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A preliminary study of ice texture and fabric on an ice core to the bedrock extracted from Glacier No. 1 at the headwater of Ulumqi River, Tianshan, China

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Abstract

Crystallographic studies of an ice core to the bedrock extracted from east branch of Glacier No. 1, Tianshan, showed changes of microtexture and fabric of the ice crystals with depth. Five different layers can be identified. 1) from top to 20 m : a deposition layer with polygonal shaped crystals, increasing in size with depth ; an ice fabric, generally randomly oriented. 2) from 20 m to 45.37 m : a transition layer with porphyrblastic crystals ; ice fabric pattern is a weak girdle-type. 3) from 45. 37 m to 65.31 m : a interlocking coarse ice crystals with small oval shaped air bubbles scattered between grains, and the elongation of these bubbles pose distinct preferred orientation parallel to the ice flow ; the ice fabrics are still weak girdle type with weak multi-maxima fabric. 4) from 65.31 m to 76.8 m : a coarse grained layer with polygonal-shaped crystals increasing in size with depth, and the neighboring crystals interlocked tightly, with very fine grains dispersed among the coarse ones ; an ice fabric was a weak multi-maxima pattern. 5) from 76.8 m to the bottom : a coarse grained layer with large interlocking and branched crystals ; a diamond pattern of fabric. The preliminary analysis showed that there existed some connection between ice crystal growth and air bubble enlongation, and the ice fabrics are greatly controlled by the flow state and ice temperature of the glacier.

1. Introduction

Although the crystallographic studies of glacier ice have been considerably well-considered both in the field and in laboratory (Gow, 1970 ; Langway *et al.*, 1988 ; Herron and Langway, 1982 ; Azuma and Higashi, 1985 ; Shoji and Langway, 1985 ; Shoji and Langway, 1987 ; Gao and Jacka, 1987 ; Duval *et al.*, 1987 ; Paterson, 1991), the research on the ice cores extracted from medium-low latitude mountaineous glaciers, especially those to the bedrock are seldom made (Oeschger and Langway, 1989).

In October and November, 1990, an ice core to the bedrock with a length of 90.24 m and a diameter of 66 mm was recovered from the east branch of Glacier No. 1 (Fig. 1) at an elevation of 4050 m a.s.l., near the multi-year mean equilibrium-line. A preliminary study of ice texture, fabric, and stratigraphy of the ice core is given in the present paper.

2. Structural characteristics of the core

2.1. Ice type

The stratigraphy of ice core was observed in combination of the snow pit observation in site. The stratigraphic analysis was carried out with a light box in a cold room at Tianshan Glaciological Station. According to the stratigraphy of the core (Wang Xiaojun *et al.*, personal communication), in the upper part of 3 m in depth, it consisted mostly of snow/firn alternative horizons with some very thin ice-lens in between. From 3 m to 20 m in depth, infiltration ice,

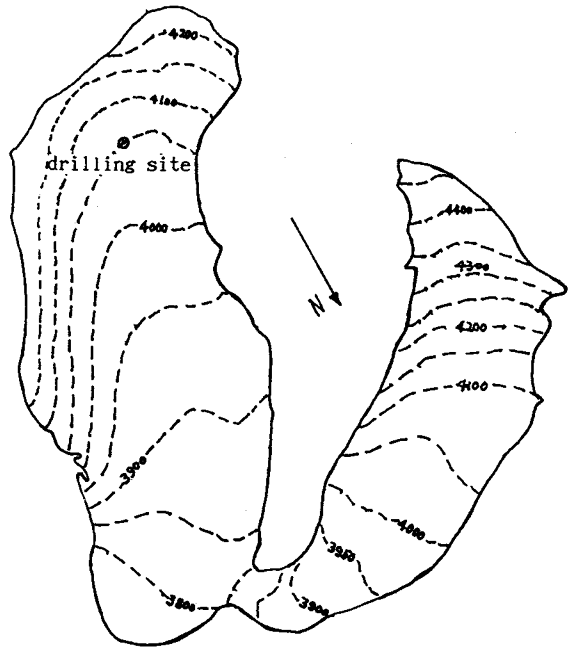


Fig. 1. The location map of drilling site.

