slightly shallow hollow, which is found east of the station. The station is thus located on the slope of the broad ridge.

Comparing the above feature with those shown in

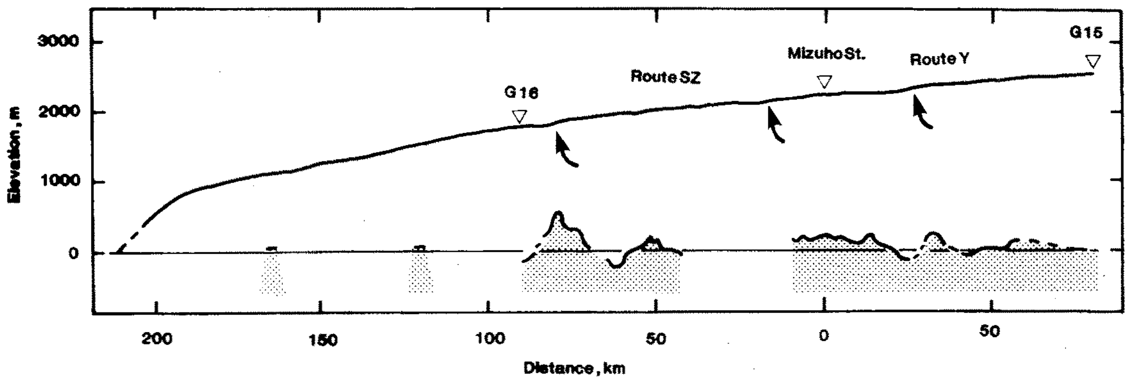

Fig. 2. Surface and bedrock profile of ice sheet along routes SZ and Y. Triangles show the position of the geodetic station and arrows indicate the location of the steep slope of the surface profile (see in text).

the map made in 1972 (Yoshimura and Kimura, 1975), it was noted that the shallow hollow did not exist in 1972 but the station was situated placed on the slope of height existing at west of the station. In the detailed map of 1978 (Fujii, 1979), which included an area of 2 km × 2 km around Mizuho Station, the hill was located west of the station measured about 10 m high.

It is considered that the hill was constructed by snow drifting for many objects of Mizuho Station. Thus, the surface elevation of the windward of Mizuho Station is shown lower than the leeward of the station.

Bedrock topography shows the various variations of bedrock reliefs. One characteristic feature of topography is two hills: one positions in the north of Mizuho Station and the other southwest of the station. A section of the bedrock topography in the northwestern area of Mizuho Station was shown by a dashed line because no bedrock echoes of radio echo sounding could be obtained. This means that the ice of this area is thick and bedrock elevation may be low. The topography resembling a valley was found from west to east under Mizuho Station. The height of bedrock in the valley decreased gradually toward the western part; therefore, no bed echoes could be measured. Based upon the bedrock topography, Mizuho Station located in the valley between two hills.

4. Discussions

In the present paper, the surface and bedrock elevations were connected to the surface elevation of Mizuho Station as the reference point. This reference surface elevation of Mizuho Station was used the value decided by the Navy Navigation Satellite System (N.N.S.S.). As the ellipsoid of the satellite (WGS -72) is different from that in the map (Bessel reference ellipsoid) in Fig. 1, the value of the altitude at Mizuho Station is different from two coordinates of the ellipsoid. At Syowa Station the difference was reported as 31 m $\pm$ 2 m (Shibuya and Ito, 1983). If the difference at Mizuho Station is the same as that at Syowa Station, all the values of the surface and bedrock elevation will decrease by about 30 m, and thus the authors adopted 2260 m height as the surface elevation of Mizuho Station. But considering the difference between the two ellipsoids, the elevation of Mizuho Station becomes 2230 m above sea level. However, at present the exact difference is not known. Therefore in the present paper, all data reference to the surface elevation of Mizuho Station, 2260 m, decided by N.N.S.S..

As the bedrock elevation along routes SZ and Y may be lower by about 30 m for the same reason, the bedrock elevation along these routes is considered to be about sea level. The elevation is lower than the average value of the bedrock elevation in the area of the main flow line of Shirase Glacier. Although no data on the ice thickness across the routes SZ and Y could be obtained, it was expected that the routes pass through the valley topography. So, though no divide is located in a surface and bedrock topography, these lower elevation of bedrock is considered to indicate that the line along these routes is the "tributary" of the Shirase Glacier. Therefore, this flow line going along routes SZ and Y passing through Mizuho Station is a important flow line that can be used to decide the age of the ice at Mizuho Station.

ice flow characteristics

As already mentioned, Mizuho Station is situated in an area containing a tributary of the Shirase Glacier and rests on the flow line of an ice sheet for a 100 km order. In this section, the local flow of the ice sheet around Mizuho Station for a small scale, such as a 10 km order, was considered. The local flow, based on the surface and bedrock topography around Mizuho Station already shown in Fig. 3, was also discussed in order to compare the two topographies, a three-dimensional perspective display around Mizuho Station was made (Fig. 4).

