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AN INVESTIGATION OF THE CRYSTAL STRUCTURE OF SEA ICE IN THE BOTHNIAN BAY

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Abstract

This report presents sea ice core measurements taken from the Bothnian Bay, March, 1984. The measurements were taken at different sites in the skerries and the basin area. The ice cores were analysed with respect to crystallographic structure using polarized light. Some ice cores were also used for the determination of ice density and ice salinity. The data give a good insight into the ice structure in a sea ice cover, illustrating a complex structure with ice types of different origins, mixed and stratified within the ice cores.

The ice cores were classified with a structural scheme. In that scheme, the sea ice is classified into three main groups: granular ice, columnar ice and mixed ice. In the examined ice cores all three groups were well represented.

Key words

Bothnian Bay, sea ice, crystal structure.

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1. INTRODUCTION

The purpose of this report is to present sea ice core measurements taken from the Bothnian Bay, March, 1984. The different sites at which ice cores were taken are given in Figure 1.

Earlier measurements of ice cores in the Bothnian Bay have mainly sampled ice cores from the inner skerries, e.g. Palosuo (1961) and Fransson (1983). The measurements presented in this work are performed in the open sea area and they are, to the knowledge of the present author, probably the first ice cores ever reported from that area.

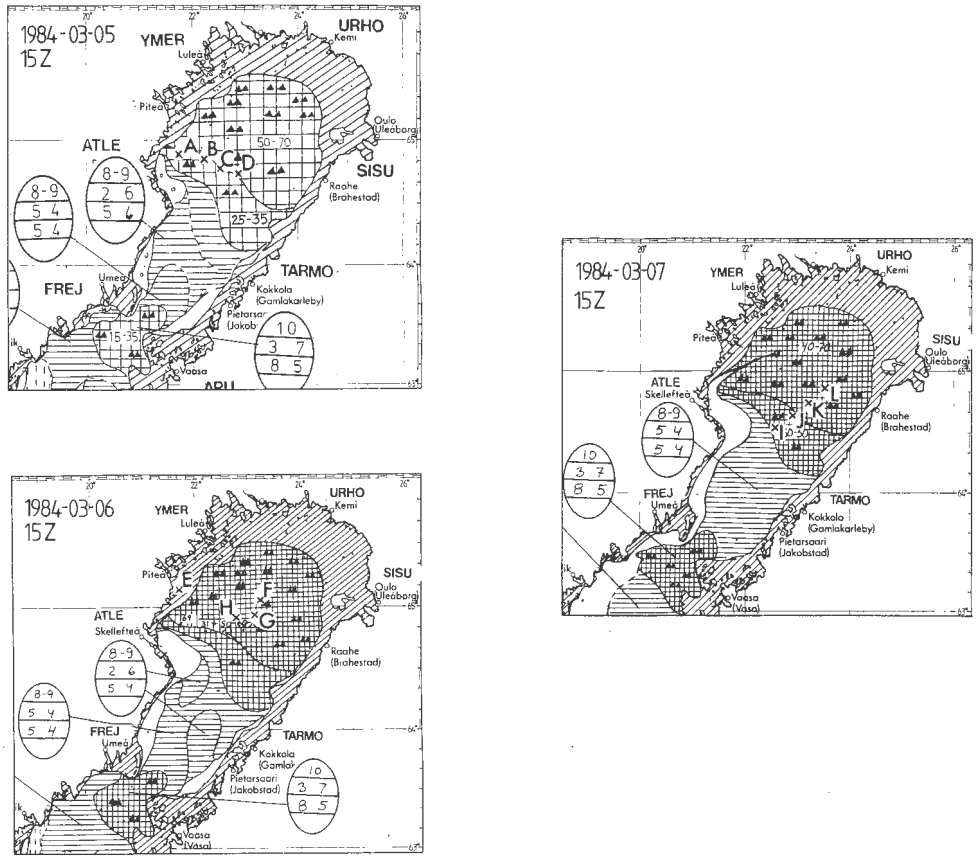

Figure 1. Ice maps over the Bothnian Bay from the 5, the 6 and the 7 of March 1984. The crosses indicate the different measuring sites.

Several other studies of the ice structure in different sea areas exist. Quite recent measurements from the Weddell Sea, the Bering Sea, Lake Champlain and the Beaufort Sea (in Weeks and Ackley, 1982, Martin and Kauffman, 1979, Bates, 1980, and Cox et.al., 1984, respectively) have shown rather complex ice crystal structure, with ice types of different origins (frazil ice, snow ice and columnar ice) stratified and mixed within the ice cores. The build up of a sea ice cover can therefore be quite complex, with ice having different origins and with ice formed under pressure during formation of rafted and ridged ice.

In the next chapter, the ice season of 1983/84 is reviewed. Then, in Chapter 3, some comments on the measurement methods are given. In Chapter 4, the classification scheme is shown. In Chapter 5, the measured ice cores are presented. Finally, a summary is given in Chapter 6.

2. THE ICE SEASON OF 1983/84

The ice season of 1983/84 was rather mild and windy. During the season several periods of ice formation and break up took place. The first ice was reported in the middle of November from the inner archipelago in the northern part of Bothnian Bay. About 23 November large parts of the northern archipelago were covered with ice. On the Finnish side of Bothnian Bay, new ice was formed at sea at this time. On the Swedish side this took place first on 28 November. In December, new ice was formed several times at sea, but hard winds caused the ice to break up. In the beginning of January, the whole Bothnian Bay was covered with ice. Because of high winds, the ice cover broke up and deformed ice was created. The ice formation and the ice growth continued but during several events high winds caused ice deformation.