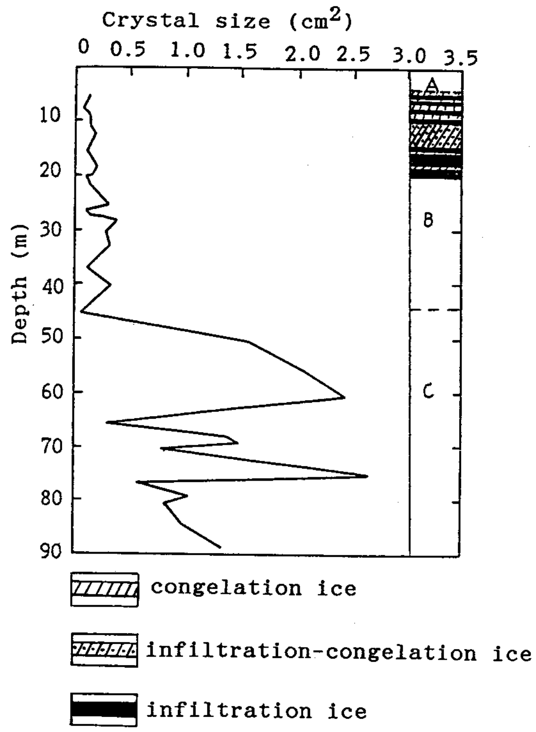


Fig. 2. a. The ice crystal size variation versus depth.
b. A stretch stratigraphic description of Glacier No. 1 core.
A : snow/firn with ice lens.
B : infiltration, congelation and infiltration-congelation ice with alternative super-imposed ice layers.
C : glacier ice with quantitive dirty particals.

milky-white infiltration-congelation ice and transparent congelation ice alternative horizons with some turbid super-imposed ice layers dispersed. Below 20 m in depth, the ice types are difficult to distinguish due to the strong dynamic metamorphism which ice have experienced, and we simply called them as glacier ice.

2.2. Crystal size

The size and shape of the ice grains were examined with horizontal and vertical thin sections through a microscope. Crystal size was obtained by counting a number of crystals (roughly 100) within a given area of each thin section. The measurements were done at the low temperature laboratory of Lanzhou Institute of Glaciology and Geocryology, Academia Sinica, with the ambient temperature of about -15°C. Below 25 m in depth, ice grains appeared to be elongated along a horizontal direction.

Vertical profile of crystal size was obtained with 42 horizontal thin sections, and are illustrated in Fig. 2. It shows that the crystal size was small down to 45 m in depth with a small fluctuation. At depths further down, the size was rather big with relatively large fluctuation.

The variation of crystal size and shape of grains with depth is shown by the thin-section photographs given in Fig. 3. Some crystals exhibited undulose extinctions below 45 m, where the crystals interlocked very tightly, and the boundaries of crystals were difficult to distinguish (*e.g.* 60.52 m in Fig. 3). It seems that the crystals above 45 m developed mainly by the grain growth, and the crystals grew up predominately by recrystallization below 45 m.

2.3. Crystal orientation

C-axis orientations of crystals were measured with a Rigsby universal stage by the method described by Langway (1958). The results are presented in Fig. 4. In the upper 20 m of the core, the c-axes appear to be quasi-uniformly distributed over the Schmidt equal area net. A trend towards a weak girdle-shaped fabric appeared at a depth of 20.59 m. Till about 75.1 m in depth, a weak multiple maxima patterns formed. It is very interesting that at a depth of 80.4 m, the c-axes appear to concentrate on some directions, and its thin section photograph (Fig. 5) shows a broken band of very fine grains. These facts seem to suggest

