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Translations

INVESTIGATION OF CONSTRUCTION AND MAINTENANCE OF AIRDROMES ON ICE

1946-1947

TRANSLATIONS

SOILS LABORATORY
NEW ENGLAND DIVISION, BOSTON, MASS.
CORPS OF ENGINEERS DEPARTMENT OF THE ARMY

MAY 1947

APPENDIX B TO
REPORT OF INVESTIGATIONS
DATED MAY 1947
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INVESTIGATION

OF

CONSTRUCTION AND MAINTENANCE

OF

AIRDROMES ON ICE

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SOILS LABORATORY

NEW ENGLAND DIVISION, BOSTON, MASS.

CORPS OF ENGINEERS, WAR DEPARTMENT

MAY 1947

Appendix B to
Report of Investigations
Dated May 1947

FOREWORD TO TRANSLATIONS

The material given herein has been translated from the Russian in the Stefansson Library.

To a considerable degree the translations have been made in fairly literal, in preference to idiomatic, English. This is more true in some of the translations than in others. In editing, clarifying words and remarks have as a rule been added parenthetically and in footnotes, in preference to altering the translator's version.

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S E A I C E

by A. Boorke

Moscow 1940

Translated at the Stefansson Library

S E A I C E

TABLE OF CONTENTS

I. Formation of Ice at Sea

The process of formation of ice in sea water differs from that taking place in fresh water mainly owing to the presence of salt in the sea water. While fresh water has a maximum density at a temperature of $4^{\circ}C$, and freezes at 0°, the temperature of maximum density of sea water (0°), and the temperature of its freezing point ($^{\circ}$) differ considerably, depending on the salinity of sea water (S°/oo).

This dependence is made clear in the table given below, and taken from "Oceanography" by Y. M. Shokalski.

Table I.

Dependence of the freezing point and of the maximum density on salinity.

Salinity in o/oo	Freezing Point	Temperature of Maximum density
0	0 (°C.)	3.98 (°C.)
5	-0.3	2.9
10	-0.5	1.9
15	-0.8	0.8
20	-1.1	-0.3
24.695	-1.332	-1.332
25	-1.35	(-1.4)
30	-1.6	(-2.5)
35	-1.9	(-3.5)
40	-2.2	(-4.5)

(It is the custom to express the salinity of sea water in "pro mille", not in "per cent", i.e. indicating how many parts of salt are contained in a thousand such parts of water. The "pro mille" is indicated by the sign $^{\circ}/oo$.)

On examining this table, we note that the temperature of the freezing point falls in proportion to the increase of salinity. Thus, it reaches -1.9° when salinity is 35°/oo, and -2.2° when salinity is 40°/oo. With increase in salinity, the temperature of the maximum density of water also falls, but much faster, and with salinity reaching 24.695, or, to put in round figures, 24.7 °/oo, it is identical to the freezing point. In Table I, stress is laid on this salinity, in the case of which 0° and 0° are identical, namely -1.332. To make it clearer, Table I is represented in a graph (Fig. 1). It is apparent from this graph that the line of temperatures of maximum density (0°) inclines with regard to the horizontal axis more sharply than does the line of freezing points (-°); both lines intersect at a point which corresponds to a salinity of 24.7 °/oo.

(Temperatures of maximum density of water, the salinity of which exceeds 24.7 o/oo are shown in parentheses on Table I, and by a dotted line on Fig. 1 because, in nature, water cannot cool down to such temperature, as it would reach the freezing point beforehand and change into ice.)

The density of water plays an important part when it is on the point of freezing. To make the entire process of freezing clearer, we shall examine the question in detail. We shall first examine the formation of ice in fresh water.

In every water basin, the cooling down takes place mainly from the surface; when cooling down, the upper particles of water acquire more density and consequently more weight, and start sinking down, thereby allowing warmer and lighter particles of water to replace them on the surface. There thus takes place a vertical circulation of water termed convection. In a fresh-water basin, covection continues only until the entire depth of water, from the surface to the bottom, has cooled down to a temperature of 4°, after which the displacement of water particles stops. In case of a further drop in temperature below 4°C, density no more increases; on the contrary, it decreases; therefore, the upper layers grow lighter in weight than the lower ones, and tend to remain on the surface.

When the temperature of the surface drops below 0°C, ice begins to form on the surface. On the surface of fresh water ice starts forming in the shape of sharp, thin needles, spreading mainly from the shoreline toward the center of the water basin. After the appearance of the first needles of ice crystals, there forms a thin ice crust, which is first transparent, and then acquires various shades as its thickness increases. From the very beginning of its formation as a thin film, fresh-water ice is considerably hard, it resembles glass and has mostly smooth level surfaces.

In sea ice, the formation of ice proceeds differently. We shall first examine waters, the salinity of which is below 24.7 ‰ i.e. so-called brackish waters. The formation of ice in such waters may have been expected to occur as it does in fresh water, because in the course of cooling of brackish waters, the temperature of maximum density occurs before the freezing point. In reality, however, the similarity is incomplete. The only similarity between fresh and brackish water lies in the fact that, in both, covection stops before the moment when formation of ice sets in; but the similarity stops the moment the first ice-crystals appear in water with the lowest possible salinity. The explanation is, that crystals of ice forming in salt water contain no salts, because, in the process of ice-formation, the salts remain in the surrounding water, thereby increasing its salinity, and consequently its density too. The new convection thus taking place owing to increase in salinity delays the freezing in consequence of the replacement of superficial particles of water by particles of a higher temperature, and originating from lower layers.

It should be further noted, that, at the beginning of their formation, salt-water ice crystals float on the surface separately and do not rapidly form into an ice-crust as it occurs in fresh water. The freezing together of ice-crystals is somewhat delayed by the increased salinity, as a lower temperature is necessary for the freezing of this saltier water than was required for the appearance of the first ice crystals. Therefore, and if cooling does not proceed too intensely, a certain time is necessary for reaching a temperature allowing the next series of ice-crystals to form in this more salty water. This second appearance of ice crystals in turn increases the salinity of the surrounding water, and this necessitates a further drop in temperature until the new freezing point is reached. A certain lapse of time is therefore again required. Therefore, the appearance of ice in sea water proceeds by stages.

(It should be taken into consideration that the delay in the freezing together of crystals described above will be noticeable only in cases when a "leap in salinity" is located close below the surface, i.e. when increase in salinity takes place in a thin layer of water. Editor's note.)

The basic difference between the process of cooling and of ice formation taking place in salt water at sea - i.e., in waters characterized by a salinity of over 24.7 o/oo - and that occurring in fresh water or brackish water, lies in the fact that the temperature of maximum density of salt water is lower than its freezing point temperature. For this reason, the cooling of surface particles of water down to freezing temperature, will provoke convection and, as a general rule, the formation of ice will be able to start only after the entire layer of water accessible to convection will have reached the temperature of freezing of water of given salinity. Upon further cooling, convection will continue. Therefore, the formation of ice crystals will continue not only on the surface, but throughout the entire layer affected by convection. Similar to the preceding case, the formation of crystals will proceed by stages.

The ice crystals which have formed within the layer affected by convection will emerge to the surface owing to their lesser specific gravity, and will remain afloat, with approximately 8/9 of their volume below the water line. As the cooling proceeds, the layer of crystals afloat on the surface of the water will gradually thicken and grow in bulk and freeze over.

As the crystals freeze together and form a coat of ice, the particles of water filling the space between crystals are separated from the general mass of water and thus remain so to speak enclosed in the ice. As the crystals grow in size, they release salt and the salinity of the water remaining in the ice is thereby sharply increased to that of a concentrated brine. Thereafter, part of the brine is squeezed out onto the surface, part remains in cavities in the ice, and part flows down into the lower layers of ice. This phenomenon will be examined in more detail in the section devoted to the properties of sea-ice.

In connection with the above described process of formation of sea ice, it should be noted that, in its initial stages, it may be distinguished from young fresh-water ice by the following peculiarities:

1) in the first stages of its formation, the ice consists of accumulations of separately floating ice crystals;

2) the second stage is characterized by the emergence of a newly formed crust of ice. This crust is not hard, glass-like ice, but is a friable, elastic, ice-like mass, which crumbles easily and bends without breaking when rocked by a mild swell;

3) owing to the brine contained between the ice crystals, sea-ice is salty.

The above described process of freezing of sea water takes place in conditions of a calm sea. In a stormy sea however, or in the presence of strong currents, the process of freezing undergoes certain variations: there occurs in intermixing of water, and this may first delay the appearance of ice, but in later stages it contributes to a greater growth of ice owing to a wide-scale cooling of very thick layers of water.

When a snowfall occurs during the freezing-up of water, the salinity of its upper layers decreases and freezing is accelerated.

II. PROPERTIES AND PECULIARITIES OF SEA ICE

Salinity of Ice

We now know that sea ice retains part of the salts contained in the water from which it was formed. We shall now examine the conditions determining the amount of salt in ice and the reasons for its variations.

The salt content of sea water changes frequently and almost incessantly, and the reasons thereto are numerous.

As indicated above, in the first stages of freezing of sea-water, the ice crystals accumulated in a disorderly mass below the water surface freeze up, entrapping a certain amount of brine which, in the consecutive freezing, i.e. in the initial stages of formation of an ice crust, is partly squeezed out onto the surface of the ice. If freezing occurs in very low temperatures, the brine which freezes on the ice surface releases dry crystals of salt, which form small bunches or clusters on the ice. The presence of salt on the surface of sea ice renders the sliding of sledges impossible. (Fig. 2)

During the formation of young ice, most of the salt settles precisely in the upper layer, where ice-crystals had accumulated in a disorderly heap prior to freezing-up into an ice crust. In the course of the further growth of ice, which proceeds from its lower surface, the newly formed ice crystals assume the shape of needles, mostly directed vertically downward. Accordingly, the amount of brine remaining in the ice is somewhat less in the lower layers than in the upper ones, as more brine has time to flow down. (Fig. 3)

The Swedish scientist Finn Malmgren (On the Properties of Sea Ice, 1930), who investigated the salinity of sea ice, has submitted the following figures:

Table II.

Vertical distribution of salinity in a sample extracted from the ice coat.

Distance from the surface of ice in cm	0	6	13	25	45	82	95
Salinity in °/oo	6.74	5.28	5.31	3.84	4.37	3.48	3.17

These determinations were reached on the ship "Maud" during the 1924/25 drift in the Arctic Ocean. The ice started forming in November 1924, and the salinity was determined in April 1925. F. Malmgren also quotes the findings of K. Veiprecht, another Arctic explorer. During the latter's voyage on the "Tegethof", he investigated ice formed in a 33°C. frost (-33°C.) 60 hours after the beginning of its formation; the salinity of the first 5 cm. from the top, was 25 o/oo, that of the next 9 cm. was 13 o/oo, and that of the last 5 cm. was 12 o/oo. On the basis of a number of similar determinations, it can now be established that the amount of salt in ice depends:

1) on the degree of intensity with which the freezing takes place; the more rapid the formation of ice, the more salt remains in the ice;

2) on the age of the ice: the brine gradually oozes from cavities in the ice into the water, and therefore, the older the ice, the less salt remains in it;

3) on the thickness of the ice: the thicker the ice, the less salt will it contain, particularly in its lower layers.

The last condition is, in part, a consequence of the first: as the ice increases in thickness, the freezing process is being slowed down, and this, in turn, contributes to the decrease of the amount of salt remaining in the ice.

The content of salt in blocks of ice, piled up by pressure onto the surface of ice, or in single blocks, decreases very fast: one-year old top hummocks turn out to be almost fresh before thawing sets in.

Changes in the salt content of sea-ice also occur as a result of thawing, and differ in the various types of ice. An important part is played by snow which produces fresh water upon melting. Dissimilarities depend on whether it is an entire coat of ice or single ice floes which are melting. These phenomena will be examined in detail in the section devoted to the thawing of ice.

Density of Ice.

It is common knowledge that water expands when freezing. The volume of fresh-water ice exceeds the volume of the water it has originated from by about 9%. The density of ice, which has formed from fresh water and contains no air bubbles, is about 0.92 (c.g.s. system). Therefore, the greatest part of an ice-floe is submerged, and only an insignificant part of it rises above the water level.

The density of sea ice is by no way expressed by a constant quantity, and may fluctuate, depending on the salinity of the ice, and, particularly, on its porosity. In most cases, the density of sea ice fluctuates between 0.80 and 0.90. The density of icebergs may be considerably less - according to Smith, it may reach 0.6

The draught of an ice-floe varies in connection with its density; it also depends on the density of the water in which it floats, and on the shape of the floe.

Professor N. N. Zubov (Sea Water and Sea Ice, Moscow, 1938) supplies a table, establishing the ratio between the submerged part of an ice-floe and the height of its floatage in connection with various densities of ice and water. This table is calculated for ice-floes with a horizontal surface and vertical sides.

Table III.

Density of Ice	Density of water 1.00	1.01	1.02	1.03
0.60	1.5	1.5	1.4	1.4
0.65	1.9	1.8	1.8	1.7
0.70	2.3	2.3	2.2	2.1
0.75	3.0	2.9	2.8	2.7
0.80	4.0	3.8	3.6	3.5
0.85	5.7	5.3	5.0	4.7
0.90	9.0	8.2	7.5	7.0

Sea ice is characterized mainly by the two last lines of this table, to the exclusion, however, of the first column, which pertains to fresh water. It may thus be considered that, usually, the volume of the submerged part of an ice-floe at sea is 5 to 8 times that of the visible part. This also refers to the draught of ice-floes, provided, however, their shape does not differ too much from the regular shape used in figuring out Table III.

In order to demonstrate how misleading it can be to judge of the thickness of an ice-floe by the part showing above water, Fig. 4 shows two blocks of ice of a density of 0.90, floating in water of 15 o/oo salinity and 1.01 density.

We shall now examine to what extent the density of ice depends on its salinity and on its content of air bubbles. For this purpose, we shall use an excerpt from a table given in Prof. N. N. Zubov's book quoted above.

Table IV.

Density of Ice.

Air Content in %	(Salinity in ‰) 0	5	10	15	20	25
0	0.918	0.922	0.925	0.930	0.934	0.938
4	0.881	0.885	0.889	0.893	0.897	0.901
9	0.835	0.839	0.843	0.847	0.851	0.855

In Table IV, the content of air in ice is given in percentage in regard to the general volume of the ice.

The horizontal rows of figures show that variations in the density of ice, conditioned by different degrees of salinity, are insignificant and do not exceed 0.02. The density of ice varies much more in connection with the content of air bubbles (see vertical column in Table IV). Air gets into the ice partly during the freezing of sea water, but it mainly penetrates into it from the atmosphere, gradually filling the cavities in the ice, from which the brine is oozing out. The content of air bubbles in sea ice varies considerably, and may be quite high, up to 13-15% of the volume of ice. Obviously, the content of air is the highest in ice, which has formed from water with a high salinity, and which is old enough for most of the brine to have oozed out of it. This has been confirmed by the investigations of F. Malmgren, who has established, at least in one instance, that the density of de-salted pressure hummocks over one year old, may be less than 0.90, reaching 0.857, while density in the basic layers of one-year-old pressure ice-floes may reach 0.91 to 0.92.

Temperature of Ice.

Table V, taken from the works of F. Malmgren, gives a clear picture of the distribution of temperatures throughout the depth of the ice cover. It gives the mean monthly temperatures of the ice, obtained in the course of two years of observation on the drifting "Maud".

This table gives temperatures for layers of ice located at various distances from the surface, from 0 to 2 m. According to F. Malmgren's observations, in layers lying close to the water, the temperature of ice is very close to the freezing point of water.

Table V.

Table of Mean Monthly Temperatures of Ice (°C.)

Months	Distance from the surface of ice in meters				
	0.00	0.25	0.75	1.25	2.00
January	-28.0	-24.1	-18.9	-14.0	- 6.5
February	-30.9	-26.9	-21.3	-16.3	- 8.5
March	-29.1	-26.0	-21.0	-16.5	- 9.6
April	-21.6	-20.1	-17.3	-14.4	- 9.4
May	- 7.4	- 8.6	- 9.3	- 9.2	- 7.4
June	- 1.5	- 3.0	- 4.1	- 4.5	- 3.8
July	- 0.0	- 0.1	- 0.8	- 1.7	- 1.8
August	- 0.0	- 0.0	- 0.8	- 1.1	- 1.2
September	- 4.7	- 1.3	-00.9	- 1.1	- 1.3
October	-12.3	- 7.6	- 3.3	- 1.6	- 1.4
November	-23.0	-17.8	-11.9	- 7.1	- 2.4
December	-29.9	-24.4	-17.7	-12.2	- 4.6
Mean	-15.70	-13.32	-10.65	- 8.31	- 4.82

In the middle and lower layers of ice, temperatures remain low for quite a long while after that of the upper layers has started rising, and even after the ice on the surface has started thawing. At such time (May, June), minimum temperatures are to be found in the middle layers of ice, and in connection with this, the growth of ice continues from below, and it even fails to stop at the beginning of the thawing period. In addition, and as evidenced by the Table, in the course of the entire period of thawing, the temperatures of the lower layers remain close to the freezing point of water. It would seem that the growth of thick ice from below stops but for a short time in summer.

At sea, ice is usually covered with snow of varying depth and of varying density; this too has an effect on the temperatures of ice, and consequently, on the growth of the thickness of ice. Up to March, Malmgren carried on observations on ice which was being cleared of its coat of snow. Thereafter, up to the beginning of the thawing period, observations were carried on without clearing the snow. He writes: "The state of the snow exercises great influence on the temperature of ice. Snow is a poor heat conductor. Therefore, when ice is covered with snow, the temperature at a certain depth from the surface is considerably higher than it would be were there no snow above."

On the basis of his observations, Malmgren affirms that ice is characterized by a thermal conductivity considerably greater than that of snow and water. This question is of primary importance in processes of thermal interchanges occurring between sea water and air through the medium of ice. Together with that of specific heat, and of the heat of fusion of ice, it is examined in detail in the following works: V. V. Shuleikin, Moscow 1933, and N. N. Zubov, Sea Water and Sea Ice, Hydrometeorological Publications, Moscow 1938.

Snow on Ice.

The snow blanket on ice plays an important part from the very beginning of the formation of ice to its complete thawing out. In the initial stages of the process - when ice crystals appear in sea water - a snowfall can contribute considerably to the formation of ice.

As we know, concentrated brine sometimes accumulates on the surface of young ice; the snow which falls into this brine creates a cooling mixture; the comparatively low temperature of the cooling mixture contributes to the hardening of the upper layer of ice and to rapid thickening of the ice coat. In this case the snow seems to itself neutralize its protective role of bad heat conductor. Apparently, we witnessed a similar case in Tikhaya Bay in 1938, when the temperature of brine on ice and under the snow was -3.3° on January 17th, and -3.7° on January 18th.

On evenly freezing ice, on level fields, the cooling mixture under the snow is preserved throughout almost half of the freezing period and produces "humidity" under the snow. This "humidity" disappears only later, with the growth of the thickness of ice. Apparently, the cooling mixture gradually turns into ice, increasing the thickness of ice from the top. After such a freezing process, it is impossible to clear the snow from the surface of the ice and obtain a smooth ice surface; in such cases, the ice is very rough.

It is common knowledge that, at sea, the ice drifts, breaks, stratifies, and heaps up into hummocks; in the course of these phenomena, the snow penetrates into the very thick of the ice. One may often clearly see the layers heaped on top of each other -

at times 10 layers of varying thickness - and from the color of the upper parts of the layers, it is evident that snow-blanketed fields were being subjects to stratification. Such stratifications harden rapidly and the ice becomes monolithic. When the ice fields break up, much snow may be driven under pressure into hummocks which are in process of formation, and, consequently, in time, the hummocks may also acquire the character of a monolithic ice mass.

At sea, the predominant type of ice is the hummocky field, which invariably has a rough surface and an unevenly distributed blanket of snow. The protruding ridges and hummocks play the part of snow barriers, and around them there accumulates more snow than on the smoother sections. Owing to these same hummocks, the snow may in some places constitute crumbly snow drifts, and in others be beaten hard by the wind. The uneven distribution of snow on ice has a very strong influence on the development and the character of the transformations of the ice surface at the time of its thawing; thus, mounds, hollows, rivulets and pools appear on the ice surface at the time of thawing. The snow thus plays an important rôle in the thawing of the ice itself.

The density of the layer of snow on the ice varies as much as does the thickness of the layer itself. In calm weather, when the snow falls unhampered, there accumulates a deep crumbling layer of snow, consisting of fluffy snow flakes. When a snowfall occurs at a low atmospheric temperature and with a fresh wind blowing, the snow becomes powdery and is beaten into a dense mass; on the hummocks and around them, there accumulate snow drifts of various density, The densest snow, however, forms at the time of cold snaps and very strong winds, when the so-called "pozemka" sweeps over the surface of the ice and the snow acquires all the characteristics of minute dust.

It would seem from the above that, when measuring the thickness of the snow blanket on the ice, the density of the snow should also be determined.

The snow blanketing the ice of polar seas may not always melt completely in the course of summer; when preserved until the next year, it freezes through and through, forming fresh ice on the surface of sea ice, and is similar to neve.

As evidence of the varying character of snow on ice, we give below a few measurements of the thickness of the ice blanket in the Kara, White and Eastern-Siberian seas.

Measurements of the thickness of snow effected by the author:

Kara Sea	Western entrance into Vilkitzky Strait. August 23, 1937. The layer of snow on the field: 10, 15, and 20 cm.
" "	West of Zarya Peninsula. September 20, 1937. Layer of old snow - 19 cm; layer of new snow 5 cm.
" "	West of Zarya Peninsula. September 25, 1937. Layer of old snow - 20 and 50 cm; layer of new snow 18 and 18 cm; general layer of snow - 38 and 68 cm.
White Sea	Central part of White Sea Basin. March 19, 1937. Layer of snow - 1.5 and 2 cm.

Measurements of the thickness of snow carried out by F. Malmgren during the drift of the "Maud" in the Eastern-Siberian Sea in 1923-1924:

1923

September	Ice, free from snow
October	do.
November 30	3-4 cm of snow

1924

January 1	about 4 cm of densely settled snow
" 31	" 4 cm " " " "
February 28	" 4 cm " " " "

March 30	several cm of snow, hoar frost on top of it
April 6	several cm of dense snow
" 18	1-2 cm of freshly fallen snow on top of the old snow
" 25	several cm of snow hardened by the sun
May 12	4-5 cm of crumbly snow

Measurements of the thickness of Snow effected by K. Tairon in the Kara Sea in 1927:
(See K. Tairon, Types of Ice on the eastern shores of Novaya Zemlya, from Matochkin Shar to Medvezhi Bay, "Notes on Hydrography", Vol. LV, 1929.)

Measurements were effected from April 1st to 10th near Cape Kankrin in the hummocks on the shore. K. Tairon writes:

"The intervals of even ice between hummocky ridges do not exceed 1/2 km, they are mostly 50 to 100 m. Owing to their protected location, the intervals are covered with unusually deep snow blown in the winds. Near the hummocks, a 3-meter long pole sinks entirely into the snow without reaching the ice."

These examples bear evidence to the fact that the layer of snow on ice may be very varied. As regards the significance of snow on ice, we shall repeatedly return to this question in the future.

Plankton in Ice.

The term "plankton" applies to small floating organisms which live in various depths in the sea or in fresh water basins. Phytoplankton belongs to the world of plants, zooplankton to the animal world. Plankton exists in all polar seas, extending to the very Pole, as evidenced by the investigations of the drifting station "North Pole", which was headed by I. D. Paparin.

When freezing sets in, part of the plankton contained near the surface may be frozen into the ice. Either the entire phytoplankton, or most of it contained in the layer of water which is undergoing freezing, may be locked in ice. As regards zooplankton, which possesses a certain mobility, it is hard to say how much of it may be locked in ice. It may be presumed, however, that a considerably part of it will be caught in the ice. Plankton organisms appear to be very sensitive to even minor fluctuations of temperature, and may partly perish even before freezing sets in.

Usually, plankton locked in ice is not immediately discovered. It becomes noticeable only in the second half of the freezing period when, during the process of hummock formation, fragments of ice fields heap up on one another. Then does it become apparent that the lower part of an ice-floe has a lightbrown or pink coloring. If you take a chunk of such colored ice and melt it in a glass, you will obtain a muddy, ash-gray sediment. The presence of plankton in ice is best revealed in the period of thawing. Pink spots then appear on the surface of the ice; as thawing accelerates, those spots gradually grow darker, first brown, then dark brown. On old ice plankton is sometimes so thick, and its color so dark, that it conveys the impression of mud or dirt.

(In addition to plankton organisms which, during freezing, get into the ice from the sea water, there are various groups of organisms which develop in summer on the ice itself, mostly at the bottom of fresh-water pools and lakes forming on the surface of ice owing to solar radiation. Accumulations of such microorganisms may be very considerable; the brown and deep brown spots mentioned by the author may often be centers of intensive growth of such microorganisms. Editor's note.)

The presence of plankton in ice does not occur everywhere and at all times. Extensive areas at sea may be covered with nothing but pure ice, in which there is no trace whatever of plankton. However, so-called "dirty ice" may be seen often enough.

Plankton in ice is an important factor, as it plays a considerable role in the melting and destruction of ice. This question will be examined in detail in the section dealing with the thawing of ice.

Structure of Ice.

While using the above term, it will be understood to mean not alone the crystalline structure of primary (pure) ice, but also the structure of secondary, and in general of all categories of sea ice.

Basically, sea ice is a peculiar conglomerate of the following components: of pure and fresh ice crystals; of brine contained in the cavities which have formed between crystals; and finally, of air, or more precisely, of a content of gas. The relationship between these component parts is by no means a permanent one; the ratio varies in connection with a number of circumstances, which have been examined above.

Consequently, ice is no homogeneous body, even when it has formed as a result of normal freezing of water in an absolutely calm sea. Despite the complexity of the "conglomerate" however, one may, in this case, detect a tendendy toward a certain order in the distribution of crystals: the crystals mostly assume a vertical position. This may be noticed in the thawing of young ice, which has formed a short time before thawing begins. In the upper layer of the field, the disintegration of level fields of such ice is similar to the breaking up of fresh-water ice into vertical needles. This phenomenon occurs only in the upper layer of the field showing above the water-line; deeper, salt ice is usually not characterized by a definite structure, and no breaking up into vertical needles may be observed. When ice has formed in windy and stormy weather, its structure is somewhat different. Primary ice crystals are considerably more broken up, and their freezing is disorderly, similar to that of snow-and-ice slush. One may thus distinguish two types of ice structure: one is that of ice which has formed in calm water, the other, that of ice formed in a billowy sea. The first type is usually called needle ice, the second spongy ice.

In nature, however, neither of the two types is encountered in its pure state. Usually, the ice which predominates has to a lesser or greater degree been subject to stratification and piling up. These processes occur from the very beginning of ice formation, and find their most decided expression in the stratification of young fields. In such case, if a field of thin ice acquires two, three or more layers before a snowfall occurs, brine may be found between the layers, and may often emerge onto the surface of the field. If snow covered the ice, layers of snow or of cooling mixture will be found in the stratified ice. Clearly, the general structure of such ice will differ from that of the first two types. (See Fig. 5).

In addition to stratification, ice fragments pile up into hummocks, which are partly submerged when pressured, or are heaped up on the surface of fields. It should not be hard to imagine what "mixture" results in the "core" of the hummock. It consists of ice, snow, brine, air, crushed ice and water. In consequence of the pressure, part of this mixture will become a shapeless hard mass; part of it will remain on top of the hummock in the form of fragments, which will gradually join and knit together under their own weight; the greater part, however, will sink into the water, where the formation of ice and the freezing together of fragments will continue; the lower parts of the hummock may also be subjected to a more or less intensive washing away by the currents. Thus, the general structure of hummock ice will differ considerably from that of the ice of a level field.

In the process of hummock formation, particularly during drifting and inter-friction, ice is ground into powder; in frosty weather this powder resembles flour, while in warm weather it is similar to snow-slush. Heaps of such ice powder later freeze into ice, but the structure of such ice will differ from all the categories mentioned above, and such ice will contain much air.

Thereafter, when thawing sets in, the upper layers of ice and the snow in particular will produce fresh water or a watery snow slush on the surface of the ice; it will, in part, flow off the ice surface, and, in part, remain in hollows on the ice. In pressure ridges, the fresh water will flow along the fissures and the inter-layers of snow and penetrate into the thick of the hummocks and freeze again in a new cold snap; this process also affects the peculiar structure of the hummock.

The so-called snow sludge (snezhura) has a peculiar structure of its own: it is a slushy, soft ice, differing in color from plain ice and originating from snow falling in frosty weather onto the open surface of the sea, or swept from the ice-fields into the leads.

All the aforesaid gives a fair idea of the diversity and complexity of the general structure of primary types of ice, and, particularly, of secondary ice formations.

Glacier ice - icebergs and their fragments - also has its peculiar structure, which we shall not deal with here.

Solidity (Strength) and Hardness of Ice.

The knowledge of the solidity (strength) of ice is of great importance to navigation and for the work of ships sailing through ice fields. We shall therefore endeavor to give the reader an idea of the comparative solidity (strength) of various types of ice which have a different appearance.

In view of the great diversity of structural peculiarities of sea ice, it is rather hard to classify various types of ice according to their solidity (strength). However, taking into account the very important fact that fresh-water ice is the most solid (strongest) ice, and that solidity (strength) and hardness decrease with increase in salinity, it is possible, on the basis of experience to draw up the following approximate scale of types of ice, classified according to degree of hardness (at the same temperature):

Hardest. 1. Glacier ice, icebergs and their fragments.

2. The de-salted surface of old sea ice - many years' old pressure ice.

3. The "Core" of hummocks, formed by pressure (when thawing, so-called honeycombe-ice results).

4. One-year old hummock ice and its fragments.

5. Thick level fields and their fragments.

6. Thin fields and their fragments.

7. Hard frozen primary ice (Nilas).

Very crumbly. 8. Slush and young ice.

This scale is but a very rough outline; for each of the these types of ice there is a possibility of considerable fluctuations in hardness. This applies particularly to 2, 4, 5 and 6. It should also be remembered that the solidity (strength) and hardness of ice depend largely on its temperature, and that they increase as the temperature falls.

It is common knowledge that many years' old sea ice (2) is, in fact, pressure ice - fields and fragments of hummock fields. The upper layer of such ice consists of fresh ice, and the older the ice, the thicker is the layer of de-salted ice. Consequently, the solidity (strength) of this de-salted ice will increase as the ice grows older. In accordance with the above, in the Central Polar Basin, the upper layers of the polar pack are similar to glacier ice as regards structure and solidity (strength). However, more crumbly ice may be encountered together with old ice: the result of the freezing of crushed ice and small chunks into "smorozi". In the period of thawing this ice is crumbly and granular, particularly when it contains plankton. However, the presence of plankton stains should not be taken as a sign of crumbly ice - later in the fall such ice may turn out to be very hard. This occurs when ice has formed through the stratification of fields containing plankton; as they thaw from above, separate layers produce a sediment of plankton on the surface of lower layers, which acquire increased solidity (strength) when melted fresh water freezes after the period of thawing.

One-year old pressure ice (4) is considerably less hard than several years' old ice because it is not topped by a de-salted surface layer. The solidity (strength) of one-year old hummock fields may vary, depending on the season and on the degree of pressure undergone: the greater the piling up of hummocks, and the nearer to the thawing period, the more will there be hard ice on the field. At the time of breaking up of hummock fields into floes and cakes, one may encounter ice of varying solidity (strength), and the hardest of all will be the "cores" of hummocks (3). Agglomerations of crushed ice will be crumbly and sticky, and in the event of thawing, so-called (smorozi) will also grow crumbly and sticky.

The above-water part of thick, level fields (5) consist of fairly hard ice, particularly when they have formed as a result of stratification. Thin, level fields (6) are considerably less solid (strong). In the initial period of thawing, interrupted by occasional cold snaps, a crust of de-salted and therefore more solid (stronger) ice may form on the surface of either of the above mentioned fields (5 & 6); but such a crust will be insignificant in thickness. In addition, the layer of snow affects the solidity (strength) of thin fields (see para. "Snow om Ice").

Ice of the hard-frozen slush ice (nilas) type (7) is not solid (strong) at all, it is rather crumbly and plastic (pliant). 5-cm thick ice is not solid (strong) enough for a man's weight; even when it is 5 to 6 cm thick, a man may not stand for any length of time on one spot - the ice will gradually bend and break. Primary types of ice, which may be distinguished by their dark color, are so elastic that they do not crack when raised by the swell - they bend in conformance with the curve of the swell. Young ice (8) is still less solid; slush (8), which consists of disjointed ice crystals has, of course, no solidity (strength) at all as an ice blanket - one may, however, speak of the solidity (strength) of separate ice crystals.

Color of Ice

The various types of ice are characterized by specific coloring. In some cases, the differences in color is insignificant, in other cases, ice stands out owing to its color, as for example in the event of plankton spots. One may also detect a difference in the coloring of ice in the periods of freezing or thawing.

In the period of freezing, the basic hues of ice are as follows. At first, young ice is transparent - its color on water is therefore dark; the slower the freezing, the longer does the ice remain dark. As the ice grows in thickness, its dark coloring gradually changes to dull dark gray; thereafter it lightens, reaching light gray at the time of formation of a thin field. Only at this third stage does the ice acquire its natural light green color over the entire thickness of the field, as may be seen from vertical crevices. Whereas in the initial stage, cracks keep their dark gray hue below water as well as above water, and this is a characteristic property of (nilas) ice.

The coloring of fragments of fields, formed by stratification is characterized by stripes, provided snow covered the ice at the time of stratification.

If, however, the ice was not covered with snow at the time of stratification, stripes can scarcely be detected, as the joints gradually disappear and the result is an even light green coloring. The presence of plankton in stratification may give an additional colored stripe above the layer of compressed snow; but this would not be light pink, as occurs on the lower, underwater part of an ice-floe - it would be a pale gray, differing only very slightly from the color of snow.

Owing to the fact that, in winter, ice is usually snow-covered, the general coloring of the ice-clad sea is white; and when there are leads of clear water, the letter seems black. The snowy whiteness of the ice surface is usually broken by heaps of newly formed hummocks, which seem greenish compared to the white snow. But when the hummocks are blanketed with snow, everything is again white. On rare occasions, however, ice fragments of a bright, pure, light-blue hue may be encountered. No trace of stratification is visible on these ice fragments; they acquire their bright hue only after a certain "blowing out" (efflorescence) of the salts has taken place.

Owing to its duller hue, crushed, small-chunk ice stands out on the rough surface of the general white background. As the thawing season approaches, accumulations of crushed (brash) and small-chunk ice gradually change in color and acquire an increasingly gray hue; when plankton is present, the coloring is pink, and later changes to brown.