The maximum extent of ice was reached on 22 March. In the northern part of Bothnian Bay, the level ice thickness reached 0.4 - 0.7 meters with lots of heavy ice ridges. In April and May the ice cover broke up and started to melt, but as late as 7 June scattered floes were observed in Bothnian Bay.

3. MEASURING METHODS

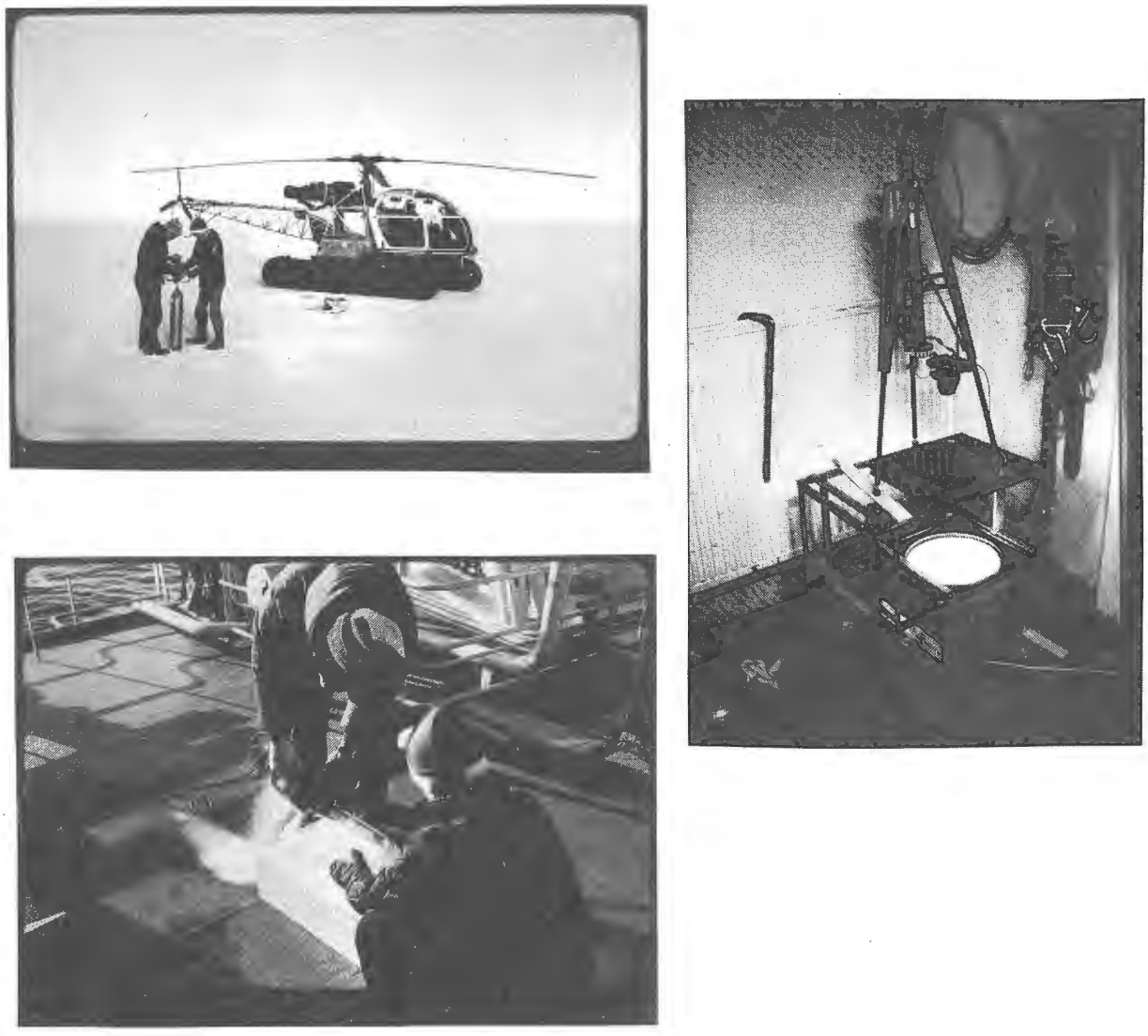

Figure 2. Measuring methods

Sea ice measurements were collected at twelve different stations during three days in March 1984, see Figure 1. The Swedish ice breaker Atle was the base during the experiment and a helicopter was used for transportation to the different stations.

To investigate the crystallographic structure of the ice, 2 - 3 ice cores were taken at each station and transported back to Atle. On the icebreaker, the ice cores were sawn and melted into thin vertical and horizontal sections, see Figure 2. The ice specimens were then put on a polarizing table, where photographs were taken.

The ice salinity and ice density were measured. The ice density measurements were based upon a volume and weight determinations of the ice cores, and the ice salinity measurements were based upon laboratory measurements of melted ice specimens, see Table 1.

Table 1. Ice core measurements from different stations in the Bothnian Bay, March 1984.

Station	Mean density (kg m^{-3})	Mean salinity (o/oo)	Ice type (%)		
			G	C	M
A	906	0.67	3	11	86
B	901	-	-	-	100
C	925	-	-	10	90
D	907	-	26	20	54
E	877	0.64	-	100	-
F	891	0.72	24	20	56
G	902	0.42	14	86	-
H	891	0.37	-	100	-
I	930	0.67	-	-	100
J	912	0.71	62	-	38
K	930	0.45	35	65	-
L	919	0.75	23	77	-

Recommendations on ice classification and standard testing method for measuring different properties of ice can be found in Schwarz et.al. (1981) and Michael (1978). However, as several of the sea ice core measurements were performed in deformed ice, the classification system presented by Cox et.al. (1984) was used in the present analysis.