Based on Figs. 3 and 4, there is the hill of surface topography on the north-west of the station. This hill corresponds almost exactly to the hill of bedrock topography located in a up-stream. In the south-western area of Mizuho Station, there is the height of bedrock and no surface hill locates corresponding to the bedrock hill but a lower area of surface topography situated. These correspondings expect the relationship between the surface and bedrock topography. In Fig. 2, arrows show the positions of the steep slope of the surface topography along route SZ and Y. These steep slopes correspond to the hill of bedrock. The surface topography along the ice flow has been reported to be provided by the bedrock topography in the glaciers and ice streams of Marie Byrd Land, West Antarctica (McIntyre, 1985). Based on these results, the slope of the southwest area of Mizuho Station is considered to correspond to locating a bedrock hill of a up-stream. Though we have no data of the ice thickness in a up-stream area, it is expected there is the bedrock hill of the up-stream corresponding to the slope of the south-west area. So, it is considered that the ice flow directs toward NW. This direction agrees with the direction of the ice flow, NW, along routes SZ and Y for a 100-km order. But the broad ridge of the surface topography near Mizuho Station runs toward NWW. Thus, it can be noted that the flow direction around Mizuho Station is between NWW and NW. This result agrees with the flow direction (303 degrees of true direction) decided by N.N.S.S..

The direction of ice flow around Mizuho Station is between NW and NWW, and the flow line through Mizuho Station shows an almost NW direction. This

a)

b)

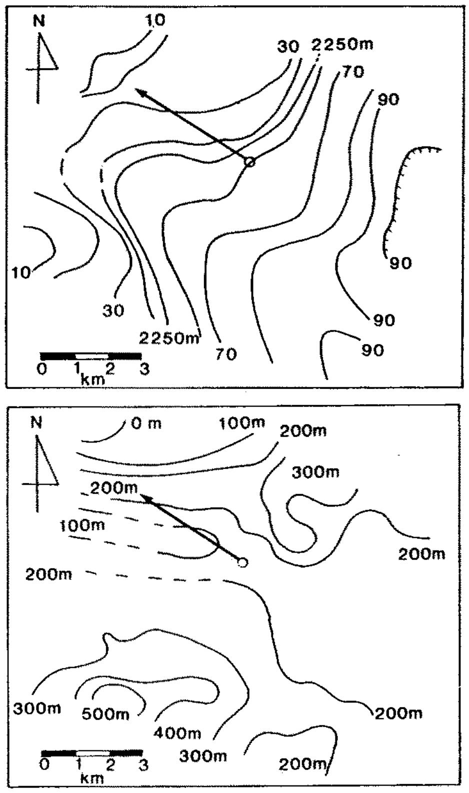

Fig. 3. Compiled maps of the surface and bedrock topography around Mizuho Station.
a) Surface topography
Values indicate the elevation over 2200 m, except 2250 m (m in unit).
b) Bedrock topography
Values indicate the elevation of bedrock. Open circle shows the position of Mizuho Station in both figures. Arrow indicates the direction of ice flow by N.N.S.S..

difference was considered to be caused by the valley of bedrock topography. In other words, the characteristics of ice flow are influenced by a large scale topography, which is the "tributary" of the Shirase Glacier, and in addition to the large scale topography the effect of local topography influences the characteristics of ice flow as a factor of a smaller scale topography. Therefore, the direction of ice flow of Mizuho Station is slightly westward by the local topography, like the valley of bedrock topography toward NWW. Furthermore, although the direction of ice flow is 303 degrees (true direction) on the surface, it is speculated that the ice flows westward in the basal layer of the ice sheet along a valley.

It was questioned whether there was any effect of local topography on the surface velocity of ice flow,

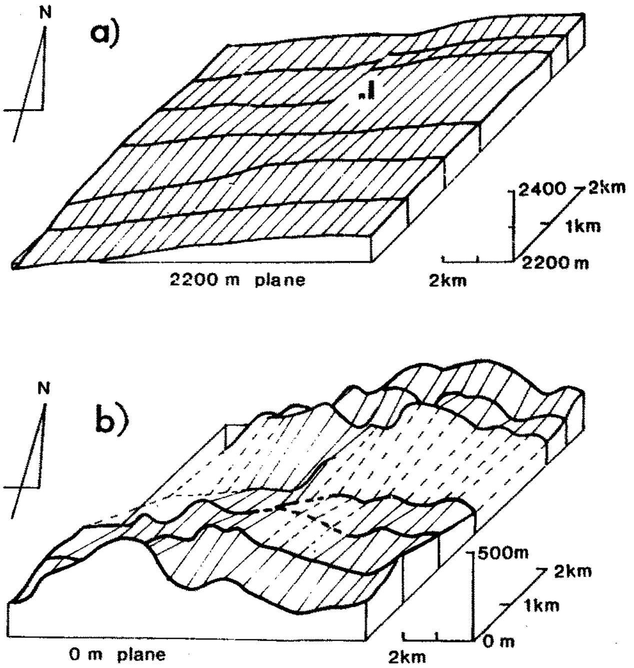

Fig. 4. Three-dimensional perspective display of the (a); surface and (b); bedrock topography around Mizuho Station. Thick dashed lines show no data of ice thickness available by radio echo sounding.

