

Crystals and fabrics analysis of an Arctic thermal growth multi-year ice sample

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Abstract One of sea ice core samples was taken from Arctic by the First Chinese National Arctic Research Expedition Team in 1999. 20 vertical and 2 horizontal ice sections were cut out of the ice core sample 2.22 m in length, which covered the ice sheet from surface to bottom except losses for during sampling and section cutting. From the observation and analysis of the fabrics and crystals along the depth of the ice core sample, followings were found. Whole ice sheet consists of columnar, refrozen clastic pieces, granular, columnar, refrozen clastic pieces, granular, columnar and refrozen clastic pieces. This indicates that the ice core sample was 3-year old, and the ice sheet surface thawed and the melt water flowed into ice sheet during summer. Hence, the annual energy balance in Arctic can be determined by the ice sheet surface thawing in summer, and bottom growth in winter. The thickness of the ice sheet is kept constantly at a certain position based on the corresponding climate and ocean conditions; A new kind of hydrodynamic-effected ice crystal was found in the analysis and was defined as refrozen clastic pieces. The newly refrozen clastic pieces are explained as that they belong to the ocean dynamic broken ice pieces that come into contact with ice sheet due to buoyancy and move with the whole ice sheet. While these pieces moved to a colder zone, they were refrozen. Therefore, its structure is different from that of first-year ice and also can explain why there are typical Arctic sea ice micro-algae in the ice core sample. The age of the ice sheet is determined to be from 1997 winter to 1999 summer.

Key words sea ice, multi-year ice, crystal, fabric, Arctic.

1 Introduction

Of sea ice in the Arctic, multi-year ice covers about 60% in area. In summer, sea ice surface thaws out and the melt water flows into the non-thawed ice sheet. While in winter, the opened brine channel is refrozen and ice sheet grows by freezing of sea water on the bottom of old ice sheet. The process of brine channel refreezing disturbs and changes the crystal structure of multi-year ice sheet. Also the summer melting and winter freezing changes

the ice sheet surface and bottom. Therefore, the surface shape of the Arctic multi-year ice may be used to determine its forming conditions. Furthermore, some phenomena of the ice cannot be explained lucidly, which will debase the accuracy of work in-situ. The analysis of crystal structure of ice core samples is the key approach to understand ice fabrics and formation mechanism. Many researchers in different fields have adopted the approach to explain their problems successfully (Shokr and Sinha 1992; Allison 1997; Eidsvik 1998; Tucker III *et al.* 1999). However, the workload is so heavy that people often cut sections at distinct positions of ice core samples to observe and analyze ice crystals. The study of first-year sea ice crystals in Bohai Sea and Antarctic has been performed in China, while the study of sea ice in Arctic has not been reported yet. At the International Conference on Sea Ice in Alaska of USA, 2000, the study of first-year ice crystal structure was the focus of attention; as for the multi-year ice, there was no report (Qin 1991; Ren *et al.* 1994; Li *et al.* 1997). To learn clearly about the crystal structure and its forming conditions of multi-year ice in the Arctic, the authors observed and analyzed two ice core samples, which were taken from the Arctic by the First Chinese National Arctic Research Expedition Team (Sun 2000). The two samples, which are 9 cm in diameter, 2.22 m and 4.86 m in length, were cut from surface to bottom. The ice core sample of 2.22 m in length is a three-year old ice sheet. The crystal of a new kind of refrozen clastic pieces, which has not been reported internationally, is defined in this paper. In addition, the fabrics and crystals of the ice core sample and, especially, the forming mechanism of refrozen clastic pieces are also discussed in here.