Note should be taken of the rather sharp difference in color of two types of ice: "snezhura" (see P. 95 & Fig. 38), and "kasha" (see P. 94 & Fig. 37). Characteristic of these two types is that they float almost entirely below the water level, they do not emerge onto the surface, only touching it slightly from below. "Snezhura" is often yellowish (cream colored) and has the aspect of submerged snow. Ice "kasha" is of a dirty gray, ashen color, particularly on the border of ice and clear water, where it forms as a result of the breaking up of ice by the swell.

The coloring of the surface of ice changes considerably when thawing sets in. First of all, the snow which has begun to melt, grows "blue". As the snow melts away, the ice is bared and it acquires an ashen-blue hue - it also grows "blue". The de-salted surface of old ice preserves this ashen-blue hue through the entire thawing period, provided there is not the slightest film of plankton on it.

Most characteristic in the thawing period is the color of ice-floes, where plankton is present, both on the surface and in the thick of the ice. On the surface of thawing fields and in hollows where melted water accumulates, there often are thick layers of plankton film, the coloring of which may attain dark brown, similar to coffee dregs. When thawing starts, the first to disappear are crushed ice and smaller chunks, which, in winter, were of a pinkish hue; therefore, in summer, the small-chunk ice located between ice fields often acquires a color lighter than that of the fields. Thus, in summer, the coloring of ice fields and of broken ice (see P. 91) is the exact contrary of that prevailing in winter.

Larger-size floes of broken ice have the same coloring as the fields from which they originated.

In practice, it is always urgently necessary to distinguish hard ice from more crumbly ice. This may only be done by the knowledge of various colors of ice, by discerning scarcely perceptible differences in shade. These pecularities will be studied in detail in the section dealing with the description of various types of ice; here, we shall but note certain differences in the coloring of ice-floes of various solidity (hardness or strength). Both in summer and in winter, sea ice which possesses its average normal properties, usually has its own distinctive light green hue. When a floe of light gray-blue color is encountered in the midst of such ice, there can be no doubt that it consists of de-salted, and therefore more solid (stronger) ice. More difficult to define by their color, but actually just as solid (strong) as de-salted ice, are the "cores" of hummocks. They are mostly of a normal light green hue, with occasional lumps of dull gray or light blue. Characteristic of the "cores" of hummocks is their rounded shape and their honeycomb pattern. So-called "dirty ice" may be of varying solidity (strength): as a general rule, many years' old ice is harder and dirtier, and its coloring is brown, while younger ice is more pinkish in color. However, ice which is at the same time very dirty and very crumbly may also be encountered: thawing lumps of crushed ice which had been frozen over; it can easily be distinguished from older ice.

III. THAWING OF ICE.

The thawing of ice will be studied exclusively from its outward aspect and in the sequence in which it takes place in the ice blanketing the sea as a whole. Basically, ice thaws in two ways: from the air, i.e. from its upper surface, and from the water in which it floats. Thawing "from the air" is conditioned by two circumstances: 1) by the absorption of direct and dispersed sunrays falling onto the ice surface, and 2) by the influx of heat from the warmer air. Thawing "from the water" occurs at the expense of the heat drawn by the ice from the water. The speed with which the submerged part of the ice melts depends to a great extent on whether the ice floats in calm water, or whether it is being incessantly washed by it. The process of thawing and destruction is greatly speeded up by the direct mechanical action of water on ice.

Melting which is caused by the direct absorption of sun rays by the ice starts long before general thawing sets in. To begin with, the snow blanketing the ice starts thawing; at the same time, only separate, bared fragments of ice located on the summit of hummocks, also start thawing. Snow thus hampers the melting of ice, playing a role similar to that it also assumes in the freezing period, when it delays freezing. A considerable amount of the thermal energy of the sun, absorbed either direct, or drawn from the warm air, is consumed by the thawing of snow. However, as evidenced by observations in Northern seas, this thermal energy proves insufficient for melting the entire layer of snow lying on the ice. In most cases part of the snow remains on the ice until the latter starts thawing under the effect of heat supplied by the water, and often up to the complete disappearance of ice; this may be observed not only in Arctic seas, but also in seas where ice is seasonal. (The terms "Arctic seas" and "seas with seasonal ice" are being used in conformance with the classification of seas given in Chapter V.)

As previously stated, the thawing of snow starts quite early; even with freezing temperatures still prevailing in the air, signs of the thawing of snow may already be observed. However, in cases of early thawing on the surface of the snow, an ice crust immediately forms the moment the action of the sunrays has stopped. Such thawing is insignificant, particularly in Arctic seas. Intensive thawing starts only when the air warms up to above freezing temperature.

During thawing, crumbly snow settles down and gradually changes into a water-soaked snow slush; settling down occurs to a lesser degree in more compact snow. The entire process of thawing of snow is further complicated and delayed by the fact that spells of thawing are interspersed with freezing spells. As a result of sluggish, protected thawing, snow in Arctic seas may often get no further than to a state of watery snowy slush when the new freezing period sets in once more; in such case, this slush again freezes over until next year. In clam, windless weather, the thawing of surface snow and ice, provoked by contact with warm air, occurs very slowly, because the layer of warm air contiguous to the ice and snow cools down considerably upon yielding its heat for thawing; it therefore grows heavier and remains near the surface of the snow and ice, and is unable to rise and be replaced by warmer air. In windy weather, when the lower, cooled layer of air intermixes with warmer air, thawing is accelerated.

In consequence of the great heterogeneity of the snow covering the ice - as regards both thickness and density - (observed not alone on hummock ice, but also on level fields) the surface of the latter acquires an exceedingly uneven aspect while the thawing goes on: the ice is bared in some spots, in others, hollows appear which may develop into through pools and rivulets, by way of which water flows down.

It is evident from what was said above that the thicker the layer of snow, the slower will the melting of ice be; in some cases, most of the heat supplied through the upper layer of the snow blanket, will be consumed by the thawing of snow alone. In order to be in a position to make a forecast of the thawing of ice; information on the thickness of the layer of snow blanketing the ice is therefore of primary importance.

Before taking up the study of the thawing of ice proper, it is necessary to point out that the time when thawing begins does not coincide with the time when freezing on ceases. Investigations of ice temperatures carried out by F. Malmgren (see page 12) show that freezing on from below continues even after ice has started thawing from above. And the thawing of snow starts much before the thawing of ice proper. Consequently, the general period of ice overlaps the period of freezing during a considerable length of time. Thawing seems to struggle against freezing, first on the surface, mainly in the layer of snow, and thereafter in the layer of ice.

The duration of the period during which both processes, thawing and freezing, run parallel, or fight each other, varies according to latitude. In seas, located in lower latitudes and covered with only seasonal ice, which disappears completely in summer, the freezing-and-thawing period is the shortest. In Arctic seas, this period lasts considerably longer, but the time comes when, here too, freezing does cease, although it may not be stated with assurance that freezing ceases completely in all sections of these seas and whatever the conditions. Thus, in Arctic seas, a considerable amount of ice still remains unthawed when the new freezing period sets in. In this connection, it may be presumed that in the more northerly sections of these seas, where a powerful pack predominates and the supply of heat is smaller, freezing-on sometimes never ceases, even in summer. It all depends on the general thermal state of the sea in the given year.

Finally, in the Polar Basin, the conditions of thawing differ from those prevailing in bordering Arctic seas: here, as a general rule, freezing never stops completely - it only considerably reduced during the thawing period. This applies to the basic type of ice of the Polar Basin - to the large, many-years' old hummock fields of the so-called polar pack. As regards the thawing of other types of ice which may be encountered in the Polar Basin, but which are a comparatively few, they will be dealt with later.

Simultaneously with the beginning of thawing of the snow covering, there also begins the surface thawing of the upper, bare ice topping the hummocks. The thawing of ice proceeds with more intensity than that of snow, because ice is a better conductor of heat, and contains air and brine (and sometimes plankton).

(The brine contained in cavities absorbs solar energy with more intensity than does the ice. This explains the part played in the process of thawing by cells of brine and by other foreign bodies contained in ice.)

Owing to its darker color, ice has a greater capacity for absorbing solar rays than snow which reflects them. As regards the ice located on the summits and slopes of hummocks, it is in a favorable position for thawing as solar rays may fall on it at less sharp angles than they do on a horizontal surface.

The first sign of thawing of upper fragments of ice on hummocks is the appearance of icicles on the protruding angles. This may be observed immediately following the first sunny days. Thereafter follows a considerably rapid settling down of the entire hummock ridge, while the water produced by the first thawing or upper fragments flows down into the central part of the hummock, where it freezes up again, forming a compact mass of ice, which will be very slow to thaw.

The next type of ice due for disappearance is crushed ice, provided it has not been compressed, but floats in a thick mass in the pools. The thawing of this type of ice is accelerated by the water which surrounds it, and whose surface absorbs heat intensely. Following crushed ice, cakes and chunks of ice also begin to disappear; the smaller the chunks into which ice is broken up, the faster it melts.

Accumulations or fields of cemented crushed ice and chunks are also subject to early and rapid thawing owing to surface warming. They are characterized by porosity and by lack of solidity, and therefore thaw quite rapidly. Characteristic of the thawing of such accumulations or fields is the absence of pools of water on their surface: the water soaks freely through the porous mass. The entire field (smoroz) grows crumbly, but not watery, and breaks up easily.

The group of so-called "nilas" ice (comprising young ice, slush, etc.), which has formed on clear patches of water just before thawing sets in, belong to the category of ice melting early in the thawing season. Thin ice fields also thaw rapidly. However, these types of ice melt rapidly from surface warming only when they have formed as a result of normal freezing over and have not been subjected to rafting and stratification. In the latter case, their thawing proceeds much slower. On these later formations, the layer of snow is insignificant and therefore does not share in delaying thawing.

Fields of thin, dark (black) ice disappear fast enough when the sunrays reach them: pools appear on them, gradually joining each other, and thereafter the remaining ice fragments soon disappear. Thin, light-gray ice melts producing pools, while its thicker parts bulge up in the form of crumbly mounds, which have the aspect of hillocks of a lighter hue. A certain degree of similarity is to be observed between the thawing of "nilas" ice and the thawing of fresh-water river ice. When affected by the heat of the sun, the latter breaks apart into vertical "needles". These needles have a polygonal section, and are thick enough, as thick as a pencil. In "nilas" ice, needles are considerably thinner, rather similar to bristles; they form but in the upper part of the ice, while lower down they form a mixed mass of needles; in addition, their coloring is light gray, not transparent and colorless, as is fresh-water ice. The nuclei of such "needle" formations are often noticeable on level fields, but then only on de-salted surfaces.

Level fields of thin ice thaw from the surface, in the same way as does the "nilas" ice. In the initial stages of thawing, when the first pools start forming, they still keep the structure of hard ice, and only just before breaking apart do they grow granular and acquire the aspect of a needly, mixed mass.

Thick, level fields, usually covered with a layer of snow, as well as level fields formed as a result of stratification, melt from the surface in the same way as does hummocky ice, which means that, while thawing, they do not grow granular and needly: the ice dwindles in size while remaining hard to the very end. When surface thawing is intense, pools of water appear on all the above mentioned types of fields; in time these pools gradually join together and the field breaks up into cakes, chunks and fragments. Similar broken up ice may form in other circumstances, but this question will be dealt with in the section devoted to the dynamics of ice.

When snow melts on a thick field, the fresh water accumulates in the lower section of the ice surface and forms pools; the latter become centers of thawing and continue to accumulate water, gradually growing in size they form so-called "lakes", which thereafter become through holes in places where ice is thin. Fig. 7 may serve as an illustration as it shows the gradual deterioration of ice as a result of surface thawing. This photo is taken from "Album of Ice Formations" published by the Northern Sea Route Administration in 1939. It shows a field of one-year old light hummock ice in the process of thawing, with pools which are starting to join together. We see snow which has not yet all melted; insignificant hummocks of early fall formation have thawed away to a great extent. In the distance, closer to the landfast ice, we see "lakes" which have already joined together, and we also see the beginning of the formation of broken ice. Characteristic photographs of ice in the thawing period may also be found in the "Album of Ice Formation", published by the Hydrographic Department (YMC PKKA) in 1931. Thus, Fig. 32 of the latter album shows the surface of paleocrystic ice which has been subjected to intense thawing. Pools, which already reach through to the surface of the sea are joining together and the ice has reached a stage close to that of broken ice. The fact that the ice is more than one year old is evidenced by its considerable size and by the rounded shape of the thawing hummocks. The ice has a de-salted gray-blue surface with no trace of diet (plankton). The rivulets resulting from trickling water flow over an old hummock. However, this aspect may also be assumed by one-year old ice, provided it forms part of landfast ice which is closer to shore, because accumulations of ice are greater near the shore than in the open sea, and the process of thawing is more rapid close to the shore.

On Fig. 44 of the same "Album" (1931), we see a hummocky field breaking up into small-chunk broken-up ice. The ice looks like one-year old ice; it may, however, contain remains of old broken ice with dirt, which has been compressed and which, in the fall, has frozen into a hummocky field. The presence of a film of plankton on this field is revealed by the darker fragments of ice, contrasting with the white hummocky fragments. Unfortunately, plain photography is not capable of conveying all the shades of the color of ice.

We shall now study the thawing of ice from the "side of the water."

The process of thawing occurring in that part of the ice which is immersed in water is just as important as the thawing occurring on the surface. In this connection, it should be taken into account that from 5/6 to 8/9 of the volume of ice is immersed in the water. In favorable circumstances (when an ice floe has drifted into comparatively warm water), the thawing of the underwater parts of the floe acquires special significance.

The intensity of submarine thawing depends on the intensity of interchange, i.e. on the circulation of water in the layer adjacent to the ice, in the same way as the intensity of surface thawing depends on the movement of air over the surface of the ice. Some dissimilarities, however, should also be taken into account. As indicated above, in calm windless weather, the particles of air cooled through the thawing process, tend to remain over the surface of the ice, thereby delaying thawing. In contrast, even in calm weather, no such standstill can occur in the water adjacent to the immersed part of the ice floe. The reason for this lies in the fact that the thawing of ice is accompanied by a sharp drop of temperature and by a drop in salinity in the particles of water closer to the ice. This produces a change in density which, in turn, stimulates the circulation of water around the ice-floe. The scheme of this circulation may be quite complicated, but the ultimate result is that comparatively warmer surface waters are driven towards the immersed section of the ice.

In consequence of an intense inflow of surface water, a hollow is grooved out in the ice on the level of water, or somewhat below it. If this occurs in windy and stormy weather, the circulation of water around the ice floe is accelerated and the grooving process develops more rapidly. (See Fig. 38).

Further erosion of the ice along the waterline may result in the breaking off of the upper, projecting edges of the ice fragment. It then changes its draught, its waterline is displaced and it often partly emerges higher above the water and changes its position. An example of such an occurence is shown on Fig. 9, where a dotted line indicates the waterline prior to the breaking off of the projecting part, also indicated by a dotted outline.

As previously indicated, during the thawing of the ice-cover from above, water resulting from the melting of snow and ice accumulates on the surface of the field, forming pools and ponds, and also flowing onto the surface of the sea, into pools (polyna) and intervals between fields. If those pools (polyna) are minor ones and are located in the midst of consolidated wind-beaten ice and fields, the layer of fresh water does not mix with the salt water, but remains on the surface of the latter. The depth of such a layer of fresh water is easy to determine; scraps of paper thrown into the water sink down after they have soaked for a time and settle onto the salt water. It is thereafter easy to measure the depth of the fresh water layer. Using this method, the author succeeded in measuring a 15 cm thick layer of fresh water in a pool (polyna) in the Kara Sea. The layer of fresh water keeps intact over the salt water in small pools only, and only until there occurs a displacement of the ice or an intermixing of water produced by wind or by the growth in size of the pool. As regards pools and ponds on the surface of the ice field, their size and the amount of fresh water contained in them may be considerable. On hummocky ice, the depth of ponds may reach 1.5 m, without reaching through to the surface of the sea. From a pond about 15 to 20 square meters large and 1 m. deep, about 200 metric tons of fresh drinking water may be obtained. When water is pumped from a pool, the level of water is scarcely affected; it is apparently compensated by an inflow of fresh water from the surrounding surface of ice and from neighboring pools. Sometimes, after water has been repeatedly pumped from a pool, it acquires a slightly salty taste, which circumstance indicates a penetration of salt water from below. Such admixtures of salt water may occur quite soon, sometimes after 20 to 50 T. of water have been pumped out of a pool.

It often occurs that the sea water underlying an accumulation of fresh water in a pool, preserves for quite some time a below-freezing temperature while the temperature of the fresh water above it may be higher than the freezing mark. In such cases, the upper parts of the ice washed by comparatively warm water, may start thawing much faster than the underlying ice. Therefore, in places where a layer of pure fresh water has been preserved, the lower parts of an ice-floe may be seen projecting below the layer of fresh water.

Judging from a series of observation, the thawing of fresh ice at sea - of icebergs, their fragments and of de-salted old polar ice - proceeds at a slower pace than the thawing of salt sea ice. This is confirmed by the fact that when ice disappears at sea, the last to go are the de-salted fragments of ice. The lesser porosity and greater solidity of fresh ice obviously plays an important part in this respect. The role of porosity in thawing stands out particularly in the case of compressed cores of hummocks which, in the process of thawing, acquire the most varied shapes with rounded hollows resembling pores, holes and apertures (honeycombed). These fancy shapes bear witness to the fact that the first to disappear is the more crumbly ice, leaving behind it the more fantastic outlines of compressed, hard ice. As regards solidity (hardness or strength) at the time of thawing, pure fresh ice surpasses even these hard chunks of salt ice.

When discussing the process of thawing and destruction of ice, it is necessary to point to another factor having an appreciable significance, namely to the movement of ice with regard to the water, and vice versa. In summer, in the period of general thawing, both the movement of ice in the water and the washing of ice by the current accelerate melting and destruction, this being connected with the increase of thermal exchanges between water and ice. Observation has shown, however, that, in the event of accelerated circulation of the surrounding water, the destruction of ice may, in some instances, occur even in winter, namely in regions where strong currents are active below motionless ice. Consequently, the destruction of ice may be brought on by the purely mechanical eroding action of water on ice (which, of course, also occurs in the thawing period).

Similar observations of the action of currents under ice were carried on in Tikhaya Bay on Franz-Josef Land in the winter of 1937/38. Here, very strong tidal currents have been observed near the Eastern cape of Scott-Kelthy Island. In November 1937, newly formed ice extending over a fairly vast area between hummock fields, had reached a thickness of 20 cm. Measurements of the thickness of ice repeated every 10 days showed that, as the layer of snow increased, the thickness of the ice started to decrease until the latter had disappeared completely by February 10th - it became dangerous to stop on the snow, men were falling through. The layer of snow was, by that time, 57 cm thick. Thereafter, the wet snow started freezing and new ice formed, but it was snow ice of a gray color, not of the usual green hue.

The erosion of ice by currents was investigated in Tikhaya Bay by means of a snow-measuring rod, which was set on ice about 10 cm thick on January 11, 1938. Through the winter, a layer of snow 89 cm thick, had accumulated. On April 28, the thickness of the snow proper was about 3 cm, while the rest of it had changed into ice 24 cm thick, and the lower end of the rod was in the water, sticking out of the ice. (See Fig. 10).

The rod was cut out of the ice together with a chunk of ice; and it was discovered that a funnel about 6 cm deep had been shaped round the rod in the lower edge of the ice. The removal of the rod proved to be timely as on May 2 a spring tide broke up the ice and a large sized pool (polyna) was formed.

Apparently, salt sea ice is much more subject to erosion by currents than fresh ice. This is confirmed by the following observation also carried out in Tikhaya Bay in the winter of 1937/38. Thus, in the above-mentioned area, icebergs are aground in the strait near the Eastern shore of Scott-Kelthy Island, on the path of the currents mentioned above. However, the current does not seem to produce any washing away or any erosion as these icebergs remain there all winter, and only at the time of the spring tides do they shift slightly (about 100 m) and again go aground. The following experiment was carried out in order to ascertain the speed of erosion of fresh and salt ice. A chunk fresh glacier ice, weighing 14.85 kg, and with a temperature of -13.6°C, was extracted from a grounded iceberg. A chunk of salt ice, weighing 14.3 kg, of a temperature of -8.5°C, was extracted from ice resulting from the freezing of snow soaked in sea water. Both chunks were placed in boxes made of wire netting and, after a weight had been attached to them, they were lowered into an ice hole in a spot where a strong current prevailed. Both boxes were attached side by side and were sunk about 2 m deep in the water. 24 hours later they were both removed and examined. What remained of the fresh ice chunk weighed 2.85 kg, and what remained of the salt ice chunk weighed 0.90 kg. The temperature of the sea water was -1.65°C. Thus, the fresh ice had lost about 81%, the salt ice about 94%.

The results of the experiments demonstrate that the erosion or the washing away of ice by a strong current may be very intensive even with a low temperature of the water and this underscores the great importance of the purely mechanical action of the current.

Thus is it ascertained that, even in winter, the increase in the thickness of ice is neither steady nor permanent in all cases - there occur a decrease in the thickness of ice, and also destruction of it.

Besides, in certain seas which are not completely ice-covered in winter, thawing of part of the ice may occur in open-water areas adjacent to ice fields, provided, however, the temperature of the water is sufficiently high. Thawing in winter will be particularly rapid when the wind drives ice into a warm water area. Similar cases may occur in any sea with seasonal ice, and as regards arctic seas, it may occur in the Barentz, Greenland, and Norwegian Seas. The border between the pack and open water may be pictured as two peculiar "fronts", incessantly engaged in an offensive against each other: on the one hand, the "cold front", on the other hand, the "warm front". No armistice is ever observed here, the struggle is relentless, and the line of the "front" varies incessantly, shifting either one way or the other. In winter, when approaching the pack from the open water at the time when the "cold offensive" is on and the wind blows from the pack, ice of primary formation is usually encountered in strict sequence: slush, young ice, thin primary (Niles) ice, and thereafter broken ice and fields, depending on time and location. If, on the other hand, the wind is blowing from the open water, slush and young ice are usually driven to form strips of accumulated crushed ice (kasha) of a grayish hue, while primary (nilas) ice is encountered in the form of pancake ice; if, in such case, wind and swell are strong enough, primary (nilas) ice of all types will accumulate into a thick, gray ice "kasha", spreading in the form of a strip before the fringe of heavier ice, and also penetrating between the latter. If, on the contrary, the wind drives the ice into warm water and the "warm offensive" is on, no primary ice formations will be encountered near the fringe of the pack as such formations melt and disappear very rapidly. In this case, and again depending on time and location, only larger formations of the basic types will be encountered.

We have examined the various aspects of the thawing of ice depending on the inflow of heat either from the upper surface of the ice, or from its submerged lower surface, as well as the process of disintegration of certain types of ice. An attempt at a generalization of the process of thawing of the ice coat at sea would be somewhat difficult as every sea has its peculiarities, aside from the differences between seas with seasonal ice and arctic seas. We shall, however, endeavor to point out certain common traits.

The ice cover of the sea or of any part of it - if it is not covered with ice in its entirety - reaches its maximum towards the beginning of the thawing period. The size of ice formations and their character or type depend on the geographic location of the sea and on other factors. In seas with strong currents, the predominant types are hummocky ice formations such as hummocky fields, fragments of ice fields, ice fields (smoroz), and masses of crushed and small broken ice. In seas where weak currents prevail, the predominant type of ice encountered is large fields, either hummocky or level ones. In the majority of cases, towards the end of winter, the sea (or that part of it which covers with ice) is covered with a thick coat of ice with but insignificant intervals of clear water.

As previously stated, the first to disappear are minor ice formations - slush, young ice and crushed ice. With the disappearance of these types of ice, a considerable surface of water is cleared amidst more important formations; however it may not be completely cleared, particularly when thick accumulations of crushed ice are present, as the latter continues for quite a time to emerge onto the surface from under hummocky fields and fragments. The cleared surface of water exercises on immediate and considerable influence on the thawing process. The disappearance of the smaller types of ice scattered between fields and larger fragments increases the mobility of the latter, and that in turn contributes to their breaking up and melting, as the smaller the ice, the more rapidly it thaws. Moreover with the appearance of patches of clear water, the absorption of solar radiation by water rises sharply and underwater thawing is thereby accelerated. As the surface of the remaining ice and its thickness decrease, the destruction of ice progresses rapidly.

Following the breaking up of hummocky fields, numerous fragments of ice which had remained under the fields without freezing on to them, emerge onto the surface: honeycomb ice chunks which have undergone pressure, also appear on the surface.

Simultaneously with the thawing and breaking up of ice in the area, where the sea is ice-covered, extensive destruction of ice also goes on the border of clear water. Here, in addition to the direct action of the heat of the water, destruction is accelerated by the swell, which contributes to the thermal interchange between ice and water, and also to the breaking up of large fields. The thinner the ice on the fringe, the deeper does the swell reach into the ice area. Apart from ice fields proper, large ice-floes, settled deep in the water, are a great check on the waves, even when they reach the size on large ice-field fragments: only a very strong swell penetrates comparatively far into an ice-covered area. In view of the complexity and variety of conditions, it is difficult to determine the distance to which the swell may reach in the ice area; it may be stated, however, that the swell may often be felt at a distance of 30 miles from the fringe, even in the event of a large amount of ice.

A word may be said about the contribution of rivers to the destruction of the ice covering the seas. Rivers break up early, discharging masses of comparatively warm water, which is carried by currents far into the sea and accelerates thawing of the ice cover. It should be noted that, in summer, the shattering and crushing of ice, particularly of fields, as a consequence of pre-sure produced by winds and currents, is considerably less than in winter; this is explained by the fact that, in summer, areas of clear water between ice fields and in general at sea, are considerably more extensive, allowing ice fields to drift freely when driven by winds and currents. The only exception is when ice is pressed to the shore by winds or currents; even in such case, the result of pressure will not be as effective as in winter because the ice undergoing thawing acts as a neutralizer.

Fig. 11 represents a section of the sea with thawing ice which has reached the last phase preceding complete breaking up. We clearly see the rounded fragments (a, a...) which have emerged from under hummocks; the overhanging edges of ice-floes (b, b...), washed and levelled by the surface layer of water; and the fragments of hummocks (c, c...). The rounded shapes indicate that breaking up has been induced by thawing and that if any shattering has been done by waves, it must have occurred much earlier, as ice freshly shattered by the swell has sharper and more angular shapes.

(An example of such shapes may be found on Fig. 45 of the "Album of Ice Formations", 1931. That photograph was taken at the border of ice and clear water, whose dark mass is visible beyond the area of ice. On Fig. 11 we also see quite a lot of clear water, but this water in the midst of ice-floes is considerably farther from the border of completely open water.)

All the aforesaid has referred to drifting ice-floes, i.e. to ice which may be put in motion by wind and current.

The thawing of stationary ice in bays, straits, between islands and near shores (landfast ice) depends on its location and is characterized by certain peculiarities. First of all, its thawing depends to a greater degree on surface warning. On the other hand, currents which wash the ice from below represent another factor, accelerating thawing. As a general rule, stationary ice disappears later than drifting ice; one of the reasons therefor is that the latter bars the swell from access to the landfast ice. The latest to break up is the ice in archipelagos, in which currents are weak and depths considerable. In shallow areas, where the action of currents is strong, the breaking up of ice proceeds more rapidly. The ice directly adjacent to the shore thaws comparatively fast if the shore warms up sufficiently and slopes down allowing the least outflow; large accumulations of ice remain only on coastal shoals and banks, and these too disappear quite rapidly when the swell reaches them. In straits, ice breaks up comparatively early, usually owing to currents; breaking up occurs later in bays and gulfs, where currents are usually weak, provided, however, there are no tidal currents and fluctuations of level, which both contribute a lot to the destruction of ice.

It often happens that drifting ice grounds in the position of "stationary" ice. This occurs when currents and winds drive a compact mass of ice towards shores or islands grounding it, and thawing is thereby delayed.

IV. DYNAMICS OF THE ICE COVER AND ITS MIGHT (MASSIVENESS)

The might (massiveness) of the ice cover depends to a great extent on the intensity of the process deforming the ice cover, and which, in their turn, depend on the movement of ice; therefore, all problems connected with the might (massiveness) of the ice will be examined while taking into account their indissoluble link with its dynamics.

The very term "might" (massiveness) requires explanation, mainly as regards the distinction between "might" (massiveness) and "thickness" of ice. It would be more correct to use the term "thickness" of ice solely when it applies to ice which has grown normally, forming a level, smooth cover. Such an ice cover is characteristic of bays and straits, protected from the swell and from pressure. The term "might" (massiveness) of the ice cover, should rather be applied to open-sea ice which, as a general rule, has formed as a result of stratification, breaking and hummocking.

We shall now examine the process of the growth of ice at sea, starting with the seasonal ice cover, which forms in the absence of old ice. It should be noted that, when studying the growth of ice, purely thermal phenomena cannot be disassociated from the movement of ice, because from the very beginning of its formation, winds and swell may produce important changes in its primary aspects.

When the surface of the sea is calm, ice forms in the following sequence: slush (salo)-patches of uncemented needles and crystals; thereafter young ice (shuga) - beginning of the hardening of patches of slush; next appear thin dark ice, and thin gray ice - two types of "niles", which, as the freezing progresses, changes into thin level ice and into thick level ice; these are the categories of ice, characteristic of calm freezing. In the event of winds, completely different types of ice may appear. When the wind is accompanied by a swell, slush is accumulated into a gray, snow-like mass, and lies no longer in patches, but spreads on the water on patches, usually following the direction of the wind, and not at a straight angle to it.

If the wind and waves drive the slush towards the shore or towards the fringe of thick ice formations, there accumulates a thick ice "kasha" of gray-ashen hue.

(Successful photographs of such accumulated slush are scarce. However, a more or less accurate idea may be conveyed by Fig. 16 of the "Album of Ice Formations", IY YMC PKKA, 1931; on this photograph one may see a muddy, gray strip of slush, accumulated close to the fringe of landfast ice.)

When gales are blowing and the swell is considerable, this gray ice "kasha" comprises not only slush and young ice, but also both types of "niles" ice; in such case, the thickness of the layer at the point where the surf breaks - either near the shore, or near the fringe of larger ice formations - may reach several meters, this of course in the limits of a strip which is not too wide. In case of further freezing of such an ice "kasha", the ice acquires a gray color, and the stage of dark ice is dropped. In the event of a weak swell, pancake ice forms from dark and gray "niles" ice; it usually is of circular shape, and actually resembles pancakes. The lesser the swell, the smaller will be the size of the pancakes, and vice versa. (See Fig. 12.)

(Some investigators are of the opinion that pancake ice may form from slush and young ice, and also from the freezing up of needles, and even spontaneously as a primary type of ice formation. To this day, there is no unified opinion on this score in science. Editor's note).

As the pancakes hit one another in the swell, they acquire raised rims of crushed ice. Later these crushed ice rims are levelled by falling snow, and they are no more observed on the next types of ice. When winds drive pancake ice onto the shore or onto thicker ice formations, layers may be constituted, the pancakes then cover one another either completely, or partially similar to roof tiles.

Pancake ice forms from "nilas" ice only. The moment "nilas" has increased so far as to have reached the first stage of hard ice, the deformation produced by the swell will result in chunks of irregular quadrangular or polyhedral shape.

Rafting plays an important part in the formation of the ice cover at sea; it occurs mainly as a result of the action of winds. "Nilas" ice is the ice most subject to rafting. The thinner "Nilas" is, the oftener and the more is it subjected to rafting. The dark, thin ice of the primary stage of formation may still have numerous unfrozen patches of water, and a weak wind is sufficient to start off rafting along the edges of these patches. Ice is very elastic at this stage, a fringe easily mounts onto another fringe, and just as easily may a "nilas" field glide over the surface of another field. (See Fig. 13). The double-decker dark ice resulting therefrom acquires a gray color at the spots where rafting has occurred. When thicker ice rafts, a certain amount of fragments usually results prior to the mounting of one fringe upon the other: this is the first "broken ice". In addition to "nilas" ice, the other type of ice subject to rafting is the ice undergoing the next stage of formation, namely level ice - such fields raft over surfaces of considerable size. As the thickness of ice grows, it loses its capacity for rafting, and in the case of shifting, hummocking sets in. It should be kept in mind that the thickness of level ice fields which have undergone rafting may not be considered as the thickness of normally frozen ice. In case of strong pressure, particularly in the coastal area of the sea, even rafted thick level ice may reach considerable proportions. After rafting, the ice rapidly freezes together owing to the close contiguousness of the surfaces, and it may be quite difficult to discern the line of rafting in a broken off fragment; however, it usually shows thanks to the presence of snow and brine on the surface of the ice.

Hummocking of Ice.

The breaking of ice fields and hummocking occurs as a result of the pressure exercised on the ice cover by currents, and particularly by the wind. The means of formation of hummocks is infinitely varied; one may pick out but a few general rules for one or the other type of ice. It should be indicated in advance that the formation of hummocks in winter differs sharply from that occurring in summer in the period of thawing, and mainly in Arctic seas. Almost all types of ice are subject to hummocking to the exclusion of primary types of young ice, including dark "nilas". Light gray "nilas" may already form hummocks. Both level and hummocky fields may be subject to repeated hummocking, but to a certain limit only, such limit being different for every sea. The magnitude of hummocking and the size of the hummocks may differ in various parts of one and the same sea. In the central parts of seas, where the mobility of ice is comparatively unhampered, the formation of hummocks will not be as considerable as in the coastal area, where the force of pressure is much greater.

The beginning of the formation of a hummock is shown in four consecutive sketches (Fig. 14). In the process of hummocking, the fragments of ice partly heap up on the surface of the ice, but the greater part sinks into the water and accumulates in a more or less vague heap under the point of breakage. In a hummock, representing a general heaping up of ice, one may distinguish the upper part - upright "ropaki", and the lower part - loose ice under the field "podsovy". In its central part, and under pressure from all four sides, ice becomes cemented into a solid mass, which no more has the aspect of fragments of fields. This compressed and harder mass of ice bears no particular name; above, we have given such ice the denomination of "core" of a hummock, but this is not a generally recognized term. At the time of thawing, the ice of the "core" of a hummock acquires the character of honeycomb ice.

The formation of a hummock is shown on Fig. 15. As indicated by the arrows, besides horizontal pressure, the following forces exercises their action on the central part of the hummock: from above, the weight of the ice, which has been raised above sea level, and from below, the force of floating or a lifting force which, roughly speaking, constitutes about 0.1 of the weight of the ice when it is completely immersed. The dotted circle in the center indicates that part of the hummock, which undergoes a maximum pressure.