Except for data given in Table 1, all data are in the form of photographs taken on the different ice cores. The data will be discussed in Chapter 5, but first some comments are made about the classification scheme.

4. CLASSIFICATION

Sea ice can be classified with regard to its origin, its grain size, crystal structure and orientation. In rafted and ridged ice areas, special considerations have to be made because of deformed ice. A structural classification scheme was therefore presented by Cox et.al. (1984), when studing mechanical properties of multi-year sea ice, see Table 2.

The scheme does not clarify the origin of the different ice types. For example, granular ice can be derived from snow ice or slush, from frazil ice and also from ice which has been granulated during rafting or ridging processes.

The scheme seems, however, useful when characterizing the crystal structure of sea ice in general, which includes first year sea ice of the types observed in the waters surrounding Sweden. The scheme will therefore also be adopted in the present paper.

Table 2. Classification scheme for sea ice according to Cox et.al. (1984)

Ice type	Code	Structural characteristics
Granular	I	Isotropic, equiaxed crystals
Columnar	II	Elongated, columnar grains
	IIA	Columnar sea ice with c-axes normal to growth direction axes may not be aligned
	IIB	Columnar sea ice having random c-axis orientation (Transition ice)
	IIC	Columnar freshwater ice; may be either anisotropic or isotropic
Mixed	III	Combination of Types I and II
	IIIA	Largely Type II with granular veins
	IIIB	Largely Type I with inclusions of Type I or II ice (Brecciated ice)

5. ICE CORE DESCRIPTION

In this chapter, one ice core from each station will be presented and discussed. The positions for the different stations are given in Figure 1. All photographs from the polarizing table, presented below, are from vertical section of the ice specimens, except Figure 14, where a horizontal section is also presented.

In Figure 3 an ice core taken from station A is illustrated. The ice core was taken close to the Swedish coast, in an area with high amounts of rafted and ridged ice. The upper 2 cm of the ice core consisted of granular ice. Below that layer,

there were layers with columnar ice mixed with granular ice. At about 50 cm there was an 8 cm thick layer of columnar ice. From 53 cm to the bottom of the core, the ice consisted of granular ice mixed with columnar ice.

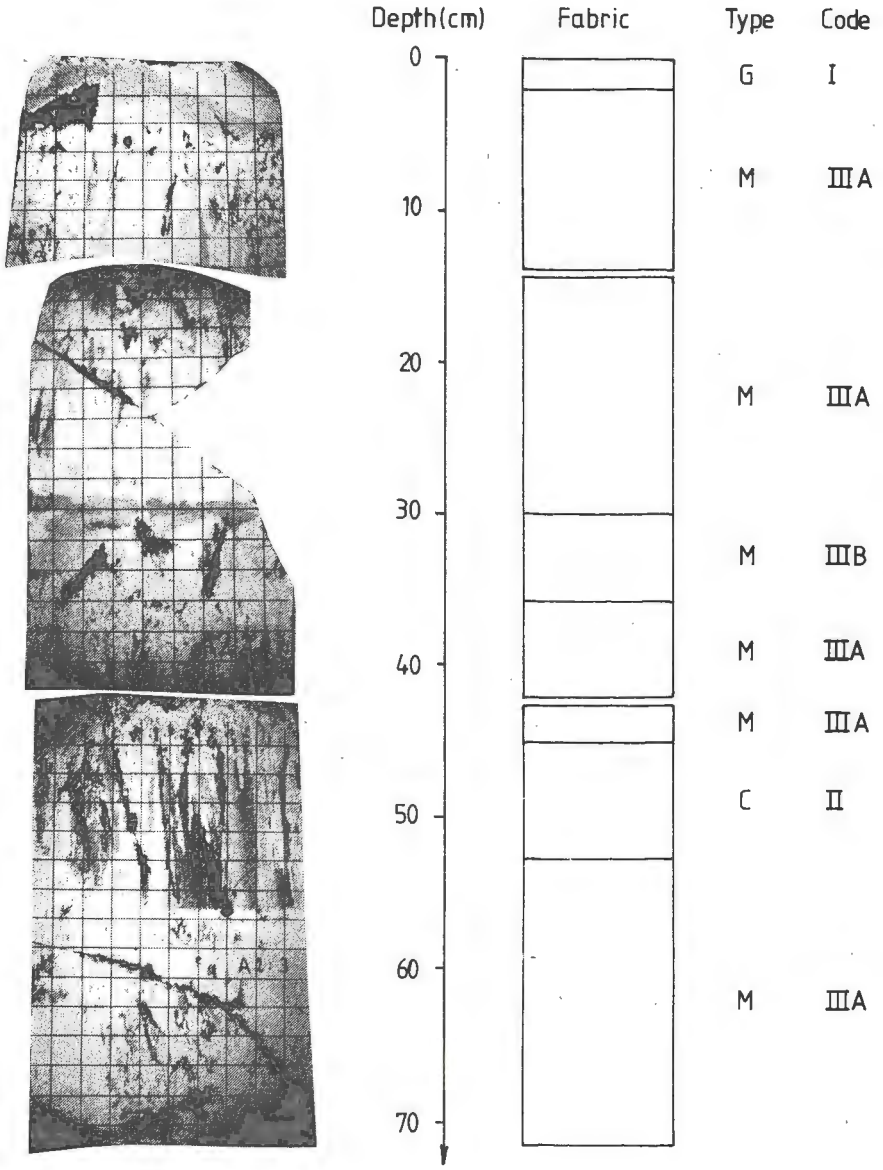

Figure 3. Vertical sections of an ice core taken from station A. The spacing of each grid is 2 x 2 cm.

