PORT AND OCEAN ENGINEERING UNDER ARCTIC CONDITIONS
TECHNICAL UNIVERSITY OF NORWAY

SEA ICE CHARACTERISTICS IN BERING SEA

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SUMMARY

Sea ice samples collected from the NORTHWIND icebreaker cruise Jan.-Feb. 1970 extending from Cape Newenham to the Russian coast were studied onboard ship. Large blocks of sea ice were obtained for their section petrofabric examination and the collection of ice-sediments. The Bering Sea ice consisted of three layers: a thick horizontal C axis layer bounded by thin vertical C axis layers at the top and the bottom. The maximum sediment concentration in Bering Sea ice was observed near the lower boundary of horizontal C axis layer. The unusual bottom vertical C axis ice layer in Bering Sea may be due to several sea ice forming phenomena. However, extreme cold weather accompanied by severe storm in this area is suggested for this ice-layer.

INTRODUCTION

The importance of ice on sediment erosion, transportation and deposition in the continents and oceans has been recognized. The study of glaciers and glacial deposits have contributed to our knowledge concerning formation of glacial ice and the manner in which sediments are plucked by ice, transported and deposited at distance from their source. Icebergs originating on continents have carried erratics even farther away from source. The importance of ice as a significant geologic agent for weathering and sediment transport in polar regions cannnot be overemphasized. For example, it is estimated that 2×10^{15} g of rock material is annually contributed to the sea from Antarctica by glacial ice.

Formation of sea ice and its role as sediment carrier, however, is not well documented. Little effort has been devoted to study the nature of sea ice and the incorporated sediments therein. Large areas of polar oceans are covered by sea ice during winter carrying significant amounts of sedimentary material. Partly this material is biogenic and the source for the rest is not known. To study the nature of sea ice and the incorporated sediments, winter sea ice samples were collected over a large area so as to eliminate the effects of regional weather and local morphological conditions (Fig. 1). Special effort was made to collect most samples at the seaward boundary. Samples from nearshore were also collected for comparison and to study the influence of depth and freshwater on the sea ice. The rate of cooling and the effects of salinity which greatly influence the nature of sea ice are not included in this study. The samples were collected from the Bering Sea during Jan.-Feb., 1970 from the U.S.C.G. NORTHWIND cruise, the area of investigation extended from Cape Newenham to the eastern Russian coast.

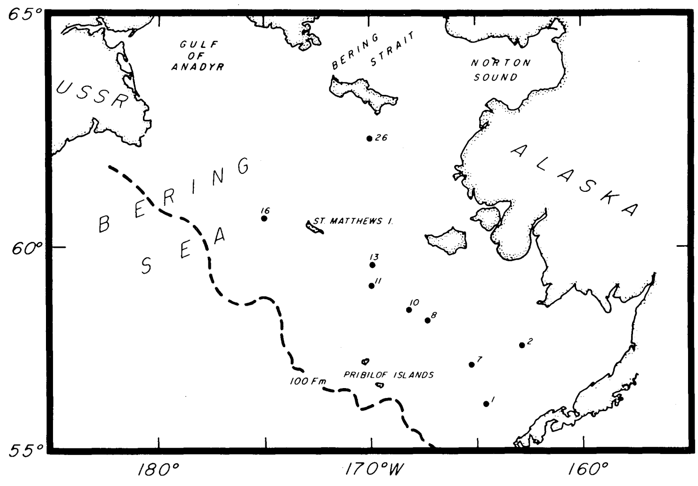

Fig. 1. Index map showing station locations.

Fig. 2. Sediment distribution in Bering Sea ice.

METHODS

Sea ice samples were obtained both by using a SIPRE ice auger for petrofabric studies and large ice blocks for sea ice sediments. The sample obtained from the auger proved unsatisfactory because the small horizontal thin sections were difficult to work with and the entire sample often became saturated with water during coring operation. The thin sections for petrofabric analysis, therefore, were cut from large blocks which had broken up from the pack ice by the icebreaker.

