ON THE CONTRACTION OF BOREHOLE AT MIZUHO STATION, EAST ANTARCTICA

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Abstract: Changes of borehole diameters at different depths down to 400 m were estimated. Results are as follows:

1) Applying the flow law which was deduced from borehole closure observations by PATERSON (Rev. Geophys. Space Phys., **15**, 47, 1977), the tertiary creep will start after about half of a year and the diameter of the hole will be 2/3 of the initial in a year and 1/10 after 2 years at a depth of 400 m, provided that the shifting from the secondary to the tertiary occurs at total strain, $\varepsilon=0.1$. But the rate is 3 to 4 times larger when the flow law derived by MAE (J. Glaciol., **24**, 53, 1979) from the flow observations at Mizuho Plateau is used.

2) The borehole closure rate has much difference depending on the flow law of ice. In order to induce a representative flow law of ice in Mizuho Plateau, the importance of borehole observation and technical development of boring is emphasized.

1. Introduction

The drilling operation was practiced at Mizuho Station, East Antarctica and it reached the depth of 700 m in August 1985. In the operation, the contraction of borehole was appreciable and the penetration of the drill equipment sometimes was not easy at the depth deeper than 300 m.

PATERSON (1977) analyzed the borehole contractions at Byrd Station and three other sites. He noticed that the strain rate accelerates with time and when the strain reaches about 0.05 to 0.2, the secondary creep shifts to the tertiary. He induced a relation between the secondary creep rate and the stress, that is the flow law, from *in situ* data of borehole closure. The result showed an extremely good coincidence of four borehole closure rates used. Following PATERSON, the borehole contraction rate at Mizuho Station was estimated. This study will give a good information for planning drilling operations.

2. Estimation of Borehole Closure

According to PATERSON (1977), the value of effective strain rate, $<\dot{\varepsilon}>$, averaged over a time interval from t_1 to t_2, can be calculated by the equation,

$$<\dot{\varepsilon}>=1/(t_2-t_1)\ln(a_1/a_2), \tag{1}$$

where a_1 and a_2 are the radii of the hole at times t_1 and t_2. An appropriate measure of the total strain, ε, in ice is

$$\varepsilon = \ln(a/a_0), \tag{2}$$

where a is the initial radius of the hole.

The effective shear stress, τ, on the wall of the hole is shown by

$$\tau = -P/n, \tag{3}$$

where P is the overburden pressure in the ice at an appropriate depth.

General equation of flow of ice is

$$\varepsilon = A \cdot \exp(-Q/RT) \cdot \tau^n, \tag{4}$$

where A; constant, Q; the activation energy, R; the gas constant, T; temperature, n; constant.

PATERSON (1977) obtained the flow law by using the data from Meigen Island ice cap, Devon Island ice cap, Byrd Station and Site-2. Derived values are $Q=54$ kJ/mol and $A=2665$ for $n=3$ at $T=251$ K.

Ice temperature along the borehole at depths 200–400 m are not obtained yet. Thus we assumed the ice temperature at the depths to be -35°C according to NISHIO *et al.* (1979).

If $T=238$ K (-35°C) the flow law obtained by PATERSON is

$$\dot{\varepsilon} = 3.75 \times 10^{-9} \cdot \tau^3. \tag{5}$$

On the other hand, based on the deformation test of high hydrostatic pressures with core ice of Byrd Station carried out by SHOJI and HIGASHI (1979), MAE (1979) obtained the values $A=3\times10^3$ (bar)$^{-3}$s^{-1} and $Q=66$ kJ/mol by analysis of ice velocity measurement at Mizuho Plateau. These values give the equation of the flow law at -35°C as

$$\dot{\varepsilon} = 9.80 \times 10^{-9} \cdot \tau^3. \tag{6}$$

The creep rate given by the equation of MAE (eq. (6)) is three to four times as large as that represented by the equation derived by PATERSON.

PATERSON (1977) derived the ratio of the tertiary to the secondary creep rate against strain from the borehole closure data of Meighen Island ice cap, Devon Island ice cap, Byrd Station and Site-2 (see PATERSON, 1977). That ratio against strain is,

$$\dot{\varepsilon}_3/\dot{\varepsilon}_2 = 1 + 6 \cdot \varepsilon, \tag{7}$$

where ε is total strain.

In calculation of hole closure, the onset of the tertiary creep is assumed to be at total strain of 0.1. Equation (5) or (6) is applied to the secondary creep regime where the strain is less than 0.1 here, while eq. (7) is applied to the tertiary creep regime (strain larger than 0.1).