2 Description of sampling area and thin sections

The ice core sample of 2.22 m in length was taken at the location of 72°24.037'N, 153°33.994'W at 00:46 – 04:30 (world time) on August 11, 99 (Kang *et al.* 1999). It was a little cloudy day, the surface of the sampling area was gray and the ice floe of 100 m in diameter had an elliptic shape. Around the ice floe existed a new ice ridge with the sail 1 – 2 meters in height. The central area of the ice floe was flat and covered with snow of only about 5 – 6 cm in depth. The thawing water developed little and the cranny took the shape of canine tooth; the ice melted strongly. At the spot about 1.5 m above the snow, it was 0.5 °C at the world time of 02:30 (15:30, local time). While the 2.22 m ice core sample (BJ-BX04) was taken from the ice floe, there was a layer of light yellow ice, enriched with living things, at a depth of 1.2 – 1.3 m from surface. Under a digital light microscope, the typical Arctic sea-ice microalgae, such as *Nitzschia frigida*, *Nitzschia grunowii*, *Pinnularia quadratarea*, *Pleurosigma* sp., *Navicula* spp., *Melosira arctica*, *Cylindrotheca closterium* were found (First Chinese National Arctic Expedition Team 2000). These microalgae growths need a good environment with increasing light and nutrient during the spring and summer times.

The surfaces of broken segments, which were caused in the process of 2.22 m ice core drilling, had no evident weak bonding or cracked layers, such as those induced by dynamics when observed under eyes and light. As the temperature was quite high while drilling of the hole to take the sample in-situ, part of brine escaped from the ice core sample before the sample was stored in low temperature, and this led to a great deal of air bubble inside the sample. At the location of 8 cm above the bottom of the ice sample, there existed a se-

ries of cavities, about 3 cm in diameter. Therefore the analysis of the ice crystals of this part could not be performed.

The ice crystal sections were cut vertically along its length. According to the length of each segment and the diameter of object lens of a universal stage, 20 vertical thin sections were cut. For checking purpose, 2 horizontal sections were cut at positions of 16 cm and 82 cm. After an ice crystal section was chipped to 0.2–0.5 mm in thickness, the distribution of bubbles could be observed under light as well as crystal structure through crossed polarizing filters. The vertical and horizontal sections of the ice core sample, photographed through crossed polarizing filters, are shown in Figure 1.

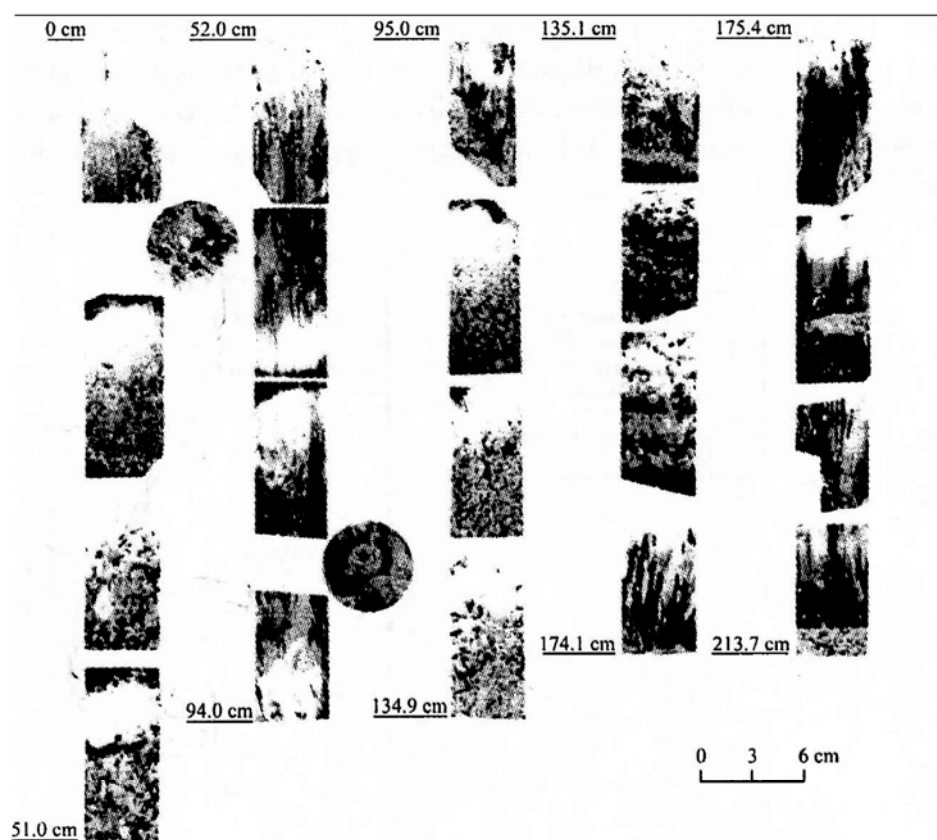


Fig. 1. Crystal photos of BJ-BX04 ice core sample through crossed polarizing filters.

