THE RECENT VARIATION OF ICE SHEET IN MIZUHO PLATEAU

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Abstract: On the basis of the glaciological survey carried out by the Japanese Antarctic Research Expedition in Mizuho Plateau, thinning of ice sheet in the observed area is discussed. The vertical profiles of oxygen isotope (O^{18}) and ice temperature at Mizuho Station are also explained by the thinning of ice sheet which commenced 100 years ago. A simple calculation of basal shear stress shows the unstable state of the ice sheet in Mizuho Plateau.

1. Introduction

The Japanese Antarctic Research Expedition (JARE) has carried out glaciological research programme in Mizuho Plateau. The main subjects of the programme are the measurements of mass balance, ice flow and surface and sub-glacier topography, and the results obtained until 1975 were published in Memoirs of National Institute of Polar Research (ISHIDA, 1977). The ice core drilling to a depth of 150 m was carried out at Mizuho Station (70°41′53″S, 44°19′54″E). The physical and chemical properties of the cores were examined and the ice temperature in the bore hole was measured. The results were published also in Memoirs of National Institute of Polar Research (KUSUNOKI and SUZUKI, 1978).

This paper is focussed on the change of the ice sheet in Mizuho Plateau in relation to the climatic change and the ice-bed interaction.

2. The Thinning and Basal Sliding of Ice Sheet in Mizuho Plateau

JARE–10 set up a triangulation chain in 1969 along the traverse route shown in Fig. 1 and JARE–14 resurveyed the chain in 1973. NARUSE (1978) analyzed the triangulation chain, taking into account the effect of the firn densification, and estimated the rate of change ($\dot{h}$) of the ice thickness (h); the main part of the route between A and C was thinning by 70 $cm \cdot a^{-1}$ which was larger than the mean square error of $\dot{h}$, 18 $cm \cdot a^{-1}$ at point A and 31 $cm \cdot a^{-1}$ at point C.

YOKOYAMA (1975) measured the snow accumulation off-set markers established along the route BC. The accumulation rate, $\dot{a}$, of ice which was calculated from

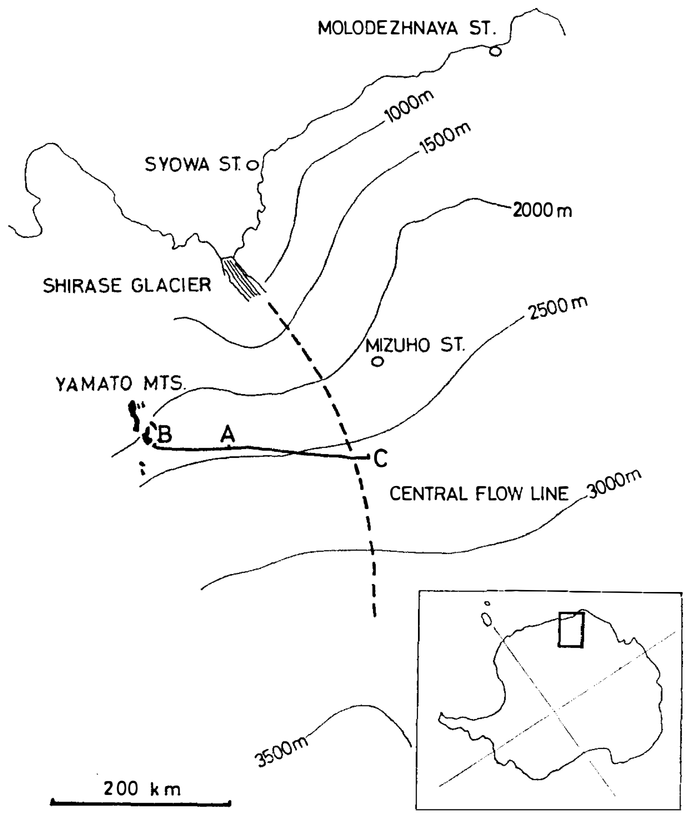

Fig. 1. The map of Mizuho Plateau and triangulation chain BC.

YOKOYAMA's measurement shows that $\dot{a}$ is about 7 cm·a^{-1} on the average along the route and the maximum is about 40 cm·a^{-1}. In the coastal area near Syowa Station where cyclones invade, the amount of snow precipitation rarely exceeds about 50 cm·a^{-1} (YAMADA *et al.*, 1978). This means that the observed thinning is too large to be compensated with the present value of snow accumulation rate observed in Mizuho Plateau, and the temporal variation of the accumulation rate can not account for the large value of the thinning rate.