(The term "ropaki" is used here not quite in the sense it is currently used. It should be taken into consideration that the term "ropaki" is mostly used to designate only separate ice fragments, standing upright on a comparatively level surface of ice, or standing out in some particular way in the midst of a general heap or ridge of hummocks. Editor's note).

The greatest amount of fragments of broken ice result from pressure and hummocking of level fields (Fig. 16). In the open sea, far from shore, the height of the upper part of hummocks may reach

2 to 4 m; in the vicinity of the coast, however, or on banks and shoals, the height may reach 7 to 10 m, and even more than that in exceptional cases.

(The photograph of a hummock, formed from a level field and close to shore is shown on Fig. 49 in "Album of Ice Formations", 1931, published by IY YMC PKKA.)

The fact that these fields are not very thick contributes to their breaking; at the same time, their horizontal size is considerable, and connected therewith is the force, which they represent when in motion.

Level fields may attain a fairly high speed when driven by the wind because the ice in their lower part is smooth and fails to sweep along with it large layers of waters as occurs with hummocky ice; the consequence is, that heaping up is more considerable when pressure occurs near the shore and when winds help the pressure. It is necessary to point out that, on level fields, hummocks are not distributed in long ridges along the edge of a field and perpendicular to the direction of the wind. Only at the beginning of breaking up, and seldom at that, does the ice break along the entire length of the field; usually, hummocking takes place in separate irregular accumulations which occur at various angles to the direction of the wind. The only exception is hummocking close to shore; here too, however, long ridges are few and they do not always spread parallel to the shore, they are often placed at different angles with regard to it, or plain disorder.

Patches of clear water, "polyna", are always present between large level fields, but there seldom are passages from one "polyna" into another, because when the fields collide while in motion, they join at numerous points. These spots are called joints. Joints are always very hummocky, and are in most cases in a state of pressure as they bear the mutual pressure of both fields. If the pressure increases owing to the acceleration of wind or current, there often occurs a further breaking of the fields. Depending on the Direction of the crevices which then occur, new joints may appear, and new hummocking set in; old joints may also drift apart, leaving ice fragments on the water. Fig. 17 shows a collison of fields, with the accompanying breaking up and hummocking: sketch II shows how irregularly and wantonly hummocky accumulations are formed in regard to the direction of forces at work (arrows at the bottom of the sketch). In order to follow the further development of hummocky ice, one should take into account broken ice, which too may be of various origin. When freezing at sea proceeds normally and level fields break, the amount of broken ice grows considerably; towards the end of the ice period, broken ice predominates and is represented in various formations, mostly in the so-called "smorozi" (see Fig. 18); in the form of broken ice proper, it remains only temporarily and in quantities which vary sharply.

The remains of level fields compressed into hummocks do not remain indefinitely as such, particularly in the event of strong prrssure. The moment pressure weakens and fissures have appeared, part of the broken ice starts emerging on the surface of the water; at the same time, part of the upper accumulations fall into the water, and broken ice and ice "kasha" appear on the surface. Only comparatively small areas of former level fields, which have undergone numerous raftings and are studded with heaps of hummocks, may remain as such up to the thawing period. In the course of winter, most of the ice repeatedly changes its type. When dispersal occurs, broken ice spreads between fields and fills most of the free space between them. These intervals between fields which fill with broken ice are no longer called "polyna", but acquire the name of "syom" (local term used on the Northern coast). When the "syoms" drift apart, the broken ice floats in what is termed a "rasplava" (See Fig. 19).

Broken ice is exceedingly varied in size and shape - from crushed "nilas" to fragments of heavy hummocky ice. Besides, and as already stated above, so-called crushed ice should also be classified in the category of broken ice in the winter time. Crushed ice forms mostly as a result of friction of masses of hummocky ice. Much crushed ice also originates from pressure, when hummocking is in process, and finally in areas situated close to open water, where the action of the swell may be felt (Fig. 20). Crushed ice plays quite an important part in the winter ice cover. As it is actually an ice mass ground into powder, crushed ice acts like cement and, in the event of freezing, it solders separate ice fragments, the result being the formation of peculiar types of hummocky ice, the so-called "smorozi."

Hummocky "smorozi" do not form exclusively as a result of unhampered freezing of broken and crushed ice; they also appear as a result of the compressing of ice followed by freezing (Fig. 18). unfortunately, this photograph was taken in summer, but, to a certain extent, it is also characteristic of winter. The ice pictured on Fig. 18 has formed in the period of frosts, after the compression of broken (beaten) ice and of masses of crushed ice, which is evidenced by the rounded edges of the frozen crushed ice. After compression and freezing, the ice pictured on Fig. 20 forms "smorozi" of light hummocky ice, which may grow to large sizes; it is fairly thick ice with an uneven surface, sometimes with regular ridges of hummocks. Ice of about the same aspect and similarly powerful may be formed as a result of compression and breaking of "nilas" and thin ice (initial stage). The "smorozi" of light hummocky ice are subject to further breaking up, and when undergoing compression thereafter, they form heavy hummocky ice.

As previously mentioned, the strongest hummocking takes place along the coast. If the sea is shallow, fairly powerful masses of ice are pressed onto shoals, and they remain there until the beginning of thawing. If no wide stretch of landfast ice has formed, then, in the course of winter, masses of floating ice drift past such grounded shore ice, producing a lot of crushed and beaten (broken) ice, which is partly carried out to sea and partly remains on the landfast ice, forming ice banks. Through the winter, such a fringe of stationary ice in no way remains permanent - it either recedes from, or advances towards the coast, this being noticeable from the banks of crushed ice spreading parallel to one another. Variations in the width of such landfast ice depends on tidal fluctuations and on fluctuations of the sea level. Heaping up of ice on separate shoals may reach considerable proportions - these are the so-called "stamukhi". Such heaping up on a shoal is shown on Fig. 21

Accumulations of ice vary according to whether they are close to deep, rocky or steep shores. When waters are deep close to shore, the strip of heaped up ice is usually narrow, and accumulations of ice do not remain at all near steep shores with considerable depths. If the shore is gently sloping above the water-line, accumulations of ice form on the shore, and may reach considerable proportions. Even in the White Sea one may observe accumulations up to 15 m. in height above the water level. (near Sosnovetz Island). Such accumulations of ice on the shore are termed "zaboyi". In the event of pressure and when the shoreline is favorable, such ice may remain stationary for quite a long time regardless of depths - it keeps to the shore **owing** to its being cemented to it. At times, entire gulfs and bays, open from seaward, are filled with heavy hummocky ice which remains stationary for very long.

Piling up, rafting and hummocking frees the surface of the sea of part of its ice. It should, however, be pointed out that, as a rule, such areas clear of ice are situated in the opposite part of the sea, far from spot where hummocking occurs. Intensive radiation of heat takes place on the surfaces of water thus freed from ice, and they very quickly cover with new ice; and if minor formations of dispersed ice are still present, they freeze together. Thus it is that, at sea in winter, one may encounter heavy hummocky ice together with new formations of young ice. Consequently, pressure and hummocking result in considerable losses of heat by the sea, and this contributes to the increase of the general amount of ice at sea.

Gradually, and with the breaking up and hummocking of large fields of level ice, the aspect of the surface of the ice cover begins to change. The size of a field may decrease in surface, but increase in thickness; hummocks are heaped on top of it, while a great amount of beaten (broken) ice, podsovi is under it. The hummocky field or the broken (beaten) ice compressed into a smoroz freeze together into a more or less compact mass only in its upper part, while a lot of loose podsovi, which have not frozen together are left in the underwater part. The podsovi are accumulated in disorder under the hummocky field, and often reach considerable depth if they stick out vertically with regard to the field and are surrounded by numerous fragments of ice of various size. As the podsovi are hidden under the field, it is hard to assess their number judging by the aspect of the latter. It has been ascertained, however, that the greatest number of podsovi is usually to be found under the largest heap of hummocks, but the height of the heap of hummocks is not necessarily proportionate to the accumulation of ice below the field. As the fragments of the latter ice are not joined together, they do not remain stationary, they often get displaced in connection with the general movement of the field, and they then tend to distribute more or less regularly, under the entire field. The number of podsovi may be assessed approximately by the height of the edge of the field above the water-line. The irregular distribution of podsovi under a hummocky field may be observed when a hummocky field breaks up; in some cases, the podsovi may emerge onto the surface only in certain spots of the crevice; in others, the entire crevice is filled with fragments of ice emerging from below the field. The irregular distribution of podsovi also depends on what particular type of ice is undergoing pressure.

The aspect of hummocky ice may vary depending on whether it was formed as a result of pressure and freezing of beaten (broken) ice, or of hummocking of level fields. Ice fields originated from compressed and frozen up masses of broken ice, from large hummocky fragments, or from crushed ice, all differ very much in aspect and also in size. So-called s'yemi usually form between such hummocky fields (Fig. 22); they contain broken ice of varying density, or sometimes rare ice, or even clear water (razvodya).

(In the above case, razvodya are fairly large intervals of clear water between fields, partly filled with very dispersed broken ice, or leads between fields completely clear of broken ice. Separate patches of clear water which do not communicate with each other and are located between fields are termed polyni. (Fig. 17).

In Arctic seas, the freezing and hummocking of ice which has not thawed through the summer, occurs somewhat differently from that of new ice formations described above.

The formation of new ice in the midst of old ice can take place only in areas clear of ice, and also in the s'yemi. The appearance of young ice in the midst of old ice immediately produces a considerable hereogeneity as regards thickness of ice and this plays an important role at the time of pressure. Most significant in the formation of ice in the midst of old ice is the presence on the surface of the sea of a very de-salted layer, and also the presence of fresh water which has penetrated into the thick of the hummocky field. Ice appears early in the de-salted layer. In the thick of the field, fresh water freezes comparatively fast; in addition, it cements and increases the thickness of the compact upper part of hummocky ice, and also freezes and joins together the podsovy lying directly under the compact part of the field. The presence of fresh water also facilities the freezing into a compact mass of part of the upper accumulations - the ropaki (upright hummocks); melted snow remaining on the ice also freezes fast.

As the pools and ponds of fresh water on the surface of fields proceed to freeze, the general roughness of some fields is somewhat levelled down. An important peculiarity of the initial freezing of old ice is that its general size or thickness does not increase immediately - a considerable amount of time is spent on the freezing through of the entire thickness of old ice (See Table III).

The freezing through of old ice is still more delayed if it is covered with a layer of new fluffy snow. Thus it is that, when old ice is present at sea, the loss of heat by the sea is hampered, while the amount of newly formed ice decreases as compared with what might have taken place in the event of cooling of a sea entirely freed from old ice. However, in the presence of the latter, additional formation of ice will occur in those parts of the sea surface, where the water will be bared as a result of pressure and hummocking.

Naturally, the hummocking of freezing old ice bears no resemblance to the hummocking of new types of ice. The basic difference here lies in the fact that, amongst the old fields, there are no large level fields undergoing rafting. When pressure occurs in the midst of old ice, the young ice which has covered the s'yemi will be immediately subjected to breaking up and hummocking. When contracting, the s'yemi form hummocky smorozi with a very uneven surface. Hummocking of the very old hummocky fields occurs only when pressure is exceedingly strong, provided, however, these fields were not noticeable destroyed by previous thawing. Thawing fragments of rounded shape are comparatively easily drawn into hummocking, and they produce considerable accumulations both on the surface of the ice and in the water under the ice. Hummocky ridges form irregularly, but sometimes appear in long, straight lines, stretching along the corresponding edges of large, powerful fields. Owing to numerous hummocking and breaking up, many years' old ice produces much more broken (beaten) ice when it disperses and thaws than does one-year old ice.

Pressure and hummocking of ice is one of the most powerful natural phenomena, and particularly so in arctic seas, where the force of pressure may rise extraordinarily high. In winter, the force of pressure grows considerably when the cold is intense and great masses of ice are consolidated into a single unit; even with an insignificant speed, the moving force may be tremendous, particularly when the ice presses on the shore. The maximum force which the pressure of ice may reach depends on how far extends the ice cover in the direction whence the ice is moving.

In the event of strong pressure, the process of hummocking first occurs in what may be termed an orderly way, and this until a great amount of broken ice has been accumulated at the spot where a break has occurred; thereafter, pressure proceeds by fits and starts. It should here be stated that pressure and hummocking produce neither a "hellish roar", nor "cannon shooting", as has been stated in descriptions which wanted to add spectacular glamor to this phenomenon which is no doubt grandiose. It should be kept in mind that sea ice is a fairly plastic mass, that it is covered with layer of snow, and that much crushed ice is contained in intervals between compact formations. This comparatively soft mass can therefore in no way produce roaring or resonant sounds. All the sounds accompanying the hummocking of ice are limited to the light muffled hissing of moving ice-floes, and to an equally muffled grinding similar to that of sledge runners on the snow, but only less resonant; occasionally, a fragment breaking off from a heap of hummocks falls with a smack onto the snow - there are no other "hellish" sounds. The sounds, however, which may be heard when a vessel has been caught in ice undergoing pressure, are of a different nature. When ice fragments are crushed or broken against a vessel's hull, the noise may resound very loud in the ship's hold and may be similar to lashing and grinding - but these are phenomena of another category, as is also the roar of the wind which is usually very strong at the time of pressure.

Drift and Dispersal of Ice.

Sailing in an ice-ridden sea is possible only when the ice is sufficiently dispersed, and it is therefore most important to know what conditions may bring on dispersal. As a general rule, they are the same conditions as produce pressure and hummocking, namely the wind and the currents. A third factor - thawing - should be added, but that has already been dealt with. Therefore, disregarding thawing, we shall examine the conditions which bring about dispersal of ice.

In the absence of thawing, ice covering an entire section of the sea may achieve dispersal only by spreading over a larger surface of water, or in consequence of a reduction of its total surface brought about by rafting and hummocking. When the wind provokes the movement of ice, or as it is commonly called the drift of ice, it simultaneously sets in motion a certain layer of water which is driven along with the ice. This layer is the more considerable, the greater the accumulation of ice under the moving ice-field. Consequently, level fields drive the least amount of water along with them, and this explains their mobility, while heavy hummocky fields drive along with them a more powerful layer of water, and therefrom derives their lesser mobility, their greater inertia. The presence of heaped up hummocks which play the part of sails is no advantage to hummocky fields and does not speed the drift, because under-water accumulations are usually greater than those on top and the density of water is considerably higher than that of air. The speed of the drift depends on the size of the ice, even in the event of a unitype formation. When the wind has started blowing, a large field will move slower than broken ice, whereas the situation will be reversed when the wind is calming down. Therefore, even in a steady wind, an accumulation of ice of varying size and thickness will not drift in uniform motion; concentration and dispersal will occur inside the ice torrent while drifting, and the latter will continue by inertia even after the wind has calmed down, provided, however, there is sufficient free space to move into. If a torrent of ice driven freely by the wind encounters an obstacle in its path, it will rapidly concentrate into a more compact mass; if the obstacle is not the shore, but another drifting mass of ice, concentration and compression will take place and, thereafter, the ice torrent will continue to drift, already presenting a more compact mass. However, hummocky fields of a large size often conserve their high speed even when they happen to drift into an accumulation of dense broken ice; they then produce considerable dispersal behind them, and compression before them (Fig. 23).

Although seemingly simple, the action of the force or the wind on the surface of the ice, is rather complex. In addition to the irregularity of the movement of drifting ice, numerous other factors complicate the situation. It is thus difficult to isolate the effect of the wind along on the drift of ice for almost simultaneously with the movement of ice, there starts the accompanying movement of a layer of water, swept along by the ice. However, when one separate ice-floe drifts along driven by the wind, there is scarcely any accompanying layer of water to speak of. Consequently, a layer of water will only be swept along in the event of a certain minimum concentration of ice. On the other hand, concentration may vary considerably and is not evenly distributed because ice may accumulate either in strips, or in separate accumulations of varying shape, or may at times be distributed pretty regularly. It should be stated that the laws of the drifting of ice and its dependence on the wind have not yet been sufficiently studied. Nevertheless, for rough practical computations, and on the basis of a fairly large number of various observations, one may use the ratio now established between the velocity of the drift and the velocity of the wind producing the drift.

This ratio, usually termed "wind coefficient" is, roughly, about 0.02. In other words, 1 m/sec. of wind velocity corresponds to 2*m/sec. of velocity of drifting ice. In regard to the direction of the drift, it has also been established that, in higher latitudes, the direction of the drift deviates from that of the wind approximately 40° to the right in the absence of obstacles arising from the proximity of shores or from other causes. The wind coefficient, as well as the angle of deviation of the drift of ice from the direc-

*Russian original shows the values given. However, it is taken that velocity of drifting ice should actually be 0.02 m/sec for a wind velocity of 1 m/sec.

tion of the wind, no doubt also depends on the degree to which the ice cover is serried.

It should be further added that, generally speaking, the effect of currents on the drift of ice is very great, and may often be of much more importance than that of the wind. Thus, if ice is drifting in the current, or is kept close to shore by the current, the wind will but insignificantly affect the movement of ice, and this will, in the main, follow the current and not the wind. Exceptions may however occur in the event of very strong winds. It should therefore in no case be assumed that a dispersal of ice is bound to take place in a coastal region when the wind is blowing seaward. The dispersal of ice in the vicinity of the shore from which the wind is blowing, will take place only if the following conditions prevail: 1) if there is no current pressing the ice to the shore, or if the wind is so strong that it surpasses the current; 2) if there is a clear area of water, into which the shore wind can drive the ice; and, 3) if in other parts of the sea there is no stronger wind, producing a pressure of ice towards the shore in question. The latter eventually is always possible because the effect of wind on continuous ice may be transmitted to considerable distances, often provoking concentration or dispersal of ice in the absence of a visible cause. In contrary conditions, i.e. when the wind blows from the sea towards the shore, the ice near the shore will thicken in all cases but one - when the ice is being driven from the shore by a current which overpowers the effect of the wind. Similar phenomena may be very well observed in the White Sea, where strong tidal currents prevail. It is worthy of note that a case of non-conformity between the direction of the wind and the pressure of ice has been pointed out by the well-known polar explorer V. Stefansson. (Vilhjalmur Steffansson, The Friendly Arctic, Glavsevmorput, 1935, p. 66). He writes:

"Upon glancing at the map, it seems strange that between Point Barrow and Herschel Island, where the westerly wind blows from the shore towards the sea, it nevertheless drives the ice towards the shore; it is nonetheless a fact confirmed by numerous observations. At the same time, easterly winds here drive the ice from the shore to such a distance, that there remains a wide, clear passage for vessels sailing along the coast."

(In this case, the cause resides apparently in the configuration of the coastline.) (Editor's note).

One may point out another instance of dispersal of ice, produced mainly by wind conditions: the case when, in various parts of the sea, winds blow in different directions, or in one direction but with various velocities. In the event of a favorable distribution of winds, local rarefactions and accumulations of ice may occur. Similar phenomena are not lasting; in winter conditions their effect is therefore insignificant, but in summer, when ice is not so serried, the results of such dispersals or accumulations may be more considerable. Amongst the wind phenomena of the ice regime, the following observation presents some interests. When winds are blowing from the ice pack towards areas of clear water, the ice drifts in the direction of the clear water as a comparatively serried body, not as scattered ice. If, prior to the rising of the wind, the ice bordering on the water was considerably dispersed, then, in the event of wind from the ice, ice-floes will form into strips, in which the ice will remain serried. It may be presumed that, aside from its very occurrence, the development of strips of ice is due to the accompanying current, produced by both wind and movement of ice. Therefore, although strips of ice first appear almost at a straight angle to the direction of the wind (N. Zubov, Sea Water and Ice, M. 1938), they soon deviate from this direction and extend along the direction of their movement and not across it. If there is a sufficient amount of ice, the strips gradually increase in length, as though sucking the ice out of the basic mass. Strips sometimes break away and continue moving independently of the general mass. If, in the case of dispersed ice, the wind blows from the clear water towards the ice, there forms a single compact strip, often with bulges, and the ice gradually grows more compact.

Strips of ice are shown on Figs. 24 and 25. It should be pointed out that the formation of strips of ice is a phenomenon occurring mostly in the summer period, and takes place only on the border of ice fields with an open part of the sea. When dispersed, broken ice, which is not distributed in strips, keeps on the border of ice and clear water, it indicates a lasting calm period and intensive thawing of ice.

Besides wind, the dispersion and accumulation of ice is affected by currents: tidal currents, permanent sea currents, and temporary currents, appearing following protracted and deep changes in wind and weather conditions. Amongst temporary currents, those caused by the wind-drift of ice may at times, exercise a certain influence.

Sea currents are a very complex phenomenon in themselves, and in the presence of the ice cover, this complexity is further increased. Numerous observations and investigations will still be necessary before it will be possible to establish the laws governing the effect of currents on the ice cover. Here, we shall examine and describe but a few of the general phenomena, such as they are manifested in nature.

Amongst the currents which are independent of the wind, the tidal currents are those which exercise the most influence on the ice cover. The action of such currents stands out most particularly in the White Sea, the only of its kind amongst our polar seas; there are no similarly strong tidal currents in any of the other seas. The White Sea may therefore serve exceedingly well for studying the effect of currents on the ice cover. Later we shall again take up the dynamics of the ice cover of the White Sea; we shall now examine the general phenomena, common to all seas, where there exist currents both independent of, and linked to, the tides.

The movement of the ice caused by tides is similar to the drift caused by wind. Thus, the displacement of ice may occur only in a direction where there is room enough for it. In the event of movement of sparse or dispersed ice in the direction of the current, one may observe something similar to drifting caused by wind, namely, that the velocity and direction of ice differs, depending on whether the ice-floes are of larger or smaller size. In other words, one witnesses a displacement of large ice in regard to small ice. The more concentrated the ice, the slower its movement, and within the ice torrent there occur local dispersals and accumulations; the latter may also have the character of compressions.

The velocity and direction of currents vary in different parts of the sea. This lack of uniformity of currents reflects considerably on the ice cover, causing either accumulations or dispersals of ice. It is not hard to conclude exactly at what spots accumulations and compression will take place: an accumulation of ice will occur in the spot where currents will collide or converge, and also in spots, where a faster current overtakes a slower one. A contrary distribution of current will result in dispersal. Differences in the velocity of currents and dissimilarity in the concentration of ice may also be linked to the configuration of the shoreline and, in shallow areas, also to the relief of the sea bottom. Thus, sailing experience in ice-ridden seas has shown that dispersed ice may be encountered near shoals and promontories bulging into the sea rather than near rectilinear shores. Generally speaking, the presence of shoals and banks exercises a considerably greater influence on dispersals of ice than the configuration of the shoreline; examples there to are numerous. These phenomena are the most sharply manifested in the region of Severnyi Koshki (Northern Cats) in the White Sea. This is also observed to a considerable extent in the Kara and other polar seas. Shore banks, and also banks located far from shore at sea, both exercise an influence on the dispersion of ice. It should here be made clear that, what is meant are banks bordering on greater depths, where currents sharply change their velocity and affect the state of the ice precisely on account of the uneven relief of the sea bottoms. Over great depths - say exceeding 100 m. - the unevenness of the sea bottom will have no effect, or almost no effect, on the state of the ice on the surface. In the case of small depths only does the unevenness of the bottom have an effect on the ice on the surface, and the sharper the unevenness, the more effect will it have on the surface ice. The following rule may be deducted from the aforesaid: in a sea covered with a thick layer of ice, the more dispersed ice will be encountered round banks and shoals because such spots are affected by currents of various velocities. This rule holds good both for banks close to shore, and for banks out at sea. On the contrary, over deep depths, where currents are weaker, ice will for the most part keep densely accumulated.

Fig. 26 shows the whirls which may occur near a cape bulging from the shore; owing to the irregularity and the whirls which occur to the current, dispersal of ice will take place near the cape. Fig. 27 (in plan) and Fig. 28 (in cross section) show the changes taking place in velocity when a current encounters a shallow spot, the result being both dispersion and concentration of ice. There may also occur local accumulations, as are sometimes observed behind large ice-floes. Apparently, such a phenomenon occurs (mostly in strips of ice) when an ice-floe, driven by the wind, and lacking a stream-lined shape, causes whirls of water, in consequence of which the ice located closer to the ice-floe's wake, sweeps into it. (Fig. 29). In addition to the above sketches, numerous and varied examples may be cited. The principle invariably remains the same: a difference in surface velocities in the stream results in a local dispersal or accumulation of ice.

The so-called "driving and overtaking" currents present a special case. As regards them, it should be pointed out that a considerable rising of the water level and the occurrence of a current flowing from the shore, may take place only following a sufficient dispersal of ice. If the ice forms a compact cover, neither the rising of the water level, nor the "driving" current will have any chance to develop. It should be noted that, in winter time, the dispersion of ice occurring as a result of all the above mentioned causes and when the ice cover of the sea reaches its maximum density, may continue indefinitely, but to a lesser degree than in summer, in the thawing season. The possibility of the dispersal of ice also depends undoubtedly on the type of ice. Beaten (broken) ice disperses faster and more easily than large fields. Therefore, areas of the sea where large fields are predominant, will be difficult to negotiate even when there are leads and pools of clear water. Large fields usually predominate in the central parts of seas; and the larger the sea, the larger in size will the ice fields be. In the coastal areas, the following conditions usually prevail: in winter - hummocky broken and crushed ice; in summer - broken ice and dispersions. In seas covering but a small area and in gulfs, there is no definite rule as regards distribution of large ice fields and broken ice.

While concluding the survey of conditions, in which dispersal and condensation of ice are being observed, it is necessary to stress that a single indication of either dispersal or concentration is in no way sufficient for characterizing the state of the ice. As regards dispersal, it may be necessary to indicate the degree of dispersal which is determined by "points" of density (concentration). (Density (concentration) of ice is figured by means of a ten-degree scale: 0 indicate a sea completely clear of ice, and 10 indicates a sea completely ice covered; the intervening figures express the degree of density (concentration) of the ice.) As regards concentrated ice, it should be borne in mind that ice concentrated to 10 points and undergoing pressure under the influence of wind or current, may nonetheless be still in a state when pressure is insufficient to cause hummocking. On the other hand, and in contrast to the preceding case, ice of a 10-point density (concentration) may remain serried even in the absence of horizontal forces acting on it - it may, so to speak, remain in a "passive" state. In both cases, the "point" of density (concentration) may be identical, while the differences may be great as regards accessibility for vessels, and particularly so in the case of broken ice. Furthermore, as mentioned above, ice often tends to grow thicker in strips separated by clear water. It is therefore sometimes possible to speak of a concentrated state of ice, when the general concentration indicates less than 10 points.

It should be remembered that when endeavoring to assess the density (concentration) of the ice cover, the height of the observer's eye and the thickness of ice-floes should be taken into consideration. Usually, on vessels, the distance of the visible horizon - when observation is carried on from a barrel on the mast- does not exceed 8 to 11 sea miles, and from the bridge the distance is still less. Therefore, if the actual density (concentration) of the ice is 5 - 6 points, it will seem greater at a greater distance from the vessel owing to the comparatively insignificant height of the observer's eye; and on the horizon, the ice will seem as though its density were 10 points. It is also clear, that the thicker the fragments of ice, the greater will its density (concentration) seem to be. Fig. 30 shows the visual ray (from point A) falling on the ice as it recedes towards the horizon. It is apparent that the thicker ice fragments will seem continuous already at the distance of Alb, while the thinner fragments will seem to be merging only at the distance of Alc. The greater thickness of ice fragments will result in a certain recession of the horizon from point A, and this will further enhance the impression of continuity of the ice. Thus, the assessment of the density (concentration) of ice may be accompanied by certain distortions; in addition, the possibility of an individual mistake by the observer should also be reckoned with. Closer to reality will be the assessment of the density (concentration) of ice made from an airplane.

Thickness of Ice and Its Amount.

Mention has already been made of the difference between the thickness of ice originating from "normal freezing", and the general size of ice, formed as a result of various deformations. In the case of "normal freezing", the thickness of ice depends first of all on the amount of heat spent by the sea. K. Weiprecht carried out his first observations on the growth of sea ice while wintering on Franz-Josef Land, and compiled the following table giving the correlation between the thickness of ice and the number of degree-days of freezing temperature. (The number of degree-days of frost indicates the total of mean, daily, below-freezing temperatures of the air.)

Table VI.

500 C	produces	ice	51	cm	thick
1000	"	"	80	"	"
2000	"	"	115	"	"
3000	"	"	145	"	"
4000	"	"	170	"	"
5000	"	"	189	"	"
6000	"	"	208	"	"
7000	"	"	222	"	"
8000	"	"	237	"	"

K. Weiprecht figured out that, in the event of uninterrupted normal freezing, paleocrystic ice in the area of Franz-Josef Land may reach the limit thickness of 2.6 m. This figure is very close to what has been observed in the open sea. Thus, on the level areas of the ice pack fields, Nansen encountered ice about 3 m thick; the thickness of ice of the drifting station "North Pole" was also 3 m.

As a result of numerous observations carried out on polar stations located in various parts of the Arctic, it has become possible to establish more accurately the correlation between the growth of ice and the number of degree-days of frost, and to determine the increase in thickness of ice in various conditions.

N. N. Zubov gives the following table of increase of ice thickness in cms during one day, with a given freezing temperature of the air (daily mean), and with a given initial thickness of ice.

Table VII.

Thickness of Ice	Temperatures, °C.					
	-5	-10	-15	-20	-25	-30
0	0.79	1.55	2.29	3.02	3.72	4.41
5	0.66	1.30	1.94	2.56	3.17	3.76
10	0.57	1.13	1.68	2.21	2.75	3.38
15	0.50	0.99	1.47	1.95	2.43	2.89
20	0.44	0.88	1.31	1.72	2.17	2.59
30	0.37	0.81	1.08	1.44	1.70	2.05
40	0.31	0.61	0.92	1.22	1.52	1.82
50	0.26	0.53	0.80	1.06	1.32	1.58

These correlations and computations hold good only on condition that the ice forms in consecutive level layers and does not change its position throughout the winter, is not broken up by either wind or currents, and is not subjected to deformations. If such were the case, it would be easy enough to figure out the thickness of the ice on the basis of temperatures and to determine the entire amount of ice in this or that sea. However, the processes which produce deformation of the ice cover disturb this simplicity, and at the present time it is still impossible to either figure out or even determine the actual mean thickness of the ice cover, which has been subjected to pressure and hummocking. We neither are in a position to determine the amount of ice in tons or cubic kilometers, and this owing to the fact that, apart from the above mentioned reason, we do not know what fraction of the surface of the sea may be covered with ice. Indeed, it would be hard to believe that there could be preserved in the open sea even the smallest strip of ice unaffected by the general movement of ice with its incessant compressions, raftings and breaking up, and its accompanying pools, leads, etc.

All the aforesaid does not, however, exclude the possibility of clearing up certain points. It can thus be stated, for instance, that the action of deforming forces leads to the increase of the amount of ice in the given units. It has already been stated that, following hummocking and rafting in the bared parts of the sea, there may occur complementary ice formations which may be approximately computed by means of the established empirical formulae and on the basis of Weiprecht's table.

Take, for example, two equal areas, on which the formation of ice takes place (See Fig. 31). Given 500 degree-days of frost, the thickness of the ice in both cases will be identical, namely 51 cm. Suppose that, thereafter, following the action of the wind, rafting has occurred and the ice of area A has been rafted on area B. In such case, the whole of area A will be clear water, while area B will be covered with ice of double the thickness (102 cm). Suppose that the formation of ice continues. The next 500 degree-days of frost will then produce an ice cover 51 cm thick on area A, while on area B, 15 cm of ice will be added to the former thickness of 102 cm. Thus, as a result of stratification in conditions of 1000 degree-days of frost, there obtains a total layer 168 cm thick on both areas, taken together. If the freezing on were taking place without breaking up and rafting these very 1000 degree-days of frost would have resulted in 80 x 2 = 160 cm on both area. Therefore, owing to the interference of the force of the wind, there obtained a "supplementary" growth of ice, an extra 8 cm on both areas taken together. This amount of ice formed in consequence of the fact, that the growth of ice was more rapid on the part which had been free from ice than the part where an ice cover was present. For we know that the latter delays heat flow, thus greatly affecting the growth of ice.

Thus we see that a "supplementary" amount of ice is being formed owing to pressure and hummocking and with a considerable thermal loss for the sea water. The oftener there occur raftings and accumulations at sea, the more supplementary ice is produced. We know too that stratifications are not limited to single raftings of one field onto another, as indicated in our example. Above, we have examined various cases of hummocking, and we know that, when great pressure occurs, large sized level fields may pile up into immense hummocks, which may be comparatively small in surface, but very important in height and depth. The result being that considerable areas of sea are freed of ice.

Accumulations of ice piled up on coastal shoals and on floating ice-fields in the form of hummocks are mostly dependent on the force and direction of the wind. It is clear that, in case of pressure, these accumulations will be the largest where an important mass of ice is in action. In comparatively closed seas, such as the Kara (particularly its south-western part) and the White Sea, piled up ice cannot be as immense in size as in the Eastern-Siberian or Chukotsk Seas, where there is open access to ice from the polar Basin (Fig.32). When winds drive the ice towards the shore, the forming of hummocks will be more intensive.

Therefore, the basic factors, exercising an influence on the formation of ice, its supplementary growth, and its general amount (its volume) are the following: 1) the temperature of the air (degree-days of frost); 2) pressure and rafting producing "supplementary" formation of ice and increasing the volume of ice; 3) predominating winds, their force and direction.

We shall now examine the factors contributing to the decrease of the amount of ice. Amongst such, the main part is played by warm sea currents. The amount of ice in any sea is directly connected to the amount of heat brought in by these currents. Thus, for instance, the ice regime of the Barentz Sea and partly that of the Kara Sea depend on the warm current of North Cape. The influence of this warm current is particularly sharp in the south-western part of the Barentz Sea, which never covers with ice.

Warm river waters also exercise much influence on the amount of ice. This is particularly strongly felt in the Kara Sea, where the rivers Ob, Yenissei and Pyassina play an almost decisive role in the ice situation prevailing in the region between Dickson Island and Vilkitzki strait. The waters of the Lena River affect the ice in the eastern part of the Laptev Sea, and the waters of the Kolyma have an influence on the Eastern-Siberian Sea, etc. However, no definite connection has as yet been discovered between the amount of ice in Arctic seas and the amount of river water flowing into those seas.

