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Preliminary Results of Structural Analyses of an 85.6 m Deep Ice Core Retrieved from Høghetta Ice Dome in Northern Spitsbergen, Svalbard.

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Abstract

In 1987 an ice core to bedrock at a depth of 85.61 m was recovered at Høghetta ice dome in northern Spitsbergen. The ice temperature measured in the borehole was −11 ℃ at 10 m depth and −9.4 ℃ at the bottom. Sudden transitions from large grains to small ones were observed in vertical thin sections of grains near the surface. These boundaries seem to indicate the discontinuity of the ice formation process which occurs periodically every year. Therefore, the boundaries can be used for identifying annual layers. From structural analyses of the ice cores at different 10 depths, it was found that grains of ice were inter-locked and have irregular boundary shapes in the middle depths. Some of them showed an elongated shape, the orientations of which seem to be perpendicular to the girdle plane derived from ice fabrics. These interlocking and elongated grains, along with characteristics of ice fabrics, can be related to a past specific stress condition in the ice body. We can speculate that the ice of the middle depth (approximately 20 m−65 m) is remnant ice from a larger ice cap than at present, spread over northern Spitsbergen after the hypsithermal period.

1. Introduction

Ice core drilling and *in situ* core analyses were performed in northern Spitsbergen by the Japanese Arctic Glaciological Expedition, 1987 (JAGE'87) with cooperation from the Norwegian Polar Research Institute (Norsk Polarinstitutt). The overall objective of the JAGE is to study the climatic and environmental changes of the last several hundred years around the Arctic region (Watanabe and Fujii, 1988), and the primary objective of JAGE'87 was to clarify these changes in the Atlantic section of the Arctic Cryosphere. Field research was performed at the top of Høghetta ice dome on Åsgardfonna, in northern Spitsbergen (79°17'N, 16°50'E ; 1200 m a.s.l. ; Fig.1) from May to June, 1987. At the research site, a distinctive boundary between the firn layer and glacier ice was found at a depth of only 0.5 m. Total length of the core down to bedrock was 85.61 m. After *in situ* analyses of the whole cores, approximately one eighth of them were transported from the research site to Japan for further detailed analyses.

Some results of the analyses have already been reported (*e.g.* Kameda *et al.*, 1989 ; Fujii *et al.*, 1990). Kameda *et al.* (1989) classified the observed pattern of the distribution of air bubbles in the ice core, and showed vertical frequency of occurrence of each pattern. They suggested the possibility of reconstructing the past environment from air bubble shapes and distributions. Fujii *et al.* (1990) determined recent chronology of the core from the tritium concentration and other information (electrical conductivity, pH, layers with visible sand particles, clear ice layers) and also the age of the ice by ^{14}C dating of small bacteria colonies and petals found in ice cores near the bottom. Since the ages of these organic matters were determined to be on the order of 5000 years B.P., they concluded that the age of the bottom part of the ice was on the order of 5000 years B.P. and there was a time gap of about 4000 years at about 50 m depth of

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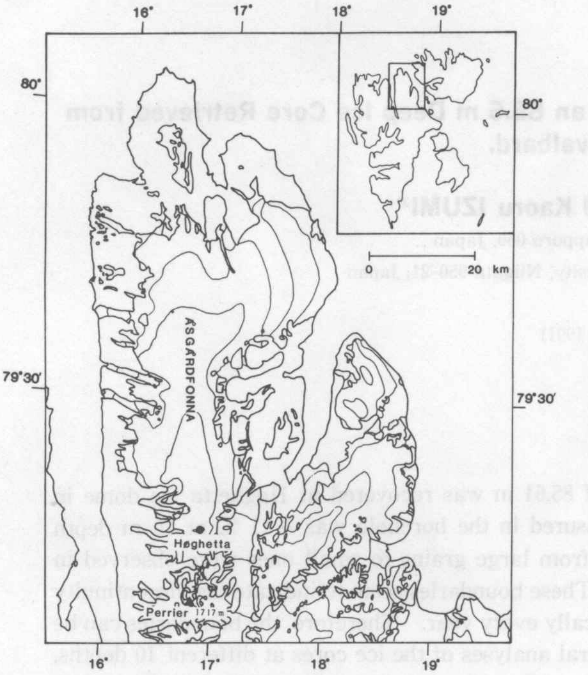

Fig. 1. Location of ice core drilling site (solid circle) at Høghettaice dome in northern Spitsbergen.

