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Stratigraphic and structural features of ice cores from Chongce Ice Cap, West Kunlun Mountains

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Abstract

Two snow/ice cores 23.10 m (B12) and 32.50 m (B8) long were retrieved near the top of Chongce Ice Cap. Sequences of the seasonal variation were found periodically. Structural analyses showed an evidence that a folding was taking place in ice at depths above 30 m, above the snow–ice transition depth in the ice cap. Ice fabric near the surface was rather random, but it changed to a small girdle pattern and finally turned to a single maximum near the bottom of one of the cores (B8). This, with additional information on the change in crystal shape along the core, seems to indicate that the deformation of the ice cap was mainly attributed to the relative displacement of ice grains rather than the deformation of each crystal. Many dust layers were found in the cores, one of which was estimated to be a volcanic ash layer originated from an eruption of a volcano in 1951.

1. Introduction

The term "stratigraphic study" of ice core, generally means descriptions of visual features, statistical analysis on stratigraphic constitution against depth, and related assessments about developing glacio–sedimentary environment in a glaciated area. However, almost every facet of the work with ice cores has to be related to the environment directly or indirectly.

Various complex structural changes are occuring in glacier ice with increasing depth. They include appearance of various visible structures and gradual evolution of inner structure such as shapes and concentrations of air bubbles, and c–axis orientations and textures of crystals. It is helpful to investigate these features not only for revealing the developing history of snow and ice, but also for understanding the dynamic metamorphism and estimating existing dynamic conditions in the deep part of the glacier.

With the ice cores extracted from the Chongce Ice Cap, the visual structural phenomena and inner structural features of snow and ice were observed.

2. Drill sites and methods for analyses

The ice cores to be described in this paper were drilled near the observation stations B8 and B12, referring to as simply B8 and B12 core hereafter (Chen, 1989). The drill sites, where most of our activities were made were 1 to 2 degree in surface inclination, although the surface slope of the ice cap in some area was 5 to 10 degree towards the south. Both of the cores were retrieved at sites on terrace platforms by a mechanical drill. The cores are 32.50m and 23.10m in length respectively at B8 and B12. The ice temperature, at a depth where seasonal variation disappeared, was −13.8°C and −15.8°C at B8 and B12 respectively (Zhou Tao, in preparation).

The stratigraphy of the ice cores was observed in combination with the snowpit observation *in situ.* Most of the stratigraphic analyses were carried out with a floresent light in a low temperature laboratory. Results are shown in Fig. 1.

The ice cores from the Chongce Ice Cap are mainly composed of snow/firn, *i.e.*, solid precipitation without any modification by melt water, and congelation ice, *i.e.*, refrozen ice from melted water of snow,

