AD 631236
TT66-61043

STRUCTURE OF SEA ICE OF GREAT THICKNESS

by

N.V. Cherepanov

Translated from
Voprosy Arkticheskogo Ledovedeniya [Problems of Arctic Ice Research]
Tr. Arkt. i Antarkt. N.-I. Instituta [Tr. Arctic and Antarctic Research Institute], 267 (1964), 13-18

by

E.R. Hope

Directorate of Scientific Information Services
DRB Canada
January 1966

T 448 R

66-041

Translated from Voprosy Arkticheskogo Ledovedeniya [Problems of Arctic Ice Research], Tr. Arkt. i Antarkt. N.-I. Instituta [Tr. Arctic and Antarctic Research Institute], vol.267 (1964), 13-18.

STRUCTURE OF SEA ICE OF GREAT THICKNESS

N.V. Cherepanov

The ice island on which drifting station North Pole 6 (SP-6 was established in 1956 was an ice-formation of a rare type encountered in the Arctic. It was a monolithic block of sea ice * about 80 km^2 in area and as much as 10 to 12 m in thickness.

In its crystalline structure ice island SP-6 markedly differs from other known drifting islands, in spite of external morphological features in common. Whereas the shelf origin of other ice islands is at present beyond doubt, our data are still inadequate as regards the origin of ice island SP-6, which some investigators are trying to relate likewise to the break-up of an ice shelf.

Not one of the types of ice studied by Crary and Marshall [4, 5] on the ice shelf north of Ellesmere Land was similar to the ice in the SP-6 island.

Although the SP-6 ice island no longer exists, the research carried out on it is of interest, because formations resembling it are quite often met with in the Arctic. They are distinct from the numerous icebergs and the larger drifting ice islands in that they have an even, flat surface, rising 0.5 to 1 m above the water level. They usually do not measure more than 0.5 to 1.0 km across. Their surface is usually free of sediments, and if there are any, they are mainly accumulations of micro-organisms or deposits of marine origin.

The petrographic studies carried out on the SP-6 ice island in 1958 are of interest for more than the possibility of answering the question of the origin of such formations. They have yielded, for the first time, data on the structure of sea ice growing under natural conditions to a thickness of 10 to 12 m. The special conditions under which these ice masses exist --- conditions relatable to their lengthy period of accretion --- have resulted in the formation of sea ice which in its structure and properties is sharply distinct from all other types of ice ever encountered in the Arctic.

As these studies showed, there were, in the structure of the SP-6 ice island, some strong distinguishing features. Unusual for long-term sea ice was its crystalline structure, with crystals uniform in shape and orientation, a unique distribution of inclusions, and a particular salinity and density.

To carry out studies at different points within the ice-island ice, six pits were dug, of depths from 2.5 to 8.6 m, presenting cross-sections of area as much as 150 m^2.

---

* In Western ice terminology it seems accepted that the name "ice island" is restricted to formations of ice-shelf origin. See T. Armstrong and B. Roberts, "Illustrated ice glossary", Polar Record, 8 (1956), No.52, p.7. [Translator.]

Over the whole thickness of the ice, only the top 30-50 cm layer stands out, a layer that contains a large amount of inclusions in the form of ramified oval bubbles and small cavities. All these inclusions are of secondary origin and are not characteristic of ice-island ice. In this same layer, at approximately the 15-25 cm horizon, there was the maximum concentration of marine silt sediments of yellow-grey color. The silt inclusions had a characteristic distribution and were deposited in the form of individual cells or nests, formed as a result of selective radiative melting. Lying in these nests sunk within the ice, the sediments were not washed out by melt water or blown out by the wind. With melting of the upper ice layers, the nests would gradually sink deeper into the ice.

The concentration of sediment in the top horizon --- about 12 to 15 g per m^2 of surface --- represents the total amount of sediment that has thawed out of the ice-bed over a long period of time. Sediments of identical silt type are found throughout the whole thickness of the ice, but their mean concentration is about 1 to 3 g per m^3.