The permanent currents carrying ice out of polar seas also have an effect on the amount of ice in those seas. In the Arctic seas of the Soviet sector of the Arctic, ice is being incessantly carried out, mainly into the Central Polar Basin. The only exception is the Barentz Sea, where the ice is mainly destroyed on the spot. At the same time, ice from one sea is being carried into another sea. Thus, a certain amount of ice is driven out of the Barentz Sea into the Kara Sea through the Kara Gates (Karskie Vorota) and through the wide passage between Franz-Josef Land and Cape Zhelaniya. Part of the Barentz Sea ice is also driven into the Greenland Sea. From the Kara Sea, the ice is carried out into the Laptev Sea through the Vilkitzki Strait, from the Eastern-Siberian into the Chukotsk Sea, etc. The amount of ice carried out depends on the velocity of currents and on the winds. In addition, the drifting of ice out of such seas also depends on the speed of the drift of ice in the Central Polar basin. As the latter is subject to fluctuations, the movement of ice in the seas situated on its periphery also fluctuates and varies from one year to the other, as well in shorter periods of time. The question of currents in arctic seas is one of paramount importance; it is also one of the most complex problems linked to the study of the dynamics of ice.

Snow exercises a certain influence on the amount of ice, and its significance has already been examined. Snow which has fallen in autumn, when the formation of ice is beginning, somewhat delays the thickening of the ice cover, thereby reducing the amount of ice in volume units. On the other hand, when a snowfall occurs before the beginning of thawing, it results in the cooling of the water, and the thawing of ice is thereby somewhat delayed; furthermore, when snow blankets the old ice cover a short time before the termination of thawing, its may altogether stop all further thawing. Therefore, the determination of the amount of snow which has fallen on the ice and on the surface of the sea - both at a given moment and throughout the year - would prove of great importance and interest.

We thus see that, apart from thawing, the following conditions have an influence on the reduction of the amount of ice: 1) warm currents and river waters, 2) the carrying out of ice by permanent currents and by the wind, 3) snow lying on the ice at the time of freezing.

As mentioned above, the presence of "old" ice, which has not had time to melt in summer and which reduces to a certain extent the thermal output of the sea at the beginning of winter, also exercises an influence on the amount of ice.

Measuring the Thickness of Ice.

As stated previously, the actual thickness of ice at sea may in no case be unconditionally compared to theoretical thickness of ice, i.e. to that of ice of normal freezing, computed on the basis of the amount of heat used up for the forming of ice.

Direct measuring of the thickness of sea ice is somewhat difficult owing to the unevenness of the upper and lower ice surface. It is quite easy to measure a smooth, even ice-field; it is sufficient to take a lath with cms marked on it and with another, shorter lath attached to its lower end at a straight angle, and to apply it closely to the lower surface of the ice, thereafter marking the height of the ice field. But such level ice is exceedingly rare at sea and may in no way be considered as characteristic. The problem of measuring a hummocky field is entirely different. Drilling through the field until water is reached and using the measuring lath thereafter cannot be expected to give accurate results, as the thickness measured applies but to the accidentally chosen spot. The following method may be applied for the approximate measuring of the thickness of an uneven hummocky field: measure the height of the floating part of the ice at several spots, determine the specific gravity of the ice, and then, using the necessary formula, figure out the draught of the field. Inaccuracy in the determination of the specific gravity and of the mean height of the ice field above sea level will not entail too great an error in such approximate measurements. Of all available methods, this will probably give a result closest to reality.

We shall cite several examples of measuring of ice thickness, carried out in 1937 in the Kara Sea on the ice breaker "V, Russanov." Fig. 33 shows the measuring of the floating part of a fragment of hummocky field, which had been formed from thin ice. The measurement was taken on August 23, near the western entrance into Vilkitzky Straight. At point A, the height of the above-water part of the fragment of field was 10 cm. At a distance of 21 m from this point, the height of the ice which was increasing gradually, reached 130 cm.

On Fig. 33 the above-water part is related to the submarine part at a ratio of 1:7; in other words, one above water part corresponds to 7 submarine parts. The scheme shows that a comparatively small fragment of field has a draught of more than 9 m. It may, however, be presumed that, in its central part, the field has a still greater draught, because the height of the ridge of hummocks rising on the surface of the field has been discovered to reach 100,105 and 145 cms. In addition, a layer of snow lay on the field, its depth fluctuating between 10, 15 and 20 cms.

In order to give a characteristic of the size of ice-fields in the Kara Sea, we shall cite two other measurements taken on September 20 of the same year to the West of Zarya Peninsula. The ice had been driven towards the shore by the current and had been subjected to pressure, which had occurred as a result of the action of wind and current. The ice-field was covered with a layer of snow 24 cms thick. Thickness of separate fragments of ice on the field reached 100-150 cms. The height of the ridge of hummocks was 300 cms from the surface of the field, and 330 cms from the level of the water. The height of the above-water part of the field fluctuated between 20 and 55 cms. The height of a separate hummock, located on a fragment of the hummocky field, reached 290-300 cms. The measuring of another ice-field yielded the following results: height of hummocks from the water level - 147-182 cms, from the surface of the ice-field - 95-130 cms. In approximately the same spot (slight farther to NE), new measuring of ice and snow was carried out on September 25 after repeated pressure had occurred. It was discovered that the layer of old (hard) snow on the ice-field was 20 to 50 cms thick, while the newly fallen snow lay 18 cms high. The thickness of fragments of hummocks fluctuated between 100 and 200 cms. The height of the ridge of hummocks was 250-300 cms from the surface of the field, and 500-600 from the level of the sea. The height of the above-water part of the ice-field, measured at several points, was 29,70 and 120 cms. The height of separate hummocks, which had formed as a result of the last pressure and at different spots, was 200,300 and 500 cms.

The data given shows to what height ice may be piled up as a result of pressure occurring in summer, and what magnitudes may be reached as regards draught of hummocky fields. Thus, if in the last case we take the height of the hummock above sea level as 5 ms, and take the ratio of the above-water and submarine parts as 1:7 the maximum draught should be 35 ms. These examples clearly demonstrate that, in arctic seas, the mean thickness of ice may considerably surpass the limit thickness of ice of so-called "normal" freezing (2.6 m). Even in the White Sea the mean thickness of ice is considerably greater. Thus, for instance, measurements carried out on the ice-breaker "V. Russanov" on March 19, 1937 in the central part of the basin near the Terski shore, yielded the following results: layer of snow on the field - 1.5 to 2 cms thick; thickness of hummocks - 1 to 24 cms. Height of the hummocky ridge from the upper surface of the field - 190 cms. Height of the above-water part of the ice field - 5 cms; height of another hummocky field above the water level - 36 cms. Height of a separate hummock on the surface of a fragment of an ice-field - 190 cms. It should be noted that, in 1937, the thickness of the ice cover must have been insignificant, as, in the course of that winter on most of the shoals known as the "Severnyi Koshki" (Northern Cats), no "stamukhi" (grounded hummocks) were observed, which occurs very seldom.

The draught of a hummocky ice field may be determined approximately upon observing over what depths it goes aground. In the Karn Sea, hummocky ice fields of medium thickness go aground over 9.5 m. depths. Separate detached fragments, accompanying the field at a greater depth cannot stop the progress of a field which is driven by wind or current as it goes aground only with its more compact mass which is frozen together. In the White Sea, hummocky fields start going aground in six meter depths. As regards ice in the Laptov, Eastern-Siberian and Chukotsk Seas, we have no sufficient data on their thickness owing to the absence of direct measurements. It may, however, be presumed that their thickness is greater as ice is here subjected to more powerful pressure. The mean thickness of ice in the Central Polar basin may be presumed to be considerably greater too.

V. CLASSIFICATION OF SEAS

ACCORDING TO ICE REGIME.

(This endeavor at classification does not claim to be thorough and refers solely to seas of the Northern hemisphere.)

To complete the characteristic of sea ice set forth in the preceding chapters, we shall give below the general distinctive traits of the various ice regimes prevailing in different geographic and climatic conditions.

Depending on the permanence of the ice cover throughout the year - on whether it does or does not disappear completely, (or partially and to what extent) in summer - and also depending on the changes in the ice regime occurring from year to year, it may be stated that three basic groups of seas should be distinguished. Their peculiarities are given below.

(A somewhat different classification of seas and sections of ocean as regards to ice conditions had been suggested by N.N. Zubov in his book "Sea Waters and Sea Ice," 1938; it could not be utilized by the author who wrote this book in the end of 1937 and beginning of 1938, while wintering on Franz-Josef Land. The author's suggestion is no doubt of considerable interest. However, his classification should be considered as a very general outline, whose practical application to different seas might require, in certain cases, some more accurate definitions as well as some reservations.)

Group I. - Seas with a seasonal ice cover. The seas belonging to this group are located in the climatic zone, whose approximate boundaries are the following: to the south - the January 0 isotherm, and to the North - the yearly 0 isotherm. As a general rule; the following peculiarities are characteristic of the ice regime of these seas. In summer, the sea is completely clear of ice. In winter, in the majority of cases, they are not completely covered with ice; often, most of the surface of the sea remains clear of ice throughout the entire year. The season of thawing is very short, and the types of thawing ice are therefore not lasting. Changes in the ice regime are very considerable from year to year; in this connection, the ice amplitude of this group is the highest of all three groups. A considerable fluctuation occurs not only as regards the surface, covered by ice, but also as regards the length of time during which ice prevails, and as regards the amount of ice. A characteristic peculiarity is that the ice, which is a "one-winter ice", reaches but a limited thickness by way of freezing on, while piled up ice may reach considerable size. The individual peculiarities of the ice regime of various seas with seasonal ice depend to a great extent on local conditions, and are therefore much more sharply manifested than in the seas belonging to the next group.

Group II. - Arctic Seas. The boundaries of the zone, taken up by the seas of this group, may be outlined only in a general orientative way: to the south, the yearly 0 isotherm, to the north - the limit of active sailing of vessels in the summer time. The Northern boundary is therefore close to the location of the slope of the continental shelf, i.e. close to the boundary of the Central Polar basin. The basic characteristic peculiarities of the ice regime of arctic seas are the following: in the summer season, the thawing of ice destroys but part of the ice cover of the sea; part of the ice remains unmelted when the new freezing period starts and therefore experiences a second winter. It should be noted that the period of thawing is protracted, it lasts throughout the entire summer; as a result, types of thawing ice undergo considerable development and may be observed at sea for a long time. As a general rule, the multi-annual amplitude of the extent of ice is less than in seas with seasonal ice.

Group III. - Central Polar Basin. The seas which should be classified in Group III, are represented by the Central Polar Basin of the Northern Arctic Ocean, and this is actually expressed in the title. The geographical boundaries of the zone are thereby also defined. The "pole of inaccessibility" should be considered as the center of this zone. The characteristic traits of the ice regime are the following: the most powerful ice formations are encountered in this zone - large sized, many-years old hummocky ice fields, which represent the so-called "ice pack", covering the entire Central Polar Basin with a comparatively solid and continuous cover. The shape and size of the fields forming the pack undergo little change during the thawing season. There occurs almost no breaking up at all of hummocky fields, only crushed and crumbled ice disappears in the pools (polyna) of water.

No considerable areas of sea are cleared of ice even toward the end of the thawing season; therefore, both the annual and multi-annual amplitude of iciness (extent of ice) are extremely insignificant.

VI. CATEGORIES AND TYPES OF ICE FORMATIONS,

THEIR DENOMINATIONS AND PECULIARITIES.

Despite the seemingly infinite variety of sea ice formations, they may be divided into several basic categories, and the latter into separate types.

We shall endeavor to establish a classification and to determine the link between various categories and types. As far as possible, we shall proceed in the sequence in which categories and types of ice appear at sea when freezing sets in and disappear when thawing is under way, and we shall use as basis the most commonly accepted denominations.

First of all, we may distinguish two basic categories: ice originating from normal freezing, i.e. ice, which has not been subjected to any deformation, and, deformed ice, i.e. which has been subjected to pressure followed by breaking and hummocking. These two basic categories may be divided into several groups, and each group into separate sub-groups or types. It should further be taken into consideration that, while freezing weather prevails, all categories without exception may be encountered at sea, starting with the initial types - slush and young ice - and ending with the most powerful accumulations of hummocks. In the thawing season, there occurs the gradual disappearance of various type of ice, beginning with the weaker and smaller sized ice. Towards the end of the thawing season, only the larger types remain in evidence. Therefore, the number of types of ice encountered in Arctic seas in the summer time, is considerably smaller, than in the season of formation.

We know that sea ice may be divided into stationary ice and drifting ice. To the first category belongs ice which is in some way attached to the shore, and also ice which is grounded on shoals. In the category of drifting ice belong ice floes ranging in size from small fragments to immense ice-fields hundreds of square kilometers in area, which move freely when driven by either wind or current.

In accordance with the above, sea ice may be classified according to the following table, which, however, include but the more important categories and types.

(Such classifications of ice exist in our country and abroad in several variations. Some of them originated from experience, others were suggested or worked out by scientists. As the study of ice developed more and more extensively in the Soviet Union, the need for a unified and generally recognized classification and terminology of sea ice, made itself more acutely felt. The result was that, in 1926, a special commission of the Hydrographic Office worked out a classification approved at the All-Union Hydrological Congress and published in the "Album of Ice Formations" (Hydrographic Office publication 1926 & 1931) and in other publications. Later, this classification was revised, and the revised form was approved on May 26, 1938 at a session of the Interdepartmental Bureau of Ice Prognoses of the Northern Sea Route Administration. This classification is now used in Soviet arctic seas. It also served as basis for the new "Album of Ice Formations"; published by the Arctic Institute in 1939.

The classification given in this chapter by the author, differs somewhat from the classification accepted by the Bureau of Ice Prognoses. Nevertheless, in order to keep a record and make the fullest possible use of the author's extensive experience, it was deemed expedient to publish his classification in the very form which it had taken as a result of many years of work in the domain of ice, and without endeavoring to adapt it to the one now accepted. This is all the more suitable, as the differences between the classifications are not substantial, while the main purpose of this chapter is to describe the peculiarities of the various categories and types of sea ice. Editors' Note.)

TABLE OF ICE FORMATIONS

SEA ICE

	Freezing Season		Thawing Season

A. Drifting Ice.

I. Normally Freezing Ice.

a. Group of Nilas Ice

	Freezing Season		Thawing Season
1.	Salo - slush	1.	)
2.	Shuga - young ice	2.	)
3.	Dark nilas - (ice rind?)	3.	(are not encountered
4.	Light gray nilas -	4.	(

b. Group of Level Ice.

	Freezing Season		Thawing Season
5.	Thin level Ice	5.	not encountered
6.	Thick level ice	6.	Thawing level fields

II. Deformed Ice.

c. Group of Broken Ice

	Freezing Season		Thawing Season
7.	Broken Ice (mixture)	7.	Broken ice)
8.	Large fragments	8.	Large fragments (thawing
9.	Small fr., brash, slob	9.	Small fragments
10.	Crushed ice	10.	)
11.	Ice kasha - ice sludge	11.	(not encountered
12.	Pancake ice	12.	)
13.	Snezhura - snow sludge	13.	) not encountered

d. Group of Hummock Ice

	Freezing Season		Thawing Season
14.	Light hummocky ice	14.	)
15.	Smorozi - floes (?)	15.	(Thawing fields (also
16.	Hummocky fields	16.	(fields with through
17.	Heavy hummocky ice (also paleocrystic)	17.	(pools of water))
18.	Pack ice	18.	)

B. Stationary Ice.

	Freezing Season		Thawing Season
19.	Level landfast ice	19.	)
20.	Hummocky landfast ice	20.	(Thawing landfast ice
21.	Stamukhi - grounded ice	21.	) Melting stamukhi

CONTINENTAL ICE AT SEA

22 Icebergs

In order to characterize the ice formations enumerated above and to help distinguish them from each other, we give below a brief description of their general aspect, of the progress of their formation, their size and other peculiarities.

SALO - Slush - is an accumulation of ice crystals (needles) in the surface layer of the sea; they have not yet frozen together into a continuous ice crust. (Ice needles is the very first stage of formation of ice at sea.) Slush floats on the surface of the sea in the guise of separate dull-colored patches, strips or accumulations. In a light wind and slight swell, these accumulations prevent the appearance of ripples; they therefore stand out very sharply on the surface of the sea, and have the appearance of patches of oil which smooth the ripples. The thickness of a layer of slush is no thicker than 0.5 cms. Slush very rapidly develops into other ice formations, and it may therefore be observed only in the period of its formation. At the end of the freezing season, slush is encountered only in pools and near the edge of ice fields, and then only in insignificant amounts.

SHUGA - Young Ice - crumbly, separate chunks of ice, of a dull dark gray color, forming on the surface of the sea, from slush (salo) which is in the process of freezing together. Freezing together starts in the center of a patch of slush, and thereafter spreads toward its edges. Slush may therefore invariably be observed on the periphery of young ice. The solidity (strength) of young ice is insignificant, and it often breaks up in the swell. The central part of a chunk of young ice is always darker in color. Its thickness is very irregular, mostly a few centimeters, but may reach higher figures when subjected to pressure.

As the formation of ice develops, both slush and young ice soon disappear and, if freezing proceeds in calm weather, they are transformed in to dark nilas; in the event of deformations, a concentrated thick mass ensues, and no pancake ice appears. In the event of an abundant snowfall; snow remains for a long time on the central part of patches of young ice. When thawing sets in, young ice disappears as fast as does slush.

DARK NILAS - forms on the calm surface of the sea as a result of the freezing together of young ice, and actually represents an already continuous although thin ice sheet of a crumbly structure. When nilas floats on the surface of the sea, its peculiar characteristic is its dark color. In the midst of old ice, particularly snow covered ice, dark nilas almost looks black. When taken out of the water, however, it turns out to be a light gray, flat, crumbly and non-transparent ice. In calm weather it may cover considerable areas of the sea with an almost continuous sheet, leaving a small number of pools with slush on the edge and clear water in the middle. Its thickness is irregular, about 2 to 3 cms. Owing to the considerable quantity of brine on the surface of dark nilas, the snow which may fall on it, does not keep long and thaws very rapidly. Dark nilas is encountered in pools or in open areas of the sea throughout the entire freezing season; with further freezing, it develops into light gray nilas; when winds blow; it may form raftings of considerable size. A characteristic peculiarity of the initial stage of rafting is the entwinement of the edges of nilas ice floes, which have rafted onto one another. As seen on Fig. 13 this occurs by means of long tongues which easily slide over the surface of the ice. At the points where rafting (Stratification) has occurred, dark nilas acquires a light gray coloring; in the event of swell, it often produces ice sludge, broken or pancake ice; in thawing, it disappears, forming no new types.

Light gray NILAS- develops from the further freezing of dark nilas, and retains the characteristic trait of nilas ice, a crumbly structure. If the freezing on takes place on a calm sea and in strong frost and in the absence of snow, salt crystals of a feather-like aspect appear on the surface of the nilas. Light gray nilas may be 7 to 8 cms thick. When freezing proceeds in calm weather, very considerable areas of the sea cover with a continuous sheet of nilas, and in the course of the entire cold period it may be encountered in pools and leads and in areas of the sea which are clear of other types of ice. In the process further freezing it changes into thin, hard ice. Light gray nilas is the very first type of ice, which retains snow on its surface. In the event of deformation, it produces broken ice, and in the event of pressure it forms insignificant hummocks; rafting may produce considerable piling on. When the swell prevails, it changes into pancake ice. When broken, it retains its characteristic gray color; while in rafting it often acquires a light greenish coloring.

THIN LEVEL ICE is the first formation of hard ice, occurring in normal freezing. It usually has a smooth level surface mostly covered with ice. Its thickness ranges between 10 and 30 cms. In calm freezing, fields of smooth, level ice may reach considerably large sizes, but if they are subjected to wind in the open sea, they raft on top of one another.

Only in closed gulfs and bays can smooth level ice develop without any rafting occurring, and later change into thick, level ice. In the event of deformations, thin, level ice may develop into various formations, into broken, crushed or hummocky ice; it may also be subjected to rafting and form 2-3-layer fields, which retain a smooth surface. In the event of hummocking, it forms very considerable ridges of hummocks, and high stamukhi (grounded ice) on shoals and banks. In contrast to nilas, the edges of broken, thin smooth ice, have a greenish color, particularly in the center, and changing to gray nearer to the upper and lower surfaces. When the thawing season sets in, large pools form on the surface of thin, level ice, which gradually grows crumbly and thereafter breaks up very easily.

THICK LEVEL ICE represents the final stage of development of thin, level ice. Its further normal freezing-on occurs for the most part in closed bays, where, in the absence of strong sub-ice currents, level ice may reach a thickness of 100 to 200 cms, depending on winter temperatures of the air, and on the thickness of the snow layer lying on the surface at the time of freezing. This type of ice is not often encountered and, in most cases, proves to be rafted ice. In the thawing season, pools form on thick level ice. When subjected to pressure, it breaks up and forms hummocks and broken ice. When thawing sets in, pools form on the surface of thick level ice, and thereafter it breaks up into separate small chunks.

Illustrations to the description of ice formations, may be seen on Fig. 35.

BROKEN ICE in all its various forms is one of the most widespread types of sea ice. Broken ice is usually encountered between ice fields, but it may often occupy extensive areas of the sea.

Broken ice is basically a product of breaking, and also of the breaking up of ice fields of various types. The shape and thickness of broken ice depends on which type of ice it has originated from. The comparative amount of broken ice in various seas is very different. In seas, where drifting ice is numerous there is more broken ice than in seas, where mobility is insignificant.

The comparative amount of broken ice also fluctuates in accordance with the season. There is less broken ice at the beginning and in the first half of winter, and particularly so when freezing is intense, the latter circumstances contributing to the freezing up of broken ice into smorozi. The greatest amount of broken ice is observed towards the end of the thawing season.

LARGE FRAGMENTS OF BROKEN ICE (Fig. 36) consists of large fragments of ice fields, and forms exclusively as a result of repeated dispersals and compressions of ice fields. During the freezing season, large fragment ice is not the predominating type of ice seen on the horizon, because it is invariably accompanied by either small fragment ice (brash, slob ice) or by ice-fields. Only in the season of thawing does one sometimes come across sea areas, where large fragment ice predominates over other types. This usually coincides with the time of breaking up of ice fields into smaller fragments, when minor chunks of ice have already had time to melt. In the event of freezing up large ice fragments form smorozi, and in the event of pressure, hummocky ice is formed. Large fragment ice may develop in considerable amounts in autumn and winter in sea areas bordering on clear water, where level ice fields or hummocky ice fields are subjected to the destructive action of the swell.

SMALL FRAGMENT ICE (brash, slob ice) (Fig. 35) consists of smaller sized fragments of ice of the most varied shapes. In lesser or larger quantities, small fragment ice invariably accompanies all other types of ice, filling up the space between ice-fields and large fragment ice. In the winter time, small fragment ice is always surrounded by either crushed ice or ice sludge. The volume of small fragment ice depends on the stage of development it is undergoing at the moment: in the event of dispersal, it spreads into a thin, rare layer of ice, while in the event of pressure, it forms a layer equal in thickness, or even surpassing that of the surrounding ice. In the thawing season, small fragment ice is the last stage through which ice passes before final disappearance.

CRUSHED ICE (Fig. 37) is a white, powder-like, granular ice mass, somewhat grayer than snow. Crushed ice results from strong pressure, and mostly from friction occurring between masses of ice in motion. Crushed ice is to be found on the edges of various formations of ice, and on their surface; particularly large accumulations of it are encountered along the edge of landfast ice, which usually borders on drifting ice. Accumulations of crushed ice are also found on drifting ice fields; the thicker the ice and the larger the size of the ice-field, the more considerable the accumulation of crushed ice.

Crushed ice is encountered almost exclusively in winter, as it disappears very rapidly when the thawing season sets in. During the freezing period, crushed ice plays a considerable role: filling up all interstices between chunks of ice, it contributes to their freezing together and their soldering into smorozi.

ICE KASHA - Ice Sludge (Fig. 37) is the same as crushed ice, the only difference being that it is not located on the surface of ice fragments, but in the water, in the interstices between them, and partly under them. It appears from the very beginning of the formation of ice, the moment deformations occur as a result of the action of wind, swell or pressure. Ice sludge accompanies all ice formations up to the beginning of thawing. Its accumulations are often very considerable, its thickness sometimes surpassing 5 to 6 meters. To a considerably greater degree than crushed ice, it contributes to the freezing together of broken ice into smorozi, and in particular cases, when accumulations thereof are very extensive, it may form independent smorozi. The latter may grow to considerable sizes.

PANCAKE ICE (Fig. 36). This denomination applies to a particular type of broken ice, which forms as a result of the breaking of nilas by the swell and of the mechanical rolling of it (see Chapter IV). Pancake ice is round in shape; the diameter of the cakes varies, their thickness may reach 7-8 cms. Owing to collision and friction, a pie-crust edge forms around the pancake, and, below the surface of the water, ice sludge fills the space between the cakes (Fig. 36). Pancake ice is a phenomenon characteristic of the beginning of the freezing period; throughout the cold season, pancake ice is encountered only on the periphery of ice formations, where a swell may be observed.

The size of separate formations of pancake ice depends on the swell (surge): the smaller the swell, the smaller the diameter of cakes, and vice versa.

SNEZHURA - Snow Sludge, forms as the result of a considerable snowfall onto the surface of the sea, when the latter's temperature has cooled down to below freezing. It has a gruel-like aspect.

In strong winds snow sludge may form in not too considerable amounts in pools from snow swept into the water from ice-floes. Snow sludge is very unequal in thickness, and is usually characterized by bursting cracks (crevices) and sometimes by curving folds. In calm-weather freezing, it acquires the aspect of gray nilas; when pressure is in action in pools, it contribuates to the formation of smorozi together with ice sludge. Fig. 38 shows snow sludge, which is being broken by the swell, originating from a passing vessel. A characteristic picture of snow sludge may be found in the "Album of Ice Formations", published by the Hydrographic Office in 1931.

HUMMOCKY ICE (Fig. 39). Initially, it forms either as a result of the breaking of level ice fields and the piling up of fragments which follows, or as a result of pressure and of the freezing together of broken ice. In the first instance, hummocky ice presents disorderly piled up ridges of broken ice fragments (hummocks, ropaki (upright hummocks)), in the midst of which area of level ice may be encountered. In the second instance, hummocky ice presents a continuously piled up and dug up surface with no level spaces, and has therefore been specially denominated "smoroz". At the time of the initial hummocking of level fields, the upper parts of the hummocks consist of fragments almost uniform in size, while the lower accumulations termed <u>podsovy</u> (under-props), although consisting of fragments of equal thickness, are more varied in size. When repeated destructions of hummocky fields take place, the number of level terrace areas decreases, while the quantity of hummocky accumulations increase both on the surface and below the ice.

The size of hummocky ice fluctuates within considerable limits, as under-water accumulations of ice may reach several scores of meters. In seas with drifting ice, hummocky ice is the prodominating type of ice, both as regards the sea areas covered by it, and also as regards the general volume of ice. Hummocky ice appears at the time of formation of gray nilas and also completes the development of the ice sheet covering the sea. In spring and summer it is subjected to thawing, and part of it disappears, while part remains and is capable of surviving through many years.

<u>SMOROZ - Ice field</u>, (Fig. 40) is broken ice which has frozen together into a continuous ice field; at the moment of freezing together it may have been either in a state of dispersal or under pressure. <u>Smoroz</u> has the aspect of hummocky ice, excluding hummocky fields of primary hummocking, where level areas may be found in the midst of hummocks. No level areas are to be found on <u>smorozi</u>. The size of thickness of a <u>smoroz</u> depends on the category of broken ice from which it has been formed. It should be stated that the size (importance, force) of a <u>smoroz</u> formed from dispersed ice is less than that of a <u>smoroz</u> formed from compressed, broken ice. Greatest of all is the force (or massiveness) of a

smoroz, formed from ice filling up a powerfully compressed s'yom (space between fields). Such a smoroz is usually more powerful (massive) than the surrounding hummocky fields and is no less solid (strong). Similar to hummocky ice, smorozi are one of the predominating types of drifting sea ice. Smorozi formed from large masses of crushed ice and ice sludge have a hillocky surface with rare fragments of ice scattered on it; when thawing, they break up very easily, and no pools of melted water are found on them. Other smorozi thaw in the same way as does hummocky ice.

LIGHT HUMMOCKY ICE (Fig. 41) is characterized by a comparatively level surface, sometimes intersected by not too high rows of hummocks. If light hummocky ice has been formed from gray nilas, its very slightly rugged surface will be almost unnoticeable under the snow. When the layer of snow is considerable, light hummocky ice will even seem to be a smooth, level field. However, its actual importance and thickness differ sharply from the latter, because the under-ice accumulations consisting of podsovy (under-props) may be very considerable in size (importance). Similar ice floes of a light-hummocky character may result from pressure nilas and pancake ice, and may reach considerable thickness, while retaining a comparatively level surface. Light hummocky ice is encountered in considerable quantities in the first half of the freezing season. Later, at the time of strong pressure, it may be transformed into more powerful hummocky formations.

HEAVY HUMMOCKY ICE (Fig. 42) is ice which has reached its maximum (for the given sea) in size and force as a result of piling up. The surface of such ice presents in most cases a disorderly piling up of broken ice, in the midst of which small, separate areas of more or less level ice are seldom encountered. Heavy, hummocky ice forms in the period of freezing when the general ice cover is already considerably developed. Strong gales occurring at that time and blowing from a favorable direction drive the ice towards shore, and heap it up in the gulfs, bays and estuaries; the ice then moves together and starts hummocking, reaching its maximum strength. Such ice can no more be subjected to further piling up. At the beginning of the thawing period, it recedes from the shore, and breaking up from the edges, it is gradually destroyed.

In arctic seas heavy hummocky ice may subsist several years; owing to surface thawing its surface smooths down to a certain extent and grows considerably more level than in the first year of its formation. The upper layers of ice undergo considerable de-salting; in winter, the layer which is frozen through and through increases, and most of the podsovy (under-props) freeze together, the solidity (strength) of the ice being thereby increased. Heavy hummocky ice is usually encountered in large-sized fields.

THE POLAR PACK (Fig. 43). Several years old heavy hummocky ice reaches its maximum development in the Central Polar Basin and is called Polar pack.

According to observations made by Nansen on the "Fram", by those of the drifting station "North Pole", and of planes which flew to the Pole and landed on the ice, it has been established that the distribution of ice is as follows: more broken and hummocky ice is encountered on the periphery of the Polar Basin, and closer to shores and shallows, while large ice-fields predominate in the central part of the Polar Basin. These fields reach tremendous dimensions. After they have undergone thawing in 2 or 3 consecutive years, and in the absence of repeated pressure, their surface grows comparatively smooth, it is slightly undulated and covered with snow which fills up the hollows and the low parts. At the points where fields join, there form high, mound-like accumulations of hummocks and crushed ice. Every year, a considerable part of the pack is driven out of the Polar Basin into the North European Sea through the wide strait between Greenland and Spitzbergen, and only a small part of it thaws on the spot.

LANDFAST ICE is stationary ice attached to the shore or to off-shore rocks or shoals. It forms mostly in gulfs and bays, and along the coast in open parts of the sea, where the width of the landfast ice depends on depths. On banks and shoals and sections of the coast protected from the onslaught of ice, landfast ice may form by way of normal freezing, and in such case it consists of level ice. At points, open to the pressure of ice, landfast ice is usually hummocky and spreads to the very bottom along the entire shallow area. In such conditions, landfast ice forms at the beginning of the thawing season and, as a rule, remains stationary until thawing sets in. At points where the coast is abrupt and steep, and depths are considerable, and strong tides prevail, landfast ice is but temporary; this, however, excluding islands, skerries and narrow straits, where landfast ice may remain for a long time despite considerable depths. In the event of a strong pressure of ice, hummocky landfast ice of great magnitude may form even off deep shores; in favorable circumstances, landfast ice may remain stationary throughout the entire winter, keeping attached to the rugged parts of the shore. In seas where strong tidal currents prevail, landfast ice often changes in size: it is larger at neaps, and decreases at springs. In summer, landfast ice usually breaks away from the shore and is either driven out to sea or melts on the spot, although, in exceptional cases, it may remain stationary throughout the summer. Sometimes, landfast ice fails to be broken up for several years consecutive.

(That part of landfast ice which is directly frozen on to the shore, and is not subjected to any fluctuations, is denominated <u>ice foot.</u> It is the completely stationary part of landfast ice while the rest, although undergoing no horizontal shifting, shows vertical fluctuations, which correspond to the fluctuations of the sea level.)

<u>STAMUKHI</u> - are separate accumulations of ice on sea or coastal shoals. The main difference between landfast ice and <u>stamukhi</u> is that <u>stamukhi</u> are not attached to the shore, and are mostly located on sea shoals. <u>Stamukhi</u> form when a floe reaches such considerable thickness that it grounds on a bank or shoal; in the event of pressure, ice is piled up in high accumulations and remains stationary throughout the winter; in some cases, it may even remain so for several years. In the White Sea, where tidal currents are strong; some of the <u>stamukhi</u> form at low tide, some again go adrift at high tide, while most of them remain stationary and may remain so throughout the entire winter.

<u>ICEBERGS</u> should not, strictly speaking, be considered as belonging to the ice cover of the sea, as they are of another origin. Icebergs are large fragments of coastal glacier ice,

which have broken away from the glaciers which descend into the sea from arctic continents or islands. These fragments may be of immense dimensions: several tens of meters above water level, and 100 or more meters deep. Common, medium icebergs of the archipelago of Franz Josef Land have a draught of 40 to 80 meters, the result being that, in coastal areas, they are for the most part grounded. Icebergs have no great effect on the ice cover of the sea, except in cases when they break ice up, or when, grounded on a shoal, they hold up the drift of ice.

The above survey of the peculiarities of the basic types and forms of ice should be supplemented by a brief explanation of certain terms and notions relating to the state of the ice cover.

The edge of ice. The border between ice and clear water is termed "edge of ice". It should be noted that this border is not always constituted by a continuous edge of ice; ice sometimes starts with rare, small formations which gradually grow more dense; it may also stretch in strips, or appear in separate patches, or may also spread in a continuous mass. In winter, slush, young ice and nilas is often encountered near the edge of ice.

Thickness of Ice. The extent to which the visible sea horizon is covered with drifting ice is termed "thickness of drifting ice". Thickness (or density or concentration, as regards covering) is designated in points according to a 10-point system, 0 designating completely clear water, and 10, designating complete ice covering. The thickness (density, concentration) of ice may also be characterized in terms as, for instance: ice "na rasplavakh" (ice on the float) is used mostly for broken, dispersed ice, which is no thicker than 5 points, and 'rare' ice (rarefied, dispersed) which may be either broken ice or fields less than 5 points thick.

Polynya is an enclosed area of water between ice floes, mostly in the midst of fields; razvodye (lead) are pools of clear water communicating with each other between ice floes, usually formed through the action of winds or tidal vurrents.