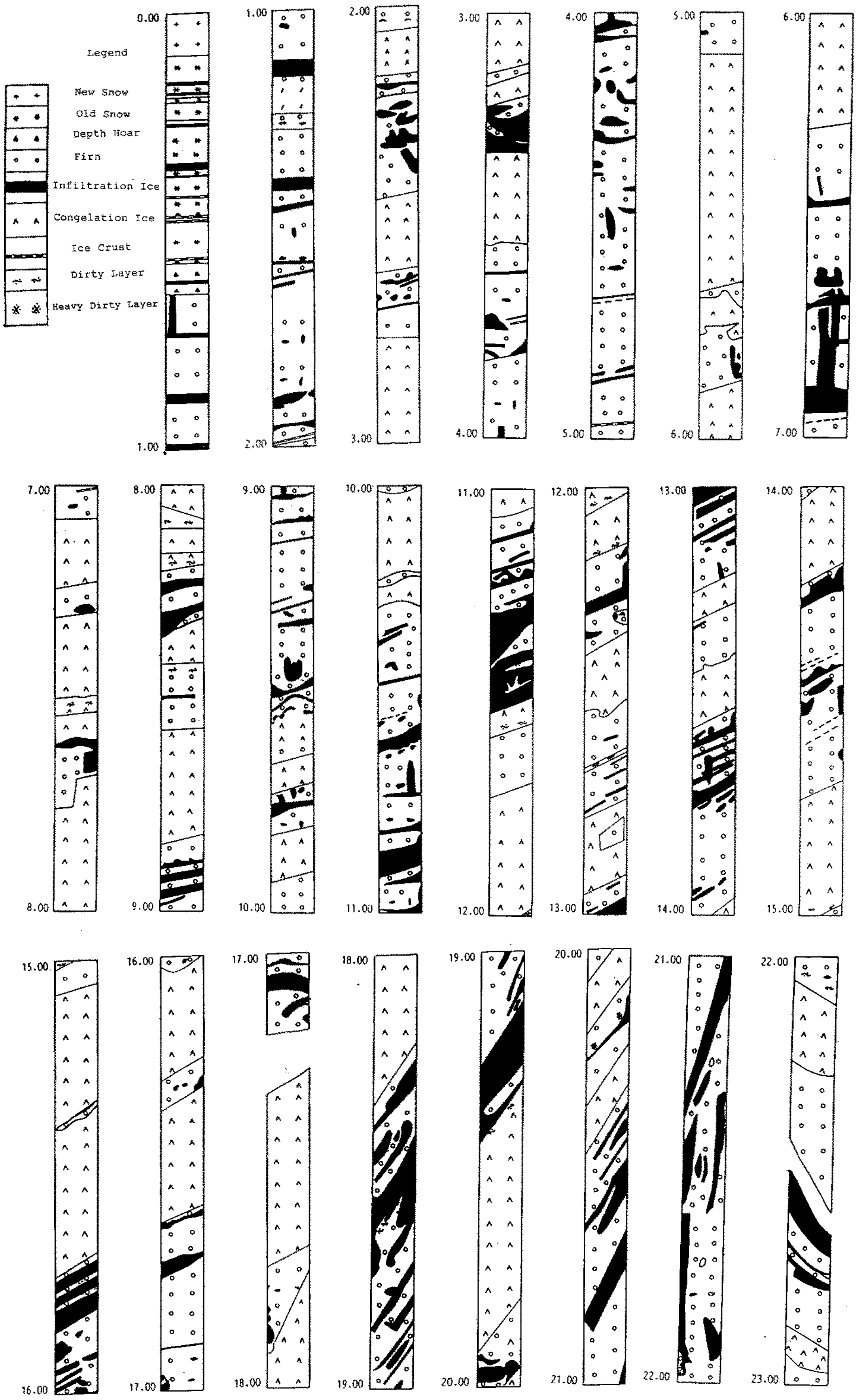


Fig. 1. Stratigraphic profile of the B12 ice core.

as well as the intermediate one in between, called infiltration ice (Xie, 1984).

It is difficult to draw a line to distinguish the latter two forms of ice, but they should have some differences in the process of formation. We propose here for the distinction:

Congelation ice: refrozen from water with a significant thickness without any indication of the previous firn structure.

Infiltration ice: relatively thick granular ice in which some firn structure remained.

Dust layer is a remarkable feature in alpine glaciers. Resulted from the deposit and concentration of dust particles during the melting of snow, most of dust layers are found in congelation and infiltration ice. However, dust layers were found even in snow layers. They are probably wind blown dust in light snow falls. All dust layers found are recorded in the stratigraphic diagram. Inclination of sedimentary bands are clearly shown in Fig. 1 by dust layers or other features. Cavities in the ice encountered in the coring were also recorded.