MAE (1977, 1978) and MAE and NARUSE (1978) studied the thickness change of ice sheet using an equation of mass continuity which was given by SHUMUSKIY and BAUER (1965). The equation of SHUMUSKIY and BAUER was simplified as

$$\dot{h}=\dot{a}-(\dot{\varepsilon}_x+\dot{\varepsilon}_y)h+u_s\alpha_s-u_b\alpha_b \qquad (1)$$

where $\dot{\varepsilon}_x$ and $\dot{\varepsilon}_y$ are strain rates at the surface, u_s and u_b are the horizontal velocities at the surface and the base, α_s and α_b are the slopes at the surface and the base.

Substituting the observed values of $\dot{h}$, $\dot{a}$, $\dot{\varepsilon}_x+\dot{\varepsilon}_y$, h, u_s and α_s into eq. (1), $u_b\alpha_b$ is obtained. Between points A and B, $u_b\alpha_b$—0, and between points A and C, $u_b\alpha_b$— 55 cm·a^{-1}. This large value of $u_b\alpha_b$ between points A and C suggests that u_b is significantly large and because $u_b\alpha_b \gg \dot{a} - (\dot{\varepsilon}_x + \dot{\varepsilon}_y)h + u_s\alpha_s$ the thinning of the ice sheet may be caused predominantly by the basal sliding. The result of radio-echo sounding shows that the slope of the bedrock at point C is large and is about 4×10^{-2}. Since $u_b\alpha_b = 45\ \text{cm}\cdot\text{a}^{-1}$, u_b at point C is about $10\ \text{m}\cdot\text{a}^{-1}$.

NISHIO and MAE (1979) calculated the vertical distribution of ice temperature beneath the route between points A and C. Their calculation suggests that the ice temperature at the base may be at the melting point. This means that the basal sliding is caused by the wet base due to a rise in temperature at the base. If we assume that the thinning rate of the ice sheet is constant, the thinning and basal sliding commenced about a few hundred years ago, because the lowering of the ice sheet around the Yamato Mountains is about a few hundred meters (MAE, 1979).

If the basal sliding is caused by the rise of ice temperature at the base, the following two causes are conceivable

1) decrease in accumulation rate,
2) rise in air temperature.

ROBIN (1955) calculated the vertical temperature distribution of ice sheet based on a simple steady-state model of heat conduction and showed that the temperature difference between the surface and the base increases as the accumulation rate decreases. A simple calculation of a propagation time of ice temperature from the surface to the base shows that the propagation time of the ice temperature change throughout the ice mass due to the change of air temperature and accumulation rate is 10^4–10^5 years. If the above-mentioned two causes are accepted, the decrease in accumulation rate and/or increase in air temperature after the last glaciation is a cause of the basal sliding which would result in the thinning of the ice sheet.

3. Change of Ice Thickness at Mizuho Station Deduced from Vertical Profile of Ice Temperature

FUJII (1978) measured ice temperature in a bore hole to a depth of 150 m at Mizuho Station as shown in Fig. 2. NISHIO (private communication) and NISHIO and FUJII (1979) analyzed the temperature profile and concluded that the ice temperature above a depth of 100 m is different from a theoretical profile (dashed line in Fig. 2) using a steady-state model, and the present surface temperature is about 1.0–1.2°C higher than the theoretical surface temperature derived from the steady-state model. This suggests that the rise in air temperature and/or the lowering of ice surface occurred recently.

WATANABE *et al.* (1978) measured the content of O^{18} as shown in Fig. 3; the value of δ increases clearly above a depth of 20 m which corresponds to the age of 100 years ago. The sharp increase in δ value near the surface suggests that the air temperature has been rising and/or the ice surface has been lowering since about 100 years ago.