In Figure 4, an ice core taken from station B is illustrated. The ice core was taken from a relatively large floe, close to a jammed brash barrier. The crystallographic structure was mainly due to columnar sea ice, but with very short ice crystals. This could be explained by flooded ice, which has been frozen during several weather events.

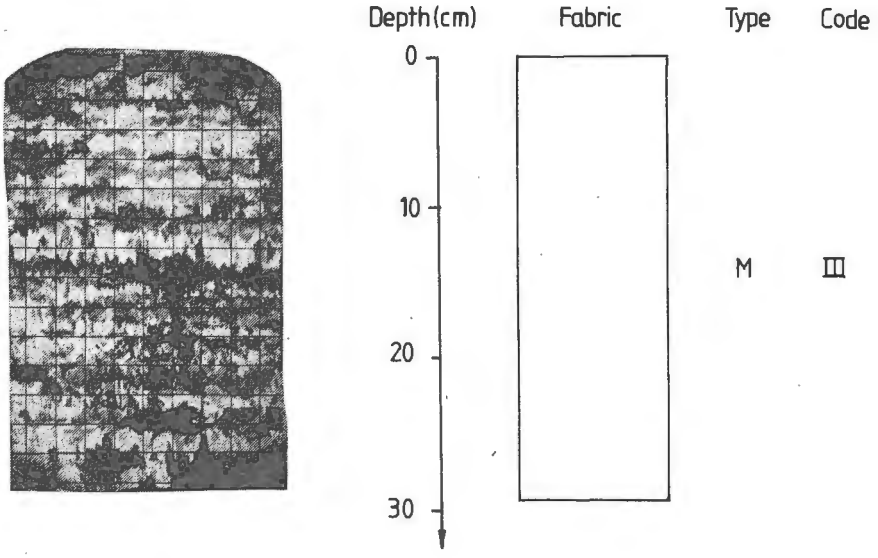

Figure 4. Vertical sections of an ice core taken from station B.

In Figure 5, an ice core taken from station C is illustrated. The ice core was taken from a sea ice area with pancake ice. The dominant part of the ice core consisted of granular ice mixed with columnar ice. Approximately 26 cm from the top of the core, columnar ice has started to grow.

In Figure 6, an ice core taken from station D is illustrated. The ice core was taken from the central part of the Bothnian Bay. The upper 12 cm of the ice core consisted of granular ice. From 12 cm to 38 cm the ice consisted of columnar ice mixed with granular ice. The remainder of the core consisted of columnar ice.

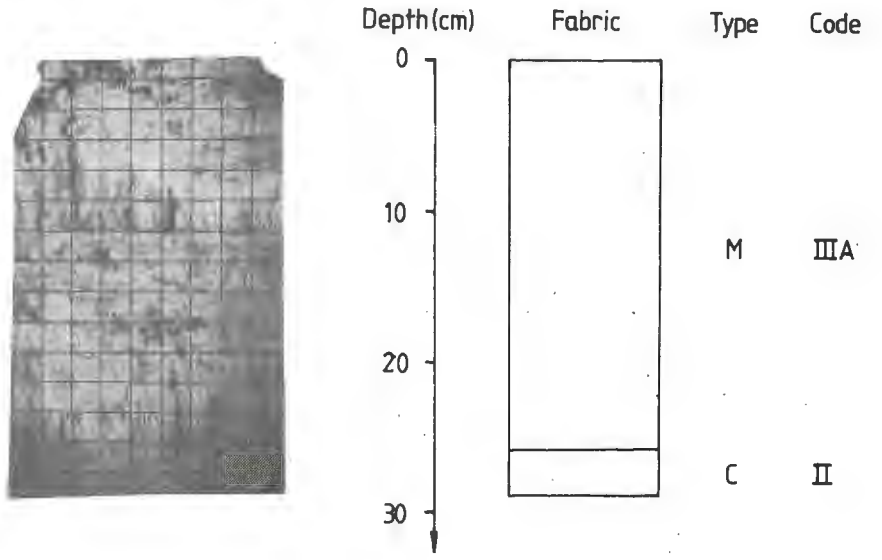

Figure 5. Vertical sections of an ice core taken from station C.