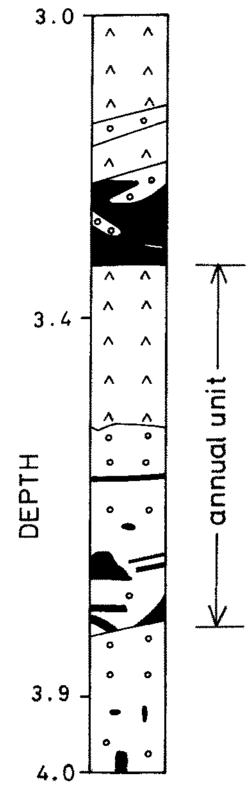


Fig. 2. An example of a stratigraphic sequence. (3 m – 4 m)

3. Stratigraphy

Figure 1 is a schematic diagram of B12 core stratigraphy in which the ice is classified according to the definition given in section 2. It looks very intricated at a first glance: snow and ice laminae are alternating one another, and sometimes ice exists as a patch, a speck, or a gland elongated vertically. As a whole, however, sequences of annual variation of stratigraphy can be recognized. For example, upward in a column shown in Fig. 2, there appear snow layers, alternation of snow and ice layers, and ice layers on the top. These remarkable stratigraphy can be explained as follows including their origins of formation.

(A) Well preserved snow layers.

Although the main period of snow fall on the Chongce Ice Cap is in summer (Zheng *et al.*, 1988), the snow layer is considered to form from late autumn to early winter. Weak solar radiation, low temperature and occasional heavy snow fall are favourable to the preservation of snow, without formation of thick layer of congelation ice.

(B) The frequent alternation of snow and ice layers, which can be attributed to the relatively strong ablation. The strata usually appear to be thick bands of infiltration ice or lamina of congelation ice in limited thickness. They are considered to form not only in one season. Snow fell on the glacier during winter and spring partly, or completely melt under strong radiation. Sometimes, even that deposited in earlier seasons can not survive as it deposited depending upon the amount of snow fall in winter and spring.

(C) Comparatively thick ice layer associated with a dark dust layer at its bottom. Its formation process was considered as follows: snow with dust deposits, melts partly, due to strong radiation in summer, then the melt water refreezes near the surface in early autumn.

It should be emphasized that there should be significant mass loss caused by runoff in the area near B12 Station from flat surface under thick snow cover even during summer time. So we presume that the above cyclic sequence represents the mass accumulated in a whole year. Calling it "annual unit" and taking it as a reference together with other stratigraphic phenomena such as depth hoar (Zheng *et al.*, 1988) *etc.*, we tried to estimate the age of the cores. It is estimated that B12 core and B8 core correspond to approximately 30 and 60 years B.P. respectively.

4. Inner structure

Empty holes were discovered in both boreholes during the drilling (Nakawo *et al.,* 1988). The depths of holes are: 17.20 m and 22.45 m for B12 core as can be seen in Fig. 1 and around 10 m for B8 core. Well developed big hoar crystals appeared at the top of the holes, and the bottom is of infiltration or congelation ice. This means that the holes had been formed for a certain period for allowing the sublimation−condensation process to form the hoar.

One of the englacial empty holes in the Chongce Ice Cap appeared to be similar to crevasses on the back wall of ice in cirque glaciers. The subglacial topography near the drilling sites, however, is not so steep as that of the back wall of cirque glaciers. The projection of B12 drilling site is located at the southwest of a ridge with the inclination of 1:5 (Zhu, 1989). As a result the hole may have not extended to and exposed on the surface, as usual crevasses do, in the Chongce Ice Cap.

Another characteristic feature we found in the cores is changing inclination of sedimentary bands. The surface at B12 drill site inclined southwestwards with a dip of 1°−2°. However, the observation showed that the dip of sedimentary bands increased greatly with depth (Fig. 3). Increasing tendency is accelerated especially below 17 m. Figure 3 shows that the dip in depth interval of 8 m to 15 m increased from some 15° to 30° at a rate of 1.6°/m. On the other hand, in the depth below the first empty hole, 17.2 m in depth, the rate increased up to 23.9°/m.

The variation from near horizontal to vertical, then the reversal of the dip of the sedimentary bands in the lower part of the ice core shown in Fig. 3 exhibits a wing of the fold having been formed within the glacier (The turn−over of dip angle was clearly revealed by adjusting the subsequent core segments at their edge of break−off). The wing indicates the obviously uneveness of englacial motion. These change in inclination of foliation is considered to be resulted from accumulated strain in ice body (Hudleston *et al.* 1980). The ice at B12 is about 67 m deep (Zhu, 1989) and the temperature at the bottom of ice is estimated by extrapolation from those in ice as low as below −10°C (Zhou Tao, in preparation). Therefore, the bottom ice is considered to be frozen to the bed.