Thus to form the upper sediment-filled layer, more than 8 m of sea ice must have melted. The existence of this top layer --- usually called the active layer --- is one of the characteristic features of old ice which has undergone melting from the surface and successive refreezings. In its crystalline structure this ice [of ours] is little different from ordinary old ice.

Below the active layer, down to depth 8.5 m, the ice was completely uniform, with a distinctly expressed fibrous texture. Air and salt inclusions formed unending chains of capillaries and minute tubular pores or separate bubbles, extending in the vertical direction (Fig. 1). Though of small cross-section (about 0.2-0.5 mm), the chains of inclusions could sometimes be traced continuously for 2 to 3 m. This, however, was not the limit; the unevenness of the pit walls did not permit us to follow their further downward development. The number of vertically orientated inclusions was so great that the whole of the ice seemed to consist of separate fibers.

A feature having a characteristic development was the drainage channels in the ice, in shape resembling a complicated system of branches and consisting of numerous tubular pores 1 to 2 mm in diameter, their sizes gradually increasing in the downward direction. They unite in the deeper ice horizons with other similar inclusions, to form unique spongy drainage beds, of diameter as much as 10 to 15 mm. Within these sponge-channels the ice is so porous that one may easily push a pencil through them.

Attaining their greatest development at a depth of 6 to 7.5 m, the sponge-channels usually end in a large cavity, like a flattened cylinder. In the main-pit section there were about twenty such cavities, the volumes of which varied from 100 to 300 cm^3. Many of the exposed cavities were filled with a brine of concentration 160-170 per mil. Characteristically there was, inside the cavities, a good deal of plastic ice-crystals, similar to the crystals of depth hoar. The drainage channels that were not terminated by such a cavity would markedly decrease, at this horizon, in their cross-section, to form a narrow hollow tube of diameter 3 to 5 mm, with characteristic nodular distentions at different depths. We were not able to trace their development below depth 8.5 m, since the pit was flooded with sea water breaking through from below. The total thickness of the ice at this point was 10.3 m.