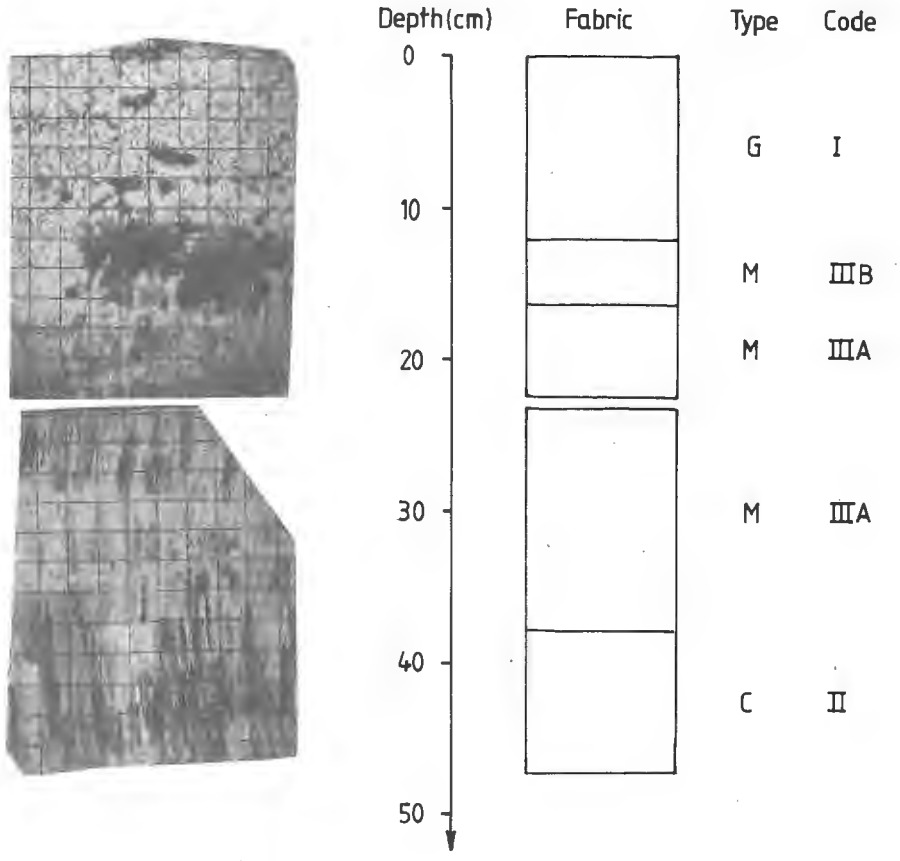

Figure 6. Vertical sections of an ice core taken from station D.

In Figure 7, an ice core taken from station E is illustrated. The ice core, was taken in the skerries, inside some small islands. The crystallographic structure was due to columnar ice, which is to be expected from ice taken in sheltered sea areas.

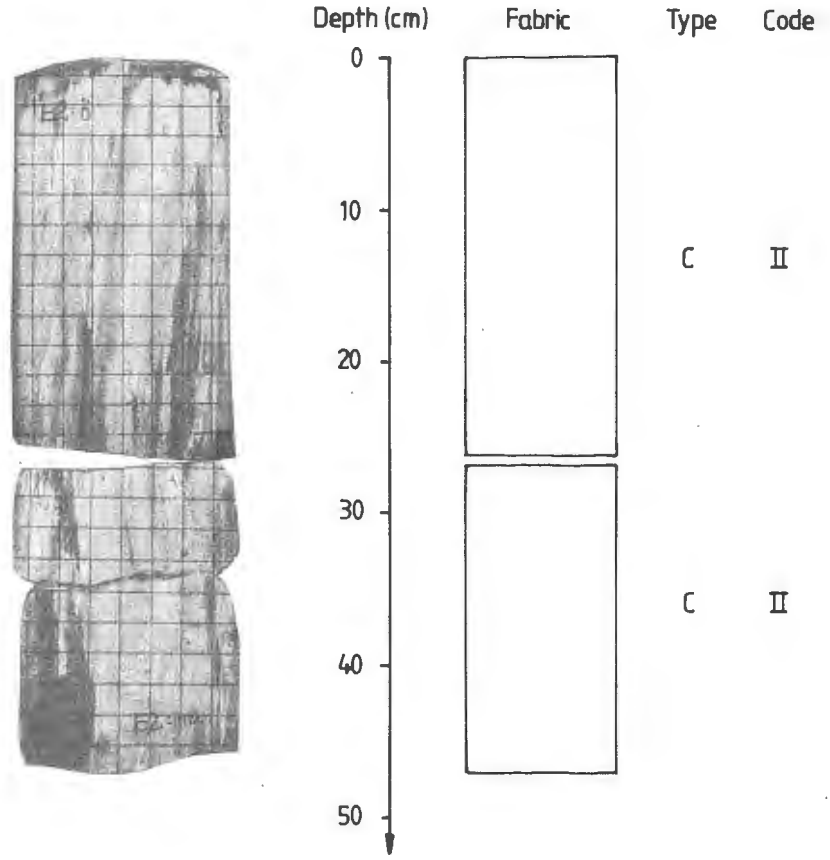

Figure 7. Vertical sections of an ice core taken from station E.

In Figure 8, an ice core taken from station F is illustrated. The ice core was taken from quite a large icefloe, surrounded by rafted and ridged ice. The upper 10 cm of the ice core consisted of granular ice. From 10 cm to 34 cm mixed ice dominates. The remainder of the core, consisted of columnar ice with the c-axis somewhat deviating from the vertical direction.

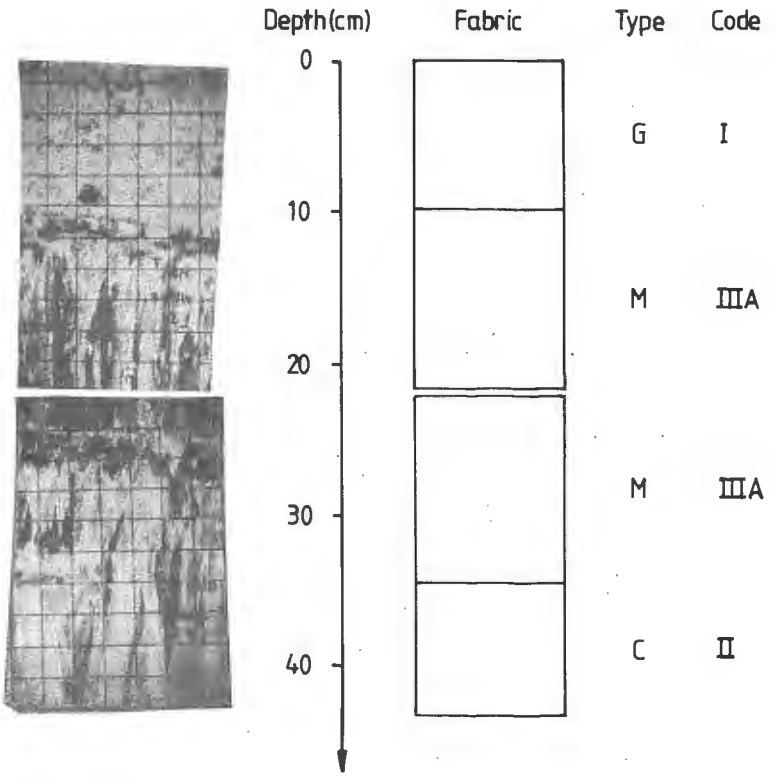

Figure 8. Vertical sections of an ice core taken from station F.

