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Fabric and crystal characteristics of Bohai and Arctic sea ice

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Abstract The fabrics and crystals of Bohai one-year ice show that the noncontinuous ice growth rate enables the level ice layers with different amount of air bubbles to be formed in lower part of an ice sheet which was clearly seen from CT technology; typical grain ice and columnar ice occur in the grey ice which grows in stable water; thaw-refrozen ice and rafted ice have their specific crystal characters. On the Arctic sea ice, the ice core located at 72°24.037′N, 153°33.994′W and 2.2 m in length was a 3-year ice floe and a new sort of crystal was found, which is defined as refrozen clastic pieces. The crystal profile of the ice core 4.86 m in length located at 74°58.614′N, 160°31.830′W shows the evidence that ice ridge changed into hummock.

Key words Bohai, Arctic, sea ice, fabrics, crystals.

1 Introduction

Bohai one-year ice and Antarctic one have the similar surface-features and corresponding fabric and crystal characteristics (Allison 1997; Li *et al*. 1997; Qin 1991). During the China First Arctic Expedition, the results in the study of one-year ice from Bohai and Antarctic were used for the field work. Because over 60% sea ice in Arctic is multi-year ice, the knowledge of one-year ice is not applicable very well for the study of Arctic multi-year ice. Therefore, the fabrics and crystals of Arctic ice core samples were analyzed for checking the applicability of Arctic sea ice fabric and crystal characteristics. Comparison is made in this paper between the fabric and crystal features of Bohai one-year ice and those of Arctic multi-year ice.

2 The fabric and crystal features of Bohai one-year ice

There are level ice and rafted ice in Bohai, ice ridge is rare and is unconsolidated. For the unconsolidated ice ridge, We have little knowledge of its internal structure, except a few measured ice ridge profiles (Chen and Yang 1989). More detailed researches are made on the level ice fabrics and crystals, and these results are used to explain some ice physical phenomena. Bohai is the southern boundary in the North hemisphere, therefore its ice thickness (15 - 40 cm) and ice period (90 - 130 d) are not noteworthy in comparison with those in other northern area. Fig.1 shows the internal structure of a level ice in the northern of Liaodong Gulf, Bohai by using CT scanner technique. The white part in the figure denotes higher density and black part denotes

lower density, such as air bubbles or caves (Li *et al*. 1994). The thickness of the ice sheet from surface to bottom was 23 cm. Due to the fluctuation of air temperature in day and night and the increasing thermal resistance with ice growing, the level ice growths are slowing down in the same temperature level. Therefore, there are clear levels in the lower section of ice sheet. These levels are the results produced by different air bubble amount enclosed inside the ice at different growth rate. Under naked eyes, there are less air bubbles in gray ice, but more bubbles in white ice. The bubble size is about 1 mm. The gray and white ice levels alternatively become more and more with the ice depth increasing. More than 19 levels were observed. Under polarized light, the crystals grow continuously without distribution.

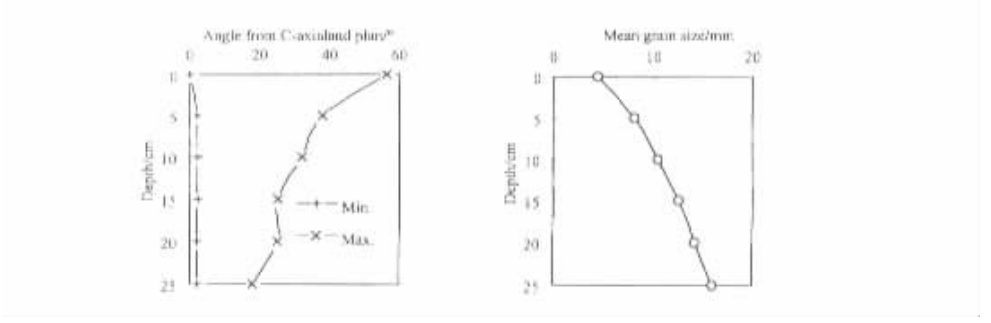

Fig.3. Angle of C-axis and level plans of S_2 ice. Fig.4. Average grain size of S_2 ice.