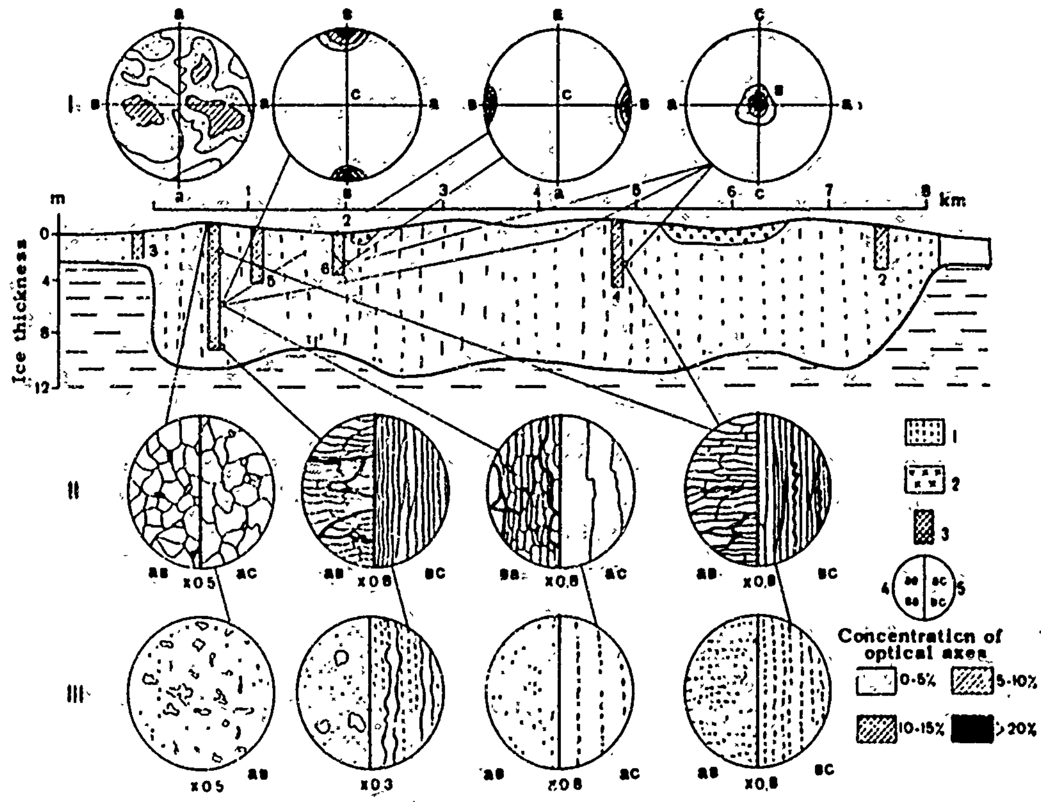

Fig. 1. Schematic structural cross-section through the ice of the SP-6 ice island.

I - stereogram of crystal orientation; II - ice structure; III - inclusions.

1 - sea ice; 2 - lake ice; 3 - pits 1, 2, 3, 4, 5, 6; 4 - horizontal sections; 5 - vertical sections.

All the ice-island ice was of parallel-fiber structure, with an extraordinary vertical development of the crystals (Fig. 2). Their vertical extents were so great that it was not possible to determine their lengths from ordinary polished sections prepared from samples 15 × 20 cm in size.

A few measurements of crystal cross-sections were made directly in the pit, where, upon formation of a sublimation crust on the polished wall, some of the vertical crystal "fibers" attained a length of over 2.5 m. Further size-observations were given up because of the very laborious work of smoothing the vertical wall of the pit. The operation was further complicated by the fact that the crystals did not maintain a strictly vertical development. Small bends or nodular distentions would cause them to deviate from the vertical direction and render them inaccessible to observation.

It is possible that under conditions of stable and very slow formation of ice, with no disturbances occurring in the crystal growth, the vertical lengths of the crystals may become practically equal to the total thickness of the ice. In our case, the length of the ice-island fiber-crystals could have been as much as 10 to 12 m.

The small crystals that were (rather infrequently) found in the cuts varied from 5 to 10 mm in horizontal cross-section, while the large aggregates, often representing coalescences of crystals having closely similar optical orientations, measured up to 100 to 200 mm. Every such crystal consisted of small elementary platelet-fibers separated by interlayers of brine and very fine air bubbles (Fig. 3). In their thickness and breadth, in their cross-sectional shape and orientation, the ice fibers were little distinct from each other, and like the crystals themselves, they lay vertically, and they grew to the same great lengths. It was characteristic that within each individual crystal the ice fibers had a definite orderly distribution, maintaining a parallel orientation of their faces. The direction of the main crystallographic (optical) axis in a platelet-fiber of this kind coincides with the direction of its flattening, while with respect to the ice-island mass the optical axes lay horizontally. Such distribution of the optical axes in these fibers permits us to suggest that they are similar in nature to the basal platelets of which the crystals of fresh-water ice consist, the only difference being that in fresh-water ice the basal platelets lie horizontally, so that their optical axes are directed vertically. It is furthermore true that, differently from basal platelets that are rather equally developed in each of the secondary axis directions, the elementary platelets of sea ice are developed only in one direction, to form the unique "ice fibers".

The thickness of the elementary platelets varied over the range 0.8 to 2.1 mm and was constant for the different horizons within the ice. Thus the mean size of these platelets was:

at depth 0.5 m	1.3 mm
at depth 2.5 m	1.4 mm
at depth 8.0 m	1.5 mm

As we here see, the platelets remain constant in cross-section throughout the whole thickness of the ice, whereas in ordinary sea ice their dimensions vary over quite wide limits. Thus according to the findings of Anderson and Weeks [3] the thickness of the elementary platelets in new ice is from 0.2 to

0.8 mm (with a mean of 0.45 mm). For old ice their thickness varies in the range 0.5 to 0.9 mm.