Large blocks of ice were also hauled on board the ship (Figs. 2, 3, 4 and 5), and the portions rich in sediments were melted in large vessels. The meltwater was decanted and the residual sediments were collected for laboratory analyses. Representative samples of sea ice were melted in enclosed bottles to avoid evaporation, and the salinity of sea ice meltwater determined.

Petrofabric studies were conducted on board ship on most samples collected. Thin slices (1-2 mm thick) of vertical and horizontal planes from samples were frozen onto large glass plates and photographed under polarized light. Additional pieces of ice were mounted on smaller glass slides to facilitate plotting the C-axes on a Rigby four-axis stage. The crystallographic data was then plotted on Schmidt equal area nets using the method described by Langway 1958[1] and Rigby 1960[2]. The petrofabric studies were made with a special reference to the amounts and location of incorporated sediments and also the shape and distribution of air bubbles and brine pockets in the sea ice.

RESULTS

Bering Sea ice throughout the region displayed a consistent crystallographic structure. Sea ice was layered, with a bubbly, milky, fine-grained layer on the top and a layer of clear, dense, bubble-free ice near the bottom. The ice near the top contained a layer with vertically oriented crystals. This layer underlain by a thick layer of clear, dense ice consisting of long, tapered crystals with horizontal C-axis. This particular crystal fabric is quite common in lake ice and stream ice. A layer of clear, very fine grained dense, bubbly milky ice was observed at the bottom (Plates I, II, III, IV and V).

Beside crystal orientation the vertical layering of the Bering Sea ice can also be differentiated on the basis of crystallinity. Maximum of five layers were observed in some samples. These layers were characterized by primarily the crystal orientation, size and shape of individual crystal, air bubbles, salt pockets and sediment or phytoplankton content in the ice.

DISCUSSION

The freezing of seawater and the resulting sea ice is a complex process in which the rate of cooling, salinity and the rate of loading play a significant role. Theoretical as well as experimental work to elucidate the formation of sea ice has been conducted by Anderson and Weeks (1958)[3], and Weeks (1962)[4]. Field observations on sea ice have been made by several investigators and these studies were conducted primarily to evaluate the mechanical properties of sea ice, better icebreaker design, sea ice landing strips, offshore drilling platforms, dredging facilities and other related structures. The petrofabric studies of sea ice have been made and described insofar as to explain the mechanical properties such as strength of sea ice etc.

Review of the literature revealed that Arctic sea ice consists generally of a top thin layer of randomly oriented vertical C axis underlain by a thick substrate of horizontally oriented C axis. The crystallinity in the substrate varies considerably and stratification within the horizontal oriented C axis can be delineated on the basis of crystal size dimensions. The petrofabric of the sea ice obtained from the Bering Sea, however, distinctly indicated three layers; top, thin layer with randomly oriented vertical C axis underlain by a thick layer of horizontally aligned C axis and the thin, bottom layer with vertical C axis. As usual many layers of various crystallinity were differentiated within the middle layer.

One sample exposed alternating layers with vertical and horizontal axis and believed to be due to fusion of two normal ice sheet. This is inferred because the second vertically oriented C axis layer is

Fig. 3. Large block of Bering Sea ice with sediments.