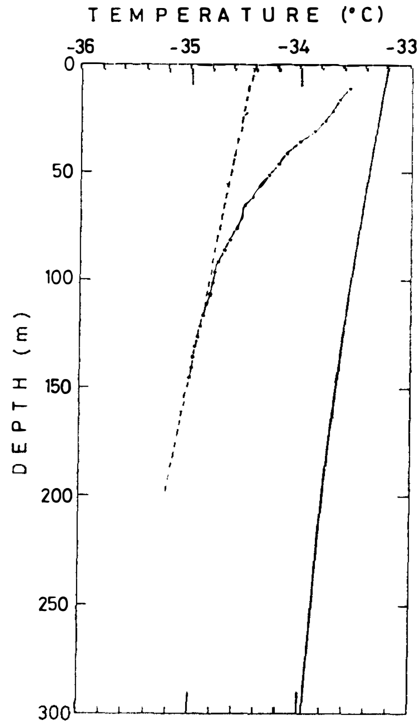

Fig. 2. The vertical profile of ice temperature at Mizuho Station. Dashed and solid lines indicate the calculated ice temperature based on a steady-state model. A dotted line indicates a measured temperature. After NISHIO (private communication).

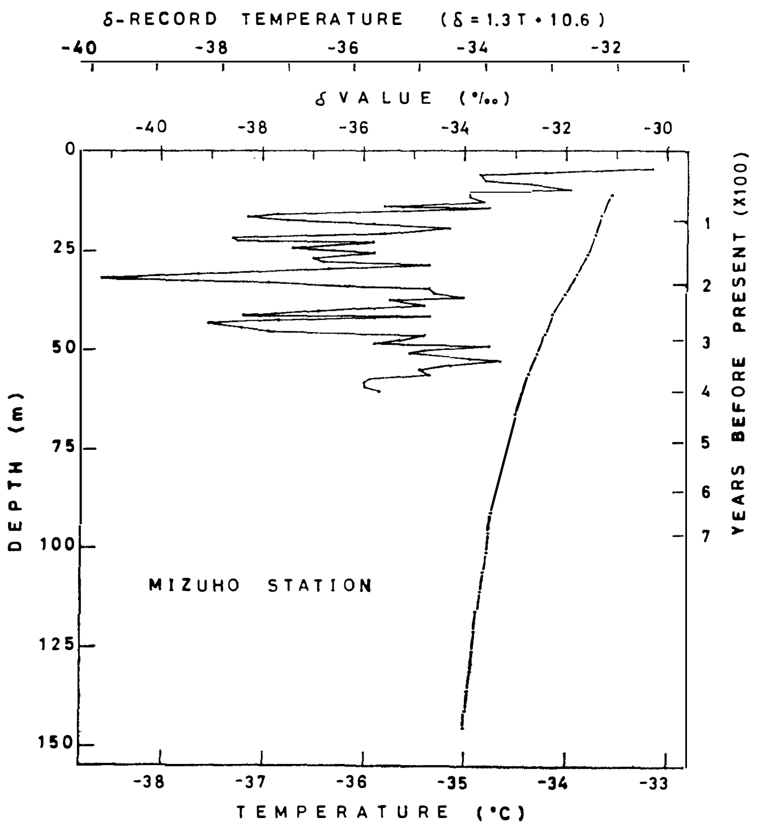

Fig. 3. The vertical profile of δ value of O^{18} (solid line) and ice temperature (dotted line). After WATANABE et al. (1979).

It is not obvious which one is the major mechanism of the increase in the ice temperature and the δ value of O^{18} near the surface, the increase in the air temperature or the lowering of the ice surface. If we assume that the lowering of ice surface is the major mechanism, since the lapse rate is about 1.3°C/100 m (SATOW, 1978) and the temperature difference at the surface (dashed line and dotted line in Fig. 2) is about 1.2°C, the thinning of the ice sheet commenced about 100 years ago and this is supported by the δ value profile. Therefore, it is likely that the thinning of the ice sheet at Mizuho Station commenced about 100 years ago.

4. Basal Shear Stress in Mizuho Plateau

The thinning caused by the basal sliding suggests that the ice sheet of Mizuho Plateau may be in an unstable state at present. The basal shear stress is an important parameter to examine the dynamical state of ice sheet. The basal shear stress, τ_b, is given by

$$\tau_b = \rho g h \sin \alpha_s \qquad (2)$$

where ρ is the density of ice and g is the gravitational acceleration.