S'yom is an interval between ice fields filled with broken ice, which may be dispersed, thickly concentrated or compressed. When sufficiently dispersed, a s'yom may be used by a vessel as a passage through ice fields.

Ice blink or ice sky is the reflection in the clouds of ice which is beyond the visible horizon.

The ice sky shows particularly well in a dark, cloudy night when, given a good transparency of the air the ice blink is visible at a distance of 20 miles. In such conditions, and when there is no ice at sea, a snow-covered shore may be visible at a distance of 50 to 60 miles.

Water sky. In covered or cloudy weather, the presence of water in the midst of ice may be revealed by characteristic dark patches in low clouds over clear water, the so-called water sky. Fog hanging over near-by polyny shows as black in the water sky. In clear weather or in a moonlight night the phenomenon of the water sky is not observed.

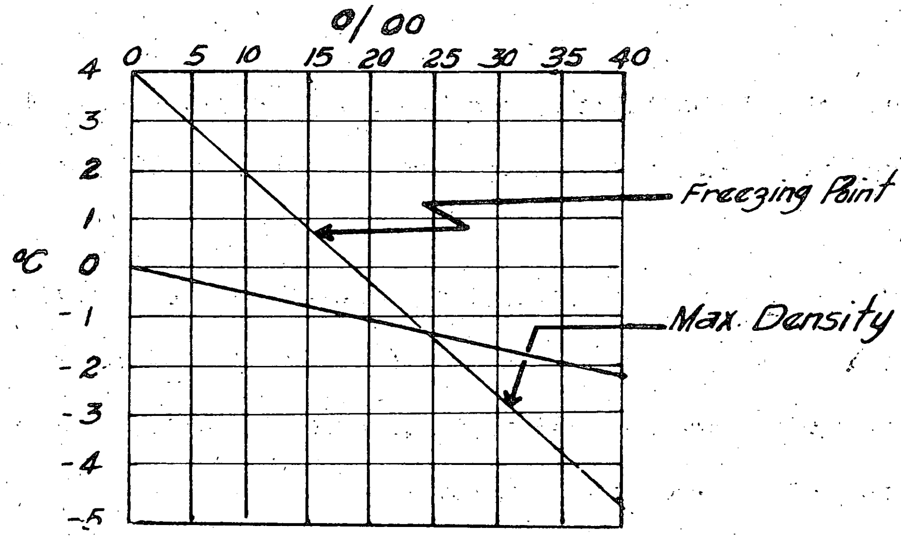


Fig. 1.- Dependence of the temperature of freezing of sea-water ($\tau°$) & of the temperature of its maximum density ($\theta°$) on salinity.

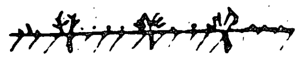


Fig. 2. Salt on the surface of the ice.

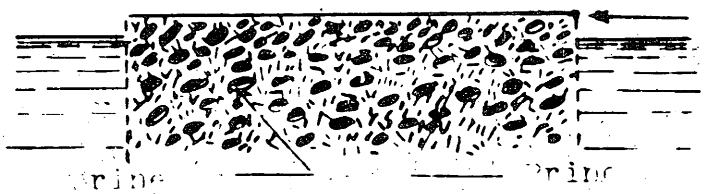


Fig. 3. Distribution of brine in ice during freezing.

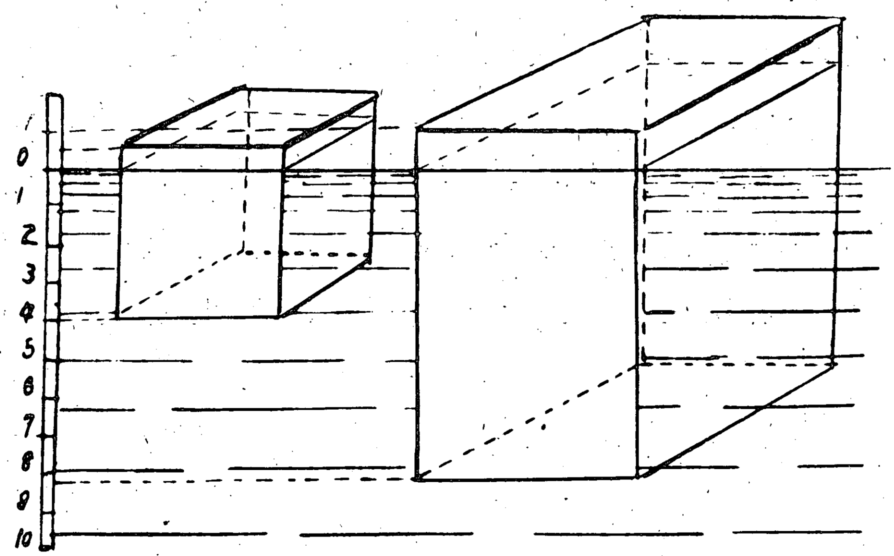


Fig. 4. Blocks of ice (density 0.90) immersed in water (density 1.01).

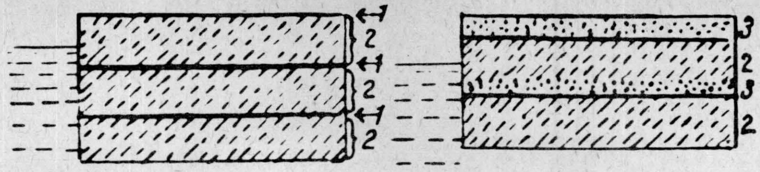
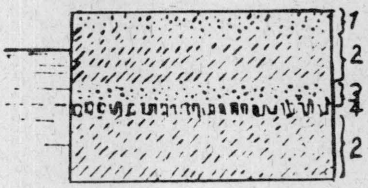


Fig. 5. Stratification of ice.
1 - brine; 2 - ice; 3 - snow.



. 6. Stripes of various hues in the cross section of stratified ice: 1 - snow, white; 2 - ice, light green; 3 - compacted snow, dirty-gray; 4 - layer of brine, dark.

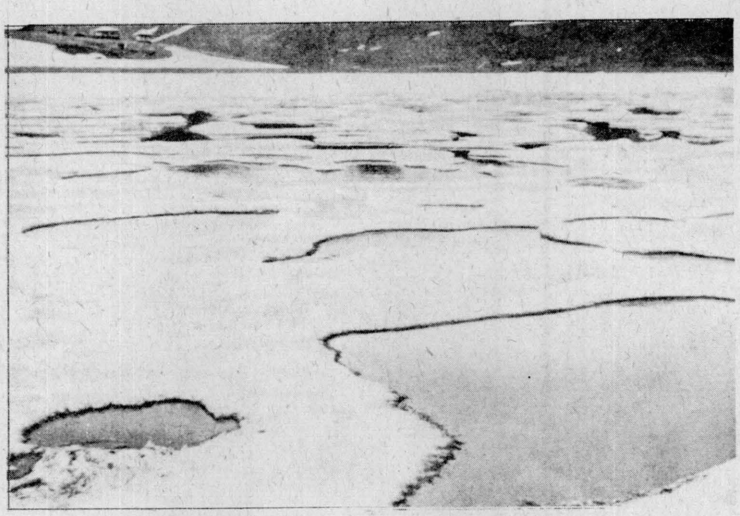


FIGURE 7 Beginning of fusion of pools on one year old, light, hummocky field with remains of snow.

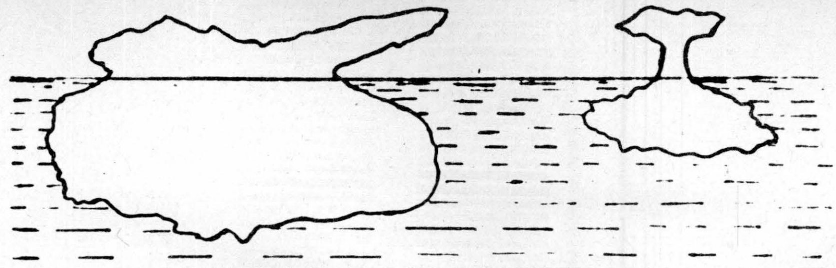


Fig. 8. Erosion of ice by the swell on the water level.

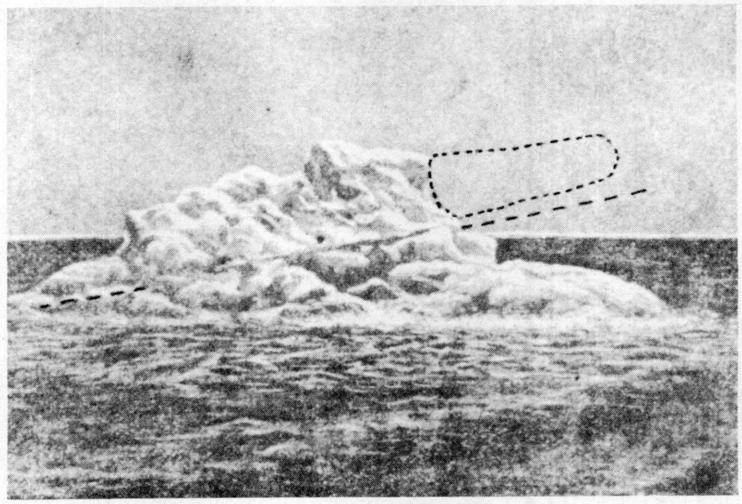


Figure 9. Destruction of the core of a hummock by the swell and shifting of its water line after breaking off of upper projecting parts

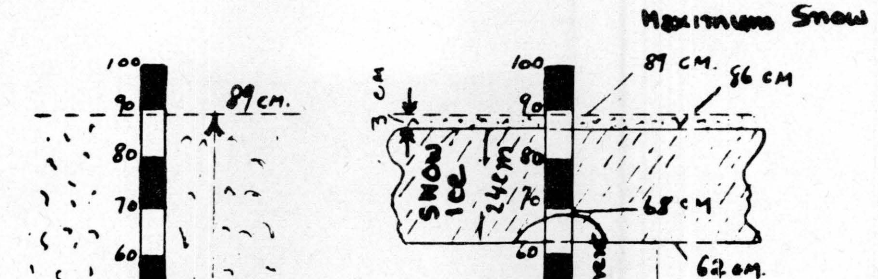


Fig. 10. Washing away of stationary ice by currents.

Figure 11. Thawing ice fragments

Figure 12. Pancake ice

Figure 13. Nilas ice

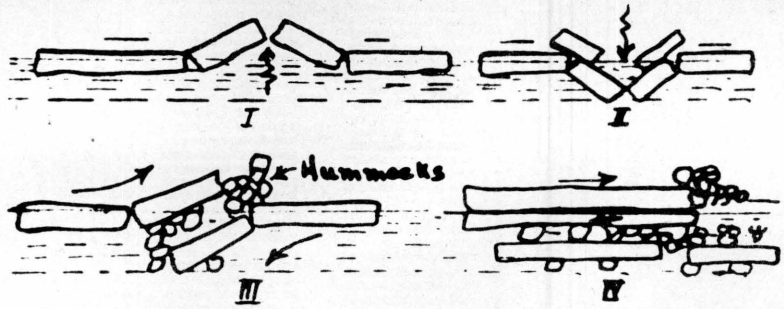


Fig. 14. The breaking of level fields in hummocking.

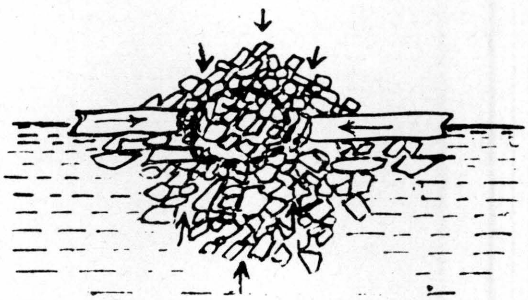
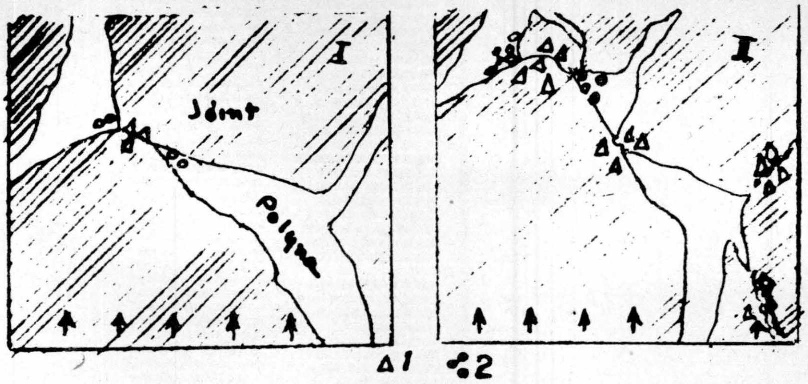
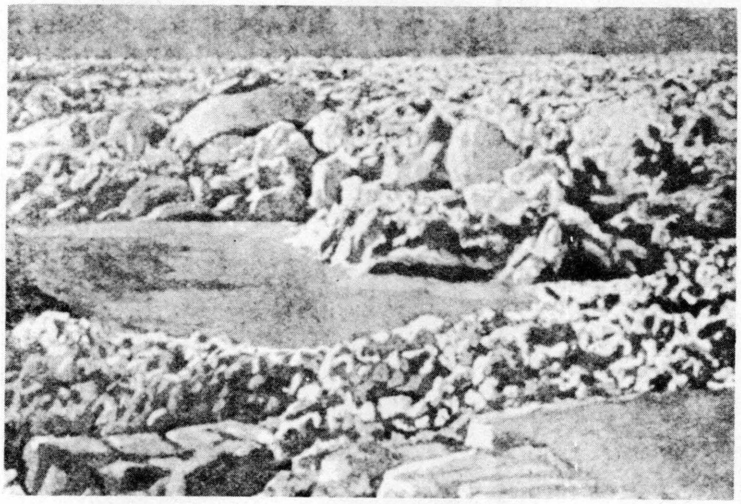


Fig. 15. Formation of a hummock & direction of forces acting on its central part.

Figure 16. Hummock formed from a level field



<u>Fig. 17.</u> Collision of level fields & formation of hummocks.
1 - hummocks; 2 - broken ice.



<u>Figure 18.</u> Smaller broken ice in compressed form - "smoroz" or hummocky field (from a summer photograph)

<u>Figure 19.</u> Broken ice floating in a "rasplava"

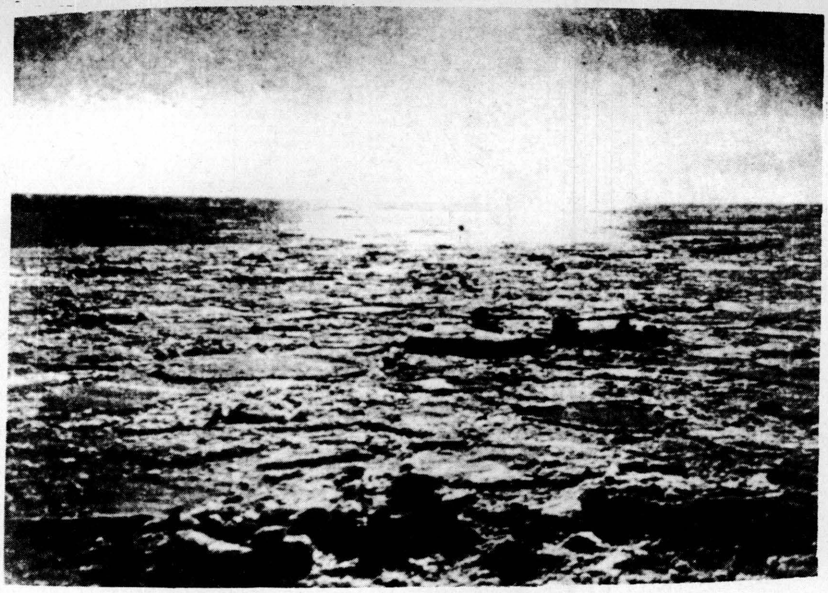


Figure 20. Smaller broken ice and crushed ice, resulting from the breaking of an ice-field by the swell.

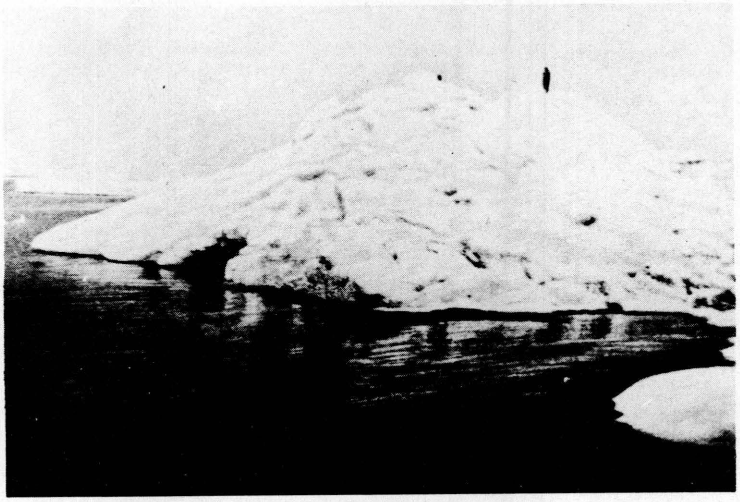


Figure 21. Ice heaped up on a shoal

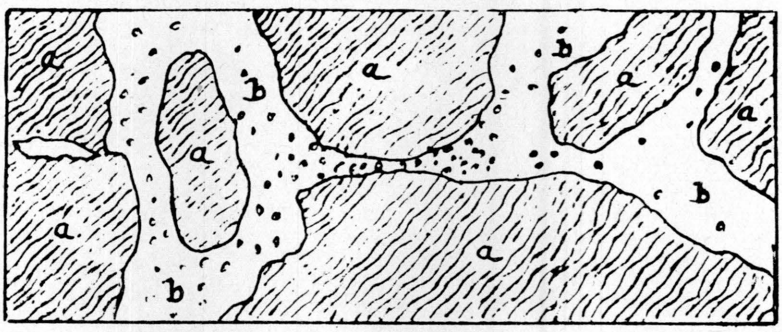
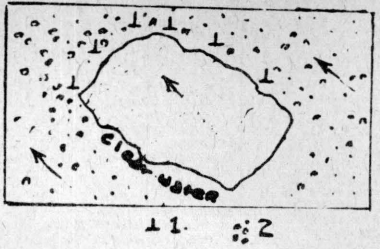
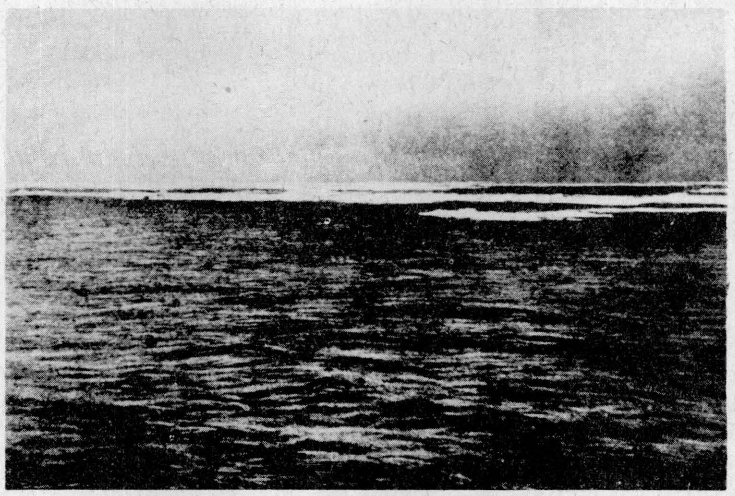


Fig. 22. S'yem sketched in plane.
a - hummocky fields; b - s'yemy with broken ice.



<u>Fig. 23.</u> Movement of a large field in the midst of broken ice. 1 - compression of ice; 2 - broken ice.

<u>Figure 24.</u> Ice strips



<u>Figure 25.</u> Ice strips

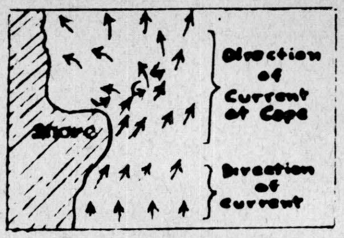


Fig. 26. Whirling of current near a promontory.

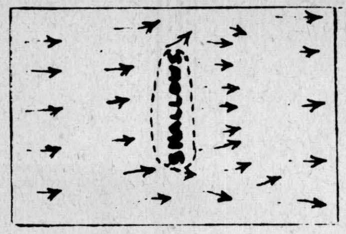


Fig. 27. Irregularity of current velocity over a bank.

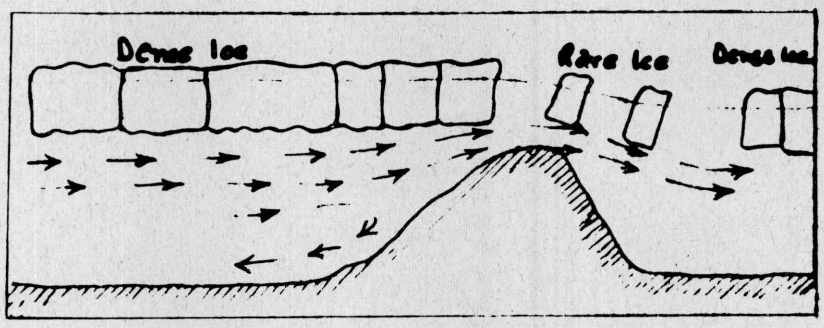


Fig. 28 Dispersal of ice over a shallow spot.

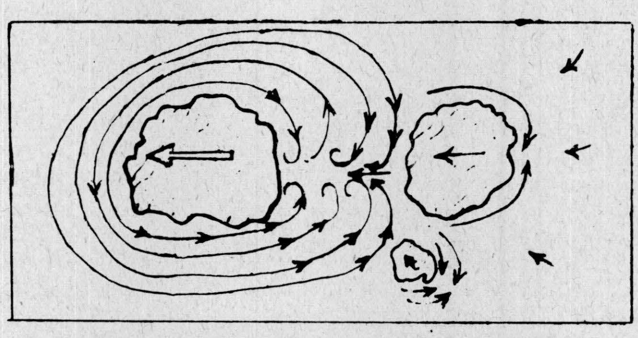


Fig. 29. Accumulations of ice behind a large ice floe driven by the wind.

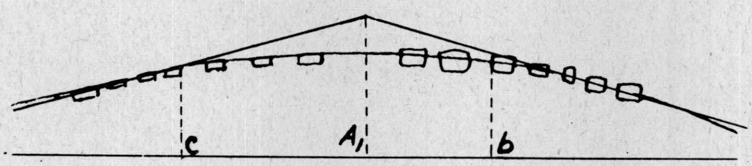


Fig. 30. The seeming increase of the density concentration of ice depending on the thickness of ice fragments.

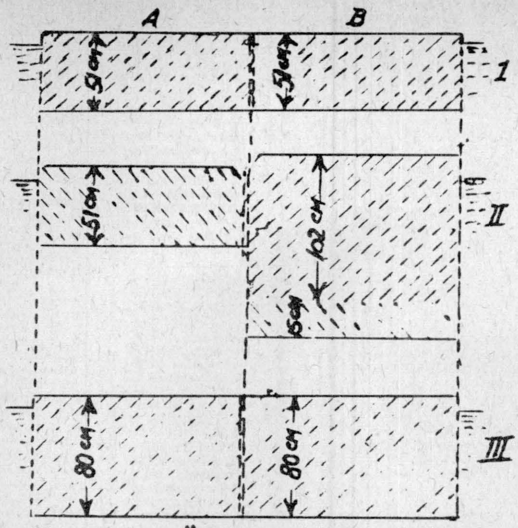


Fig. 31. "Supplementary" formation of ice.

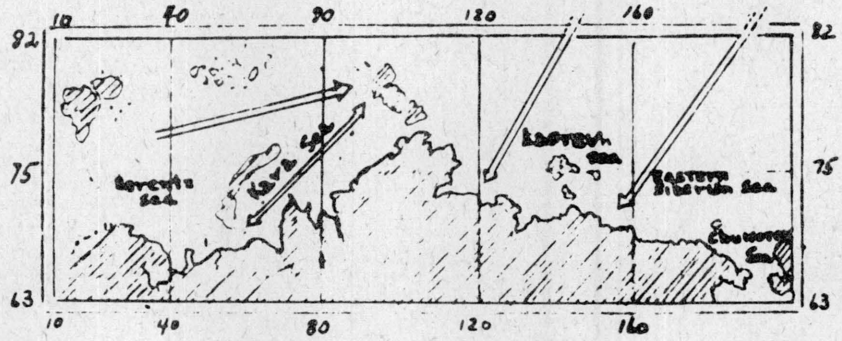


Fig. 32. Direction of the maximum wind-driven pressure of ice in North-Siberian arctic seas.

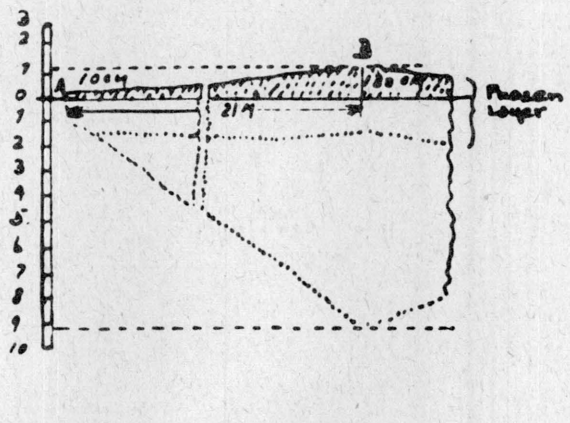


Fig. 33. Measuring of the height of the floating part of a fragment of field.

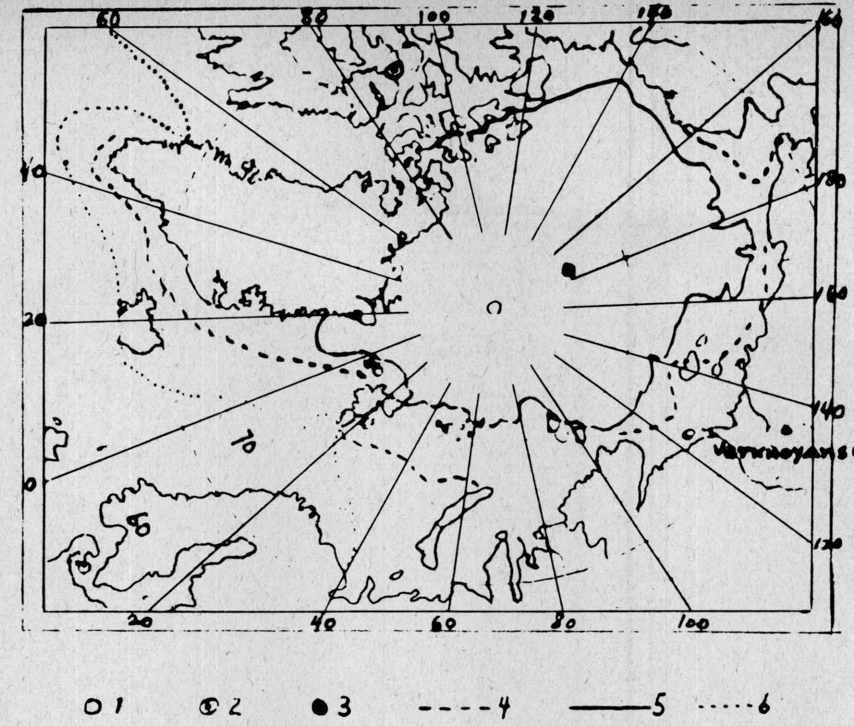


Fig. 34. Noteworthy spots in the Arctic.
1 - geographical North Pole; 2 - magnetic Pole of the Northern Hemisphere; 3 - Pole of Inaccessibility; point situated at the maximum distance from the northern extremities of the Polar Islands; 4 - average southern boundary of sea ice in August; 5 - northern boundary of sailing; 6 - extreme southern boundary of the spreading of sea ice.

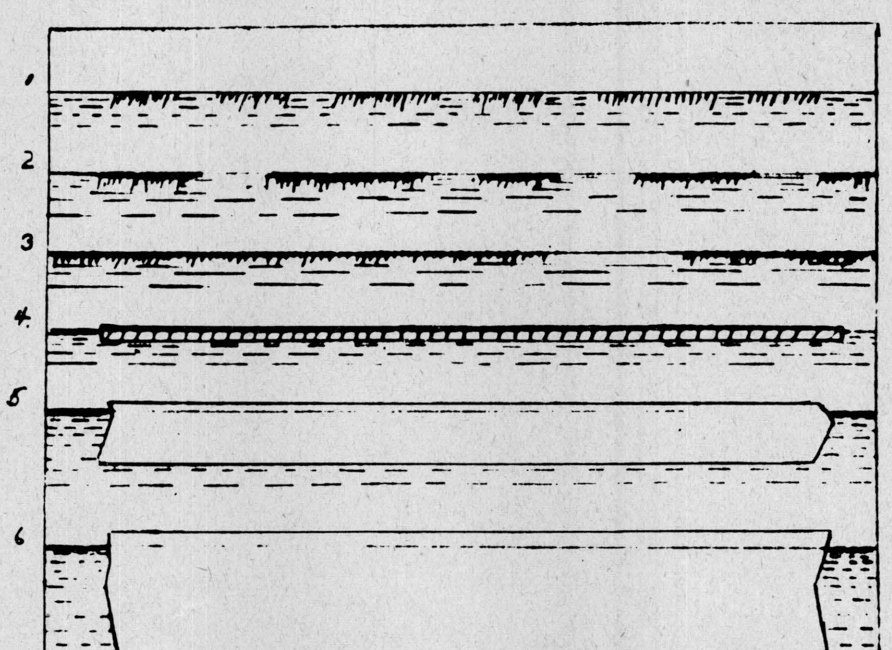


Fig. 35. Slush (1), young ice (2), dark nilas (3), light gray nilas (4), thin level ice (5), thick level ice (6).

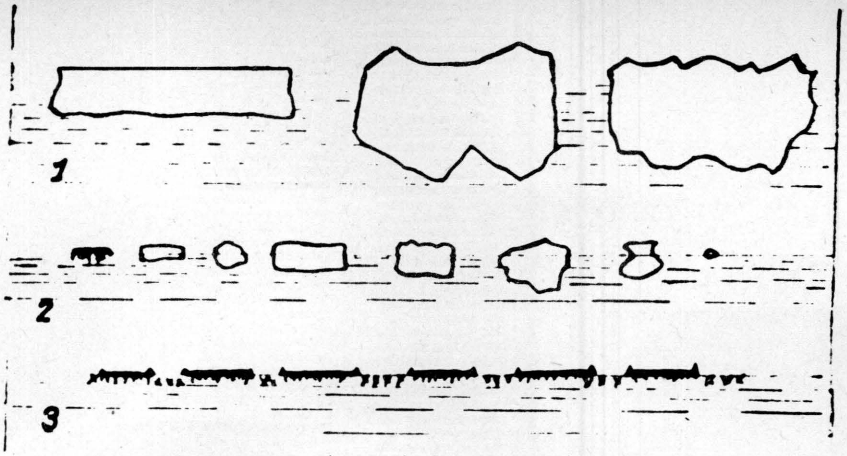


Fig. 36. Large fragments of broken ice (1), small fragments (2), pancake ice (3).

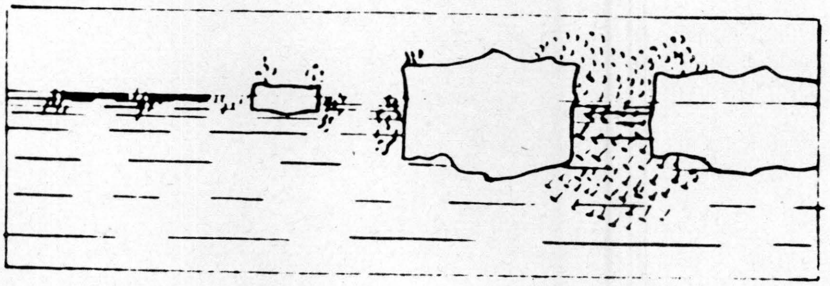


Fig. 37. Distribution of crushed ice and of ice sludge in the spaces between ice fragments.

Figure 38. Snezhura - snow sludge

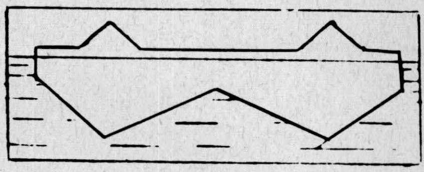


Fig. 39. Hummocky ice

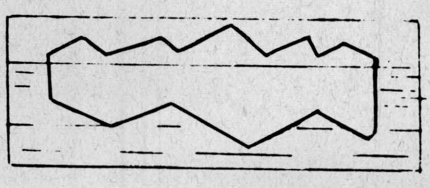


Fig. 40. Smoroz

Fig. 41. Light hummocky field.

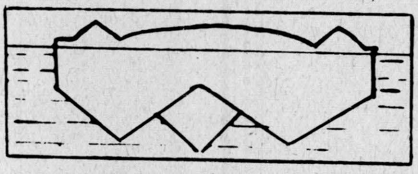


Fig. 42. Heavy hummocky field.

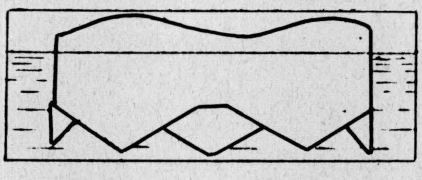


Fig. 43. The Polar Pack.

Selected excerpts from

"IN THE CENTER OF THE ARCTIC"

A book by N. N. Zubov

Leningrad (Glavsevmorput), 1940

Translated in the Stefansson Library

Foreword to

Translations From "In the Center of the Arctic"

Page references given in margin of text refer to the paging in the Russian original.

Unsigned footnotes are those of the original author; those added by Dr. Vilhjalmur Stefansson carry his name.

STATION "NORTH POLE"

As we have said, the region of the North Pole had been reached page 64 only four times prior to 1937.

The first time the visitor was Peary (April 6-7, 1909) who came afoot and spent about 30 hours at the Pole; the second was Byrd (the 9th of May, 1926) who came by airplane; the third was Amundsen in the dirigible "Norway" who crossed the Pole on his way to Alaska on May 2 of the same year; and the fourth was Nobile in the dirigible "Italia," which cruised above the Pole for about two hours on the 24th of May, 1928. Besides this, as we have seen, there were many unsuccessful attempts to penetrate into the Central Arctic basin.