In Figure 9, an ice core taken from station G is illustrated. The ice core was taken in an area with broken ice floes surrounded by ridged ice. The dominant ice type was due to columnar ice, but with a layer in the middle of the ice core consisting of granular ice.

In Figure 10, an ice core taken from station H is illustrated. The whole ice core was made up of columnar ice.

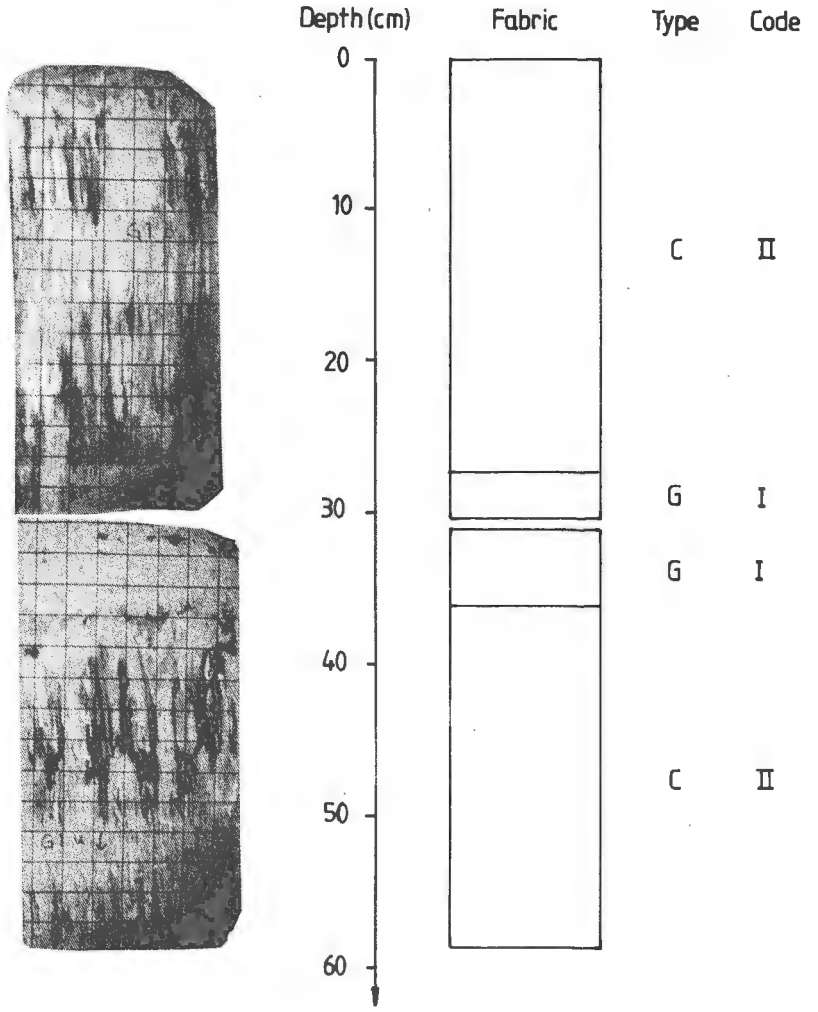

Figure 9. Vertical sections of an ice core taken from station G.

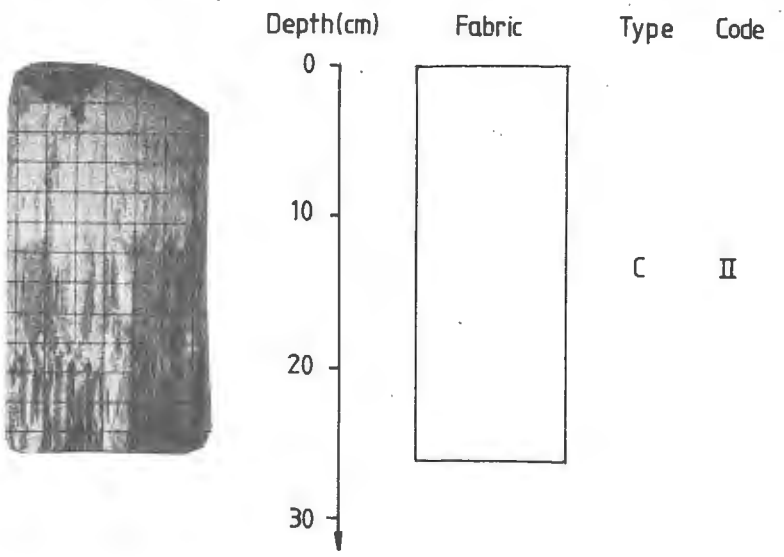

Figure 10. Vertical sections of an ice core taken from station H.

In Figure 11, an ice core taken from station I is illustrated. The ice core was taken from a rather smooth ice area, close to thinner ice. The whole ice core consisted of granular ice mixed with columnar ice fragments.