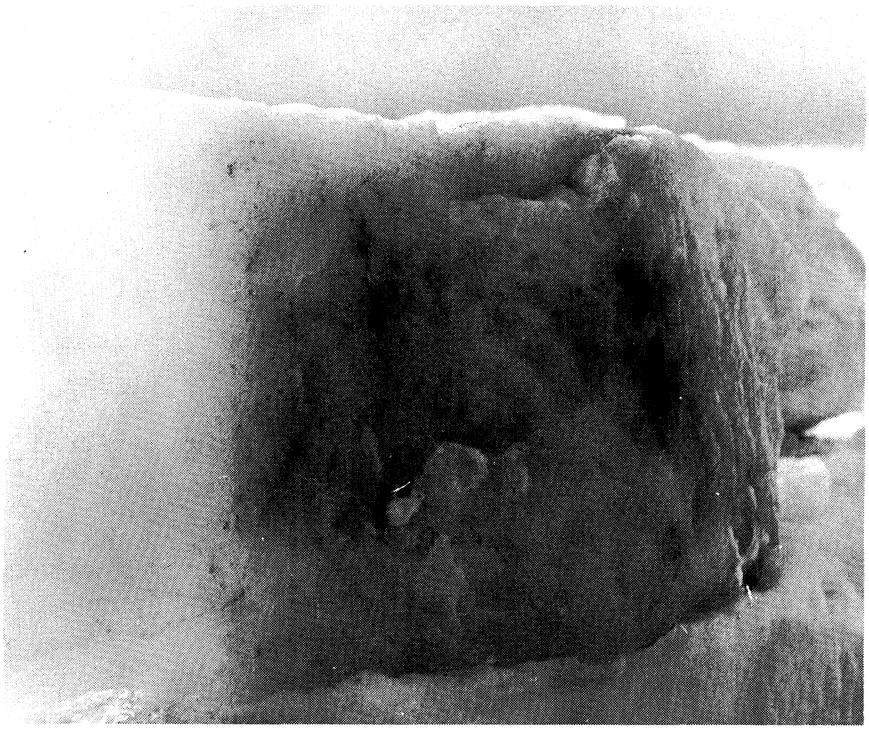

Fig. 4. Layering of sediments in Bering Sea ice.

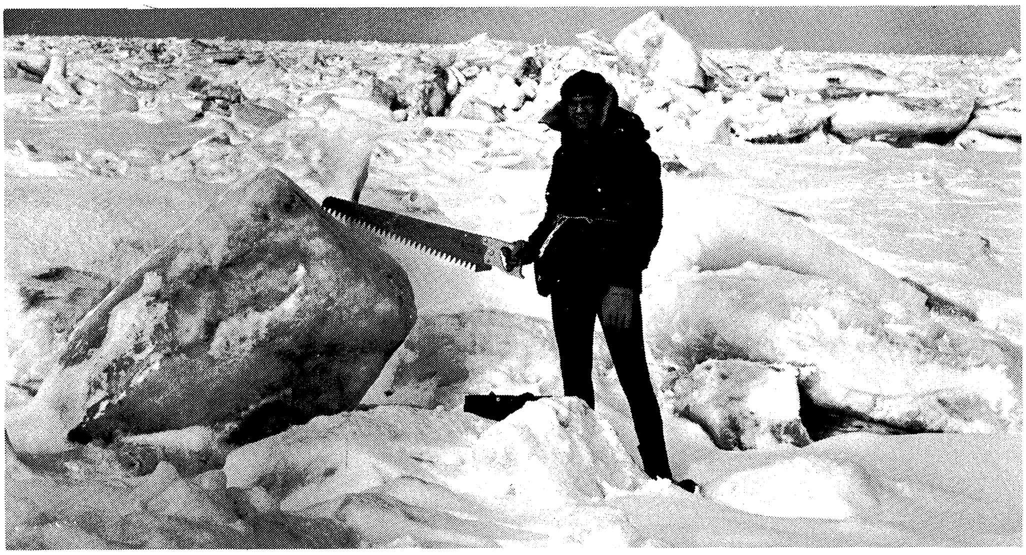

Fig. 5. Sediment laden sea ice in Bering Sea.