These expeditions, however, were not connected with each other by any continuous investigations and they were not distinguished by systematic observations. It is therefore understandable that they added little to our scientific knowledge of the Arctic. Only those expeditions which, for one reason or another, have been conducted in the Arctic during a more or less prolonged time, have produced significant results. The expedition of Nansen on the Fram, which gave us the first real information concerning the central Arctic page 65 basin, was the only one in that category. Therefore, in spite of the four brief visits to the pole, the need to establish stations for continuous observations on the ice in the central part of the Arctic (if possible at the Pole itself) has been felt for a long time.

For instance, "The International Society for the Study of the Arctic with the Aid of Air Communication"* had even worked out a project of establishing a series of stations with the aid of a dirigible.

The first president of this society, Nansen, advocated such a drifting station enthusiastically. He considered its realization to be the chief problem of the society; and saw in it the possible solution of many problems connected with the scientific "conquest" of the Arctic.**

However, at that point there had not been considered a very important condition, namely: observations of any one of such stations would be fully valuable only when these observations were organically connected with and based upon observations of a widely developed net of polar (pripolyarnikh) geographical stations and corresponding sea and air expeditions. The importance of the above statement can be best confirmed by the following.

During the Fram expedition very careful meteorological observations were made, but in those days the radio had not been invented yet, and the meteorologists learned of these observations only several years after they had been made; i.e., after these observations already lost their interest to a large extent. Besides this, when subsequently an attempt was made to evaluate and compare Nansen's observations with those of the then existing meteorological stations

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* Most of the prime movers in this group were German but its president was the Norwegian Fridtjof Nansen. (Note by Stefansson)

** The well known polar investigator Sverdrup even made calculations as to what equipment would need to be transported to the ice at the Pole in order to make wintering and systematic observations possible there. He considered it necessary to use about 29 tons, which would require the full cargoes of two dirgibles.

— it proved to be almost impossible to do so. In those days the polar (circumpolar) stations were too isolated. One cannot judge the processes developing over a large area of the earth's surface by observations at one point. page 65 contd.

As the Soviet Arctic came to be more and more investigated and understood, more and more new problems appeared. The thoughts of the scientists turned more and more frequently to the "White spot" in the center of the Arctic. Soviet scientists have long dreamed of building a station at the North Pole. An enthusiastic supporter of this idea was Professor Weise and Hero of the Soviet Union, M. B. Vodopianov, had a firm determination to carry out the idea. page 66

Soviet flyers were learning to deal with polar spaces and dreamed of visiting the North Pole by airplane.

Our previous chapters have stated briefly how fully the coasts and seas of the Soviet Arctic had been studied by 1937, how many Soviet polar stations had been built, how many marine, air, scientific and commercial expeditions had been conducted, and to what extent a corps of trained Soviet polar workers had been developed at that time.

Thus, by 1937 all the preparations for the establishment of a meteorological and geographical station on the drifting ice floes in the central part of the Arctic had been made. The necessity was dictated not only by the need of acquiring further knowledge of the Great Northern Sea Route (The Northeast Passage), but also by the logic of continuing the study begun in 1937 of the Great Northern air route, connecting Moscow across the pole with the centers of North America -- San Francisco, Vancouver, etc. page 66 contd.

Preparations for the construction of the polar station were carried forward during a period of 1-1/2 years, and with a care and forethought which made possible the success of this unusual undertaking.

The 22nd of March, 1937, a Soviet air expedition headed by O. Y. Schmidt, and consisting of four heavy and one light planes, flew from Moscow and on the 18th of April made a landing on Rudolph Island (northernmost of the Franz Josef group).

This island was chosen not only because it is closer to the Pole than all the other Soviet islands, but because the ice cap which covers it makes a good natural aerodrome.

On the 21st of May, 1937, Vodopyanov's plane landed on an ice field at 89° 26' N. and 78° 00' W. Polar Station No. 56 of the Chief Administration of the Northern Sea Route, the station "North Pole," had thus begun its scientific works.

ON THE DRIFTING ICE FIELD

Prior to the organization of the station "North Pole" very little was known about the movement of ice in the middle polar region. It was supposed that this station would function about a year, after which it would be picked up by the same airplanes with the aid of which it was organized.

And essentially because of this station was named page 67

Actually, these expectations did not work out. The ice field on which the station was located began to move -- at first slowly, and then faster and faster -- toward the strait between Greenland and Spitsbergen (which does not have a name but which could be justly called the Papaninite strait) and into the Greenland sea.

In the following table, latitudes and longitudes for station "North Pole" are indicated as of the first of each month:

Dates	Latitude North	Longitude
1937		
~~March~~ May 21	89° 26'	78° 00' West
June 1	89° 06'	33° 00' East
July 1	88° 32'	13° 00' East
August 1	87° 53'	4° 07' West
September 1	86° 55'	2° 00' West
October 1	85° 25'	30' East
November 1	83° 55'	2° 20' East
December 1	82° 46'	5° 53' West
1938		
January 1	79° 54'	7° 18' West
February 1	74° 16'	16° 24' West
February 19	70° 47'	19° 48' West

* The four-engined planes, each with a pay load of 2-1/2 tons, left Moscow on wheels and transferred to skis en route. (Note by Stefansson.)

During its drift, which continued 274 days, the station covered in a straight line more than 2100 k.,; if all the zigzags which the ice field described are taken into account, the distance will be more than 2500 km. page 67 contd.

However carefully the expedition was organized, and however scrupulously the clothing and food had been provided, the winterers still experienced considerable difficulties during this drift. During the summer season the greatest trouble was from the melt water on the surface of the ice field and the constant dampness.*

When the frosts set in, and especially the polar night, the greatest annoyance came from the snows and storms. Most of the scientific apparatus demanded work without gloves, and in severe cold the metal parts of the apparatus would burn the hands. Often it was page 68 impossible to travel about on the ice because of strong winds; the winterers were forced to stretch a rope between the little houses scattered on the ice, in order to find the way back to the base tent in the dark or during a snow storm.

We know from the history of polar travel that the crew of the expedition vessel Hanza (following the vessel's demolition by the ice on October 22, 1869, on the (east) coast of Greenland) had lived on drifting ice for two hundred days. A well known polar explorer, Stefansson, had spent not a little time on the ice of the Arctic ocean, on the American shores during his sledge expeditions of 1914-1917.

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* Rainfall took the place of snowfall for about five weeks in midsummer. (Note by Stefansson.)

The pre-1937 record in this was established by Storkerson (of the Stefansson expedition) who spent 238 successive days on the ice pack in the Arctic Ocean, in the region north of Alaska.* page 68 contd.

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The winterers of the station "North Pole" not only lived on the ice field longer than anyone else, but they worked uninterruptedly 10 to 14 hours a day, without disturbing their regular observations during their entire stay on the ice.

Meteorological observations were made every four hours, and were transmitted over the radio to the Soviet Union. Every two hours various changes in the weather were noted. The winterers started their meteorological observations on May 21, 1937, and closed them on February 19, 1938, the day on which they were taken off the drifting ice field.

Although it was supposed that the floe, on which the station "North Pole" was maintained, would not remain in the same place, it was nevertheless considered that the drift would not be great, and that therefore the chief importance of the station would reside in its meteorological observations from the center of the polar region. Other observations, of a nature such that they are not worth while making often at the same location, had been given a relatively unimportant place in the program of the station. These suppositions,

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* On the 15th of March, 1918, the Storkerson party started out from Cross Island, located on the coast of Alaska at approximately 150° West Long., intending to spend a whole year on the Arctic ice, procuring food by hunting. Because of the illness of Storkerson himself, the party returned to the continent at the estuary of the Colville River on November 8, 1918. For the narrative by Storkerson see appendix of Stefansson's The Friendly Arctic. (Note by Stefansson)

as is now well known, proved to be incorrect. The speed of the drift of the station "North Pole" proved to be on the average two and a half times greater than expected. page 69 contd.

In fact the supposedly fixed polar station "North Pole" turned out to be a polar expedition. The ice field began to move at first very slowly, and then faster and faster. This put on the shoulders of the winterers an additional load. The observations which had been expected to be supplementary turned out to demand a great deal of work. Thus, for example, in order to determine the relief of the ocean bed sufficiently along the path of the drift, the workers had to take 33 bottom soundings, of which 14 were of a depth greater than 3 kilometers.

It would seem at first glance that these measurements of depth, the soundings, would not present any great difficulties. But if we imagine that for this purpose it was necessary in some cases to drop into the sea 4 km. of sounding line (tros) with heavy equipment (so called loto) at the end, and then to pick up (vibraty) this cable and wind it carefully on a drum, then this business will look far from simple to the reader. Every measurement of a depth more than 3000 meters demanded concentrated physical labor on the part of all four winterers for a stretch of 4 to 6 hours.

During the period of the drift 38 hydrological stations were set; each of the stations made its own determinations of temperatures and obtained specimens of water with special apparatus -- so-called bathometers -- from various strata of the sea, including the very bottom ones. Each of these hydrological stations demanded work which was not less but several times greater than in the measurement of depth. page 70 contd.

Along the whole course of the drift there were also established 22 hydrobiological stations for the collection of marine organisms inhabiting various depths of the ocean.

To the above mentioned labors of the winterers we must add the measurements of the speed and direction of the drift of the ice field itself, and of the sea currents under the polar ice -- measurements which were conducted with special instruments, so-called windmills -- vertushka.* Altogether 600 such measurements were made. Through July-September observations were made daily at the rate of 5 to 6 times a day.

With the same regularity and approximate uniformity during the entire drift, the winterers recorded the force of gravity. These observations were conducted at 22 points; at each of these points the observations were made for between 2 and 3 days and consisted of several 8-hour series.

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No less attention was paid by the winterers to the magnetic observations. During the expedition they made 55 sets of determination of the curve and the level constituting the force of earth magnetism.

Besides this 36 measurements were made of the magnetic incline.

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* The word implies spinning around, so probably of the nature of a seaman's log or of a vaned or cupped current meter such as used for stream velocity measurements. (Note by Stefansson.)

During these measurements, not merely the significance of the figures for the given moment was determined, but there were also observations made of their change in the course of a day. To this we must add 14 daily sets of measurements of the fluctuations in the magnetic pole of the earth.* In July and August, several sets of measurements were made of the gradient of potential concentration of electricity in the atmosphere.** After the onset of darkness (discontinuance of the 24-hour daylight) monthly observations were made of the polar lights.

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contd.

A geophysical or oceanographic observation has value only when it is known exactly where the observation was made. With this in view, the winterers made careful and frequent astronomical determinations of the geographic location of the drifting ice. This was all the more necessary since the drift was unpredictable in its direction and unexpectedly great in its speed.***

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*   See below, "Earth as a magnet" (Chapter III)

**   This refers to the change in electric content of the atmosphere.

*** Stefansson, among others, can testify to the correctness of the assertion frequent in this manuscript that the speed of the Papanin drift was unexpected. For one thing, there was general agreement among students that average drift speed would be small at and near the North Pole, for we had assumed they would be similar to the average drifts of ships like the Karluk, Jeannette and Fram. Then the scientists of the Arctic Institute in Leningrad had written letters to their fellow scientists abroad, among these Stefansson, asking estimates of the speed of the drift. Stefansson's reply was probably typical. He was of the opinion that it would likely be around half a mile per day right near the Pole, in the direction of Iceland, and that this speed would increase slowly with decreased distances from the open water of the North Atlantic. As the author of our present book has pointed out, such speeds were far exceeded by the actual drift of the floe that contained the Papanin establishment. (Note by Stefansson)

Altogether during the expedition 534 measurements of the height of sun and stars were taken, and 374 directions were measured for the determination of the orientation of the ice field in relation to the meridian. This made it possible to obtain about 150 precise geographic controls for the drifting field. Besides this, careful log (vertushechniye) measurements of speed and direction of the drift of the field allowed a calculation with limited accuracy of the drift of the ice in the intervals between points of astronomical determination.

It is notable that all the observations of the winterers were performed by instruments that were made from Soviet materials, by Soviet workers and in Soviet shops. All this "armament" functioned the entire time smoothly (bezukorizneno) without interruption (bezpereboyno) and without failure, under very difficult conditions.*

Even from this dry and brief enumeration, we can see what a tremendous quantity of scientific material the winterers brought back with them to the Soviet Union. This material is all the more valuable because the workers during the drift of the floe not only collected and wrote down all the data, but in part worked out the preliminary calculations.

In quantity of collected material the expedition surpassed all

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* This comment is less gratuitous than it may seem. For instance, the third Stefansson expedition carried many scientific instruments that were made in Germany and some made in France, with the rest mainly British. It would not have been easy at that time (1913) to equip an expedition satisfactorily with scientific instruments made in the United States. (Note by Stefansson.)

polar expeditions of previous times, including the famous expedition of Nansen; although in the "Fram" expedition 12 men took part for three years, while the station "North Pole" consisted of only 4 men and lasted only 9 months. page 72 contd.

On February 19, 1938, station "North Pole" ceased its remarkable investigations and the Papaninites, together with their instruments and the priceless notes of their observations, were taken aboard the icebreakers Taimyr and Murman when they reached the drifting floe. In fact, however, that day was not the end of this rare expedition, for the party still had a tremendous labor ahead of them to complete their writing and calculations and to publish the collected material. When this is done, the Soviet explorers will have another problem: to correlate their observations with those of many previous expeditions and with the observations of the Soviet Union's polar* coastal stations.

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* The term "polar station" has acquired in the Soviet Union a technical or special meaning. It refers to a research station similar to that which the Danes have long maintained at Disko Island on the west coast of Greenland, where scientists are quartered for one or several years, with replacements when any scientist leaves. These establishments are sometimes referred to, in non-Soviet publications, as meteorological stations, and that is correct to the extent that meteorology and radio are always included. However, "reserarch station" or "scientific station" would be a better translation, for it is seldom that activities are confined to weather observations and weather reporting. The establishments vary in size, some of them containing representatives of half a dozen sciences such as botany, marine biology, economic geology, parasitology. A few of the stations are so large that they have separate hospitals and schools. One of them, Rudolf Island, northernmost of the Franz Josef group, had in 1937 seven airplanes of its own, in addition to those which came and went. (This last is according to the verbal statement of Valeri Chkalov to Stefansson when Chkalov visited New York at the completion of his flight from Moscow by way of the North Pole to Vancouver, Washington.) (Note by Stefansson.)

Even the preliminary results of the observations indicate results of value. The expedition established the fact that in the region of the North Pole there are not nor can be any islands; the bottom relief along the entire drift has been revealed in detail; it was established that warm Atlantic waters penetrate by deep currents from the Greenland sea right to the very pole; and that in the deep basin the Arctic ocean the temperature of the water rises because of the internal warmth of the earth; the ideas of Nansen and others concerning complete lifelessness of the central polar region have been disproved; for the first time a study was made of how the wind moves water masses in a cold layer of polar waters of 200 meter thickness, which layer is superimposed upon warm Atlantic waters. Valuable gravimetric and magnetic results have been obtained. The meteorological observations of the Papaninites destroyed previous ideas of the structure and circulation of the atmosphere in the central polar region.

But the greatest practical and theoretical significance is in the observations of the drift and behavior of the ice in the central Arctic: the very fact that the Papaninites, after 9 months, found themselves south of 71° N. Lat. (contrary to their expectation, that they would be spending a year in high latitudes) proves how erroneous were our ideas concerning the movement of ice in the central part of the Arctic basin. It is interesting to note the correlation between the drift of the ice and the wind which caused the drift. No less interesting are the observations of the fate of the ice fields which were formed in the central Arctic and were carried out through the "Papaninite Strait" into the Greenland sea.

(Here a chapter "Transarctic Flights," is omitted, for it does not contribute materially to the elucidation of the problems dealt with in our report.)

DRIFT OF THE ICEBREAKER SEDOV*

In contrast with the drift of the Fram, and the drift of the station "North Pole," the drift of the Sedov was not planned or deliberately organized. page 79

October 23, 1937, together with the Icebreakers Sadko and Nalygin, the icebreaker Sedov was beset by the ice of the Laptev Sea at 75° 19' N. Lat. and 132° 25' E. Long. Thence it was carried off by the ice drift.

In April, 1938, when the drifting icebreakers were between 79° and 80° N. Lat. three planes flew to them, directed by Heroes** of the Soviet Union Alekseyev and Golovina and the flyer Orlov and took back with them to the mainland 184 men from the vessels' crews. So these flights proved over again the high quality of our planes and the skill of our flyers; they proved that the successes of Soviet polar aviation are not an accidental matter, but constitutes an active knowledge that can be relied upon.

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* Was named in honor of the first Russian who strove to reach the North Pole, it was built in England in 1909 for Canada and subsequently acquired by the Russian Government. The length of the ship is 77 m., its width 11 m.; its draft 5 to 6 m.; engine 2860 horsepower; speed, about 12 knots; capacity, 1,600 tons.

** In Soviet honorific usage the word Hero does not connote great heroism so much as distinguished leadership. For instance, the order Hero of Socialist Labor does not indicate bravery as a worker or leader of workers so much as ability and success in relation to industry. (Note by Stefansson.)

On August 28, 1938, there was a caravan of drifting vessels at 83° 06' N. Lat. and 138° 24' E. Long. On this day the icebreaker Yermak led the Sadko and the Malygin out of the ice into the open sea. The Sedov, however, had suffered serious damage in its rudder construction (rulevogo upstroystva) during the winter, so it was impossible to free her from her ice imprisonment. So 15 voluntary winterers, headed by Captain Badigin, remained on the Sedov. And from then on the ship, which has now become historic, continued its amazing drift in the less accessible part of the Arctic ocean. page 79 contd.

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Certain circumstances of this drift give it a special theoretical and practical interest. First of all, it started while the drift of the station "North Pole" was still in progress. So, through the drift of the Sedov it is possible to study as an uninterrupted observation the movement of ice in the central Arctic during a period of almost three years. Then, soon after the Sedov drift started, the drift of the icebreaker Lenin commenced in the same Laptev Sea, to end on August 7, 1938. Thus, during a period of 9 months two vessels drifted simultaneously at some distance from each other: one in the southwestern part of the Laptev Sea, the other in the northeastern part of the same sea and in the region north of the Novosibirsk islands. Correlation of these two drifts gave important results. Differing from each other only in details, these simultaneous drifts reveal amazing similarity, which shows that they were accomplished not under the influence of accidental factors but under conditions that are general (characteristic) for that region. These general factors were the dominant winds and the constant currents. page 80 contd.

The third point of interest is that soon after the Sedov drift page 82 started, the ship found herself in the same region where the Fram had begun its drift. She drifted in general on a course approximately parallel to that of the Fram, though considerably more northerly.

Comparision of the Sedov drift with that of the Lenin, and with the drift of the station "North Pole", and finally a comparison of the Sedov drift with the drift of the Fram has special theoretical and practical value. Besides, the comparison between the drifts of the Sedov and Fram has a particular interest because, as we know, the drift of the Fram occurred under climatic conditions considerably different from those we now have in the Arctic. As has been proven, the atmosphere and hydrosphere of the Arctic are now considerably warmer than they were in the time of Nansen.*

The drift of the Sedov was first straight north, at approximately 133° E. Long. After a month, when the ship neared parallel 78, the drift turned east; on the 2nd of March, 1938, the Sedov was at 78° 25' N. Lat. and 153° 26' E. Long. This point proved to be the most easterly reached by the Sedov. From then on, she began to move slowly west, heading at the same time northward.

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* Zubov wrote this in 1940, at which time Soviet writers were emphasizing, and many scientists in other countries were believing, that there really was a progressive change in Arctic climate towards warmth of both air and water. Now (1947) Soviet writers are generally commenting that we are probably dealing here with a short cycle, rather than with a "permanent" change (long cycle). (Note by Stefansson).

On the 18th of February, 1939, the Sedov was at 85° 56.7' North and 119° 59' East. On this day, she broke the record established by the Fram for the highest latitude reached by a vessel drifting with the ice. (Forty-four years before this -- November 15, 1895 -- the Fram had reached 85° 55.5' N. Lat. and 66° 31' E. Long.) page 82 contd.

After this, the Sedov continued drifting generally, in a north-westerly direction; on March 22, 1939, she reached 86° 34.7' N. Lat. and 108° 50' E. Long. Further on, she began to incline gradually southwest. From the 17th of May to the 27th of July, 1939, the paths of the Sedov and the Fram become, in a manner, overlapping; after that the Sedov begins rapidly to ascend north, and on the 29th of August, she reaches the most northerly point of her drift -- 86° 39.5' N. Lat. and 47° 55' E. Long.

Farther on, the drift of the Sedov again crossed that of the Fram and then, describing a series of zigzags, proceeded between the drifts of the station "North Pole" and the ship Fram towards the wide strait dividing Greenland from Spitsbergen.

From the 4th of September to the 20th of October, 1939, the Sedov having moved southwest, was approximately at the same latitudes where two years before on the same days the station "North Pole" had been. From the 20th of October, the Sedov begins to fall back in latitude from the "North Pole" position. On the first of December, she is at 83° 46' N. Lat. and 7° 19' E. Long. (The station "North Pole" on the 1st of December 1937 was at 82° 46' N. Lat. and 5° 55' W. Long.) In 40 days, the Sedov fell back in latitude from the station "North Pole" a distance of 60 sea miles, or 111 km. page 84

The first of January, 1940, the Sedov was at 81° 15.4' N. Lat. and 4° 16' E. Long.; on January 13 she was at 80° 46' N. Lat. and 2° 30' E. Long. Then the flagship of the Soviet icebreaker fleet, the Josef Stalin, came along and helped the Sedov to get out of the ice. Thus ended the magnificant drift, which enriched science with new information about the central Arctic basin. page 84 contd.

In the following table latitudes and longitudes for the first of each month are given:

DRIFT OF THE SEDOV

Date	Latitude North	Longitude
1937		
October 23	75° 21'	132° 15'
November 1	76 19	131 18
December 1	77 39	135 51
1938		
January 1	78° 24.3'	141° 44'
February 1	77 55.5	151 14.5
March 1	78 31.5	153 03.5*
April 1	79 07.2	151 35.3
May 1	80 03	147 12
June 1	80 56	143 09.3
July 1	81 17	137 57
August 1	81 51	135 53.5
September 1	83 11	137 35
October 1	84 19	137 15
November 1	84 35	131 01
December 1	85 29	123 48
1939		
January 1	84° 44'	129° 10'
February 1	85 33	123 14
March 1	86 20	117 03
April 1	86 16	107 25
May 1	86 22	81 40
June 1	85 25	78 30
July 1	85 25	63 05
August 1	85 55.5	57 05
September 1	86 37	45 05
October 1	85 17.5	30 30
November 1	84 38.5	19 15
December 1	83 46	7 19
1940		
January 1	81° 15.4'	4° 16'
February 13	80 46	2 30

* Coordinates of the most easterly point of the drift on the 2nd of March, 1938, were 78° 23.7' N. Lat. and 153° 26' E. Long.

Two basic problems were facing the crew of the Sedov -- to preserve their ship for the Soviet icebreaker fleet and to make a maximum use of the conditions of the drift for conducting fuller and more exact scientific observations. page 84 contd.

The first problem was not easy. The Fram had been specially constructed for drifting in the Arctic Sea pack. The Sedov was built for working the coasts of Newfoundland and the Gulf of St. Lawrence, where there is neither heavy ice nor crushing pressure. page 86

Taking into account the experience of their first winter, the Sedov men gave special attention to the preservation of their ship. First of all, insofar as it was within their power and insofar as the ship's materials allowed it, they added to the strength of the ship's hull. Second, and more important, they worked out a special technique for combating the pressure of ice with explosives. In winter when the ice pressures are most dangerous, they always had ready on board a load of ammonal explosive and roundabout the ship there were previously prepared crescent-shaped holes in the ice (lunki).* These ammonal explosions were intended for destroying the sharp angles of the ice cakes that pressed (poked) into the side of the ship, and for the formation around the ship of a cushion of ice chips which would distribute the pressure of the oncoming ice.

The Sedov's men experienced 153 ice squeezes, some of which were

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* The meaning seems to be that holes were dug in the ice to be ready to receive explosive charges.

so serious that the crew started preparing to abandon ship. On one occasion the ship keeled over 30 degrees, water gushed into the ship through openings. Only the dogged work of the mechanics saved the vessel from disaster. page 86 contd.

The Sedov party faced another difficulty. After the winter 1937-38 the Sedov not only lost the ability to move under her own power, but also the ability to follow in tow of another ship. This damage had to be repaired. The Sedov men managed to solve this problem also. So when the icebreaker J. Stalin reached her (Jan. 13, 1940), the Sedov first took a tow and later was able to reach the harbor of Barentsburg under her own power, there to stay until she could be coaled. The further journey from Barentsburg to Murmansk was made by the Sedov in tow; in Murmansk she was able to enter the harbor. This shows that the Sedov crew solved adequately the problem of preserving the ship, and in good order at that.

The Sedov crew had the further problem, to make use of the drift for conducting scientific investigations. In this respect, they had before them the admirable example of how the Papaninites had accomplished much good work under difficult Arctic conditions.

Like the Papaninites, the Sedov's men conducted singularly concentrated scientific work with an approximately the same program and the same instruments as those of the station "North Pole."

All together during its independent drift (from September 1, 1938, to January 13, 1940) they made 415 astronomical determinations of the location of the vessel; they measured 37 oceanic depths, obtaining at the same time specimens of the bottom; established 43 hydrological stations, accompanying some of them with di- page 87 rect measurements of the elements of sea currents; they made collections of plankton. Besides this, they measured the thickness of the ice of various ages every 10 days. They measured the elements of the earth's magnetism at 78 points, and conducted serial observations giving a picture of the change in these elements during the 24 hours -- at 11 separate points. They determined the force of gravity at 66 points. They gave their greatest attention to the recording of meteorological observations, which they conducted regularly every two hours. Four times a day they sent information over the radio to the Soviet Union. page 87 contd.

The value of the Sedov observations is great, for since Nansen's time they were the first to spend over two years in the central Arctic, along a course where prior to the Sedov not a single ship had drifted, where not a single plane had flown. In the following table can be seen the number of days in the drifts of the Fram, the station "North Pole," and the Sedov at high latitudes.

Number of Days Spent in Drift North from Indicated Latitude

Expedition:	Fram	"North Pole"	Sedov
General number of drift days:	1055	274	812
Among them north			
of 89°	--	14	--
88°	--	77	--
87°	--	102	--
86°	--	123	131
85°	121	146	289
84°	428	166	398
83°	539	192	422

From this table we see how clearly how interesting the Sedov observations were; for they were 85° N. two times longer than the station "North Pole," and two and a half time longer than the Fram. page 87

Some of the observations had great difficulties for the Sedov's men. Since the vessel was not prepared for work at great oceanic depths, she did not have a special capstan and special equipment for measurements of a great depth. Therefore, during the drift itself, the men constructed with their own power on electric winch (v'yushka), and besides this, they spliced strong stout wire that was on the ship into separate sounding lines to a total of over 14 kilometers. Carrying on this sort of work at thirty Centigrade degrees below zero temperature is a task requiring the most dogged peristence. page 88

Only three polar expeditions (the Fram, the station "North Pole" and the Sedov) have so far coperated to open to us the hydrometeorlogical regimen of the central Arctic. But it would not be right to think any of them as duplicating any other. Each of the three expeditions is unique in its own way; the observations of each of them are priceless; they all complement each other beautifully.

The Fram and the station "North Pole" were special scientific expeditions, specially organized for the study of the central Arctic. The Sedov expedition became a scientific one only by accident.

There were no professional scientists in the Sedov crew. Excepting B. H. Buynitzky, a student of the Hydrographic Institute, the rest of the Sedov men were ordinary seamen. But they all understood perfectly that the most reliable beacon in navigating the Northern Sea Route is knowledge, and they did everything in their power to see to it that this beacon would shed as bright light as possible on the Soviet polar workers. page 88 contd.

For a period of two years, these seamen " wrote down what they had observed and did not write down what they had not observed" in a very exact and painstaking manner. Their work, based on that of the whole remarkable collective of polar workers, which was nurtured by the great Stalin, has already born fruit. Doubtless, the results will be multiplied when all the material that the Sedov men accumulated is gone over.

In Russian history there are some names of sailor-explorers, of whom we can be justly proud. To these names belong: Lt. Hariton Laptev and Lt. Dmitry Laptev, Maligin, Pronchishchev, pilots Minin and Sterlegov, ensign (praporshchik) Pakhtusov, Lt. Litke, adm. Markarov, senior Lt. Sedov and many others. But these able and daring explorers of the past worked singly and often without any support. Everybody knows of the tragic fate of the seaman-explorer Georgy Sedov, in w hose honor the icebreaker, which now completed its drift, was named.

The work of the Papaninites and the Sedovites was done under entirely different conditions. The party and the government protected with tireless care the participants of these heroic drifts (see Fig. 7) throughout. The whole country followed with greatest attention the course of the drifts, because the Papaninites and Sedovites have once more shown to the whole world what capacity page 89-165

there is even in small collectives of Soviet people when they can depend on the powerful multi-millian collective, the name of which is the Union of Soviet Socialist Republics.

page 89-165 contd.

(Here we omit several chapters because their subject matter is not pertinent to our report.)

SEA ICE

The (drifting) ice cover of the seas in the northern hemi- page 166
sphere, at the time of its highest development, takes up a tremendous area — about 12 million square kilometers. Every year, during the summer season, the general quantity of ice diminishes by approximately a third. The area of ice in the central part of the Arctic Ocean, i.e. in the deep basin which is enclosed between the extreme northern islands of Europe, Asia and America, takes up an area of about 5 million square kilometers. This area is never free of ice.

The ice in the sea is differentiated sharply according to its origin into river ice, glacier ice and sea ice.

The river ice is carried out during the spring period of ice movement (ledokhoda) by the rivers which fall into the Arctic Ocean. It is distinguished by its reddish-brown color, its muddiness, and is found only at the very estuaries of the rivers. The river ice melts during the polar summer and really has no significance in the regimen of the ice in the Arctic basin.

Glacier ice, drifting in the shape of icebergs, is formed as a result of the breaking up of glaciers moving down from the land into the sea.

The basic mass of ice in the Arctic Ocean is composed of whitish-greenish sea ice which is formed from the sea water itself.

The most amazing property of sea ice is its salt content, which is approximately four times less than the water from which it originated.

Another remarkable property of sea ice is its gradual freshening in the course of time till in the end it becomes suitable for consumption. These properties of sea ice are explained by its structure. page 166 contd.

Ice formation in the sea begins with the appearance of thin ice needles — crystals of pure ice woven into a curious net. In the course of time these crystals become enlarged, retaining their purity, page 167 and the salt solution and the various mixtures of organic and inorganic origin, as well as air bubbles which are found in the sea water, become concentrated in the spaces between the crystals. In this manner, the sea ice after its formation consists of crystals of pure ice between which there are cells with salt solution and bubbles of air.

The changes in the temperature of sea ice during its life span, either one way or the other, are followed by changes in the size of the cells that contain the salt solution. Thus, when the temperature is lowered, the formation of additional ice crystals is followed by increase in dimension and consequent bursting, formation of tiny cracks along which the salt solution from the cells gradually runs down, which causes the freshening of the ice. It is noted that saltiness of the new ice is greater as the temperature of the air is lower, which makes the formation proceed faster. Under very low air temperatures the salt solution not only does not have time to run down, but even becomes squeezed out onto the top surface of the ice. Thus, the ice surface which was formed under very low temperatures always seems somewhat moist from the salt solution. Under still lower temperatures the surface of the sea becomes covered with remarkably beautiful so-called "ice flowers." These "ice flowers" consist of the thinnest crystals of ice, the tips of which are encrusted, as it were, with salt crystals. This phenomenon is so characteristic that many explorers can tell of the great handicapping of sledge travel by young ice which was formed during low temperatures. The impression is that the sledge will not glide on the ice but grinds along as if it were on sand. page 167 contd.

Ice formation in the sea does not always begin on its surface. If the waters of a sufficiently chilled sea become churned up by wind, by waves, or by strong currents, then the initial formation of the ice may take place in the body of the water or at the very bottom.* The particles of ice which are formed at a depth do not at once come up to the surface of the sea, but are carried from place to place by the same forces which caused their formation. Further on the particles of depth ice, consisting of distinctly round disc with mirror-like sides, freeze together as they unite, become thus enlarged and finally rise to the surface of the sea.** page 168

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* Formation of such bottom ice had been repeatedly observed in the sea of Azov.

** In the history of navigation there are incidents when in the beginning of the winter in the Baltic, sailors found themselves surrounded with ice on all sides which had suddenly floated up from the bottom. It is also known that the bottom ice at the rocky shores of Greenland, Labrador and Spitsbergen often lift up with them chunks of stone and soil. In Newfoundland, bottom ice is encountered at depths of 20-30 meters. At the shores of Labrador, one time a box with instruments was brought up by the bottom ice upon the surface of the sea. This box proved to belong to a vessel which had been lost many years before in Hudson Strait, several hundred kilometers north from where it was found.

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contd.

Formation of depth ice and also of bottom ice in the sea requires, as in rivers, low temperatures of air, strong churning of the waters by currents and winds and an absence of ice on the surface of the sea. As soon as the surface of the sea becomes covered over with ice that had formed on the surface, or with bottom ice that had come up to the top, formation of depth ice and bottom ice in most cases ceases.

Sometimes the initial crust of ice on the sea is formed by snow falling on the surface of the water. Such ice has peculiar characteristics in its structure, is distinguished by its white color, and goes by a special name -- snowy ice (snezhura).

As we have seen under calm conditions of the sea, and absence of wind on the surface of the sea, tiny crystals in the shape of needles appear. These first formations gradually develop, coalesce and form on the surface of the sea which in appearance resemble congealing fat and are called ice fat. Ice fat is usually of dark lead color, not much different from water in cloudy weather. In form it resembles finely crushed ice.

A sea which is covered with ice fat creates a curious impression. The sea water seems heavy, it appears to behave like mercury. Since ice formation is usually begun not with uniformity over a whole area, but in separate, more or less infrequent spots, the surface of a sea which is covered with ice fat appears like watered silk (moire).

With further cooling and calm condition of the sea, the entire surface becomes covered with a thin sparkling crust of ice which is called sklyanka -- sand-glass or watch-glass. When a ship goes through this glass-ice a characteristic noise can be heard, which is produced by breaking ice chips and their scattering over the surface of the ice. page 168 contd.

Initial formation of ice under a slightly disturbed condition of the sea is quite different. It starts out as if from many centers, and almost perfectly circular discs measuring 30-50 cm are formed. A characteristic of these discs is their border of little nodules which result from friction between the discs. These raised edges make the discs look like flat frying pans. Such ice is called, in all languages, pancake ice or plate ice. page 169

The edges are higher above the water than the discs themselves, and their color is therefore whiter. A sea covered with young pancake ice looks as if it were covered with a white net.