3 Analysis of the fabric and crystal of the ice core sample

The section from 3 to 16 cm below surface of the ice core sample was columnar ice and its corresponding grain size was about 10 mm. By the sides of the columnar crystals existed evidently different fine crystals that were the brine channels, which were melted and refroze again. At 16–29 cm there existed a layer of fine grain crystal ice that was of different completely from that of first-year ice. These differences are: 1. the majority of ice crystals was small in grain size, with the larger grain crystals mixed; 2. there was an interface between upper columnar ice and the granular ice; 3. there existed the refrozen ice body in the shape of pore. The ice crystals mentioned above are not found in crystals induced by thermodynamics, which has not been reported up to now. Here the special granular ice is defined as

refrozen clastic pieces. From 29 cm to 51 cm, there was granular ice, which looks like the ice crystals found in Bohai (Li *et al.* 1992). Beneath the granular ice, there was columnar ice again and the average size of the crystal increased clearly with the depth and the C-axis was oriented between the positions of 51 – 102 cm, which was the same as first-year S2 sea ice classified according to ice forming environments (Michel and Ramseier 1971). From 102 to 135 cm, there were refrozen clastic pieces where columnar ice fragments were mixed with refrozen pore ice. From 135 to 167 cm there was granular ice with round crystals that was layered horizontally; there was no annular enclosure on the boundaries of the ice crystals. From 167 to 212 cm there existed columnar ice again with the trend of average size increased with depth and its C-axis oriented gradually. From 212 to 214 cm there reappeared refrozen clastic pieces. The ice core sample below 214 cm was broken because the sample had a series of cavities about 3 cm in diameter, and its crystal analysis could not be made. According to the above results, the ice sample reflected three cycles processes and showed that the ice sheet was three-year old. It formed from a typical thermal growth of multi-year ice (see Figure 2).

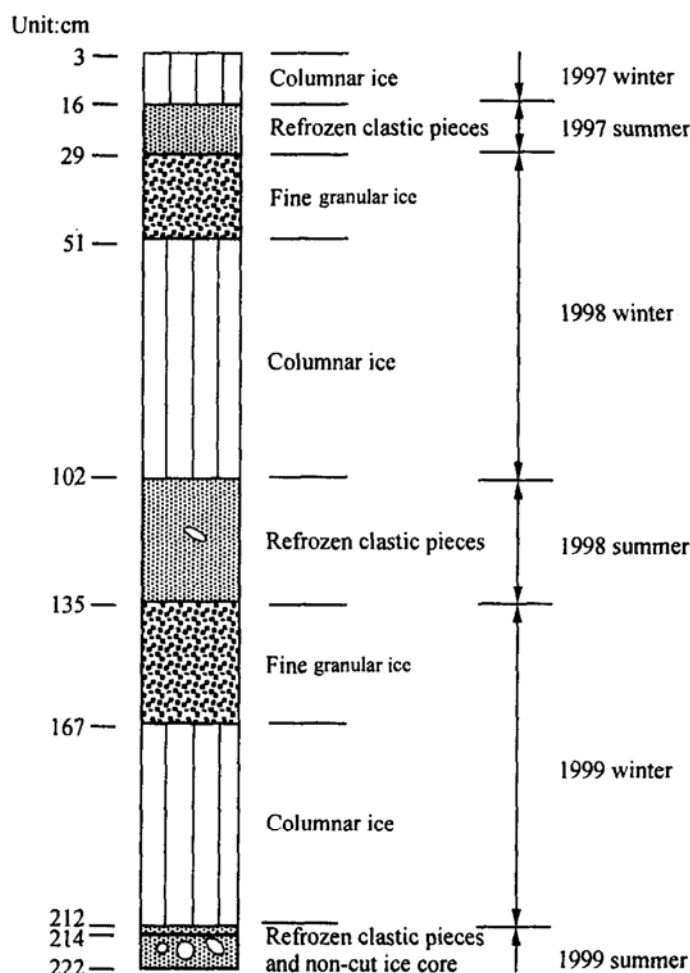


Fig. 2. Vertical fabric profile of BJ-BX04 ice core.