The main part of the traverse route runs into the Shirase Glacier. Then, τ_b along the central flow line of the Shirase Glacier drainage basin is calculated from the surface morphology shown in Fig. 4 which is drawn with various data. Fig. 5 shows that τ_b increases with distance from the coast, reaching the maximum of 1.8 bar around 100 km, and then gradually decreases. The increase in τ_b from the coast is due to the increase in h, while the decrease in τ_b beyond 100 km from the coast is caused by the decrease in α_s. The curve of τ_b along the central flow line of the Shirase Glacier is very different from those of stable glaciers and ice sheets, but is

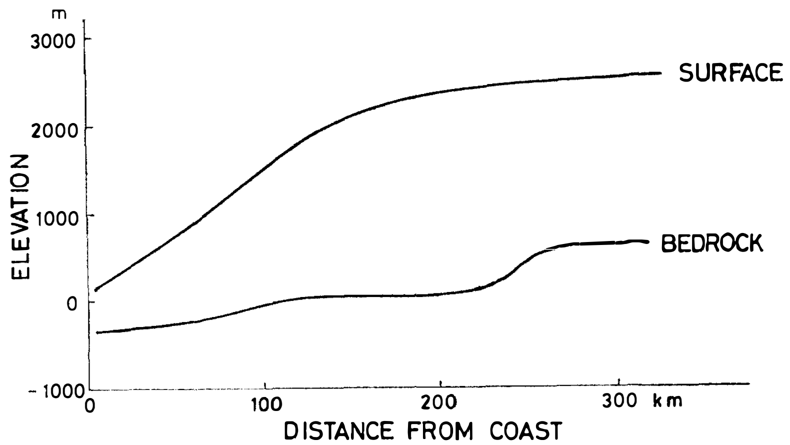

Fig. 4. The morphology of the surface and bedrock along the central flow line of the Shirase Glacier.

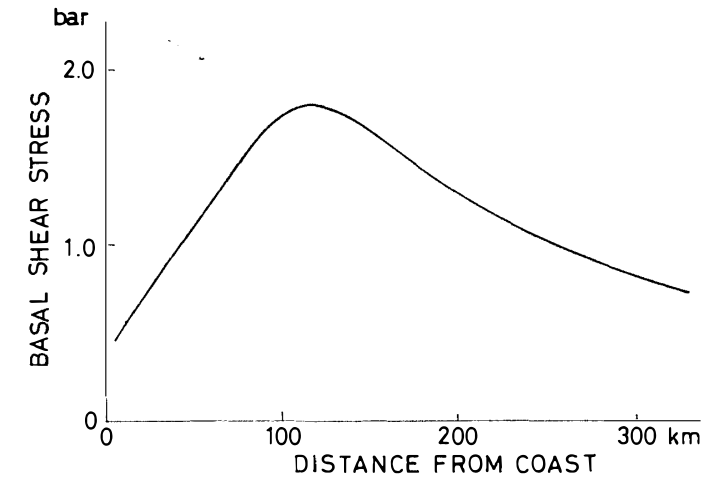

Fig. 5. The basal shear stress along the central flows line of the Shirase Glacier drainage basin.

similar to the glaciers in a presurge state (ROBIN and WEERTMAN, 1973). This may suggest that the ice sheet in Mizuho Plateau is not in a stable state. Therefore, it is very important to investigate the dynamical state of the ice sheet for the future ice sheet variation.

5. Discussion

Mizuho Plateau is not a large area in East Antarctica. However, the thinning and unstable state of ice sheet occurring in Mizuho Plateau is possible to occur in other areas of East Antarctica. The East Antarctic ice sheet is divided into three areas; Queen Maud Land area, Lambert Glacier area and Dome C area. In the Queen Maud Land, mountains and nunataks located at about 2000 m above the sea level are obstacles to the flow of ice. The ice of the central part of drainage basin in East Antarctica flows into the Lambert Glacier as well as the ice into the Shirase Glacier. In the Dome C area the shape of ice sheet is like a cap. Therefore, the feature of the ice sheet of Mizuho Plateau is similar to that of the Lambert Glacier area and it is very important to measure the change in the ice thickness of the Lambert Glacier area. In Mizuho Plateau, it is urgently needed to measure the change of ice thickness and to carry out the analysis of ice cores retrieved from many places in the plateau, especially from the down stream area where the basal shear stress is much higher than at the route BC.

The basal sliding in Mizuho Plateau is caused by the wet base. One of the most efficient methods to detect the wet base is radio-echo sounding. The phenomenon called "spatial fading" due to the roughness of the bedrock surface causes a regular echo pattern. OSWALD (1975) pointed out that when water film exists at the bottom the spatial fading length appearing on the continuous records of radar echo extends more than 200 m. On the other hand, when the bedrock is frozen, the length is approximately 5 m. Therefore, if it is possible to carry out radio-echo sounding in Mizuho Plateau, we can know the area of wet base.

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