With increasing thickness of sea ice the sizes of the elementary platelets increase --- which, it seems, is quite reasonable, since under conditions of slower freezing accretion, thicker platelets are formed. From this we may conclude that a considerable part of the upper layers of the ice-island ice, along with earlier sea-ice formations, has melted. Since at the level of the ice-island surface these platelets had a thickness of 1.4 mm, the thickness of the melted-off layer was not less than 6 to 8 m, a conclusion already supported by the data re sediment accumulation on the surface of the island.

Quite unusual for sea ice was the exceptionally well-ordered optical orientation of the ice crystals in the SP-6 ice island (see Fig. 1). Besides the fact that all the optical axes of the crystals, as we have mentioned, lay horizontally with respect to the ice bed, they also had an orderly spatial arrangement: all the crystals were of closely similar spatial orientation. For occasional crystals the departure of the optical axes from the general direction would amount to 15-20°; only 1 to 2% of all the measured orientations gave departures greater than 30 to 35°. This mainly refers to crystals which in their structure, and in their small vertical and horizontal dimensions, were markedly distinct from the other crystals. Their length usually did not exceed 10 to 20 mm, nor their cross-section 3 to 5 mm; they usually consisted of 3 to 4 basal platelets. The reason for the formation of such crystals with an orientation sharply distinct from the habitual orientation is, it would seem, the introduction of stray crystallization centers into the ice during the period of its accretive freezing.

Such structure was the consequence of a stable congelation regime, promoting a spontaneous growth of crystals which, free from external disturbances, grew into vertical fibers some meters in length. In the process of growth the original orientation of the crystals was maintained. It is possible that this phenomenon is similar to one of the rare phenomena noted by Shumski [2], a non-operation of the law of geometric selection in the growth of ice crystals in an ice sheet. This takes place in two opposing positions, with the orientation of the optical axes of the initial layer either exclusively normal to the surface of freezing, or exclusively parallel thereto.

Also possible is another and, in our opinion, more probable thesis as to the ordering of the optical orientation in the crystals of ice-island ice. Freely growing ice crystals at a temperature above -15°C have a maximum rate of growth in the basal plane and particularly in the directions of the secondary axes; this indeed is what causes their plastic form.

It is quite likely that under the conditions of very slow accretive freezing of the ice-island ice the only crystals to be preserved and to grow were those for which the direction of maximum growth-rate coincided with the direction of heat flow within the ice.

One cause of orderly spatial orientation of the ice crystals remained unclear to us --- when we found that in all the faces cut in all the pits over the whole area of the island (about 80 km^2) the direction of the crystal optical axes was at 50 to 60 degrees of magnetic azimuth.

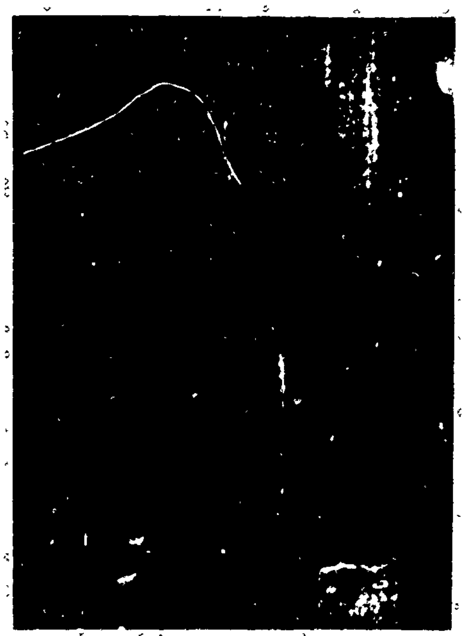

Fig.2. Parallel-fiber structure of ice-island ice. Section made in the direction of growth. X1.