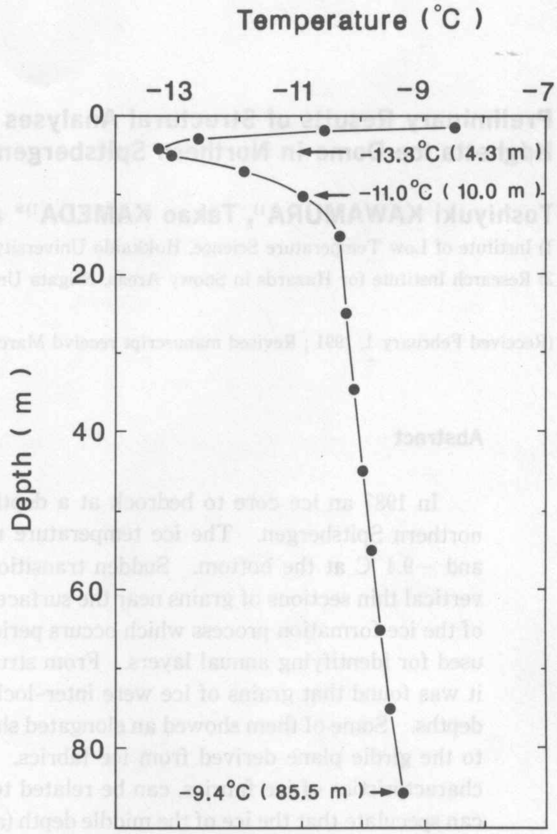

Fig. 2. Temperature profile in the glacier ice at Høghetta ice dome in northern Spitsbergen on June 4, 1987.

the ice core.

In this paper, we report preliminary results of structural analyses (grain features and ice fabrics, *i.e.* c-axis orientations) carried out both at the research site on Høghetta ice dome and in the laboratory with the portion of the ice core that was transported to Japan. We also speculate on environmental conditions for reasonable explanations of the results.

2. Results

2.1 Ice temperature at the research site

The ice temperature profile is shown in Fig. 2. Minimum temperature was −13.3 ℃ (June, 4, 1987) at a depth of 4.3 m, and 10 m ice temperature was −11.0 ℃ (June, 4, 1987). The ice temperature at the bottom of the borehole was −9.4 ℃. Judging from the air bubble shapes, ice structure (Kameda *et al.*, 1989) and ice temperature profile, a sudden change from firn to glacial ice at a shallow depth can be attributed to the refreezing of the percolated melt water during the summer season on the cold ice body. This type of glacier ice is known as superimposed ice (Paterson, 1981).

2.2 Vertical structure of grains.

Figure 3 shows three vertical thin sections of the ice core from the depths ; 0.56 m to 0.68 m, 0.68 m to 0.84 m and 0.91 m to 1.06 m, respectively. These sections were made just after the core recovery and were photographed between crossed polarizing plates with transmitted light. Sudden transitions from larger grains (diameter of about 8 mm to 12 mm) to small ones (about 2 mm to 4 mm) were observed at about 0.58m, 0.80m and 0.95 m depths as indicated by arrows. Distances between two adjacent arrows (0.22 m and 0.15 m) coincide nearly to the mean annual accumulation rate of the ice (0.20 m/year) during the period from 1958 to 1964 (2.5 to 1.5 m in depth), which was determined by measurements of tritium concentration (Izumi, in preparation). Therefore, we suppose that the boundaries between large and small grains correspond to discontinuites in the ice formation process which occur periodically every year near the surface, and these can be understood as the annual