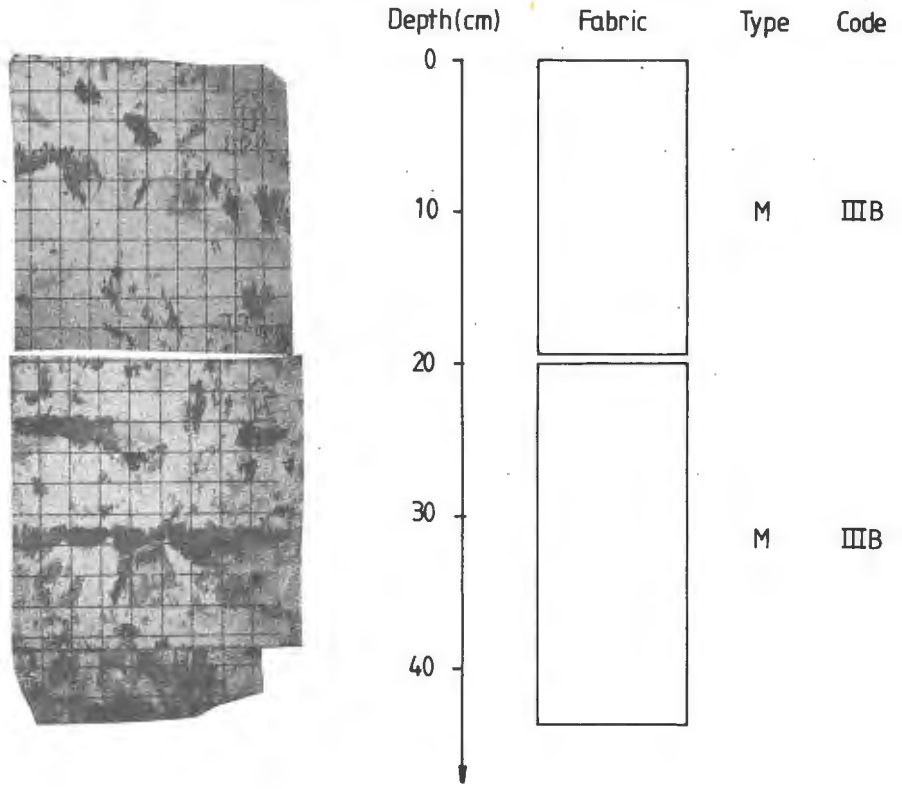

Figure 11. Vertical sections of an ice core taken from station I.

In Figure 12, an ice core taken from station J is illustrated. The upper part of the ice core consisted of granular ice. From about 10 cm to 23 cm, columnar ice was mixed with granular ice. The c-axis also deviated somewhat from the vertical direction in that layer. From 23 cm to 40 cm, granular ice dominated. At the bottom one can also observe a thin layer of columnar ice mixed with granular ice.

In Figure 13, an ice core taken from station K is illustrated. This ice core together with the cores taken from station L, were drilled from a rather smooth sea ice area. The upper 14 cm of the ice core consisted of granular ice. The remainder of the core consisted of columnar ice.

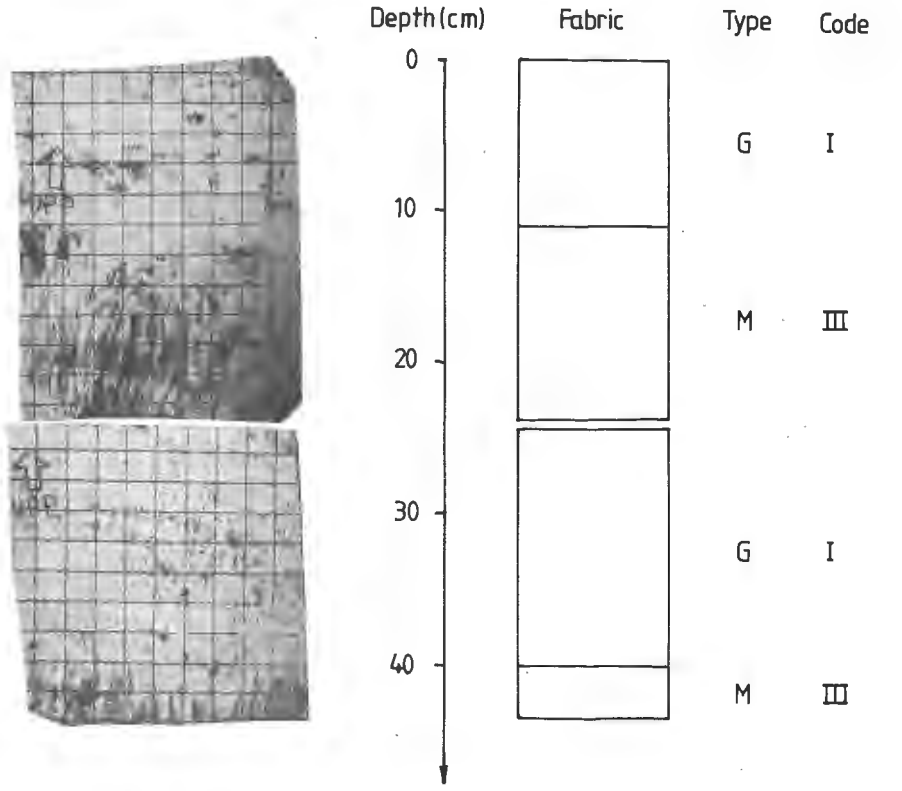

Figure 12. Vertical sections of an ice core taken from station J.