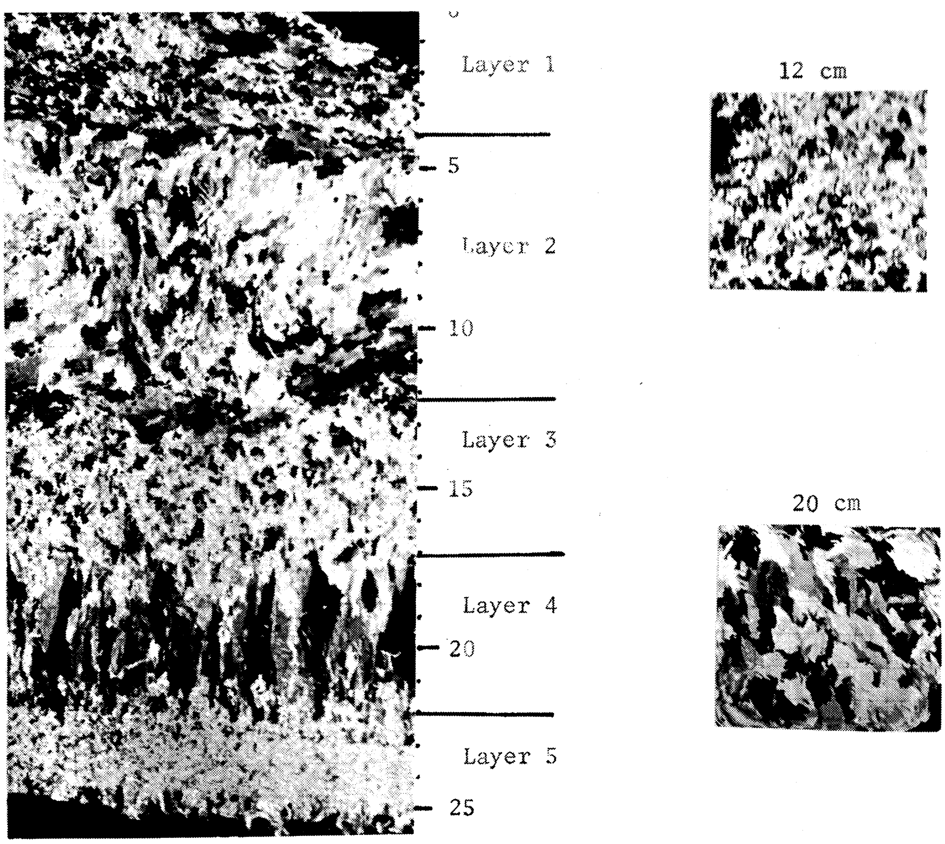

PLATE I - Vertical and horizontal thin sections of ice sample number 3 in polarized light.