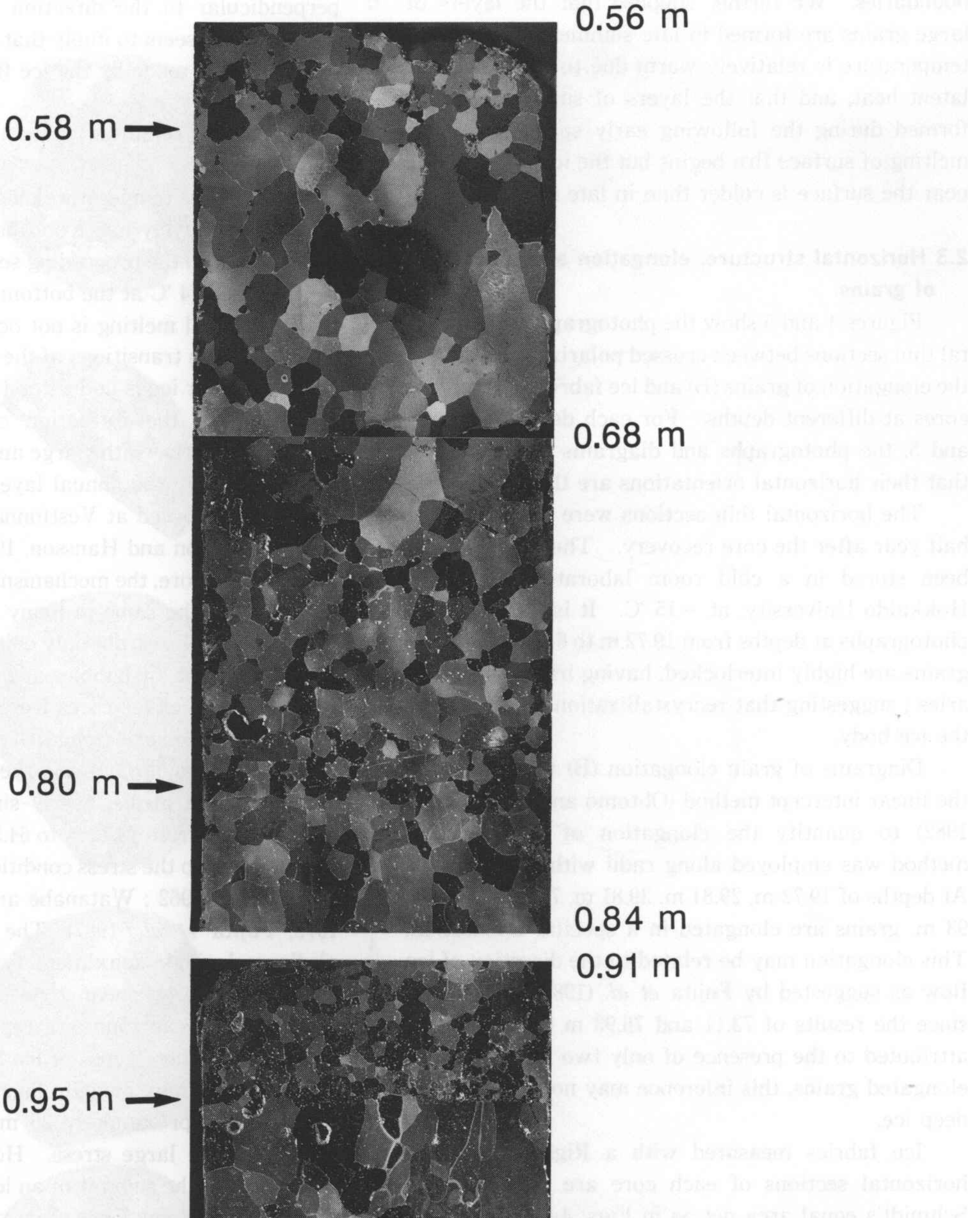

Fig. 3. Vertical structure of superimposed ice of depths from 0.56 m to 0.68 m, from 0.68 m to 0.84 m and from 0.91 m to 1.06 m. Sudden transitions from large grains to small ones are indicated by arrows (0.58 m, 0.80 m, 0.95 m depths).

boundaries. We further suppose that the layers of large grains are formed in late summer when the ice temperature is relatively warm due to the release of latent heat, and that the layers of small grains are formed during the following early spring when the melting of surface firn begins but the ice temperature near the surface is colder than in late summers.

2.3 Horizontal structure, elongation and ice fabrics of grains.

Figures 4 and 5 show the photographs of horizontal thin sections between crossed polarizing plates (A), the elongation of grains (B) and ice fabrics (C) of 10 ice cores at different depths. For each depth in Figs. 4 and 5, the photographs and diagrams are placed so that their horizontal orientations are the same.