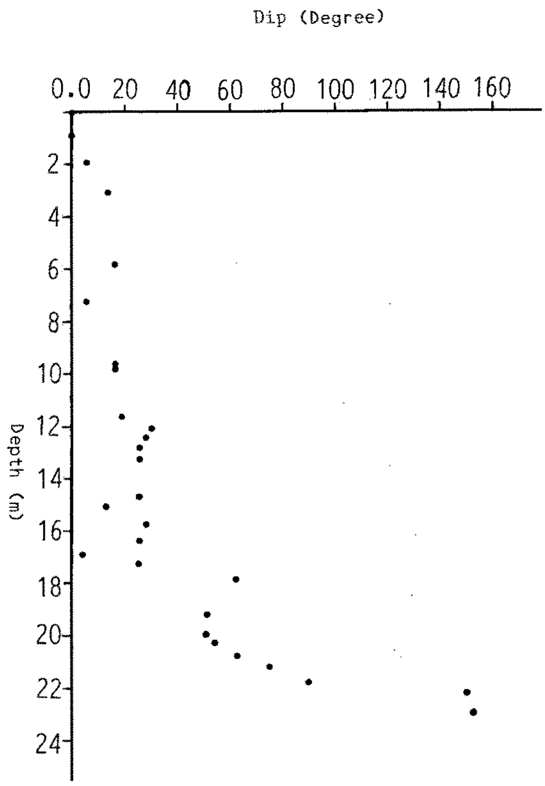


Fig. 3. The variation of dip of sedimentary bands against depth for B12 core.

To realize the uneveness of ice motion within the ice cap caused by subglacial topography, we should have a close look at the evolution of inner structure of firn and ice. Generally, the firn does not behave as a distinct deformed mass until reaching the transition depth to ice. The transition depth for B12 core estimated from the extrapolated density−depth profile is about 40 m (Zhou Tao, in preparation). However, a horizontal section the firn at 17.70 m (Fig. 4a) shows elongated voids and grains taking preferential arrangement in one direction. This indicates that a certain deformation took place even in firn layers at this shallow depth. Inner structures of ice at depths with inclined sedimentary bands exhibit the above features more clearly. Figure 4b is a vertical section cut perpendicularly to the inclined bands at the depth of 20.15m. Crowded bubbles, near to close off, at crystal boundaries are elongated in the direction of inclined strata. The quasi−hexagonal crystals, either of the firn or of the ice were obviously elongated in the same direction. These features indicate that firn densification took place in association with the dynamic pro-