After the surface of the sea is covered with a thin layer, further growth in the vertical dimensions of the ice is the more rapid the lower the temperature of the air, and is the more retarded the greater the thickness of the formed ice. It is considered that under average conditions of the Arctic Ocean the thickness of the ice which is formed by natural growth from below for a period of a year does not exceed 2 to 3 meters. Great thickness of ice may result from the piling up of separate ice bodies, one upon the other.

So polar workers classify the ice floes into those made by growth and those made by piling.

In relation to its origin and its distribution sea ice is divided into shore ice, drifting ice and pack ice. During winter in the Arctic basin, the shore ice takes up 15-20% of the entire ice area. Drifting ice (not a permanent element of the pack) constitutes approximately 10 to 15%. About 70% of the total ice consists of pack ice, also constantly moving, filling the central part of the Arctic basin and being bordered on the periphery first by drift ice and still closer to shore -- in the wintertime -- by shore ice. page 169 contd.

Shore ice represents immobile ice which is formed in the winter time along the shores and attains towards the end of winter a thickness of about 2 meters. In the summer time shore ice thaws out in places in places it breaks up and is carried out to sea.

It is estimated that in the winterime, shore ice extends from the land to where the sea attains a 25-meter depth.* Shore ice achieves its greatest width at the shores of Siberia, on the meridian of the river Yana, where it extends almost 400 km. north from the shore. This is explained by the shallowness of the adjacent region and by the presence of a large number of islands. page 170

Drifting ice, as its name indicates, is found in constant movement, becoming partly destroyed during the summer, and partly surviving the summer and again freezing into newly formed ice.

Among the drift ice there is ice of varied origin and of varied form and varied age. It is estimated that the region of distribution of drift ice is bordered (or limited) on one side by the 25-meter depths (within which, towards land, there is shore ice in the winter time); on the other side it has the boundary line between the shallow

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* This does not necessarily conflict with statements made by Peary, Stefansson and others that sea ice has a maximum grounding depth of 20 fathoms, for they add that such ice may go adrift with a combined high tide and strong wind. (Note by Stefansson).

and deep sea (the line of the continental shelf).

Pack ice represents the farthest developed form of sea ice. It consists mainly of large fields of relatively even ice having a thickness of 3 to 5 meters, having piles of ice around the edges, and cut across in some places by hillocks of 8 to 10 meters in height. These hillocks are a result of piling up of ice under pressure. In certain separate regions the pack ice is a chaotic mass of erected blocks (or slabs) piled on top of each other. In their distribution there can be detected no order whatsoever.

Several processes are required for the formation of pack ice, which is characterized by monolithic structure and an absence of foreign mixtures (absence of salt-solution cells and air bubbles). First is required a natural thickening of the ice; second, a thickening of the ice by a piling of one ice chunk upon another; third, a change in the structure of the ice caused by periodic changes in temperature; fourth, solidification of the ice by periodic compressure; and, fifth, a leveling off of the surface of the ice.

The last process begins when the ice has attained such thickness and solidity (strength) that further disturbance (roughening by pressure breakage) becomes difficult. Winter storms, blowing the snow from place to place, gradually fill up the various depressions on the surface of the sea ice. The polar sun of summer, rising comparatively low above the horizon, acts almost exclusively upon the various protrusions from the surface of the ice, thawing and leveling them off.

Pack ice (such as here described) is impenetrable to any type of vessel.

Although patches of clear water between separate fields of pack ice are insignificant (even in the fall they constitute not more then 1% or 2% of the entire area)* they nevertheless allow for a certain amount of movement of the fields even in winter. It is not difficult, for example, to compute that the mass of the ice field on which the station "North Pole" was located, was approximately 10 million tons. It is understandable that if such a field, under the influence of wind or currents, attains a certain speed and then bumps against a shore (or against another ice field, either stationary or moving with a somewhat different speed) then the ice breaks at the points of contact, no matter how strong it is, and causes tremendous crushing (i. e., the formation of a pressure ridge or ridges.)

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Badigin describes a winter crushing: "It is difficult to describe the accompanying sounds: they are now a wailing of the wind, now a monotonous hum of a motor, now a groan of some unkown beast, and now the noise of a sea tide."

In contrast, all the observers have been astonished by the quiet that prevails during a summer breaking up of ice which is in most cases more impressive to the eye than the same process in winter. Enormous monolithic ice breaks off, rears up, and fall, producing

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* Stefansson thinks this may be an underestimate.

no noise even when there is no wind.*

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* These descriptions by Badigin and Zubov illustrate, by their contrast with others, that observers are liable to generalize from too few instances. We quote from Stefansson's THE FRIENDLY ARTIC, pages 19-20, where he quotes other observers and then gives his own experience:

"In the far North not only is the ground continually cracking when the temperature is changing and especially when it is dropping, but near the sea at least there is, not always but on occasion, a continuous and to those in exposed situations a terrifying noise. When the ice is being piled against a polar coast there is a high-pitched screeching as one cake slides over the other, like the thousand-times magnified creaking of a rusty hinge. There is the crashing when cakes as big as a church wall, after being tilted on edge, finally pass beyond their equilibrium and topple down upon the ice; and when extensive floes, perhaps six or more feet in thickness, gradually bend under the resistless pressure of the pack until they buckle up and snap, there is a groaning as of supergiants in torment and a booming which at a distance of a mile or two sounds like a cannonade.

"The eternal polar silence, "writes the poet in his London attic. But Shackleton's men, as quoted in his book "South,' now and again commence their diary entries with the words "din, Din, DIN,' Robert Service some distance south of the artic circle in a small house in the city of Dawson, wrote much of the arctic silence. But we of the far north never forget the boom and screech and roar of the polar pack."

Badigin, Zubov, Nansen, Stefansson and others who have described the noise of winter crushing, do not really contradict each other but instead describe, each as accurately as he can, what each has seen and heard. A good over-all description will have to be a composite of numerous reports from varied experiences.

As for the complete silence of summer crushing described by Zubov: The explanation probably is that his observations were made from the deck of a ship where there were many noises, among them those of engines and of men. Stefansson has had similar chances of observation from a steamship deck and would insofar agree with Zubov; but he has also had chances of observation from rowboats temporarily idle, from becalmed sailing ships, from drifting floes, and from shore. He agrees that in many cases there can be a considerable amount of ice crushing, and the tumbling of great blocks, without noise that carries to any great distance. But he has also found at time that there is a variety of noises, among them splashes, thumps, and even explosive booms like the muffled sound of a remote gunshot or a dynamite explosion. He has noticed these sounds chiefly in fogs, which probably is for a reason analogous to the well-known fact that a blind man hears more than one who has good eyesight, which is not because the blind man's ears are better, but because he concentrates upon them more. In a fog, when your eyes are of little use, you naturally listen more attentively. (Note by Stefansson).

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contd.

The astounding sound phenomena which accompany the breakage of ice in the wintertime, and absolute quiet accompanying the more grandiose summer breakage, are explained by the mechanical properties of the ice. The solidity (strength) of the ice depends mainly on its temperature. With a temperature of below -9° the hardness of ice is about like that of a well baked brick; with a further decrease in temperature the hardness increases little. With the raising of the ice temperature to the thawing point, the hardness of the ice decreases rapidly and approaches zero. Ice under high temperatures changes into a pudding mass.*

The temperature of sea ice changes constantly during its existence. It is specially characteristic for the temperature of the lower surface of the ice to be constant and to be approximately equal to the temperature of the freezing of sea water, i.e., 1.6 – 1.8° below (Centigrade) zero. The temperature of the upper surface of the ice field follow s approximately the temperature of the air and sometimes drops lower than -40° (C). Accordingly, the dimensions of the lower surface of the ice field always remain the same, and the dimensions of the upper surface either increase or decrease. For example, the upper surface of the ice field on which the station "North Pole" drifted could change its horizontal dimensions during the year by 1 or 2 meters only under the influence of the change in the temperature. This change in dimension causes for-

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* Except for the decomposition of fresh ice into candle ice, Stefansson is not able to agree with (or at least does not understand) this "pudding" simile. (Note by Stefansson).

mation of cracks which in the wintertime are accompanied by sounds resembling loud gun shots. page 172 contd.

The men of the station "North Pole," during their stay on the ice field, learned to differentiate various sounds with which the Arctic basin is filled in the winter time.

In the course of winter, the increase in size of separate ice bodies takes place vertically through the heaping up of pressure ridges and horizontally by the freezing together of different pieces. Thus enormous ice fields are created, which also get broken up sometimes by fierce winter storms. The ice cover of the Arctic attains its greatest development in area and depth approximately by May; but the "internal" thawing of sea ice begins considerably earlier and is expressed first of all in the lessening of its solidity (strength).

Actually, as we have seen, the sea ice consists of crystals of pure ice surrounded by cells containing a salt solution of sea water. These cells reach their smallest size at the moment when the temperature of the ice reaches its minimum. As soon as this temperature begins to rise, the dimensions of the salt-solution cells begin to increase, the concentration of the solution in them correspondingly decreases -- and the ice begins to thaw as if from inside.*

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* Here a study should be made of the paper by Professor W. G. Whitman, "Elimination of Salt from Sea-Water Ice," in American Journal of Science, February, 1926. Dr. Whitman's original manuscript from which the published article is a condensation may be seen in the Stefansson Library. (Note by Stefansson).

The rise in ice temperature is caused by absorption of the part of the ice of warmth from the air, from the water surrounding the ice, and by absorption of sun warmth when after the end of the long polar night the sun begins to show more and more above the horizon. page 172 contd.

The absorption of sun warmth by the ice takes place with interesting variations. Among all the natural winter coverings, a snow covering is the most nearly perfect reflector; water on the contrary is the most perfect absorber of sun energy. Therefore, it is understandable that with the approach of spring and summer the thawing of ice proceeds fastest of all in those places where there is most clear water between the ice fields. The water appears to ingest the sun's warmth into itself and as it touches the ice, it transfers to it the warmth, and thaws it.

On the ice fields the absorption of sun warmth is concentrated around the dark objects which are encountered on the surface of the ice. On coastal ice, the dark particles represent the dust of coastal origin which was brought to the ice by the winds. On the ice in the open sea, the dark particles are mainly of organic origin: tiniest organisms, living or dead, which have one way or another frozen into the ice.

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It was already noted in the times of Nansen, that the thawing of many-year-old ice proceeds mainly from the top down and the freezing from below -- all the foreign materials in the ice are therefore gradually lifted upwards, so that in the end they appear on the surface. These particles are the centers around which the absorption of the sun's rays and the ice-thawing are concentrated.

But however great the reflective quality, a certain amount of sun warmth is absorbed by snow. It is understandable that the uppermost snowflakes succumb first, melting enough to again congeal with each other into a solid mass, a crust, which possesses a great reflective power. The snow covering at this time takes on a blindingly white color, causing during early spring in the polar countries a severe inflammation of the mucuous membrane of the eyes, which is called "snow blindness."*

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Due to intense reflection, the horizon at this time even with a cloudless sky becomes dim, and strong refractions are observed. If the sky is covered with a thin layer of clouds, the whole atmosphere seems to be filled with a special silvery light, which resembles a light reflected by a polished silver (lamella) plate.

In the polar region, even when the temperature of the air in the early spring does not rise above -30°, there appear on surfaces facing south the first liquid drops of salt solution, and the sharp edges of the ice begin to change by thawing, to get rounded out. With further rise in temperature of the air, and the rise of the sun

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* If taken within the limits no doubt intended by Zubov, this statement is right. However, one of the best established things about snow blindness is that it occurs most quickly, and with the greatest severity, not when the eyes are "blinded" by the glare of a clear sun or shimmering snow but, on the contrary, when there is no such glare because the sun is partly hidden behind moderately dense uniform clouds, producing the condition know as diffused light. (Note by Stefansson).

above the horizon, the uppermost layer of snow becomes saturated with water. Its capacity to absorb the sun's warmth then increases. page 173 contd.

Every time there is a sudden drop in temperature (after a thaw) an ice crust is formed on the surface of the snow, which plays the role of the glass cover of a hot bed (parnikovy).

Due to these effects there is a gradual accumulation of warmth both in the snow and in the ice, which is shown by the rise in temperature of the entire illuminated part of the ice. In the depths of the ice this warmth is absorbed first of all not by the crystals of ice themselves, but the extraneous matter between them. This, by the way, explains why ice which was formed during a quiet condition of a pond will, when melting, acquire a characteristically uniform (sotoobrazny) appearance; and that every kind of ice, including sea ice at the time of its final destruction, falls into separate needles, which represent the remains of the crystals.*

In the course of time, there are formed on the surface of the ice first dark spots, and then little lakes of thawed snow water, page 174 which are called snezhnitzi (snow things). These continue to get larger even during sudden freezing, due to the protection action of the ice crust which is formed on their surface under such circumstances. Not infrequently there may be observed on the ice little

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* Stefansson has not observed the formation of needle ice except from (a) ice that was always fresh and (b) ice that has become fresh (through the process described by Whitman and Zubov). (Note by Stefansson).

lakes of thaw-water (temperature above 1^{o}), which are covered on the top with a layer of ice up to 10 cm. in thickness.* page 174 contd.

In clear sea ice the centers of absorption of sun energy are the salt-cells, the dimensions of which in the course of time and with the rise of temperature gradually increase, which hastens the downward movement (niskhodyashcheye divzheniye) of the salt solution and the freshening of the ice. Thus, under the influence of solar energy, and conduction of warmth in the sea ice, deep internal changes take place. These at first have little effect on the external form and dimensions of the ice, but they decrease its solidity (strength, hardness) and capacity for resisting various external pressures.

In the meantime, the little lakes of snow water on the surface of the ice continue to increase: slowly when they are covered with thin transparent freshened ice but considerably faster when, due to the raised air temperature, the lakes are free of ice. The snow water penetrates into the cracks that are found in the sea ice. Coming in contact with the ice, the temperature of which is considerably below freezing point, this water freezes, seals up the cracks and thus stops the drainage of the basic mass of water under the ice.

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* Zubov does not mention what stefansson frequently observed that after a small water hole had frozen over, the water in it subsided enough to leave an air space of a fraction of an inch up to one or several inches. Naturally, this would apply only to holes of a few feet, or at most, a few yards in diameter. (Note by Stefansson).

Thus, the primary thawing of snow on the ice surface causes ponds of fresh water to appear on the ice. These gradually increase and unite with each other. In the end they give the surface of the thawing ice the appearance of a sea covered with small pieces of floating ice. During this period there can be seen as emerging from under the water (the depth of which in the southern regions of the Arctic basin may reach 1 meter and more) only the tips of the hummocks of many-year-old (paleocrystic) ice. The resemblance between the ponds on the ice and the opened sea increases further when a wind covers their surface with ripples and light waves. page 174 contd.

Formation of lakelets of fresh water on the sea ice in the course of the polar summer are not confined to the southern regions of the Arctic Ocean, where these lakes have long served as supplies of fresh water for sea voyagers.*

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It is well known that during the drift of the Fram, its crew frequently amused themselves by sailing in small boats on the lakes which had formed during the summer on the ice fields. The same kind of lakes were observed by the party of the station "North Pole," who had to build special canals to drain them off. The largest of such lakes was 200 by 400 meters across, and 2.5 m. in

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* During the voyage on the Sadko in 1935, in the northwestern part of the Barents Sea, we took several hundred tons of fresh water from one lake that we found on the ice.

in depth. The _Sedov_ crew also sailed on such lakes.*

It is natural that into the deeper parts of each separate reservoir all extraneous mixtures gradually wash down. In these hollows there is an accumulation and development of organic life. Due to the dark color of these accumulations, absorption of warmth is more intense here. Gradually these hollows penetrate down to the salt water beneath, whereupon the whole volume of the lake's snow water will pour down into the sea beneath the ice. In one or two days the surface of the ice then seems to dry up and emerge from under the water. On the surface of the ice there now remain only the lakes which have a water level either higher than that of the sea (i. e., lakes where no perforation into the sea has yet taken place); or else sea-level pools in which the water is salty.

The surface of the ice after the drainage of the thaw water appears to be extremely uneven, dug up with pits. Frequently, after the ice dries up, cracks in the ice field will appear, and the central or the thinner ice under the lakes breaks and then floats up.

The drainage of fresh snow water under the ice is followed by another characteristic phenomenon (which was first observed by Nansen

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* Stefansson never observed lakes, even on plaeocrystic ice, that were more than hip or waist deep, thus only half the depth reported by Zubov. However, the Stefansson parties were sledgers who were always crossing the ice ponds at what seemed the likeliest fords. Then it may be that lakes near a wintering ship would have a lot of debris in them, as described by Zubov in the next paragraph; while the lakes crossed by the Stefansson sledgers were remote from human locations and thus free of all large accumulations of garbage and such. (Note by Stefansson).

and was confirmed by the Sedov party), namely: formation under the (salty) ice of an additional layer of completely fresh ice. This latter fresh ice if formed as a result of the contact of the drained fresh water with the sea water, the temperature of which at that time is about -1.8°. Thus, according to the Sedov observations the summer of 1939, such water running down under the ice and freezing from below, increased the thickness of the ice by from 5 to 55 cm. page 175 contd.

The thawing of the ice on the sea increases specially after the temperature of the air rises above -2°. Gradually the ice fields weaken to such an extent that one or two storms are enough to break up fields which only recently have been quite strong. It is most noteworthy that from their outward appearance it is very difficult to tell in what stage of thaw a given ice field is. Sea ice, as was said, thaws as if from the inside, and the last thing to break up is the shape (the frame). page 176 As was shown by the observations of Soviet polar stations such straits as, for example, Matochkin Shar and Yugorsky Shar, are opened up (i.e., the large floes and fields break into smaller floes and cakes) sometimes when the thickness of the ice cover is not less than 1 m.

During the breakage of ice fields in the course of the polar summer, under the action of storms, the areas of clear water between the floes increase, and this creates for individual ice fields and floes a certain freedom of movement. There are no two ice bodies in the sea that are alike; upon each the wind and the permanent and temporary sea currents act differently, causing the individual fields, floes and cakes to move with different speed and in different direction. This leads to inevitable and frequent collision which is accompanied by breakage and further increase in the areas of clear water between the ice. The more there is of clear water the stronger is the movement of individual ice bodies in relation to each other, and the more rapid is their thawing and their disintegration. page 176 contd.

When warmed by the sun the uppermost particles of the water touch the ice and cool off, and get heavier, and thus sink to a greater depth. New drops of thaw water flow down off the ice to take their place, so that there are perpetual streams of water in the direction toward the ice and, at a certain depth, in a direction away from the ice. Thus, each ice body in the sea represents in a way an independent (self-acting) pump. A similar circle of warmth is created in the air, also. Over the open surface of the sea evaporation takes place, which is followed by a cooling of the upper layers of the water; and the warmth, which was taken away from the water during evaporation, comes out. These processes are inevitable during contact of water and ice. Condensation of water vapor over ice causes fogs, which are so common over the polar ice in the summer time.

In the border seas of the Soviet Arctic one-year-old ice predominates. In the Central Arctic basin, many-year-old (palecrystic) ice predominates.

Particularly interesting are the observations of the Sedov party, who during the 20-month drift could follow the regime of growth of the paleocrystic ice.

We know theoretically that the thickness of ice cannot increase from year to year indefinitely. If, in some region of the ocean, the number of degree-days (graduco-dney) of frost, i.e. the sum of the average daily negative temperatures of the air, and the extent of the summer thaw, remain from year to year constant, then the thickness of ice that is increasing by freezing alone, tends to a certain limit. page 176 contd.

Thus, under a condition of 6,000 degree-days of frost and under a decrease in the thickness of the ice during summer by 1 m., the thickness of the frozen-over ice (l'dov narastanya) cannot exceed 265 cm.; but with the same number of degree-days of frost and a total of summer thaw equaling only 30 cm., the limit of ice thickness rises to 790 cm. It is reasonable that only a limited amount of ice thickening occurs, since the thicker the ice is the more slowly it will obviously grow in thickness under the same temperatures of air. When the ice reaches the thickness which is characteristic for the given Arctic area, then it increases only as much during the winter as it decreases during the summer. page 177

The Sedov party gave much attention to their observations of the polar ice. Besides writing scrupulous descriptions of the conditions of the ice, and of the snow cover, the Sedovites every ten days took measurements of the thickening of the ice that came about from natural freezing, i.e. without breakages and piling up.

It is interesting to correlate the measurement of the thickening of level ice, formed by a natural process of freezing, according to records made by the Fram and by the Sedov. In the first (or Fram series of measurements) the thickening of the level ice fields came to a little more than three meters. (The greatest thickness of level ice measured by Nansen was 365 cm.) page 177 contd.

Now the Sedov was beset in ice which had lived through the summer of 1937, so we consider the ice surrounding her as having been made in 1936. For comparison we give the Fram measurements of ice which had formed in 1893.

"Sedov" Measurements				"Fram" Measurements	
Date	Ice Formation in cm. 1936	1937	1938	Date	Ice Formation in cm. 1893
10 March 1939	189	170	163		
20 March 1939	195	176	170		
4 April 1939	198	182	179	10 April 1894	231
11 April 1939	204	188	186		
10 May 1939	215	201	198	21 May 1894	252
19 May 1939	217	216	201		
31 May 1939	218	206	202	9 July	258
10 June 1939	218	207	204		

On the whole the Sedov drifted along a course considerably more northerly than that of the Fram; nevertheless the thickness of the ice at the time of the Fram drift (as is shown in the date) was considerably greater than at the time of the Sedov drift. This again confirms that a warming up of the Arctic is now in process. (But see previous footnote on this.) page 178

In addition, the Sedov observations confirmed once more the following facts:

(1) The growth of the polar ice continues during the summer, due to low temperatures retained in the middle portions of the ice.

in spite of the relatively high temperatures of air.

(2) That which has become impregnated with water, from the thaw of the snow cover, stays a longtime in a stage of freezing (promerzaniya) and does not increase in thickness. Thus, the increase in thickness of ice, in the region of the Sedov drift, began only about the first half of December, although freezing temperatures of the air had started in the second half of September. Thus, it took about two and a half months for the ice to freeze (to freeze through and through) and for thickening to begin.

It has already been indicated that the thickness of many-year-old ice depends not only on the number of degree-days of frost but also on the extent of the summer thaw.

The Sedovites calculated for the winter about 6,000 degree-days of frost. Then what could be the thickness of the ice during the drift under different degrees of summer thaw? Below are certain calculations, according to the author's empirical (empiricheskaya) formula.

Summer Thaw in cm.	Ice of 1936	Ice of 1937	Ice of 1938
10	342	279	196
50	291	253	196
100	241	225	196
150	208	205	196

From this table it is clear that the slight thickening of the ice in the region of the Sedov drift must be explained not so much by the rise of winter air temperatures as by the increase in ice thaw during summers that has taken place in recent years.

The ice field of the station "North Pole" had a thickness of 3 meters. The question naturally arises: where was it formed, whence was it brought to the North Pole? page 178 contd.

It is clear that the ice field on which the station "North Pole" rested must have originated in considerably colder parts of the Arctic, in regions where the number of degree-days of frost is somewhat larger, and the summer thaw considerably smaller than along the course of the Sedov drift. page 179

(Here a chapter is omitted)

As already shown, drifting and pack ice are found in constant motion summer and winter. These movements are of a three-fold (four-fold) nature: constant ones, caused by the predominant and constant winds (conditioned by the distribution of constant fields of atmospheric pressure in the regions adjoining the Arctic) and by the constant currents; seasonal ones, connected with the seasonal changes of centers of atmospheric action; periodic ones, conditioned by the tidal phenomena; and temporary ones, created mainly under the influence of temporary winds. page 188

Known drifts of vessels in the ice indicate that movement of ice is never in a straight line. Ice fields move in one direction, then in another, or go back to the first direction, or describe curious loops and zigzags. Only prolonged observations reveal the seasonal and constant movements which have the most significance for the understanding of the picture of circulation of ice in the Arctic basin. page 189

Our concepts of the movement of ice in the central part of the Arctic basin are as yet not sufficiently exact, and are based on the study of comparatively few drifts of ships, and also on the study of paths of special beacons (buoys, casks), thrown out in various parts of the Arctic basin by individual expeditions.

As far as we can judge by available observation, the migration of ice from the coastal seas of the Soviet Arctic into the central part of the Arctic basin predominates over the entrance of ice from the central part into these coastal seas.

In the very center of the Arctic basin, as far as we now know, there exist two basic movements of polar ice. One of them, a general movement, is directed from the Arctic basin into the Greenland sea and is conditioned by the flow of coastal waters and corresponding winds; the other, anticyclonic, with a center located approximately between 83° and 85° N. Lat. 170° and 180° W. Long., conditioned by winds connected with the region of increased atmospheric pressure (located at the quiet-oceanic part of the Arctic). These movements are confirmed by all known drifts of vessels -- accidental and planned.

Thus, the vessel Karluk (of the third Stefansson expedition) under the command of Captain Bartlett in 1913-14 drifted with the ice for a distance of 500 miles, approximately from Cape Barrow in Alaska to the island Wrangel. Another notable drift, that of the vessel Jeannette, 1879-1881, which drifted from Wrangel Island to the Novosibirsk (New Siberian) Islands, a distance of 750 miles. The Fram, Nansen's vessel, drifted from the Novosibirsk islands to the strait between Spitsbergen and Greenland, a distance of 1400 miles. Finally the vessel Maud of the Amundsen expedition of 1922-24, drifted from the Wrangel Island to the Novosibirsk islands, a distance of 750 sea miles. The drift of the Maud almost repeated the drift of the Jeannette, indicating by this the relatively constant direction of the movement of the ice. See Fig. 28.

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The general movement of ice from east to west parallel to the continent curve of the Eurasian shore is also proved by observations made during the sledge expeditions of Parry (1827), Cagni (1900), Nansen (1895), and around the continent curve of America by observations of Stefansson (1914) between 130° and 140° W. and by his observations (1915-1917) between 110° and 130° W.

Numerous beacons (drifting buoys) tell us the same thing. These have been thrown out by Soviet expeditions in the Kara Sea and the Laptev Sea and subsequently found at the shores of Greenland, Iceland and Norway. Thus, the drift of ice forms one uninterrupted line along the periphery of the central Arctic basin from 150° W. Long. to 0° Long. embracing more than half of its circumference. Such a drift takes ice from Bering Strait till it is carried out into the Greenland Sea, on the average in 4.5 to 5 years.

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The direction of the drift of ice on the remaining coast of (the islands north of) America has not been studied as much. Here we have findings by Peary, that during his repeated sledge travels north of Greenland and Grant Land the movement of ice was directed from west to east -- thus towards the wide strait between Greenland and Spitsbergen, " the Papanin Strait."

Observations of the station "North Pole" are specially valuable in that they were first to demonstrate that ice from the North Pole moves directly into the Greenland Sea. page 191

During his expedition Nansen spent a great deal of effort on the study of conditions of the drift of the Fram. He observed that the ice fields of the central Arctic very readily yield to the action of a (local) wind, and change their speed and direction according to the changes in speed and direction of the wind. He established the following two simple rules:

(1) The speed of drift is approximately one fiftieth of the speed of the wind which causes the given drift.

(2) The direction of the drift inclines on the average 30° – 40° from the direction of the wind which caused this drift.

The last phenomenon Nansen ascribed to the influence of the deviating (otklonyayushchey) force of rotation of the Earth. This explanation has been judged correct, and was later taken as a basis of contemporary theories of sea currents.

The deviating force of Earth's rotation* possesses remarkable properties. It originates together with the beginning of any movement on the Earth and ceases together with its cessation. It is proportional to the mass of a moving body. It is proportional to the sines of geographical latitude: it equals zero on the equator

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* Or the force of Coriolis, named after the scientist who first explained the origin and the significance of this force.

and increases in the direction of the poles, where it attains its page 191
greatest value. This forces is proportional to the speed of movement, perpendicular to any horizontal movement on the earth; in the northern hemisphere it is directed to the right and in the southern to the left, independent of the direction in which the movement itself is taking place.

The following will give us an understanding of the magnitude page 192
of this force: At the poles where the force of Coriolis is greatest, with such insignificant speed of an object as 1 cm. a second (or in other words, 0.036 km. a second, or 0.864 km. a day)* it constitutes about one seven-millionth part of the force of gravity.**

The Coriolis force in the northern hemisphere turns artillery shells to the right. Due to this force the inside part of the right rails (if you look according to the movement) on a railroad become worn, etc. But the Coriolis force exerts the greatest influence upon the movement of water and air masses.

The erosion of their own shores by rivers is explained by this force. In rivers, no matter in what direction they flow, the right

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* This is correctly copied from the book. Apparently "0.036 km. a second" should read "0.036 km. an hour" (translation note).

** Let us recall that the maximum vertical component of the tide-forming force of the moon equals only 1 nine-millionth, and the maximum horizontal component is only the twelve-millionth part of the force of gravity, and nonetheless these forces cause such grandiose phenomena in the ocean as the tides.

shore in the northern hemisphere always tends to be precipitous and the left more flat. Sea currents, no matter how caused, always tend as far as possible to incline to the right. Thus, the direction of the general circulation of waters of the ocean are conditioned to a great extent by the force of Coriolis. The same applies fully to the atmosphere. page 192 contd.

It came about that drift conditions as elucidated by Nansen were checked on many expeditions and at many polar stations. Remarkable deviations from the above rule sometimes helped to understand very complicated phenomena. Thus, for example, as was already indicated, the angle of deviation in the Fram drift, in separate instances, on the average fluctuated about 40 degrees to the right. But **when Nansen calculated the mean direction of the wind for all** the three years, it turned out that the Fram inclined 1 degree to the left. From this Nansen concluded that the Fram's drift was really composed of two drifts; one under the influence of local and brief winds, the other a general drift, connected with the general circulation of the ice in the Arctic Ocean.

A more striking example (if correlations of direction of wind and wind-drifts of ice fields are valuable) is the discovery of the island Weise in the northern part of the Kara Sea.

The year 1912 was very difficult for the Russian polar workers. During this year three expeditions went out into the Arctic Ocean:

(1) The expedition of second Lt. Georg Yakovlevich Sedov page 193
on the vessel St. Foke, whose aim was to reach the North Pole. This expedition ended with the death of its leader.

(2) The expedition of the geologist B. A. Rusanov, on the vessel Hercules, which perished in the attempt to navigate the Norther Sea Route (the Northeast Passage). Up to now only traces of this expediton have been found.

(3) The Expedition of Lt. G. L. Brusilov on the vessel St. Anna whose aim was also to navigate the Northern Sea Route.

The expedition of Brusilov reached the Kara Sea. On the 2nd of October, 1912, it was beset in the vicinity of the western coast of the Yamal peninsula. Later the ship was carried out from the Kara Sea north, along the eastern coast of Franz Josef Land, and then it drifted into the Central Arctic basin. April 23, 1941, when the vessel was at 83° 17' N. Lat. and 60° E. Long. eleven men of the crew, headed by the pilot B. I. Albanov, abandoned the ship. On the 8th of July they reached the southwest cape of Franz Josef Land; on July 22 only two of them reached Cape Flora; the pilot Albanov and sailor Konrad; the rest perished, partly from exhaustion and partly from unkown causes.

On Cape Flora, Albanov and Konrad began to prepare for wintering. But they did not have to winter there; for on August 2 the St. Foke reached the cape with the participants in the expedition of Sedov who were returning to Archangel.

On the way to Franz Josef Land Albanov had not conducted observations because of travel difficulties. None the less the Albanov trip is important, for on the way from the St. Anna he crossed the exact location where the charts indicated Peterman Land and the Land of King Oscar, and thus proved that these lands do not exist.

Albanov saved the log of the St. Anna in its entirety; also the complete notes of his meteorological observations during the time he was on the ship. This enabled scientists to reconstruct the conditions of the St. Anna drift.

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In 1924 Professor Weise, while analyzing the St. Anna observations, came upon a curious peculiarity of her drift between the 78th and 80th parallels and between the 72nd and 78th meridians, East. Here the vessel, which was drifting in a general northward direction, inclined from the direction of the wind not to the right, as would follow from Nansen's second rule, but to the left. Prof. Weise came to the conclusion that this peculiarity could be explained by the presence of land between 78° and 80° N., towards the east and not far from the line of the St. Anna drift. Such land was actually discovered, in the shape of an island, by the expedition on the icebreaker Sedov in 1930; it is located between 79° 29' and 79° 32' N. Lat., and 76° 46' and 77° 20' E. Long. This island was with propriety named for Weise.

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Because of the scrupulous and numerous astronomical determinations of the position of the drifting ice field, and determinations by instruments of the speed of the drift, which were taken by the station "North Pole," a picture (map) of the drift of the ice field was reproduced with such details as no other study of a drift has given us before.

It was understood already that the direction and speed of drifting ice depends to the greatest extent on the force and direction of the wind. These meteorological elements were determined by the Papaninites every 4 hours. A special apparatus, "anemograph" was used from May 21 straight through the middle of October 1937, recording uninterruptedly the speed of wind. Due to this, the correlations which can be made between the speed of the drift and the wind have an exceptional accuracy. page 194 contd.

A schematic chart of the drift, Fig. 5 indicates that the ice field carrying the station "North Pole" described curious zigzags and sometime even loops, while retaining at the same time the same general direction from the pole into the Greenland sea, and later along the eastern coast of Greenland.

The dependence of the drift of the ice field upon the wind was demonstrated in the first month after the station was established. Thus, (from late May) approximately to the 5th of June northwestern winds predominated in the region of the station, and the ice field moved practically straight southward. From June 5 to 21 the northwesterly winds were replaced by southwesterly ones and the ice field began moving eastward. Thus, invariably under the influence of the wind the ice field changed the direction of its course. In connection with the change in force and direction of the wind, the speed and direction of the ice drift, naturally, changed also.

The speed of the general movement of the ice field southward changed too. The mean speed of the drift for the entire period was about 9km. a day. However, there were periods when the ice field remained in one place for the duration of several days; on page 195 still other days the speed of drift increased to 43 km. a day. It is noteworthy that the speed of the drift increased in direct proportion with the passage of the ice field south. Thus, from the pole to 85° N. the mean daily speed of the drift southward was about 5 km. a day. From 85° to 81° N. it increased to 9 km. a day; in February to 23 km. a day. page 195 contd.

The preliminary study of the drift conducted by Fedorov and Shirshov (members of the Papanin expedition) indicated that the ice field was drifting under the influence of that wind which was blowing at the given time in a given place, and simultaneously under the influence of the general movement, directed southward and independent of the local wind. Thus, during the absence of wind, the ice field invariably moved south. North winds hastened its movement southward, south winds retarded or even arrested the action of the constant drift, even to the extent that the ice field drifted northward temporarily, as we can see in the accompanying illustration (Fig. 29).