such as on the direction of ice flow. Fig. 5 illustrates the relationship between a driving stress ($\tau_b = \rho gh \sin\alpha$, α; surface inclination, h; ice thickness, ρ; ice density, g; gravitational acceleration) and the value of surface velocity by N.N.S.S. divided by ice thickness at geodetic points on routes SS, SZ, Y in Fig. 1 and around Mizuho Station. The values around Mizuho Station (hatched part) disperse, because only one value of surface velocity and many values of b are used in the calculation. Fig. 5 compares the data of the present study and the values calculated along Byrd Glacier, West Antarctica (McIntyre, 1985) and the regression line of many data compiled on a polar ice sheet (Budd and Smith, 1981). Although the values scattered the characteristics of ice flow in the area of the Shirase Glacier drainage naturally fall under the category of a polar ice sheet. In comparison with McIntyre's data, the ice flow characteristics at the geodetic point G 16 and around Mizuho Station, where the ice flow is faster than in the surrounding area, and those in the area of geodetic point G 15 suggest an ice dome, where ice flows slowly. Therefore this tributary of the Shirase Glacier appears to be an ice stream that moves down-stream of to a place near Mizuho Station. This characteristic of ice flow is caused by the valley of bedrock, because ice is streaming along a valley. Considering the flow near the basal layer, it will be important to note that the local topography with a width of the valley topography is becoming to narrow from upper area of Mizuho Station to the lower area. In the steady state, in which ice thickness does not change, if we consider the flow velocity of the basal layer which means the ice mass near the ice sheet bed, the velocity may be larger than in the basal layer without valley topography because a large ice mass is centered into a valley with the width of flow volume being narrow. In the case of the flat plane without a valley, the width of flow is constant and the velocity of ice is also constant. On the other hand, in the shallow-depth layer which means it is not the basal layer, the effect of a local bedrock topography is small and its condition of flow is characterized by a large scale of ice sheet, and thus the velocity is almost constant with a depth. Furthermore, a larger shear may exist between the basal layer and the surface layer, where the laminar sheet flow is domi-

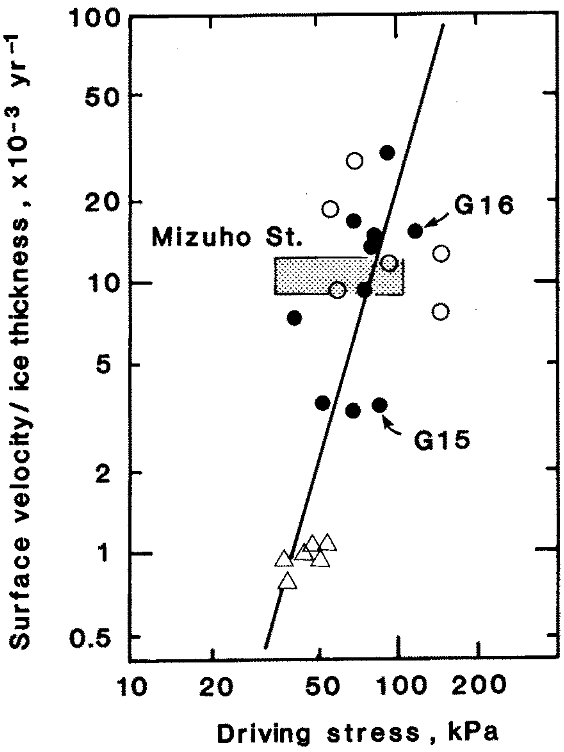

Fig. 5. Relation between driving stress and surface velocity /ice thickness. Hatched area shows the calculated values around Mizuho Station, and darkened circles indicate the values at geodetic points on the routes SS, SZ and Y shown in Fig. 1. Open circles and open triangles indicate the values corresponding to the area of ice stream and of the accumulation area of the up-stream of Byrd Glacier, respectively (after McIntyre, 1985). Thick line shows the regression line of many values for the polar ice sheet examined by Budd and Smith (1981) (after McIntyre, 1985).

nant. But in the non-steady state, as the ice mass flow more than the steady state as like as a surging glacier, the change of the ice thickness of ice sheet may also occur around Mizuho Station, such as the condition of thinning occurring in the drainage area of the Shirase Glacier, as discussed by Mae (1979).

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