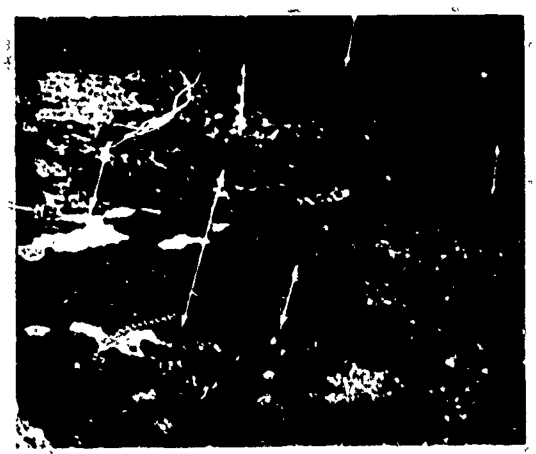

Fig.3. Ice structure in horizontal section. Arrows indicate directions of crystal optical axes. X0.5.

It is possible that such a well-ordered spatial orientation of the crystal optical axes might be due to a temperature gradient established by a non-uniform distribution of air temperature over sea and land during the period of initial ice formation.

Also of interest are our data on the distribution of salinity and density in the ice-island ice, as obtained from study of numerous ice samples taken from a pit.

In Figure 4 we show a graph of the vertical distribution of ice salinity and density. It is quite characteristic that the mean values of salinity and density are quite near to those found in old ice. Thus the mean salinity for the SP-4 ice floe was 2.2 per mil, while for the SP-6 ice island it was 2.26 per mil.

M.I. Ivanov's [1] figures for the salinity of ice-island ice (4 to 7.5 per mil) are exaggeratedly high, on account of his taking, as his salinity test sample, a rod of ice from the bottom of a borehole into which brine was filtering. This was particularly noticeable during the more lengthy interruptions of the work of drilling the borehole.

The increased ice salinity in the higher horizons, as seen in Figure 4, is apparently the result of a less abundant migration, due to lower temperatures long preserved in the body of the ice. Moreover, when the upper ice-layers melt they undergo a desalinification, and the brine formed in the interlayers between the crystals filters down into lower horizons.

The data from our observations on the ice texture, crystal structure, salinity and density testify to the marine origin of the SP-6 ice island. *

REFERENCES

1. IVANOV M.I. Priroda, 1958, No.7.

2. SHUMSKI P.A. Osnovy Strukturnogo Ledovedeniya [Principles of Structural Glaciology]. Moscow, USSR Academy of Sciences Press, 1957.

3. Anderson D.L. and Weeks W.F. Theoretical analysis of sea ice strength. Tr. Amer. Geophys. Union, 1958, vol.39, No.4.

4. Crary A.P. Arctic ice island and ice shelf studies. Parts I, II. Arctic, vols. 11, 13, 1958, 1960.

5. Marshall E. Structural and stratigraphic studies of the northern Ellesmere ice shelf. Arctic, 1955, No.8.

* The marine origin was also suggested by M.I. Ivanov in 1958.

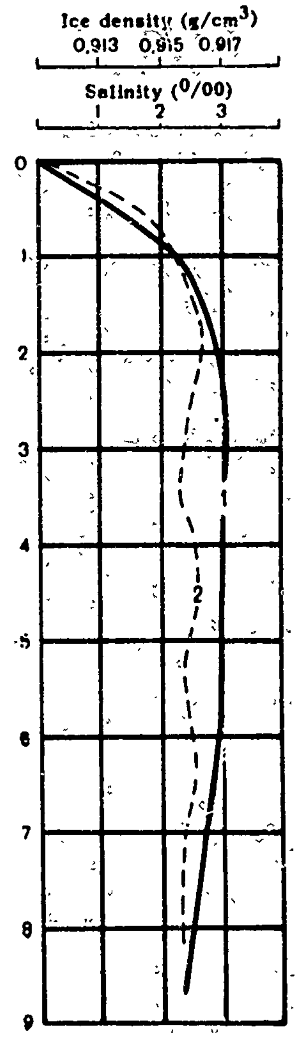

Fig. 4. Distribution of salinity (1) and density (2), by horizons.