The horizontal thin sections were made about a half year after the core recovery. The ice cores had been stored in a cold room laboratory of ILTS, Hokkaido University, at −15 ℃. It is found from 6 photographs at depths from 19.72 m to 64.56 m that the grains are highly interlocked, having irregular boundaries ; suggesting that recrystallization took place in the ice body.

Diagrams of grain elongation (B) were made by the linear intercept method (Ohtomo and Wakahama, 1982) to quantify the elongation of grains. This method was employed along radii with 10° intervals. At depths of 19.72 m, 29.81 m. 39.81 m, 73.11 m and 76. 93 m, grains are elongated in a specific orientation. This elongation may be related to the direction of ice flow as suggested by Fujita *et al.* (1987). However, since the results of 73.11 and 76.93 m depths can be attributed to the presence of only two or three large elongated grains, this inference may not hold for this deep ice.

Ice fabrics measured with a Rigsby stage for horizontal sections of each core are shown in the Schmidt's equal area net as in Figs. 4-(C) and 5-(C). The number of measurements is shown at the right side of each fabrics diagram. Various patterns of the ice fabrics were observed ; random type (0.5, 1.4, 73.11 and 76.93 m in depths), two maxima type (19.72 m), great girdle type (29.81, 39.81 and 49.61m) and nearly -single maximum type (59.98 and 64.56m). However, the diagrams of 29.81, 59.98, 64.56, 73.11 and 76.93 m depths may not be statistically significant due to the small number of measurements.

It was found that the plane of the girdle in the large girdle type (29.81, 39.81 and 49.61 m) was nearly perpendicular to the direction of elongated grains. These results seem to imply that the large girdle types of fabrics are made by the ice flow (Budd, 1972).

3. Concluding remarks.

1. Since the ice temperature measured in the borehole was comparatively low from the melting point of ice as described in the proceeding section (−11 ℃ at 10 m depth and −9.4 ℃ at the bottom), it can be concluded that subglacial melting is not occurring at this site.
2. The sudden transitions of the grain size in the near surface glacier ice is understood as a result of seasonal change of the formation of superimposed ice. Boundaries between the large and small grains can be used to identify the annual layers. Such boundaries were also observed at Vestfonna (Palosuo, 1987) and Stroya (Jonsson and Hansson, 1990) in northern Svalbard. Therefore, the mechanism of glacier ice formation must be the same in many glaciers in Svalbard. Structural analyses, not only on the grain size but also on the shape of air bubbles are important to identify annual layers for ice cores from Svalbard islands.
3. Grains of ice are elongated in a specific direction from 19.72 m to 39.81 m, and the ice fabrics show two maxima, great girdle, nearly-single maximum types for each core from 19.72 m to 64.56 m. Ice fabrics are often related to the stress conditions exerted on the ice (*e.g.* Kizaki, 1962 ; Watanabe and Oura, 1968 ; Budd, 1972; Fujita *et al.*, 1987). The two maxima, great girdle and single maximum type are normally observed in a large shear zone (Kizaki, 1962 ; Budd, 1972). If a shear zone is a representative place for formation of these types of ice fabrics, these particular ice fabrics may indicate that the ice body between the depths approximately 20 m and 65 m has been subjected to a large stress. However, since the research site is the summit of an ice dome, it is difficult to imagine that any large shear stress is exerted in the ice at present. Therefore, we may speculate that the ice at the middle depth (20 m to 65 m) was a part of an active glacier which flowed to the research site from another ice cap. Since the bottom part of the ice was formed in the hypsithermal period (Fujii *et al.*, 1990), this implies that a larger ice cap at present existed at some time around the research area after the hypsithermal period. This suggestion of a larger ice cap is consistent with the determination of the maximum advance of the glacier terminus during the Little Ice Age glaciation in Spitsbergen, which was discussed in