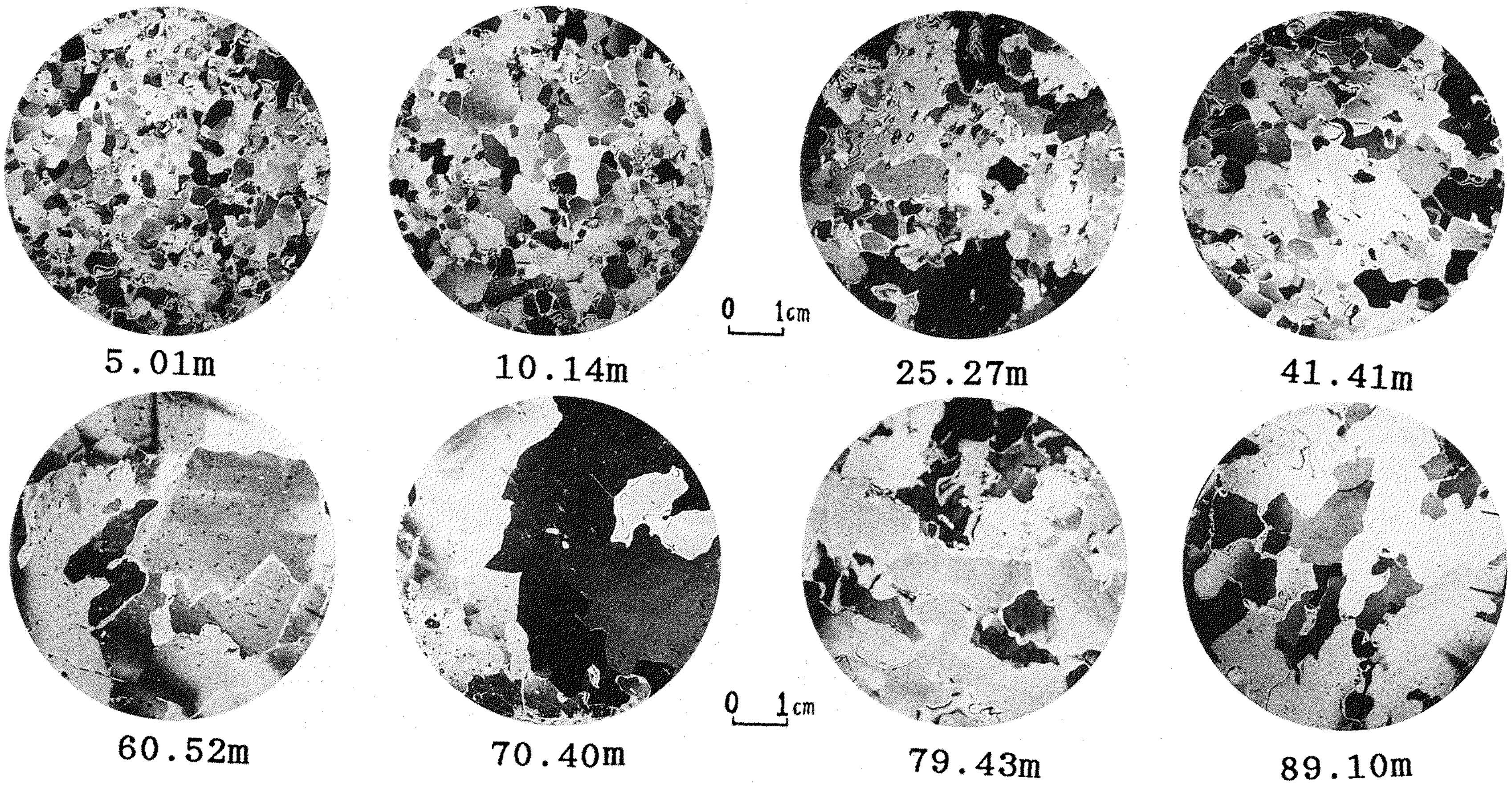