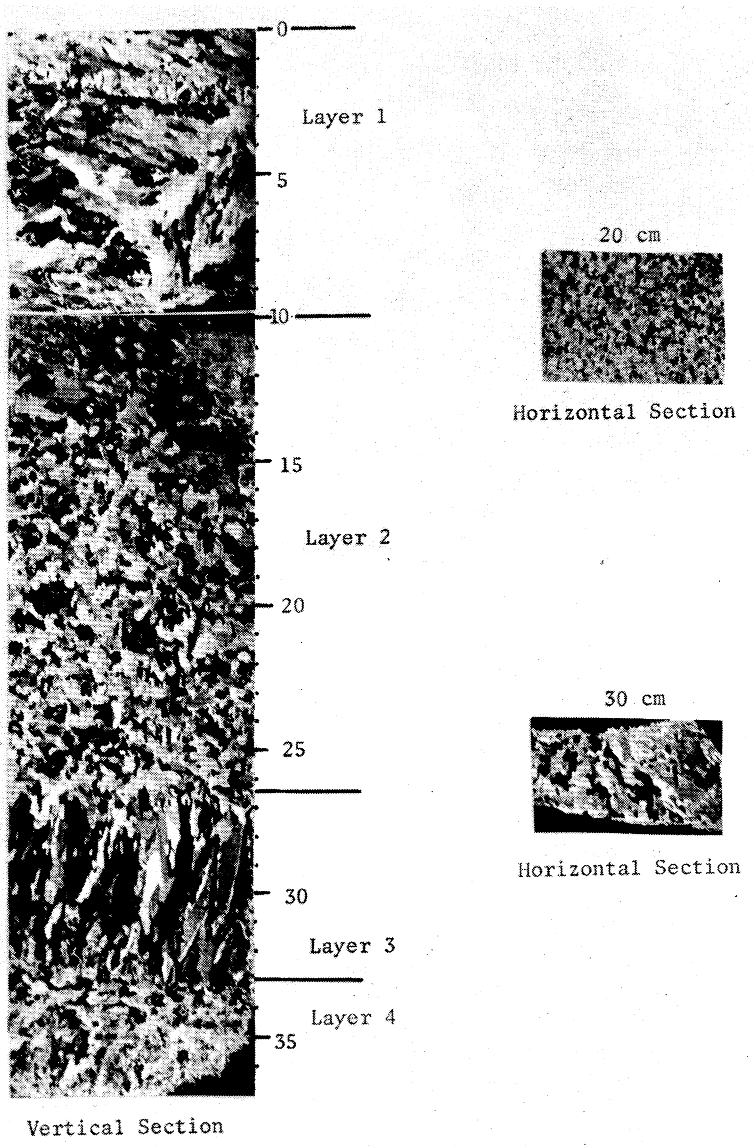

PLATE II - Vertical and horizontal thin sections of ice sample number 5 in polarized light.

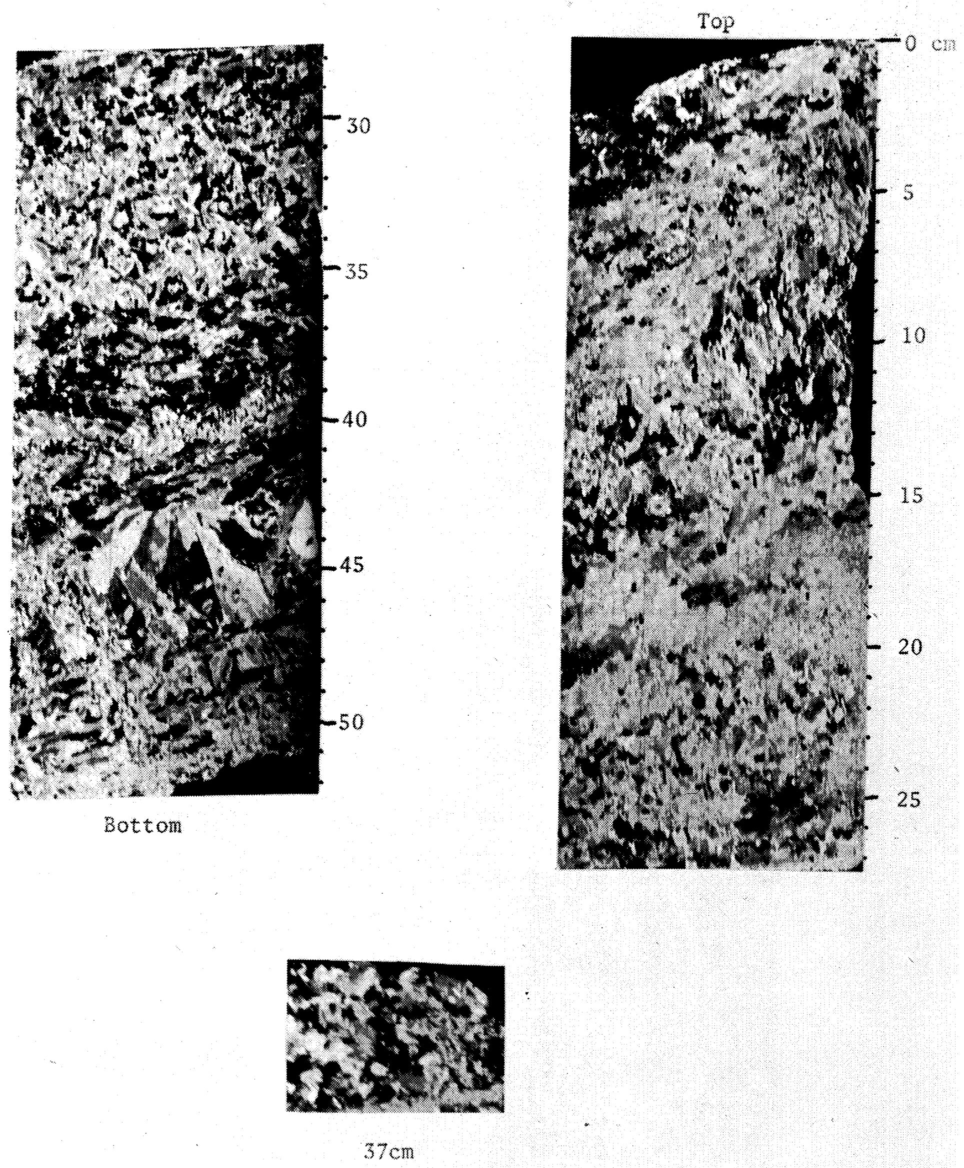

PLATE III - Vertical and horizontal thin sections of ice sample number 6 in polarized light.