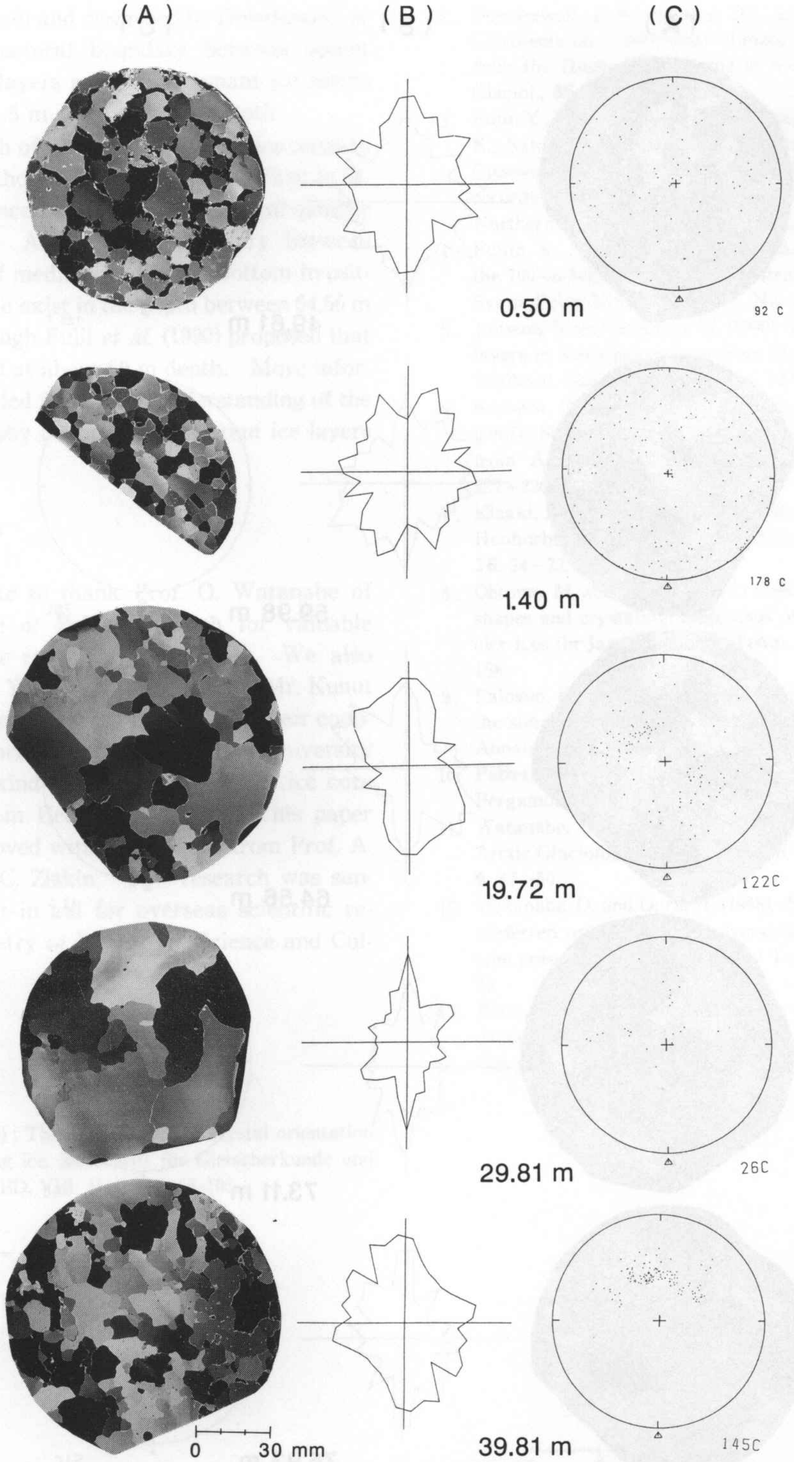

Fig. 4. Horizontal structure of grains (A), elongation of grains (B) and ice fabrics (C) for 5 ice cores of the depth from 0.5 m to 39.81 m. Ice fabrics change from two maximum type to random type between 19.72 m and 1.40 m in depths. Horizontal orientations of the photographs (A) and diagrams (B) and (C) are coincident at every depth of the core.