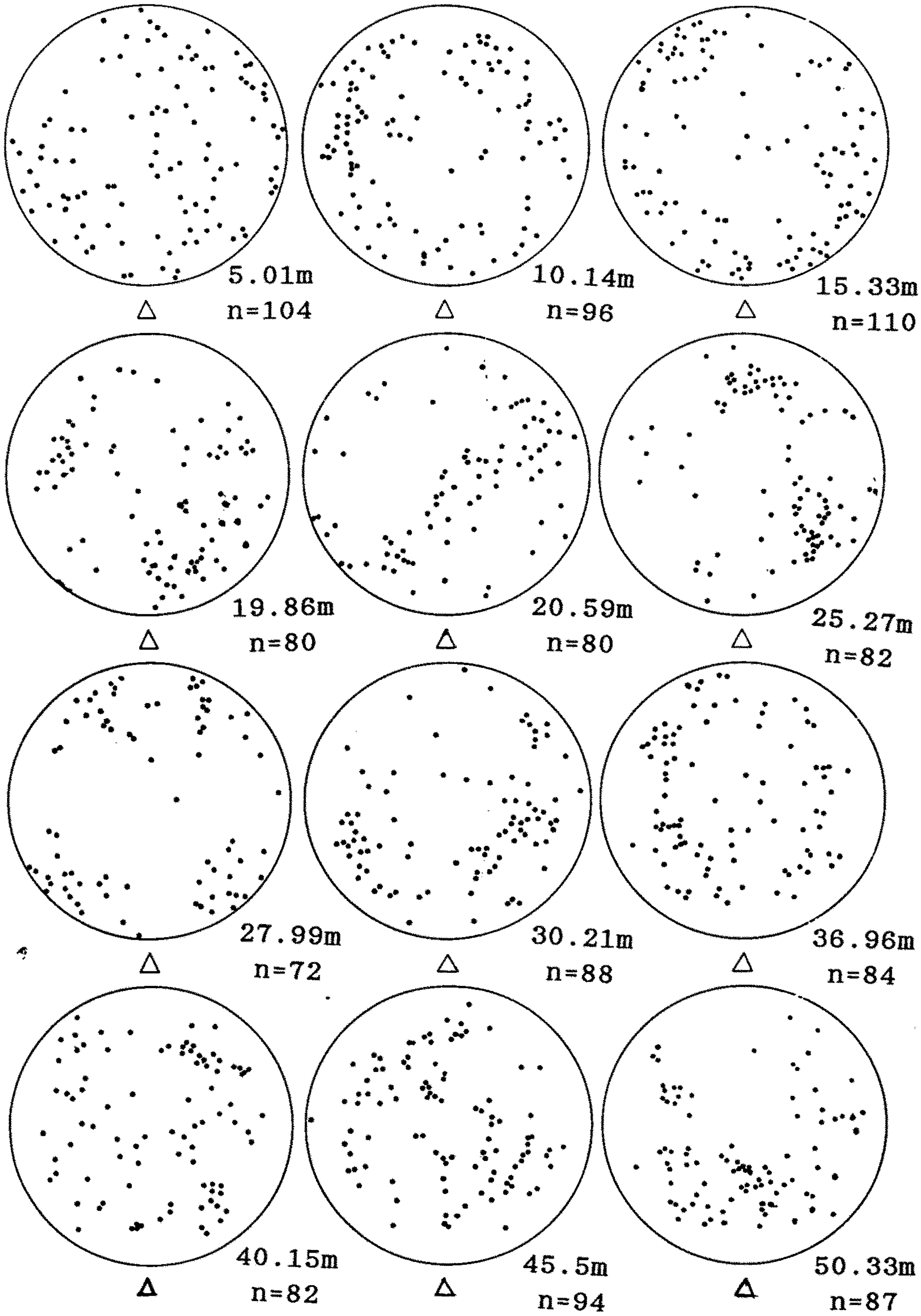