Figure 1 shows the result of calculation. According to the estimation, the hole at a depth of 300 m remains well even after 4 years. The radius contracts to 2/3 of

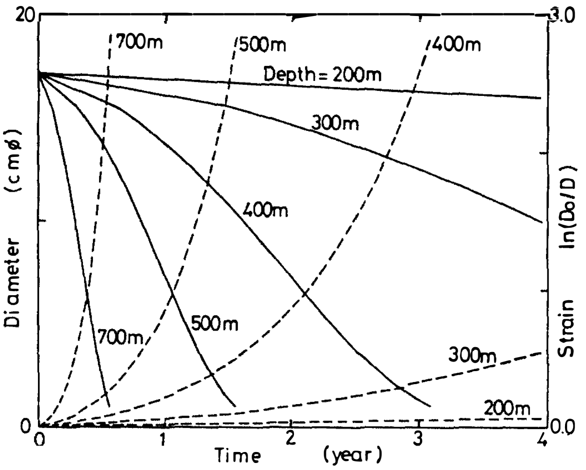

Fig. 1. Calculated curves of creep and strain.

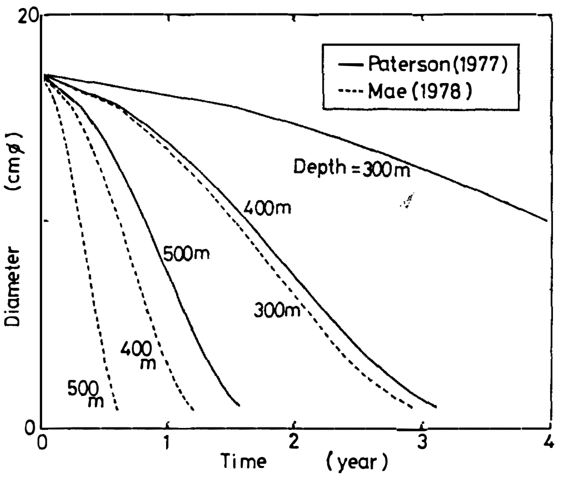

Fig. 2. Dependence of hole closure on the flow law of ice.

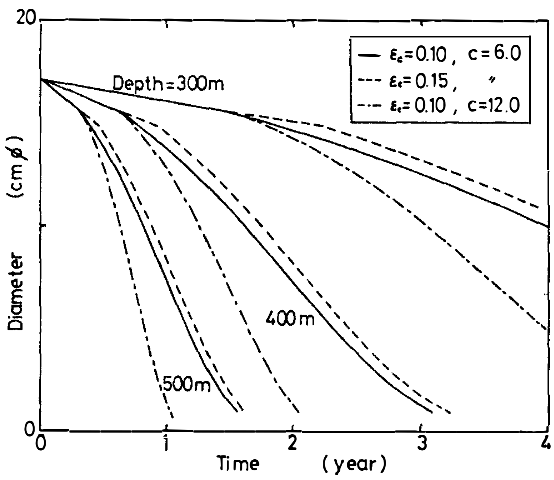

Fig. 3. Comparison of calculated curves of creep with different conditions in the value of total strain at the onset of tertiary creep and higher rate of tertiary creep rate.

the initial in 4 years at that depth. On the other hand, it takes only two years at a depth of 400 m and less than a year at 500 m that the radii of hole contracts to about 1/10 of the initial.

Figure 2 shows the dependence of hole contraction on the flow law of ice.

The borehole closure rate has much difference depending on the flow law chosen. Figure 3 shows the dependence on the value of total strain at the onset of the tertiary creep and on the coefficient of (ε) in eq. (7). They produce a considerable effect on the rate of borehole contraction.

3. Conclusion

Contraction of borehole at Mizuho Station was estimated. It is obvious that estimated contraction rates are much different depending on the flow law chosen.

It should be noticed that the flow law by PATERSON (1977) was derived from borehole closures and that the flow law by MAE (1979) was obtained by the flow model for the whole ice layer from the surface to the bottom.

The value of total strain at the onset of the tertiary creep makes large difference in borehole closure, especially at the deep. The ratio of the tertiary to the secondary creep rate also produces a considerable effect on the rate of borehole contraction. However, there is no data to evaluate these conditions in the calculation of borehole contraction at Mizuho Plateau. Measurements of borehole contraction should be repeated to find the flow law and the shifts from the secondary to the tertiary at each depth. It needs continuous measurement at deeper places because of rapid contraction. To practice the observation, measuring technique should be improved.

Besides the observation of borehole closure, the data of ice from the surface down to the depth of 400 to 500 m are needed, such as the ice temperature, flow velocity, accumulation-ablation, etc. Using these data, one can obtain relations among secondary creep rate, ice temperature and other flow law parameters to induce the representative flow law of ice in Mizuho Plateau. It is desired to compare the flow law with the core sample analysis in order to explain dynamical characteristics of ice in Mizuho Plateau.

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