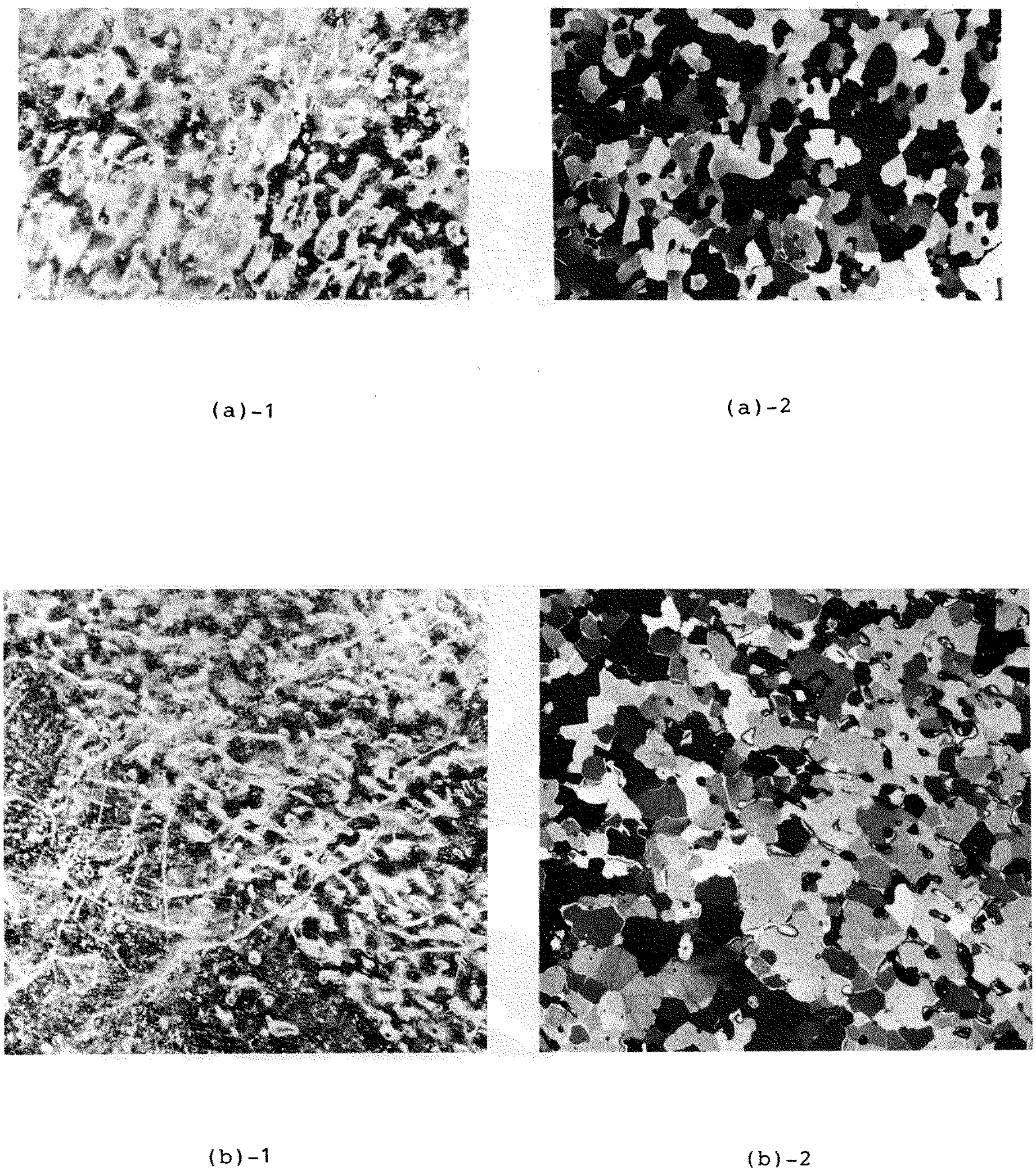


Fig. 4. Photographs showing the variation of inner structure of snow and ice

(a) A horizontal section cut at a depth of 17.7 m.
(b) A vertical section cut at a depth of 20.15 m.
(a)−1 and (b)−1 were taken under ordinary illumination.
(a)−2 and (b)−2 under crossed polaroids.

cess in rather shallow depth of the Chongce Ice Cap.

Fabric patterns of ice crystals in B12 core exhibit no remarkable change, all random fabric. Figure 5 shows the fabric pattern for B8 core plotted on the Schmidt net, in which the center of the circle corresponds to the vertical direction. The pattern is random near the surface, although the crystals tended to elongate close to vertical. At 25.20m, it becomes a small girdle pattern. At a depth of 30.00 m, a single maximum pattern is found , of which center is inclined in the same way as the dip of inclined sedimentary bands at this depth.