The ice frozen in stable water mainly is level ice. Its upper part is grain ice and then is columnar ice, Therefore, level ice occurs in harbors and tidal channels in Liaodong Gulf, Bohai. The lower part of a level ice sheet mostly is S_2 ice, and the crystal structures of S_2 ice and

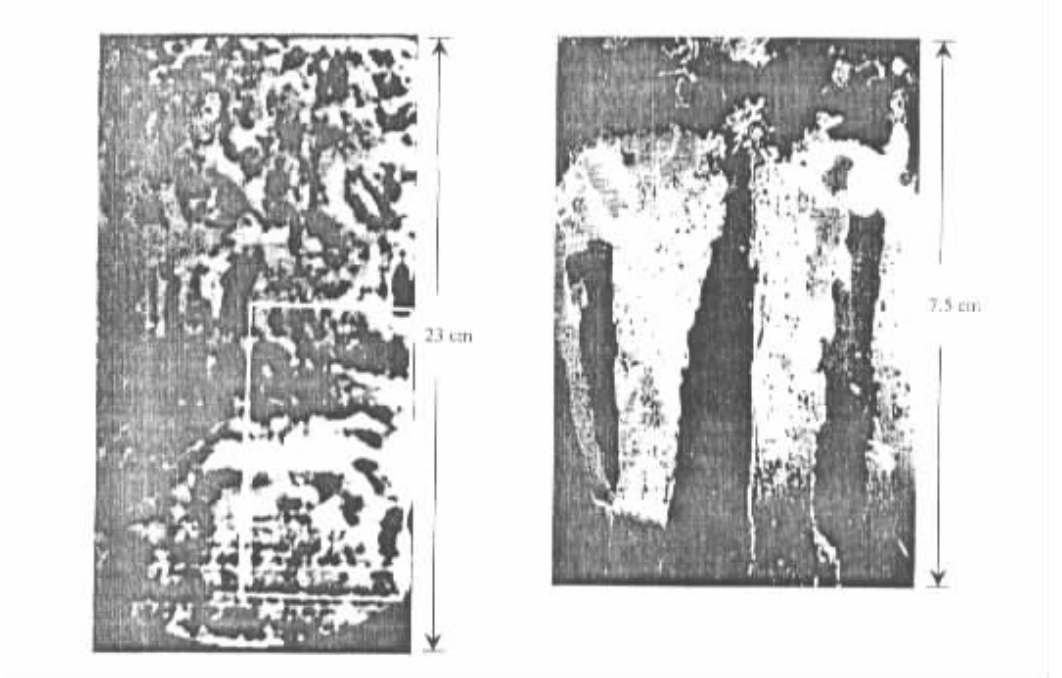

Fig.1. Macrostructure of a whole ice sheet of Bohai. Fig.2. Grain and columnar ice crystals of Bohai.

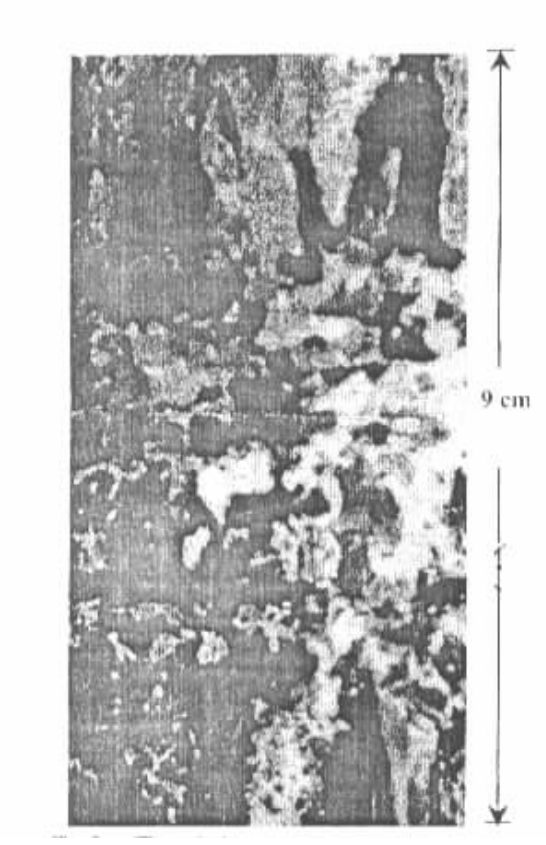

Fig.5. The rafted ice crystals of Bohai.