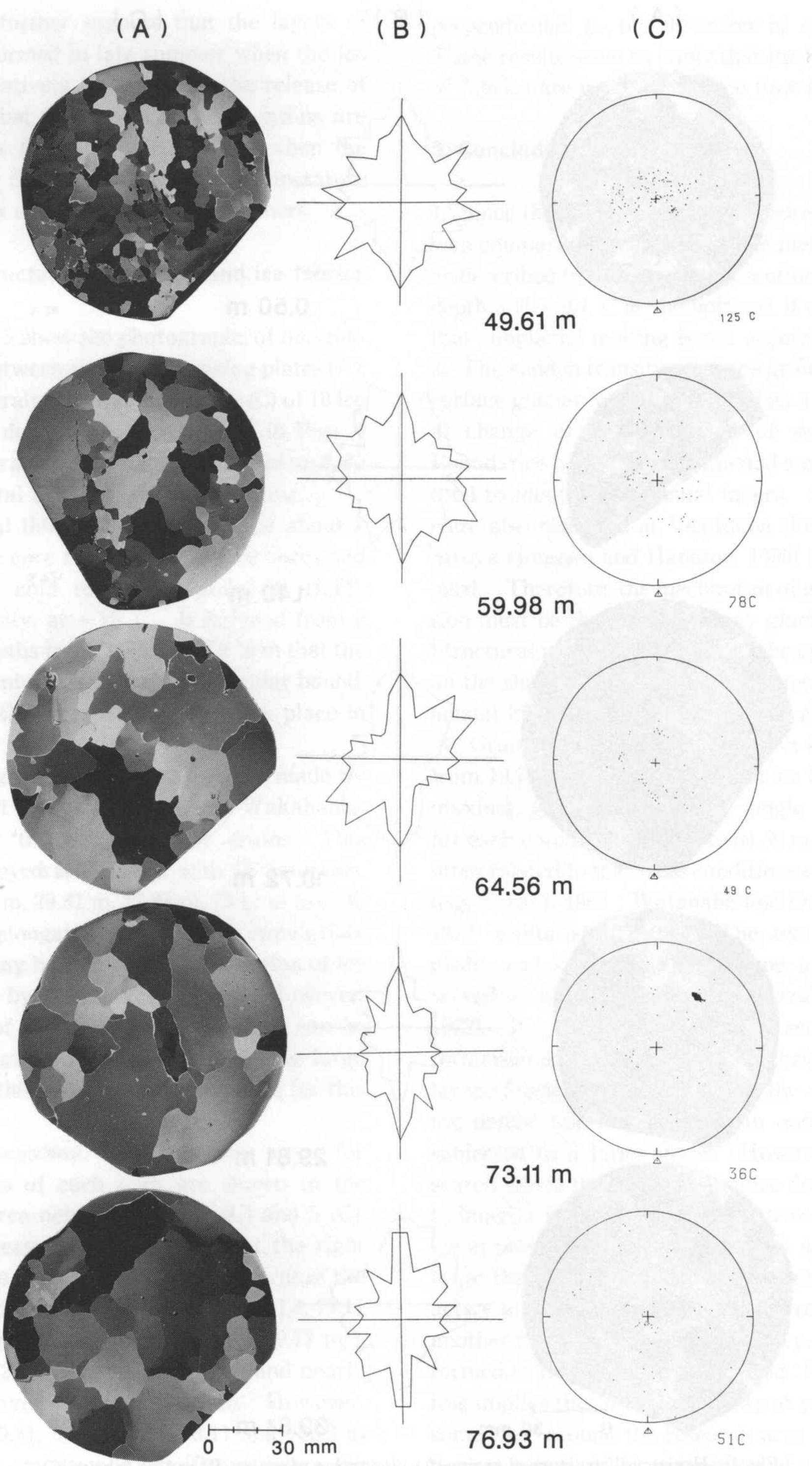

Fig. 5. Horizontal structure of grains (A), elongation of grains (B) and ice fabrics (C) for 5 ice cores of the depth from 49.61 m to 76.93 m. Ice fabrics change from random type to nearly-single maximum type between 73.11 m and 64.56 m depths. The same remarks on the orientation as in Fig. 4 apply.

Werner (unpublished) and described by Dowdeswell *et al.* (1990). A structural boundary between recent superimposed ice layers and such remnant ice seems to exist between 1.5 m and 19.72 m in depth.

4. Below the depth of 73.11 m, the ice fabrics seem to be different from those of the upper ice (19.72 m to 64. 56 m), in spite of uncertainties due to the small number of measurements. A structural boundary between the remnant ice of medium depth and bottom hypsithermal ice seems to exist in the depth between 64.56 m and 73.11 m, although Fujii *et al.* (1990) proposed that a time gap existed at about 50 m depth. More information is still needed for the full understanding of the peculiar stratigraphy of the three different ice layers described above.

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