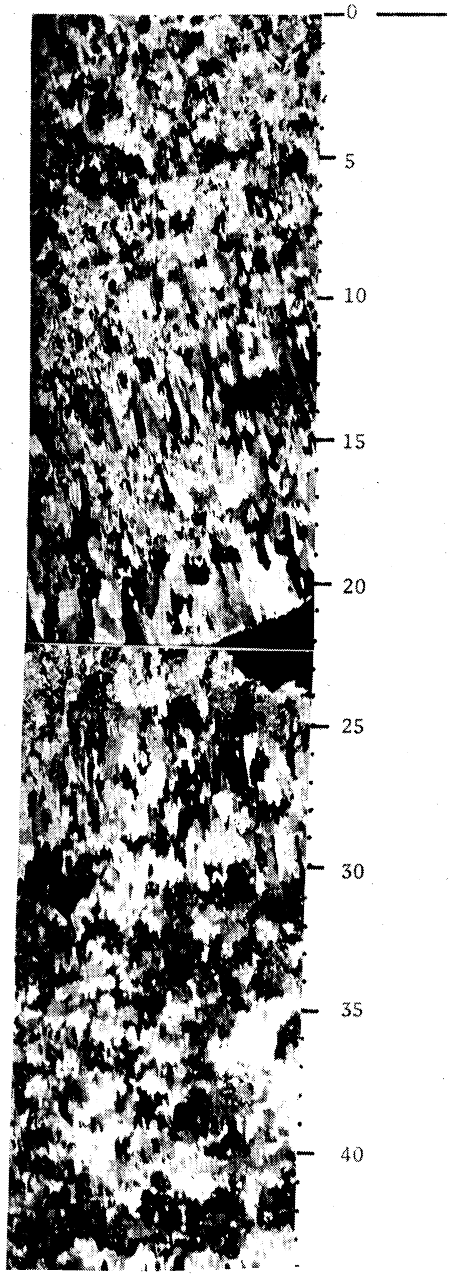

PLATE IV - Vertical thin section of ice sample number 7 in polarized light.