thaw-frozen S_2 ice in Liaodong Gulf were studied. Under the polarized light, the crystal distribution is clear, C-axis of ice crystal can be determined by using universal stage, air bubbles in ice section can be observed. Fig. 2 shows the photos of crystals of a level ice in Liaodong Gulf. The angle of S_2 ice crystal C-axis with the level plane decreases with depth of ice sheet, and is randomly distribute in plane (see Fig.3). The average grain size increases with the depth (see Fig.4). The features are not different from those of other one-year S_2 sea ice structure (Mechal and Ramseier 1971).

For the rafted ice with smooth surface, its internal structure shows obvious crystal discontinuous development, this discontinuous interface is very clear under polarized light. Fig. 5 shows an example, the ice sample was 9 cm in thickness. From crystal analysis, it was a part of rafted ice with two levels. In the middle part, the ice was granular crystal (Li *et al*. 1997).

3 Analysis of fabrics and crystals of Arctic multi-year ice

In Arctic, over 60 % ice is multi-year ice (Tucker *et al*. 1999). Multi-year ice is normally defined to be ice which has survived at least for two summer seasons. According to the ice surface characteristics of Bohai one-year ice, which we referred to in the study of Arctic multi-year ice, it is often not possible to distinguish first-year ice, or second-year ice from ice which is older.

Multi-year ice is formed from second-year ice by continuing dynamic action and by melting and refreezing. Old ridges become smoothed by melt action into surface hummocks and subsurface bummocks. The melting water gathered in the depressions to form ponds and drained away or refrozen again in the following winter season; surface snowdrifts may flood and freeze; and if the winter season is cold enough and the ice thin enough, continuing additional freezing may occur at the bottom surface of the ice. A typical undeformed floe might contain about 10 annual layers, especially if it has grown in quite stable conditions (Sanderson 1988).

During China First Arctic Expedition, 13 ice core samples were drilled from ice surface to bottom at 11 locations and all records in-situ said that they were one-year ice or multi-year ice floe (Kang *et al*. 1999). Therefore, two of these ice cores were selected for the crystal analysis. The crystal sections were cut vertically along ice core samples. 20 vertical sections were cut from a 2.22 m ice core and 53 vertical sections were cut from a 4.86 m ice core.

The fabric and crystal analysis of the 2.22 m ice core sample, which is located at 72°24.037′N, 153°33.994′W, indicates that the crystal character of the multi-year ice floe is the repeat of grain ice, columnar ice and refrozen clastic pieces. These ice crystals formed in the situations of thermal fast growth, thermal stable growth and ocean dynamic breaking respectively. The ice core sample has three cycling processes of ice growth and melting. Therefore it is a typical three-year ice floe, not one-year ice as the in-situ judgement. In addition, the refrozen clastic pieces were not reported in the fabric analysis of one-year ice in Bohai and Antarctic. Li and Kang (2001) (gave the newly-found feature of refrozen clastic pieces and its formation. Fig. 6 and Fig. 7 give the evidences of frozen water bodies and broken columnar ice blocks in the refrozen clastic pieces.

The conclusions from the typical multi-year floe are: (1) Multi-year ice in the Arctic generally reaches an equilibrium thickness of about 2 – 6 m, when annual melting just equals to annual freezing. (2) The ocean dynamic action during summer makes the columnar ice bottom break up, crash, grind continuously and refrozen. A special kind of crystal is located on the bottom and becomes the evidence of summer season. It is defined as refrozen clastic pieces. (3) In the fine clastic pieces, the refreezing water body, broken columnar ice block and plentiful typical Arctic algae were found. (4) The refrozen clastic pieces have not been found in one-year ice in Bohai and Antarctic.