At the same time photographs of thin horizontal section taken under crossed polaroids revealed the following variation of crystal textures. On the top, regular crystal grains have straight boundaries. With

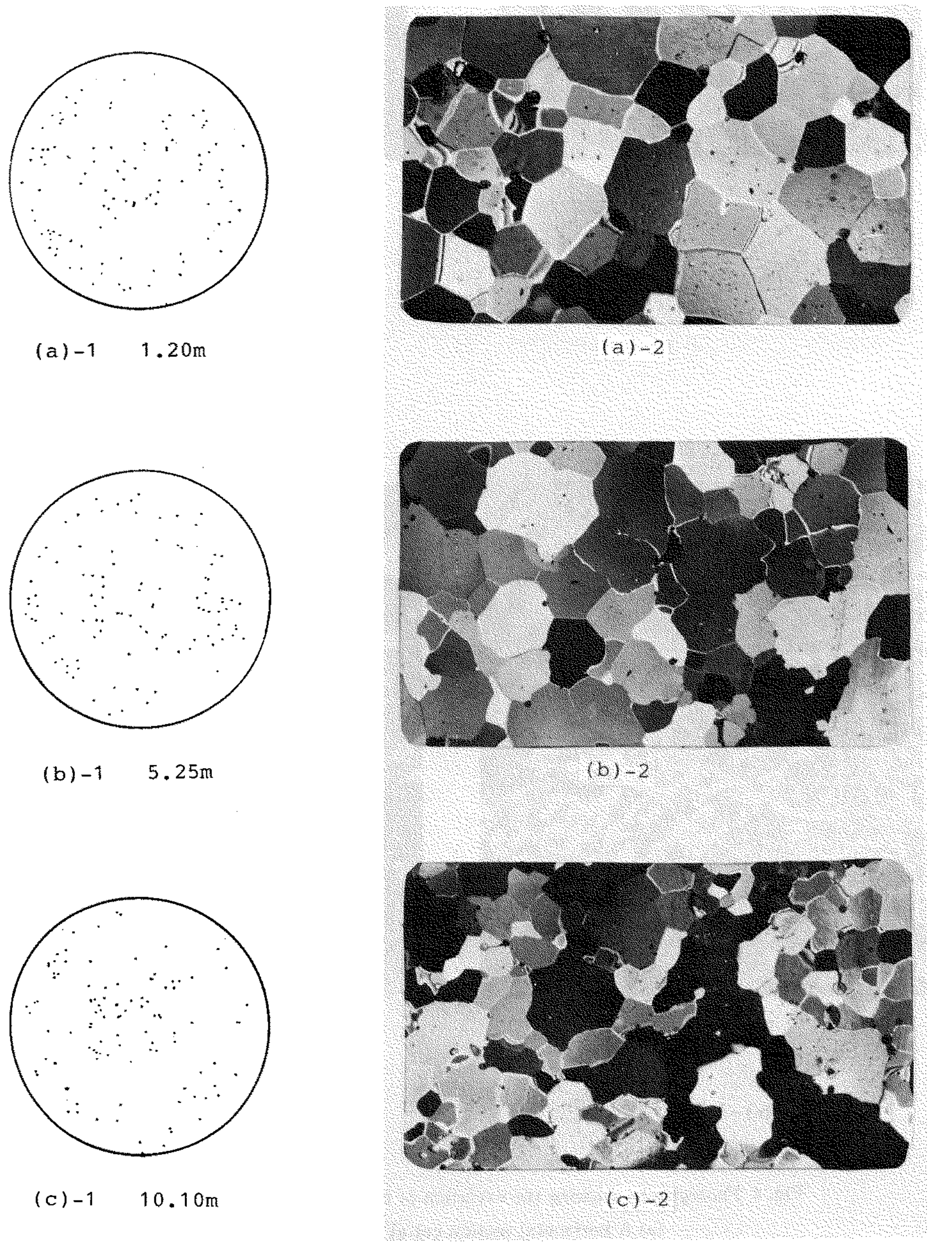
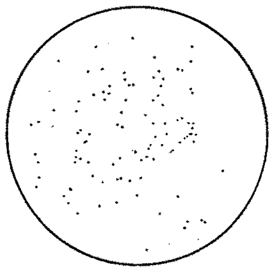
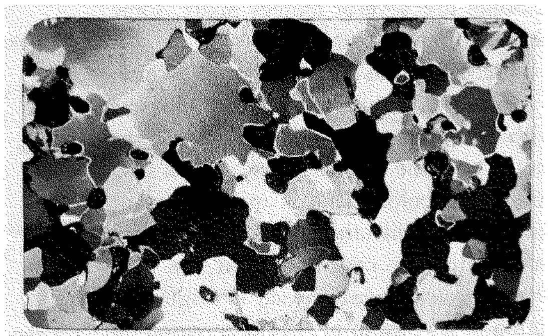


Fig. 5. Fabric diagrams and thin section photographs of ice at corresponding depths.