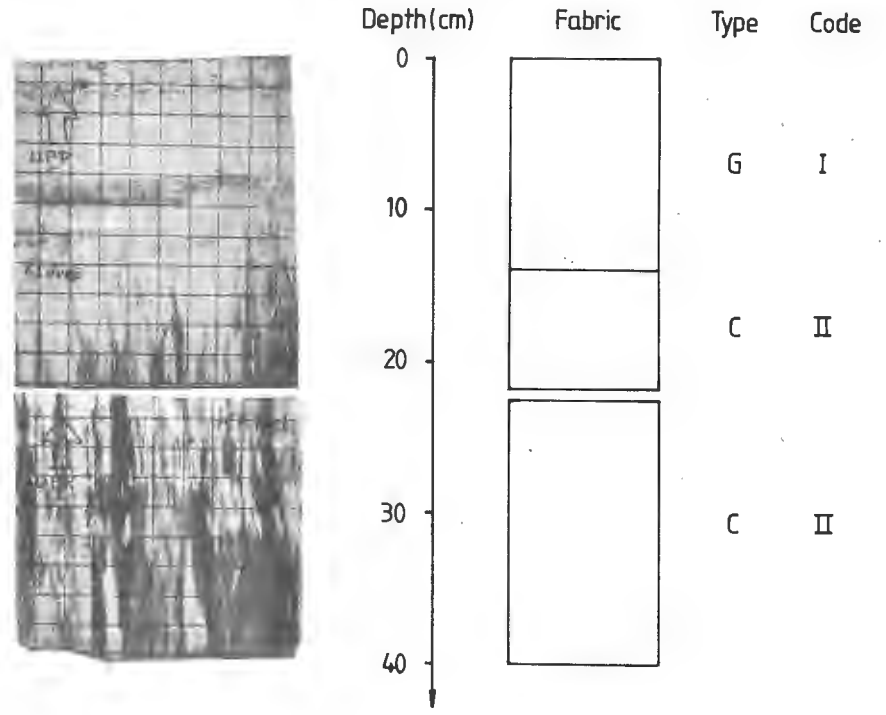

Figure 13. Vertical sections of an ice core taken from station K.

In Figur 14, an ice core taken from station L is illustrated. The upper 8 cm of the ice core consisted of granular ice. Below this layer, the core was made up of columnar ice.

In Figure 14, a thin horizontal section of the ice core from station L is also illustrated. The horizontal section is illustrated both by a visual photograph and by a photograph taken from the polarizing table. From the visual photograph, one can notice small air bubbles together with larger channels for salinity drainage. The measured salinity in ice core L was 0.75 o/oo, which is about 4 - 5 times as low as the underlying water salinity.

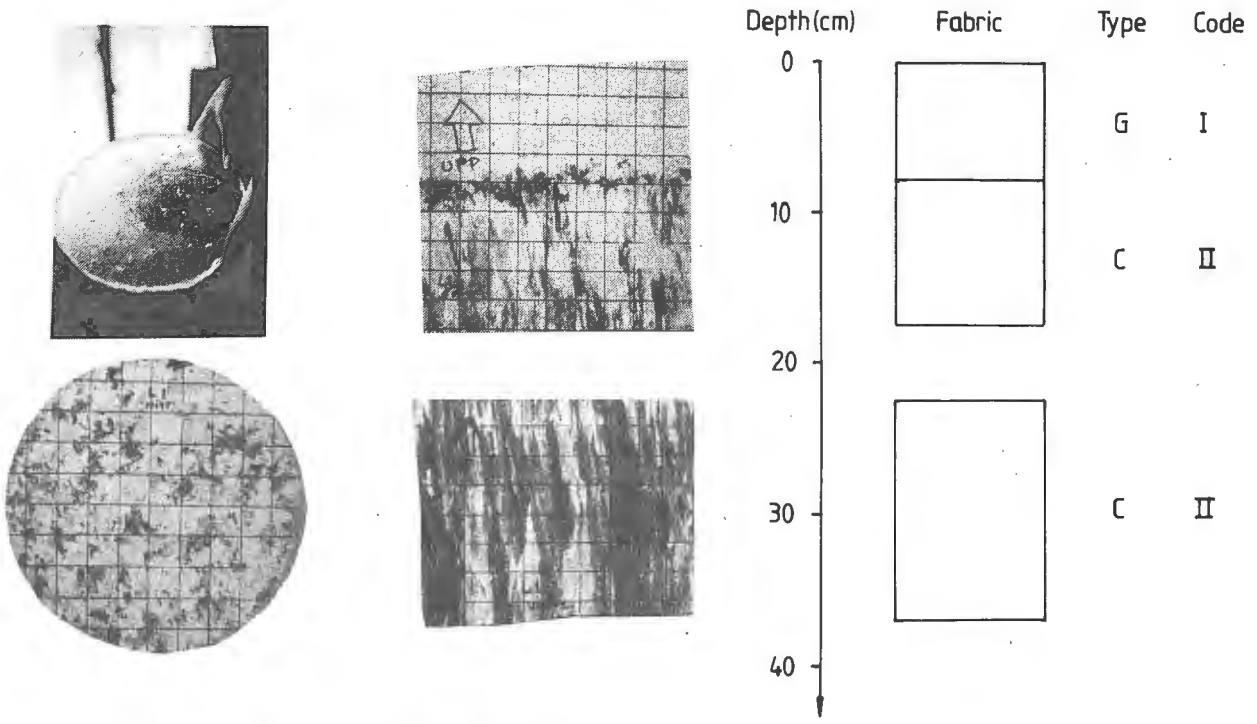

Figure 14. Vertical sections of an ice core taken from station L together with a horizontal section cut from the middle of the ice core.

6. SUMMARY

In the present report, sea ice core measurements from twelve different sites in the Bothnian Bay have been presented. The ice cores were analysed with respect to crystallographic structure, using polarized light. Some ice cores were also used for the determination of ice density and ice salinity.

The data give a good insight into the crystal structure in a sea ice cover, illustrating a complex structure with ice types of different origins, mixed and stratified within the ice cores. The ice cores were classified with a structural scheme presented by Cox et.al (1984). In that scheme the sea ice is classified into three main groups: granular ice, columnar ice and mixed ice. In the examined ice cores all three groups were well represented.

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