Fig. 3. Thin-section photographs of the 90.24 m long Glacier No. 1 core. These photographs were taken between crossed Polaroids.


5.01m
n=104
10.14m
n=96
15.33m
n=110
19.86m
n=80
20.59m
n=80
25.27m
n=82
27.99m
n=72
30.21m
n=88
36.96m
n=84
40.15m
n=82
45.5m
n=94
50.33m
n=87

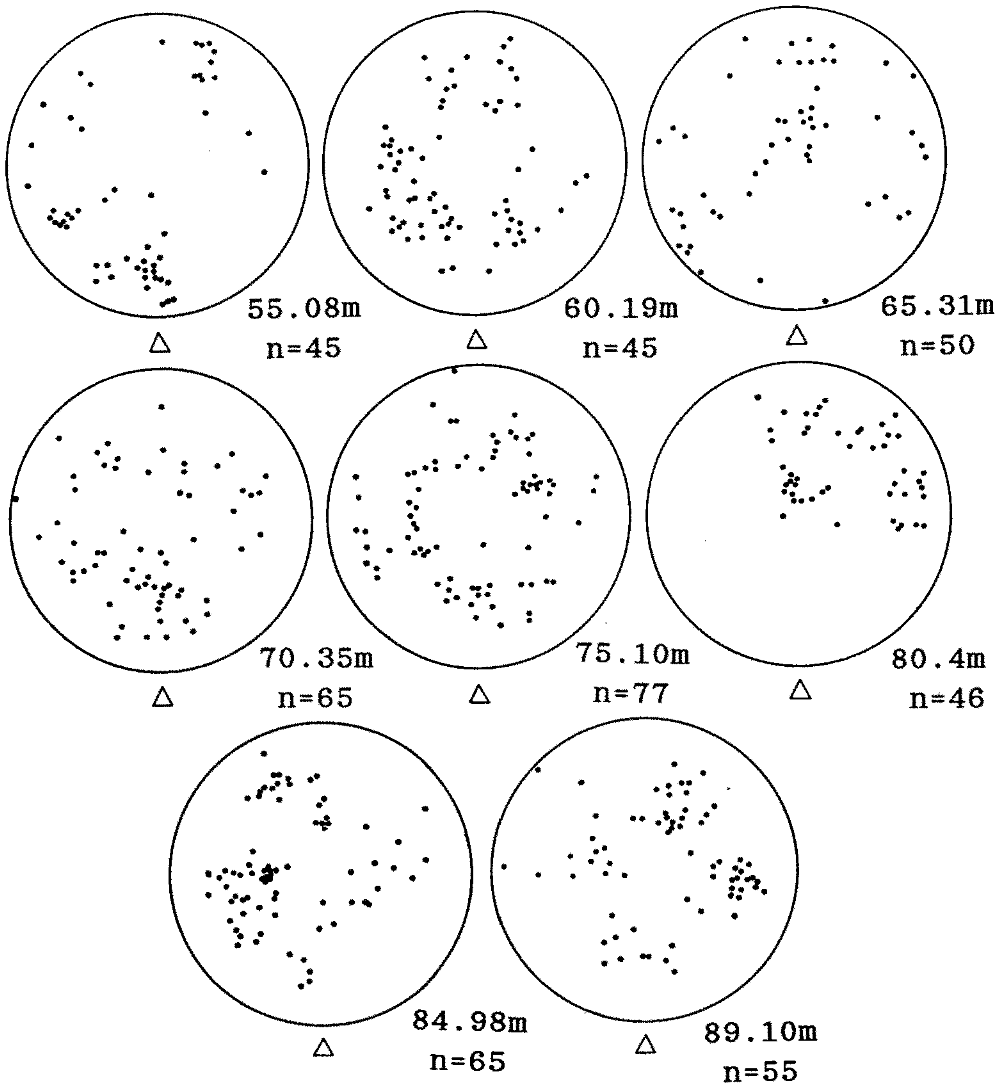


Fig. 4. Fabric diagrams. The center of the fabric diagram represents the vertical direction. The number of c-axes measured is given below each diagram.

a presence of a strong shear zone, which located just at the 1/5 thickness of the ice from the bottom. In the bottom part of the core below 75.1 m, the ice fabrics show weak multiple-maxima patterns similar to the "diamond-pattern". The occurrence of the basal diamond pattern at Glacier No. 1 probably reflects a combination of the relatively undulating bedrock topography and the relatively warm basal ice temperature of −1.1 °C (see Fig.6).

2.4. Air bubbles

Air bubble observation was made with the normal light photographs, concerning with bubble shape and elongation rate. The variations in elongation rate of air bubbles with increasing depth are shown in Fig. 7. From upper part to the 45 m in depth of the core, the air bubble elongation rate is rather high. The air bubbles were elliptical with a preferred elongation direction. Below 45 m in depth, the bubbles were small in size, and the elongation rate was also small. Since the crystal size was small at the shallow depths, and large at deeper portion (Fig. 2), it can be said that air bubble elongation rate decreases with increasing of grain size. More observation and analysis, how-

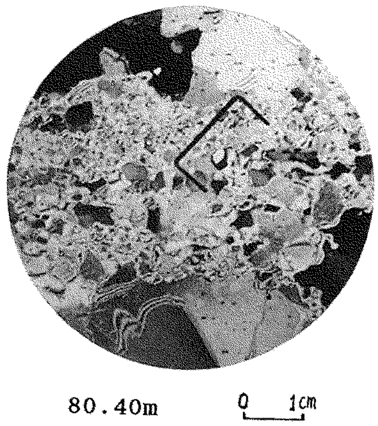


Fig. 5. A thin-section photograph of the ice crystalline texture at depth of 65.71 m in Glacier No. 1 core showing a strong broken band of crystals.