The air bubbles in the refrozen clastic pieces were 4% of the volume and well distributed like pellets about 1 mm in diameter. In columnar ice, the air bubbles had an elliptical shape with long axis in vertical direction, with a porosity of 15%. The proportion of air bubbles in granular ice was the highest, nearly 15%–30%, and their shape was spherical, with an average diameter of 1 to 3 mm.

It is necessary to point out that the ice core sample was not an orientational coring, so the C-axis orientation of the whole ice core from surface to bottom can not be analyzed because of no comparison made between the ice sections in different segments of the ice core sample. In the future study, it is better to sample in orientational coring.

After knowing the cyclic characteristic of the ice crystals, it is necessary to determine when the ice sheet is formed. The forming process of the Arctic multi-year ice is different from that of the Antarctic land ice and glacier ice. It can not remain at a fixed site, except for little coastal fast ice, due to the hydrodynamic moving. Thus it seems improbable to trace its growth history. In addition, the age of the Arctic multi-year ice is much younger than that of Antarctic land ice and glacier ice and is shorter than that of physical measurement accurate. Hence, the methods in determining of ice age for the Antarctic ice and the glacier ice are not useful. However, the analysis of fabrics and crystals of the Arctic ice core also offers references to determine its forming time.

On the analyzed ice core sample, it was in the middle of August 1999 when the sample was drilled. The ice surface melting had come to an end, and ice bottom growth did not start. It is easy to find that the refrozen clastic pieces of 2 cm in the last ice section belonged to the same type of ice with the broken ice core segment that could not be cut into sections. Both the two types of ice went through the spring and summer of 1999 and were distributed by ocean hydrodynamics. Especially the cavity, about 3 cm in diameter, in the broken ice blocks provided powerful proof to explain the pore shape of water bodies inside other layers of refrozen clastic pieces being refrozen into new structure of ice crystals. The phenomenon shows that the refrozen clastic pieces went through the spring and summer and enclosed inside the pore shape cavity is the water of the same temperature at the zero point. In the following winter, it refreezes to form the new structure crystals, which grows in circumference on the inner wall of the cavity to form an array of ice needles 2 mm in breadth, 7 mm in length.

At depths of 51–102 cm, there was columnar ice 10 mm in grain size with brine channels refrozen. Based on first-year ice columnar grain size and crystal characteristics, the columnar ice 10 mm in grain size should exist at the depth of 30 cm beneath the ice surface in the case of thermal growth. Therefore, the obtained conclusion is that the ice sheet lost the granular ice and part of the columnar ice. The reason is that the ice surface thawed in summer and the majority of melt water went to the thawing water berth. Small part of the melt water moved down along the broadened brine channels under the action of the gravity and was frozen into another type of crystals at low temperatures. Hence, the annual energy balance in the Arctic melts the ice sheet surface in summer, and freezes at the bottom in winter.

According to the above analysis, the changing process of the multi-year ice through the whole summer in the Arctic can be summed up as follows: In winter, grain ice grows on the bottom first, then the columnar ice grows. After winter, the ice surface thaws in spring and summer due to solar radiation, and the thawed water gathers and seeps down. On the bot-

tom, part of the ice was broken by hydrodynamics and later was refrozen to form the newly refrozen clastic pieces. The yearly cyclic process develops such fabrics and crystals of grain ice, columnar ice and refrozen clastic pieces. The phenomenon of surface thawing in summer and bottom growing in winter is just the embodiment of annual energy balance of the multi-year ice in the Arctic.