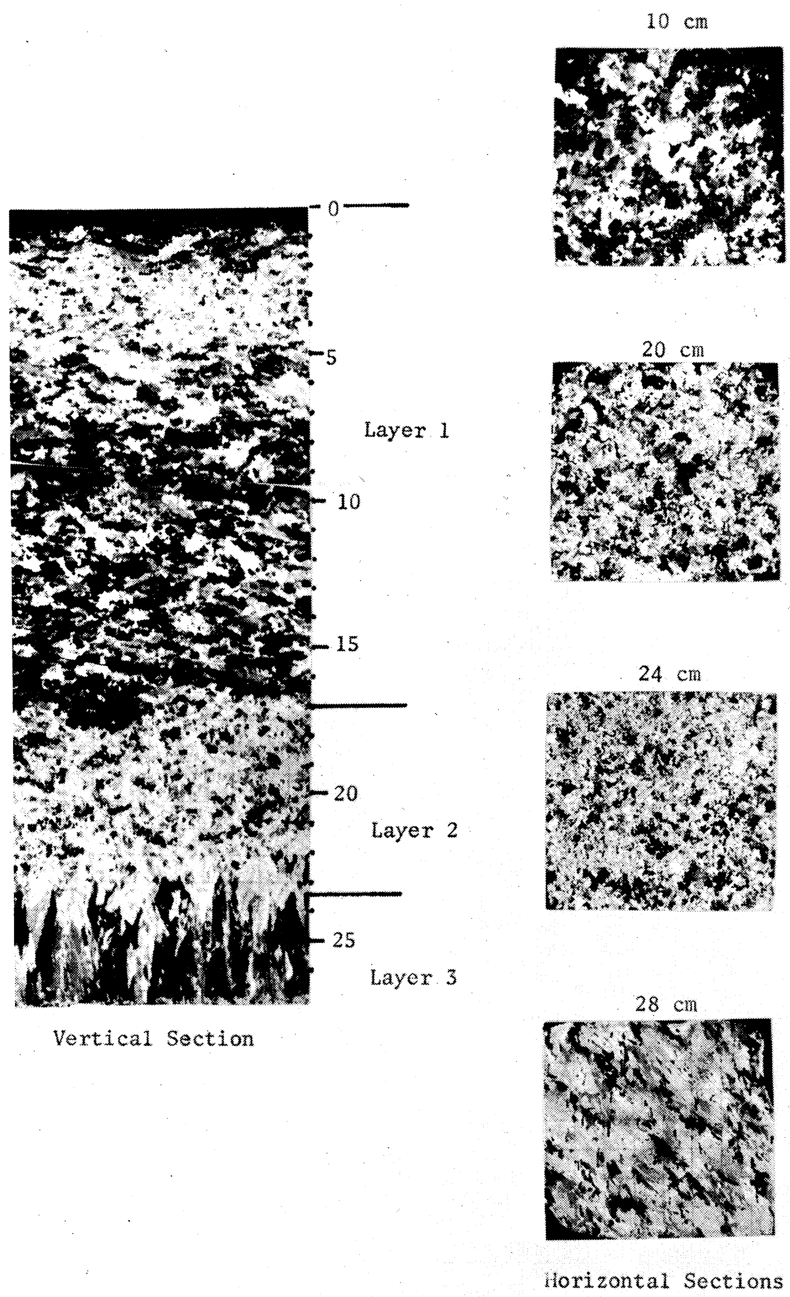

PLATE V - Vertical and horizontal thin sections of ice sample number 8 in polarized light.

very thick followed by a thick layer of horizontally oriented C axis.

The crystal orientation may reflect the condition under which sea ice was formed. Sea ice with vertical C axis suggests quiet and smooth sea surface while randomly oriented vertical C axis is indicative of turbulent sea. The effects of rate of cooling, salinity and incipient temperature on ice are not included in this study. The salinity of sea ice measured for a few samples was 6.2 °/₀₀. The sediments incorporated in the sea ice were silty clays. The mineralogy of these sediments was determined by X-ray diffraction and was found to be uniform. This suggests a common source for the sediments frozen in sea ice. Uniformity of mineralogy of sediments leads us to believe that most of these sediments were suspended in seawater during freezing of seawater and aggradation of sea ice. Further investigation is needed to confirm this deduction.

CONCLUSIONS

1) The Bering Sea ice is multi-layered with each layer having a unique crystal structure and fabric.

2) The top layer appears milky, contains numerous spherical to tabular air bubbles, and has vertical to randomly oriented C axis.

3) An intermediate layer of clear, dense bubble free with horizontal C axis was observed at a depth of 20-30 cm. This particular crystal fabric is identical to that of lake ice and stream ice.

4) The bottom layer consists of fine grained, bubbly, equigranular ice with randomly oriented C axis.

5) Sediment particles and algae were found in fine to medium grained ice with vertical C-axis.

BIBLIOGRAPHY

1. Langway, Chester C., Jr., 1958, Ice fabrics and the universal stage: U.S. Army SIPRE Tech. Rept. No. 62, August 1958.
2. Rigsby, George P., 1960. Crystal orientation in glacier and in experimentally deformed ice: Journal of Glaciology, V. 3, No. 27, p. 589-606.
3. Anderson, D. and W. Weeks, 1958, A theoretical analysis of sea ice strength: Trans. Am. Geophysical Union, V. 39, p. 632.
4. Weeks, W. F., 1962. Tensile strength of NaCl ice: Journal of Glaciology, V. 4, p. 25-52.

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