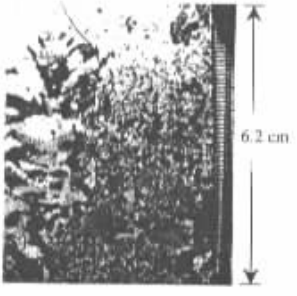

Fig.6. Frozen water body in refrozen clastic pieces.

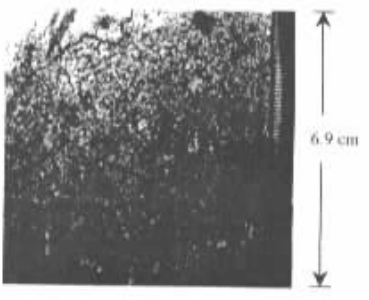

Fig.7. Broken columnar ice blocks in refrozen clastic pieces.

The fabric and crystal analysis of the 4.86 m ice core sample, which is located at 74°58.614′N, 160°31.830′W shows the evidence that ice ridge surface changed into hummock. Fig. 8 shows the crystal profile of the 4.86 m ice core sample. While it was sampled by drilling in the field, its surface was flat and air bubbles in the ice core were inclined in arrangements. The ice core was almost same under naked eyes, therefore it was concluded that the ice core was multi-year ice floe. From the crystal profile, the sloped columnar ice, even leveled columnar ice can be seen. The refreezing ice particles and interfaces between two ice blocks are clear. Also the last 4 sections from bottom shows the thermal growth of new ice. From the above mentioned, the ice core was taken from a typical hummock, not from a multi-year ice floe.

4 Summary

Although the Bohai ice is disturbed by thermal fluctuation, its effect on ice crystal and fab-

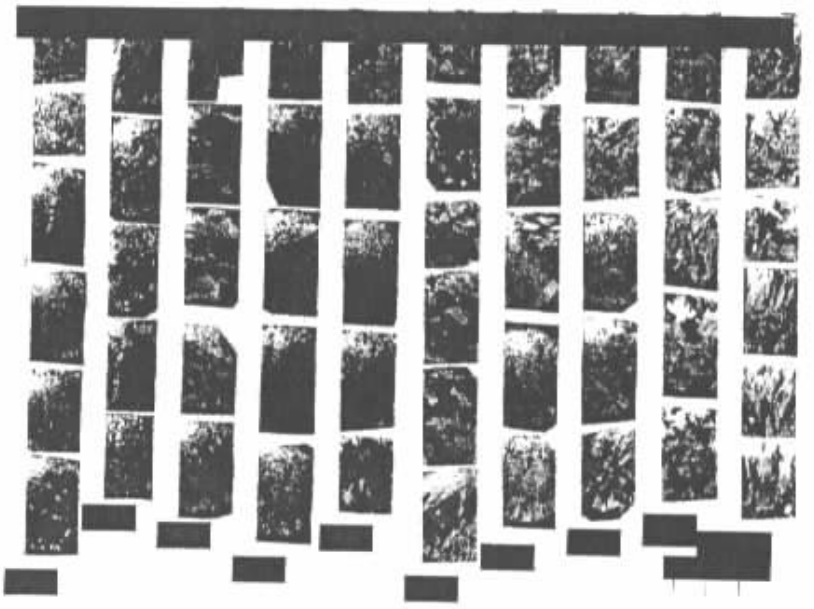

Fig.8. The ice crystal profile of a hummock with flat surface.

ric has much difference, based on the CT scan image of ice internal structure and level ice crystal photos. The fabric and crystal analysis of the 2.22 m ice core sample shows three cycling processes and proves that the sampled ice core was a typical three-year ice, not a one-year ice. In addition, the refrozen clastic pieces found in the Arctic multi-year ice floe did not occur in one-year ice in Bohai and Antarctic. The crystal profile of the 4.86 m ice core sample indicates that the sample was taken from a typical hummock, not from a multi-year ice floe. Considering the above mentioned, the recognization of surface-features from Bohai and Antarctic one-year ice could not solve the problem in what condication the Arctic multi-year ice was formed.

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