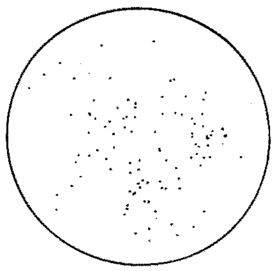
increasing depth, the polygonal shape of crystal grains is disappearing. Finally they become interlocked with each other, suggesting that shear strain increased with depth. Under normal conditions, the single maximum pattern of crystal fabric, elongated bubbles and interlocked texture with rather small crystals, all appear at depths below the transition depth from snow to ice. They are typical indicators of strong shear strain upon crystals (Han and Young, 1988). Since the combination of random c—axis orientation and elongated voids were found well above the transition depth, in B12 core, the mechanism of ice motion there must be unusual. The displacement of firn grains relative to their neighbor grains is considered to be the main mechanism for the deformation of ice body in relatively shallow depth at least above about 30 m.



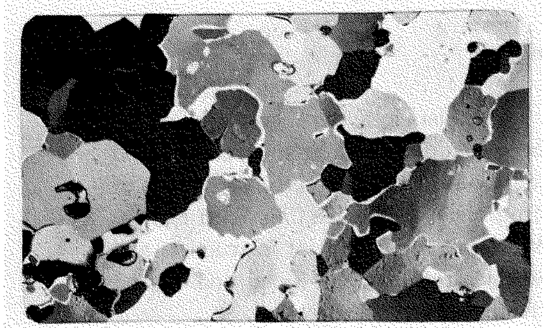
(d)-1 18.15m



(d)-2



(e)-1 25.20m



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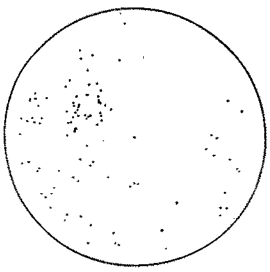
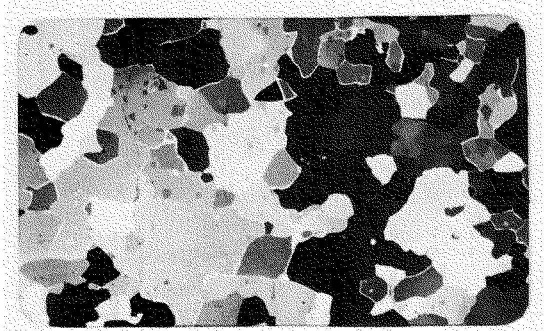


(f)-1 30.00m



(f)-2

5. Dust layers

Many dust layers were found in both cores drilled at the Chongce Ice Cap. Actually there are 14 dust layers in B12 core, 37 in B8 core. There are recognizable dust grains in some of them, but mostly dust layers exhibit only slight dark colors in ice. Most of the dust layers are found in ice, but a few in firn bands. We noticed that the intervals between two dust layers vary greatly. Some are several meters apart, some with a distance less than 10 cm.

It is also noticed that the dust layer at 20.20 m in B12 core is contained within both snow and ice. Examining with fluorescent light, the dust itself has red−brown color and, the ice including dust is also tinged with the same color. This is quite different from dark−brown color in other dust layers. From this characters, it may be concluded that the dust layer at 20.20 m is volcanic ash, which is originated from the eruption of a volcano in Ashikule region on May 27, 1951 (Liu *et al.*, 1989), since the tentative age of the ice at this depth is very close to 1951.

Acknowledgments

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