4 Characteristic of refrozen clastic pieces

Refrozen clastic pieces are not found in first-year ice in Bohai sea and the Antarctica. Its growth characteristic is different because from the grains ice formed by fast freezing of seawater under low air temperature. With the ice growth in winter coming to the end, the contribution of thermodynamics to ice thickness terminates. First-year ice thaws in spring, but multi-year ice remained through the summer. Under the ocean hydrodynamic conditions in the Arctic, the skeleton layer and a part of columnar ice above the ice sheet bottom are broken. The temperature of seawater mixed with the broken ice pieces keeps at the freezing point, about -1.8°C . While the freezing temperature of pure ice crystals is about 0°C , which is higher than -1.8°C , so the broken ice pieces in the seawater do not thaw but can be broken, crushed, milled continuously under the action of the ocean hydrodynamics (see Figure 3). These ice pieces attach to the bottom of the ice sheet because they can float on water surface. If they move and meet the areas of little lower water temperature, the ice pieces refreeze. The bigger seawater cysts contained in the broken ice pieces remained liquid due to the same temperature at the freezing point of seawater. When following winter comes, they begin to freeze from outside to inside and form the tubiform crystals. The fact that on the bottom of the broken ice core, the remaining cavity's inner wall is similar in shape to that of crystals contained in tubiform water bodies in other two layers of refrozen clastic pieces supports the above analysis (see Figure 4). Besides, a small part of unbroken ice block still remains in the columnar crystal shape (see Figure 5).

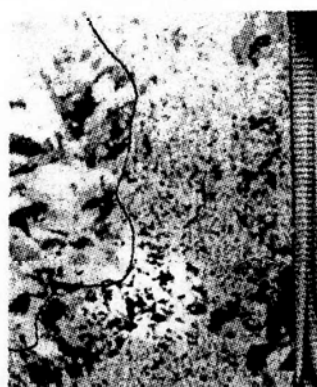


Fig. 3. Frozen crystals in the pore in refrozen clastic pieces.

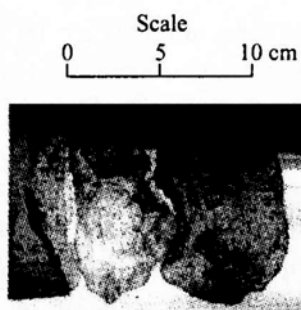


Fig. 4. Internal wall of the pore at the end of the ice core sample.

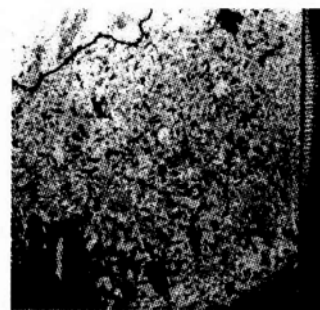


Fig. 5. Columnar crystal blocks in the refrozen clastic pieces.

5 Conclusions

(1) The fabric and crystal analysis of the 2.22 m ice core sample shows three cycles of processes, and indicating that the sampled ice sheet was a typical three-year ice, rather than first-year ice.

(2) The characteristics of the multi-year ice crystals and fabrics in the Arctic, induced by thermodynamics and hydrodynamics, are fine grain, columnar, refrozen clastic pieces, which correspond, respectively, to the thermal fast growth, thermal stable growth and hydrodynamic break in summer and thermal freezing in cold temperature. The refrozen clastic pieces are not found in first-year ice in the Bohai and Antarctic.

(3) The phenomenon of surface thawing in summer and bottom growth in winter is just the embodiment of thickness balance of multi-year ice in the Arctic. Ice on the surface thaws in summer and the majority of thawed water flows to the low-lying areas. Small part of the thawed water moves down along the broadened brine channels under the action of the gravity and is frozen into another type of crystals when it contacts regions at lower temperature.

(4) The analysis of crystals shows that the yellow layer of the ice core sample located at the depth of 1.2 – 1.3 m from the surface belongs to the refrozen clastic pieces in the spring and summer of 1997. The summer is the ideal season for the propagation of these typical Arctic living algae.

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