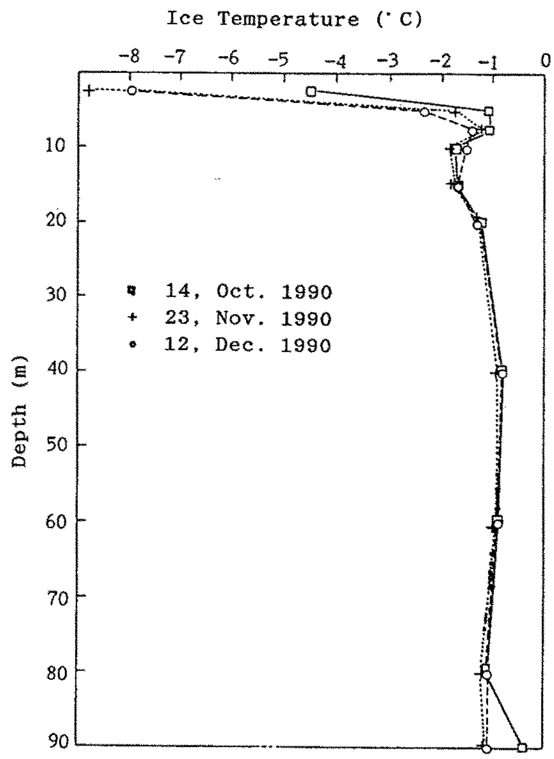


Fig. 6. The borehole temperature measured at different depths.

ever, both in the field and in laboratory, are required to draw a firm conclusion.

3. Discussions

Since the Glacier No. 1 ice core was extracted

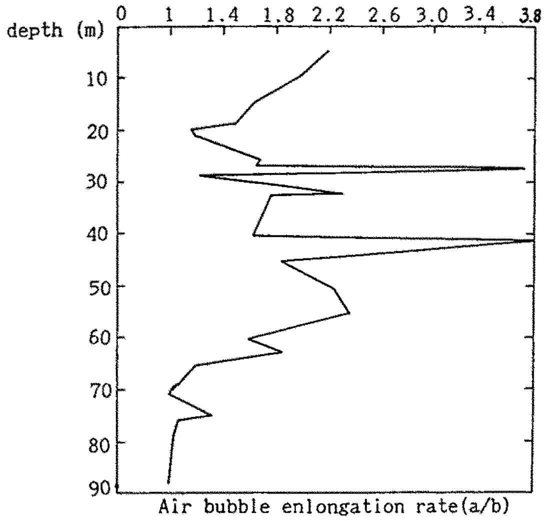


Fig. 7. The air bubble elongation rate versus depth.

from the site around the multi-year mean equilibrium line, it would be very sensitive to climate changes. When the equilibrium line was located above the drilling site, no superimposed ice developed, and the congelation ice will be preserved in the deposition (Xie Zichu, 1985), which reflected the temperate climatic period over this depth interval. Otherwise if the equilbrium-line locates below the drilling site, the perennial superimposed ice developed, the infiltration ice will be preserved in the deposition (Xie Zichu, 1985), reflecting a relatively cold climatic period over this depth interval. The change from fine-grained infiltration ice at about 20 m in depth to infiltration -congelation ice, and to congelation ice at about 3.0 m in depth (see Fig. 2) suggest an increase of air temperature and a decrease of accumulation over the recent several decades years, which was supported by climatic records of Tianshan Glaciological Station and Daxigou Meteorological Station.

Grain growth, driven by the free energy at grain boundaries, occurs in the top to 45 m depth of the Glacier No. 1 core, this is in accordance with the low strain-rates (Han Jiankang *et al.*, 1985), (Jing Xiaoping *et al.*, 1992) in about upper 45 m of ice at Glacier No. 1. Below 45 m in depth to the basal layer, the grain growth was greatly controlled by recrystallization, due to the large total strain rate (Jing Xiaoping *et al.*, 1992) and rather high ice temperature (close to the pressure-melting point).

In the upper layer of Glacier No. 1 where the major stress is vertical compression and the flowlines are converge in the down stream direction, dynamic recrystallization plays a minor role as one of several processes that accommodate incompatible deformation between adjacent grains, grain rotation produces a girdle type of fabric. With increasing depth, shear becomes progressively more important, but due to the high ice temperature in Glacier No. 1, the recrystallization becomes progressively more important with increasing depth also. A combination of these two mechanism results in the absence of the single-maximum fabric eventually. At high stress and high temperature in the base layer of Glacier No. 1, multiple -maxima fabrics are probably induced by recrystallization. Such c-axis fabrics induced by intracrystalline glide and preferred growth of crystals are related to the deformation history of ice and to the stress state in Glacier No. 1.

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