The speed, independent from the local wind movement of the ice in the immediate vicinity of the Pole, was approximately 2 km. a day. As said, this speed gradually increased southward; between parallels 70 and 75 it reached 10 to 12 km. a day.

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The speed of the drift increased sharply when the station floe began to drift along the coast of Greenland. Evidently the wind is not the only cause of the gradual increase in speed of the ice field as it goes southward. Undoubtedly an important role was played here by the considerable freedom of movement of the ice as it approached the spacious, ice-free Greenland sea. Thus, for example, in August the mean speed of the wind was somewhat greater than in December, and the direction of the wind was approximately the same; nevertheless, the floe drifted in Decem r with a speed almost three times greater than in August. Obviously the chief role was played here by the East-Greenland current. page 196 contd.

The drift of the Sedov, as well as the drifts of the Fram and the station "North Pole," did not proceed in a straight line. The Sedov frequently back-tracked, describing zigzags and loops. All this was connected with the changes in the direction and speed of the wind.

In Fig. 30 the Sedov drift is shown by the continous line and the path of the wind by the dotted line, from the 1st of September 1938 through the 1st of February 1939, on the assumption that the Sedov drift and the path of the air particles on the first of September began at one and the same point.

The scale of the speed of the drift and the speed of the wind is accepted according to the rule of Nansen, i.e. the speed of the drift is one fiftieth of the speed of the wind.

We can see from Fig. 30 that where the wind retains its direction during a more or less prolonged time, the drift of the Sedov, in that place is also more or less steady.

In October the wind describes a figure eight, and almost the same figure is described by the Sedov. At the end of Novembor the wind describes peculiar zigzags, and a similar zigzag is described by the Sedov. Between January 1 and 20 the wind describes a loop, and the Sedov describes the same kind of a loop.

Thus, the drift of the Sedov repeats the path of the wind, with the difference that it is inclined from the wind at 30 to 40 degrees to the right. If in certain points of the drift we have a small deviation from the Nansen rules, it should be explained by the incompleteness of information from the Sedov.

The author's work on the Sedov observations proved that in this region of the drift a constant current was very weakly indicated; for practical purposes we may consider it as absent. Due to this circumstance, there were almost laboratory conditions for the study of the connection between the drift and the wind. Divorced from the distorting influence of land and constant currents, the wind-drift occurred in an almost pure form. page 196 contd. page 197

Simple examination of the illustration shows how correct the two Nansen rules are. We cannot dream of a better confirmation of these rules.

We must emphasize once more that in contrast to the meteorological observations of former polar explorers, analogous observations of the Sedov staff (as well as the Papaninites) were conducted during the existence in the Arctic of a modern Soviet net of polar stations, with a modern level of knowledge about the Arctic. This circumstance, together with the high accuracy of observations made by the Sedov personnel, enables us to draw extremely valuable conclusions from the observations. Thus, a further analysis of the drift of the Sedov, and its correlation with the charts of distribution at atmospheric pressure drawn up by the Soviet weather service for the same period, gave the author an opportunity to add to Nansen' rules two more that are equally simple:

(1) The drift of ice is directed along isobars, i.e., along lines connecting points on the earth's surface where the atmospheric pressure is the same at a given moment. During this the drift is so directed that the place of the raised atmospheric pressure is at the right, and the place of lowered pressure to the left of the line of

the drift.

(2) The ice drifts with a speed proportional to the gradient of the atmospheric pressure; or, in other words, inversely proportional to the distance between the isobars.

The first of these two rules is not difficult to evolve, in the following manner: At moderate and high latitudes the wind, from contact with the earth's surface and under the influence of the declining force of its rotation, is directed approximately 30 to 40 degrees to the left of the corresponding isobar. The drift of the ice, according to the second rule of Nansen, is inclined away from the direction of the wind at approximately 30 to 40 degrees to the right. Thus, we have the real drift of ice along the isobar lines.

The second rule was formulated in the following manner: In the absence of constant currents and the distorting influence of land, the ice moves with a speed proportional to the speed of the wind. The latter in its turn is proportional to the gradient of atmospheric pressure -- the closer together the isobar lines on the synoptic chart drawn for some region, the stronger is the wind in the given region. This gives the possibility, supported by purely theoretical deductions, that we can measure on the synoptic chart, not only the direction of the ice drift, but also its speed.

During the drift of the Sedov from September 1, 1938, through February 1, 1939, southeasterly winds predominated, and the vessel in general drifted towards north-northwest. From this it follows that on the average during this time the area of raised pressure was somewhere towards east-northeast from her -- in other words, that the Sedov drifted along the periphery of the Chukotsky anticyclone.

During separate intervals of time, however, the barometric circumstances of the Arctic changed radically. Thus, in the first ten days of December, 1938, the Sedov was under the action of western and southwestern winds, and correspondingly drifted southeasterly. From this it follows that during that time the area of raised pressure would have been southwest from the ship. In the third ten-day period of December the vessel was under the action of easterly winds and correspondingly drifted northwest. The area of raised pressure should then have been in the vicinity of the North American Arctic archipelago.

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In Figs. 31 and 32 we have charts of distribution of pressure in the Arctic for the first and third ten-day periods of December 1938. They indicate the general drift of the Sedov during this time and supply ample proof of the correctness of the aforementioned supposition, that ice tends to drift along isobar lines.

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In Figs. 33 and 34 we have charts of the average distribution of atmospheric pressure in the Arctic during summer and winter. The general drift of the Sedov for the same season is superimposed on them.* These charts are very similar; they differ from each other in only a few details.

From these charts we can see that the basic features of the circulation of ice in the central Arctic, which explain all the drifts of the ice, and many other phenomena. But from an examination of

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* Figures 33 and 34 in original do not show path of Sedov, apparently an oversight (translation note).

these charts it also follows that, in order to judge as to whether page 200 contd. the drift of ice, or the passage of a ship moving with the ice, will be directed, it is not enough to know the disposition (polozheniye); one must also know the time of this position determination. Thus, for example, if the Sedov at the beginning of April 1939 were discovered to be at the same latitude, but not at the hundredth meridian of East Longitude as she actually was, but approximately at the meridian of Bering Strait, then she would have been carried not eventually to Papanin Strait (between Spitsbergen and Greenland) but towards the northern shore of America. page 201

The movement of ice along isobar lines explains why the vessel Maud of the Amundsen expedition, which in 1922 entered the ice in the vicinity of Wrangel Island, moved with the ice along the continental curve of the Asiatic coast, i.e. along the parallel of latitude and not along the meridian of longitude, in order to drift across the North Pole. We see that the isobar lines in the Wrangel region usually, and specially so in the fall, trend approximately along the parallel.

According to the new rules, in the monthly charts of pressure over the Arctic basin made up by the weather service, there was a calculation of the theoretical drift of the station "North Pole" page 202 (from the 21st of May 1937 through the 1st of February, 1938); and of the icebreaker Sedov from the 1st of November 1937 through the 1st of Oct. 1939) and of the icebreaker Lenin (from the 1st of November 1937 through the 1st of August, 1938).

The lines of theoretical and actual drifts of the icebreaker Sedov coincided best of all, which, by the way, is natural, for this ship drifted under extremely favorable conditions. page 202 contd.

The theoretical drift of the icebreaker Lenin also proved to be closed to the actual one (See Fig. 35); the theoretical line however trended somewhat more south and east. This is explained by the distorting influence of the nearby continental coast and the Novosibirstk (New Siberian) Islands which interfered with the drift of the icebreaker in the southern and eastern directions. The similarity of the theoretical and actual drifts of the icebreaker Lenin is particularly significant, for this drift was through that region which is equipped with the most numerous meteorological stations, and in which the isobar lines are drawn on the basis of actual observations and not on conjectures, as is true of the central regions of the Arctic. page 203

The theoretical drift of the Station "North Pole," calculated by the same formula, differs considerably from the actual drift. First, the theoretical drift of the station comes out at the coast of Greenland, and second, it is shorter than the actual one (considering the latitude) by 550 sea miles. Such a difference is entirely understandable: When the theoretical drifts were constructed, only the influence of local winds was taken into account, while the movement of the ice is determined not only by winds, but also by constant currents.

Naturally, in the regions where the constant currents are weak, the local winds do have the primary influence on the speed and the direction of drift.

With nearness to the Greenland Sea, the local winds exert less influence on the ice fields, because of the strong East-Greenland current. Weak winds, the direction of which is contrary to the constant current, only slow down or temporarily hold up the general drift southward. Such was the case with the station "North Pole" and with the icebreaker Sedov.

The second circumstance which influenced the difference between the actual and theoretical drifts of the station "North Pole" was the following:

The speed of the wind-propelled drift of the solid ice fields in the central Arctic, as was stated above, is 50 times less than the speed of the wind which caused this drift. The speed of the drift of ice, under the influence of the wind, increases considerably if there is an open sea ahead of the ice fields that are being pressed forward by the wind. In such cases the speed of the drift may attain one tenth of the speed of the wind, and sometimes more. Precisely such conditions are created under northern and western winds in that region of the central Arctic which lies next to the Greenland Sea, and in the Greenland Sea itself.

Passing to the lower latitudes in its drift from the North Pole south past 81° N., the Papanin floe entered the Greenland Sea and then began to move through the board shallows that overly the continental shelf along the east.* Here it found itself in the famous Greenland current of ice-filled waters that move south along the eastern Coast of Greenland. This current is thought of as beginning at the island's northeastern caps and extending to its southermost cape, Farewell, and then sweeping northwest along the western coast of Greenland up into Baffin Bay. This uninterrupted ice current, moving continuously though with changing speed summer and winter, constitutes one of the most remarkable phenomena of nature -- no less remarkable than the Gulf Stream although less well known. page 204 contd.

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The origin of the Greenland current, or the East Greenland current, may be considered to be: Each year there enter the Arctic Ocean about 5000 cubic km. of river waters. Beside this, each year there pour into the Arctic basin through the Bering Strait about 30,000 cubic km. of Pacific Ocean waters, and from the Norwegian and Greenland seas more than 100,000 cubic km. of warm Atlantic waters. A small portion of these (inflowing) waters find egress to Baffin Bay through the numerous but shoal (and narrow) straits of the American archipelago; but the main mass of (outflowing) water enters the Greenland sea through Papanin Strait, creating the East Greenland current.

If we look at maps on which the directions of the predominant winds are indicated for the months of January and July (Fig. 36), and the chart of constant currents in the North European sea (Fig. 37), and compare these with isobar maps for the summer and winter

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* No ship has ever been in the Greenland current north of 78° N. Lat., so all observations made by the station "North Pole" in this region are of special interest.

seasons, represented in Figures 33 and 34, we will see that the Greenland Current, being basically a drainage current, is at the same time a drifting current, conditioned by the predominant winds. page 205 contd.

The East Greenland Current, like the drifting currents, is sufficiently strong so that it not only carries out of the polar sea the entire volume of river waters that have come into the Arctic basin, but it also forces Atlantic waters, in compensation, to flow up into the Arctic basin.

The eastern border of the Greenland current has an almost immovable position throughout the whole year. It approximately coincides with the eastern borders of the continental shelf that flanks Greenland. Thus, the ice-laden current roughly corresponds to the shallow belt of water.

The ice of the Greenland current is divided into three parallel currents. The first, or most western, is closer to Greenland, and page 206 carries ice which had been formed in the numerous fjords and carried out from them together with the icebergs which fill these fjords. The central stream consists of pack ice, carried out into the Greenland Sea from the central Arctic basin. Finally, the most easterly stream consists of ice that has been carried out into the Greenland Sea from the regions of Spitsbergen, Franz Josef Land, Northern Land. There is in it also the ice formed in the Greenland Sea itself.

The speed of the Greenland current is not uniform. At 80° N. Lat. it is about 3 to 3.5 km. a day. This speed increases gradually southward, and in the Denmark Strait (between Greenland and Iceland) it reaches 20 to 30 km. a day. Neither is the speed of the three parallel streams (composite parts of the general Greenland current) the same. Apparently the central stream has the greatest speed. It was in this stream that the station "North Pole" drifted. page 206 contd.

The difference in speed of the various segments of the current had been known, but it is specially clearly shown by the drift of the station "North Pole." Actually while the floe was drifting in the Arctic basin, its position in relation to the meridian remained almost the same. Thus the impression was created that the floe, in spite of all the curves in its passage, was taking part in a general movement of the wide area of pack.

After the floe entered the Greenland Sea it began to spin on its axis frequently, now in one direction, now in another, which was undoubtedly caused by friction of its margins, due to the unequal speed of separate floes. Together with the increase of speed of the current, as it moved south, the width of the Greenland current naturally decreases. At 80° N. the width of the moving ice belt reaches 400 km.; at the 70th parallel it decreases to 200 km.

Frequent attempts have been made to calculate the quantity of ice flowing south through the strait between Greenland and Spitsbergen, but to the present no accurate results have been obtained, due to the lack of sufficient data. First, the mean thickness of the ice is not known; second, the speed of movement at different times of the year has not been sufficiently studied; third, it is not known page 207 what percentage of the sea is occupied with ice and how the ice is distributed in relation to the time of year.

Calculations made by the German oceanographer Krummel gave a 12,700 cubic kilometer of ice a year, which constitutes approximately one third of the entire pack ice filling the central Arctic basin if we assume that 7/8 of it is covered by ice of a 5-meter mean thickness.

The calculations of V. Y. Weise give 8,000 cubic km. According to very cautious calculations of the present author the quantity of ice carried is even less than that. He considers that the Greenland current, due to favorable winds, is very uniform, and that its speed is from 8 to 12 km. a day, with a width of about 200 km. Then we find that this current carries out each year from the Arctic Ocean up to 1 million square kilometers of sea ice, i.e. from 13% to 20% of the entire area of ice in the central part of the Arctic basin.

To be cautious, let us assume that the thickness of the ice carried out by the Greenland current averages 3 m., then the annual quantity of ice will equal 3 thousand cubic km., or about 3 million tons (metric) of sea ice. In order to thaw this ice it would be necessary to discharge more than 200×10^{12} gram calories of heat (a gram-calorie heats by 1° more than 3000 cubic cm. of air.) Thus, in the winter time the cold air masses cause a formation of ice during which heat of thawing is released, raising the temperature of these air masses.

Part of the ice formed is carried out into more southerly latitudes, and as a result the climate of the Arctic basin is softened. Thus, the Atlantic and Pacific Ocean waters, and the river waters, constantly bring warmth into the Arctic basin, while the Greenland ice stream as constantly carries cold out of the basin. The quantity of warmth entering the Arctic basin, as well as the quantity of cold leaving it, does not remain unchangeable, but is subject to considerable change from year to year. These changes effect, in a very essential manner, the conditions of weather on the western borders of the seas of the Soviet Arctic. page 207 contd.

Observations of the station "North Pole" are valuable because, being a vital addition to the observations made before by the Soviet explorers in the Greenland Sea, they for the first time enable us to calculate the quantity of ice carried out from the central Arctic basin and to follow them up further to learn their fate. At the same time the results of the Papanin observations raised new and important problems. Does the great speed of the Papanin drift represent a phenomenon which is usual for the Greenland current, or is it merely connected with special climatic condi- page 208 tions of the winter 1937-38, and to what degree is it connected with the general warming up of the Arctic, observed since 1920?*

From the history of exploration of the Arctic many instances of drift of vessels in the Greenland ice are known. For instance, that is what happened with the Soviet vessel Murman during the operation of relieving the station "North Pole." As we know, the Murman was beset by ice south of Jan Mayen and then carried with the pack out through Denmark strait into the region south of Iceland, where it was freed.

The most remarkable drifts of vessels in the Greenland ice were the following:

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* As already pointed out, this discussion is dated; for Soviet scientists, like others who temporarily held those views of climatic change, have since concluded that only a short cycle was involved. (Note by Stefansson)

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In June 1777 several vessels of the Holland whaling fleet were beset at 76° N. and were carried with the ice south, through Denmark Strait, at a rate of 18 to 20 km. a day. The Hansa, sailing vessel of the Second German Arctic expedition, entered the ice on September 14, 1869, at 73° 25' N. Lat. and 189° 39' W. Long., 70 km. from the eastern shores of Greenland, and was carried in a southern direction. On October 22, 1869, the Hansa, was crushed by the ice at 70° 52' N. Lat. and 21° W. Long. (i.e., at a point somewhat more northerly and westerly than the place where the winterers of the station "North Pole" were on February 19, 1938, when taken off by the icebreakers Murman and Taimyr). The hull of the Hansa drifted on with the ice along the eastern coast of Greenland and finally, after 200 days, found herself at 61° 21' N. and 42° W. The crew then transferred to three boats and in them reached the coast of Greenland. Altogether 2000 km. were covered in the drift. The coincidence of the place of relieving of the station "North Pole" and the place of the beginning of the drift of the Hansa enables us to calculate the ice movement from the very pole to the southwestern coast of Greenland.

It was known that floes from the central part of the Arctic, which enter the Greenland Sea, are comparatively large. But numerous observations of commercial and scientific vessels were to the effect that in the region between Jan Mayen and Iceland only relatively small fragments of the heavy Arctic floes and fields are encountered, measuring usually 30 to 40 meters across. These little chips from the heavy ice fields are called "storis" by the Danish and the Norwegions, meaning literally "big ice". Therefore, in the Greenland Sea between Northeast Foreland and Jan Mayen there must have occurred a breaking up of the large ice fields of the Arctic. It was not known just how this breaking up takes place.

Already during the Chelyuskin expedition it had been noted that sometimes, especially during hummocking of ice fields, there seemed to be running over the ice waves under the action of which the ice fields began to rock.*

These conditions were well known to Shirshov and Krenkel (of the Papanin expedition) who had been members of the Chelyuskin expedition. For that reason Fedorov (of the Papanin party) observed with special attention during the drift the behavior of the bubble in the level of the theodolite, established on the floe, in order to determine these fluctuations.

The drift of the station "North Pole", as we have seen, at first proceeded in general extremely calmly. The winterers sometimes discovered cracks in their floe, which had been produced through change of temperature, but breakage or sharp jolts were not observed till the end of January. Even the turns of the ice field around the vertical axis were comparatively small, specially at the beginning of the drift.

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* The meaning is that when pressure ridges are being formed in one or more places on a large ice field then there is a sort of wave motion in the parts of the field where no hummocks are actually being formed. The accounts of the third Stefansson expedition refer to this as a quivering of the ice-- usually not perceptible to the human senses but so pronounced nevertheless that sextant observations could not be taken because of waves produced in the mercury horizon. (Note by Stefansson).

The first strong jolt was noted on January 20; the first fluc- page 209 contd.
tuations in the level of the theodolite were found only on the 21st of January, 1938, when the floe had reached the Greenland Sea, approximately at 77° N. Lat. No doubt this was connected with the storminess of the whole of January in the Greenland Sea. Wind velocity frequently reached 30 m. per second. Because of that force of the wind, and because the eastern part of the Greenland Sea is always free of ice, the floes began moving in response.

On January 26 the six-day storm began, and the floe began to experience greater rocking. The period of the rocking was 10 to 12 seconds (approximately the same as observed with sea waves in a storm); the inclination of the ice field reached 60 seconds of arc, and more. As a result of this rocking, tension was caused in the ice. Finally on February 1st, the ice field broke along lines approximately perpendicular to the direction of the wind. There is no doubt that the cause of the rocking, and the breaking of the ice, was a great swell that was caused by the storm winds in the nearest ice-free region of the Greenland Sea, which swell, according to general law, was dispersed in all directions.

After the breakage of the ice field the winters of the page 210
station "North Pole" found themselves on a floe measuring 30 by 50 meters, separated from other floes by cracks of 1 to 5 meters in width. When the wind subsided, the floes began to get closer to each other and freeze together; by the 19th of February the distance from the station to the edge of the new field on which it was located was already about 2 km. But the new field, formed from the

broken parts of the old ice fields, was naturally not as strong as the old one had been; of course, even weak winds could have broken it up later on.

During its drift the station "North Pole" dropped south in latitude 1,120 sea miles. The passage was accomplished under the influence of a constant current and of local winds. If we take into account the observations of P. P. Shirshov and E. K. Fedorov, made by them during the drift of the station "North Pole", of the direction and speed of the constant currents, then we shall see that about 600 miles of the general extent of the drift is accounted for by the favorable currents and only 520 miles are chargeable to the favorable winds. Moreover, the theoretical drift of the Sedov is shorter than the actual one by 550 miles -- precisely because, when sketching (forecasting) it, we took into account only the local winds.

Considering the observations and calculations of P. P. Shirshov and E. K. Fedorov, we undertook to calculate the drift of the station "North Pole" as conditioned on the one hand by the distribution of atmospheric pressure and on the other by the permanent current. Comparing the actual location of the station "North Pole" on February 1, 1938, with the theoretical, calculated with the present author's formula, taking into account the permanent current, we find that the true location of the ice floe differed from the theoretical by only 50 miles, i.e., diverging only 5% from the length of the drift along the meridian. Such coincidence must be attributed in part, to the accuracy of the data upon which the calculations were based. So this coincidence emphasizes once more the amazing accuracy of observations on the part of the Sedovites and Papaninites.

In the Central Weather Bureau daily maps are constructed indicating the distribution of atmospheric pressure over the Arctic basin, and on them isobars are traced. From these maps it is not difficult to take the direction of the isobars and the distance between them at any point on the earth's surface. From this may be computed according to formulas obtained as a result of the analysis of the drift of the Sedov, the speed and direction of ice movement in any region of the Arctic Sea. page 210 contd.

page 211

In fig. 38 we have a map of mean- monthly atmospheric pressures over the Arctic basin for January, 1939. In the same illustration the actual drift of the Sedov for the same month is indicated with a double arrow. As we see, it coincides with the isobar.

The drift of ice in various regions of the Arctic basin during January, 1939 is indicated simultaneously in the same figure. The directions of the arrows indicate the direction of the ice drift, and the length of arrows indicates the speed of the drift. From examination of this illustration it becomes apparent that the ice of the central Arctic basin moves not at all as one whole, but with varied speed and in various directions. There are zones of rapid movement, and of relative calm. At the point where the arrows meet, a compression of ice, with breakages, takes place; and where the arrows part the ice becomes less dense and patches of open water form between the separated ice fields.* page 211 contd.

Obviously, whenever the movement of the polar ice is away from the Soviet Arctic coast we may expect favorable ice navigation conditions in the waters of the Northern Sea Route.

Whenever the polar ice moves away from our shores, there is also an increased off-shore movement of local ice, which had formed in our border seas. Reciprocally, with the approach of the polar ice towards our coast the outflow of local ice ceases. It also happens that ice from the central basin is carried into the border seas. Then, of course, sailing conditions grow correspondingly worse along the Northern Sea Route.

From this we can see how important are the new rules for improvement of ice prediction, which elucidate the distribution of ice on separate parts of the Northern Sea Route during the course of navigation. These predictions are based on the observations of the meteorological stations and on the ice exploration which has been carried out during Arctic navigation by airplanes and ships. Observations made by the meteorological stations cover only the coastal page 212 portions of the seas; observations by plane and ship cannot be constant nor do they take in all regions. So there must be dependence upon a constant scrutiny of the movements of the ice fields in the

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* Illustration 38 would seem important for study. (Note by Stefansson).

light of weather charts made every day with the aid of the discovered method. page 212 contd.

In this possibility lies one of the greatest practical results of the Sedov drift. This achievement was made possible by the excellent work of the remarkable collective of Soviet polar workers, specially the magnificent work of the crew of the icebreaker Sedov.

We have many famous names among sailor-explorers, of whom we are justly proud. To this list are now to be added the names of the Sedovites. They were not only able, under very difficult conditions, to keep safe their ship, a member of the Soviet icebreaker fleet, but were also able to conduct a series of most valuable observations in the Arctic regions, where before them not a single ship had passed, nor a single airplane. Thus they have shed much light on the problems of the Soviet explorers, which problems were set for them by the XVIII Congress of the Party and personally by Comrade Stalin: to transform the Northern Sea Route into a normally functioning sea magistral (main line). page 213

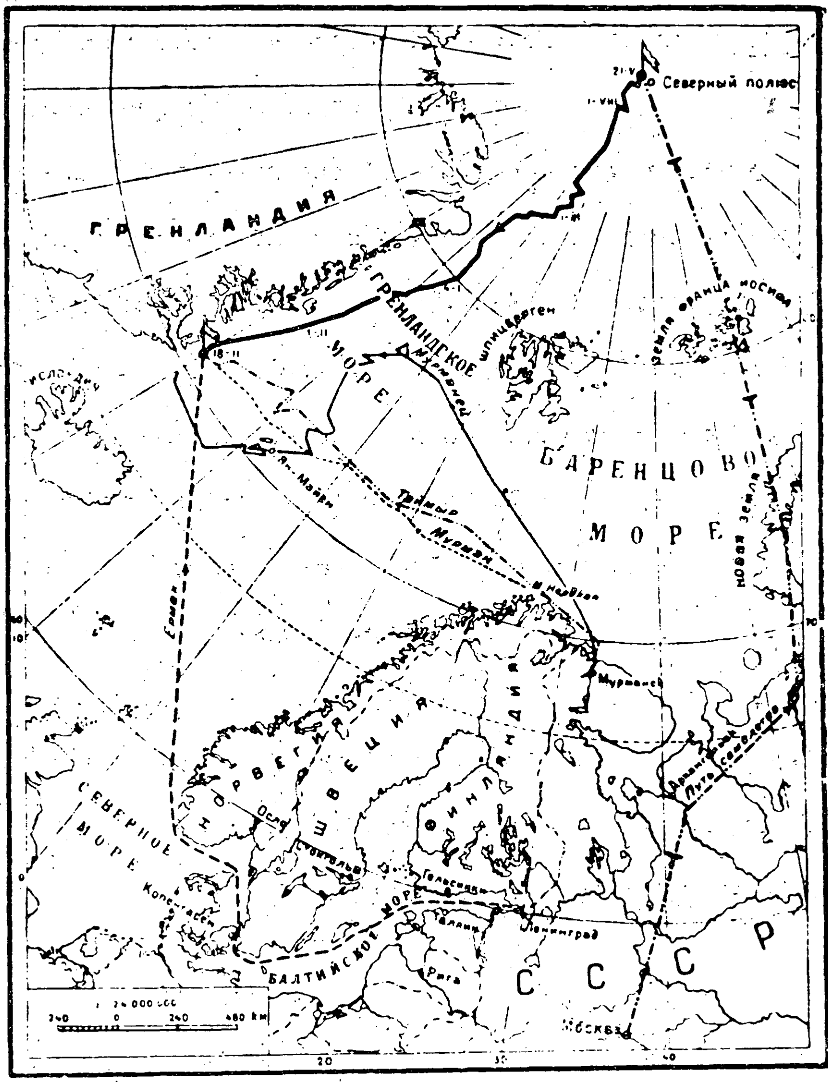


Fig. 5. Map of the Drifting Station "North Pole"

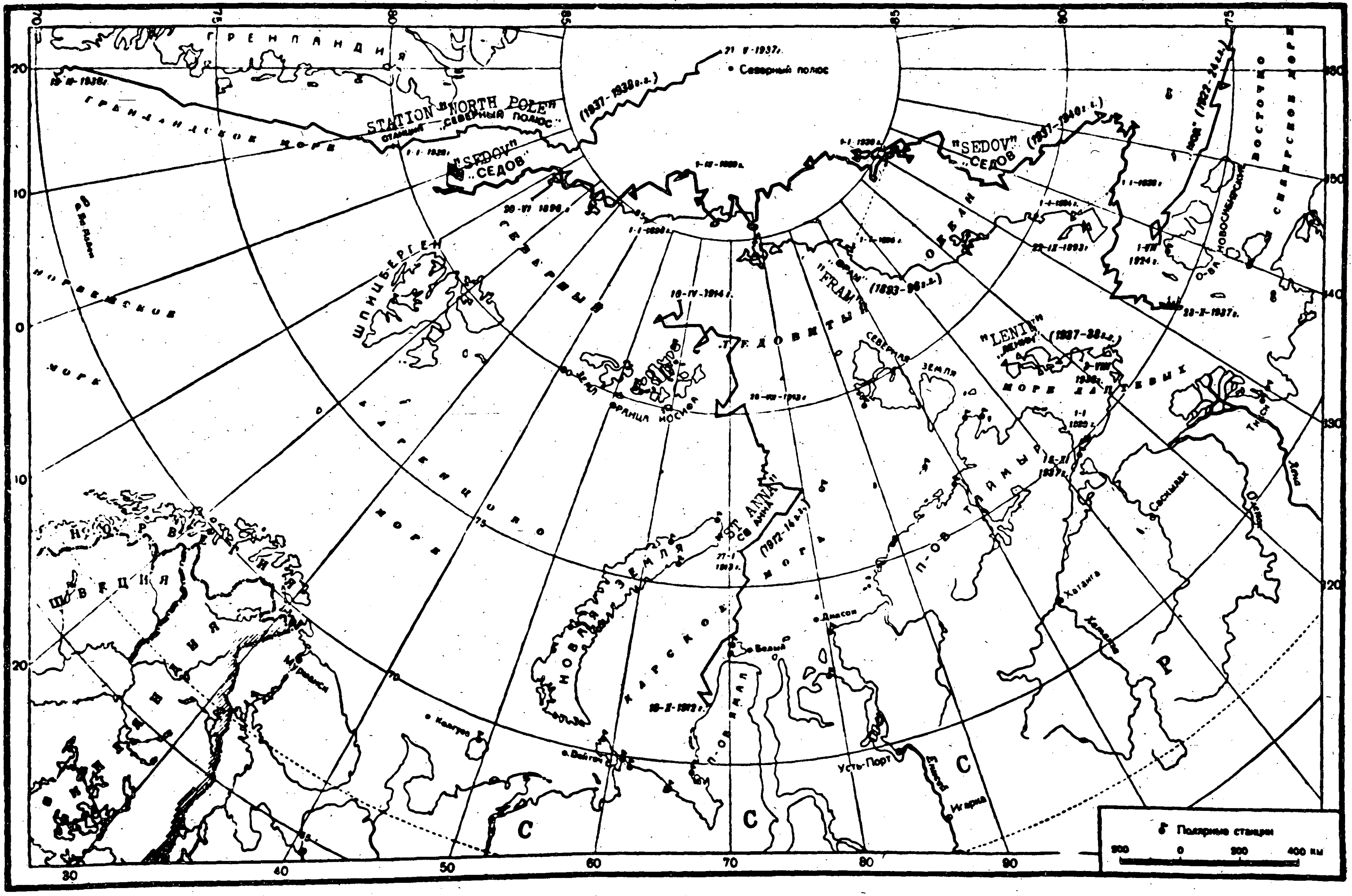


Fig. 7. Scheme of the Drift of Ships in the Arctic Ocean

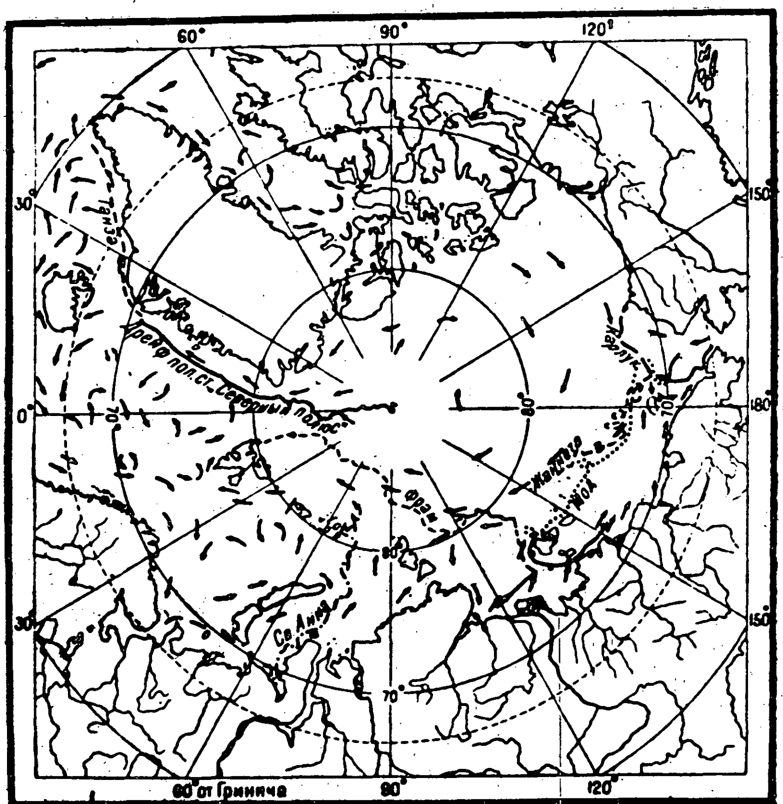


Fig. 28. Map of ice drifts and of surface currents of the Arctic Ocean.

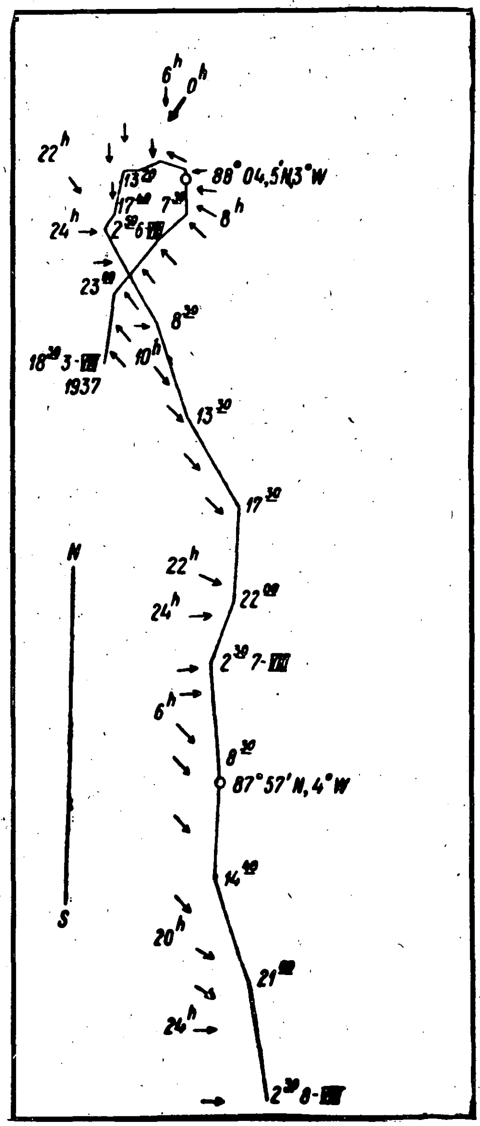


Fig. 29. Relation between the action of the wind and the drift of the station "North Pole" from 3rd. through the 8th. of August, 1937 (according to Shirshov). The speed of the wind is not indicated in the illustration.

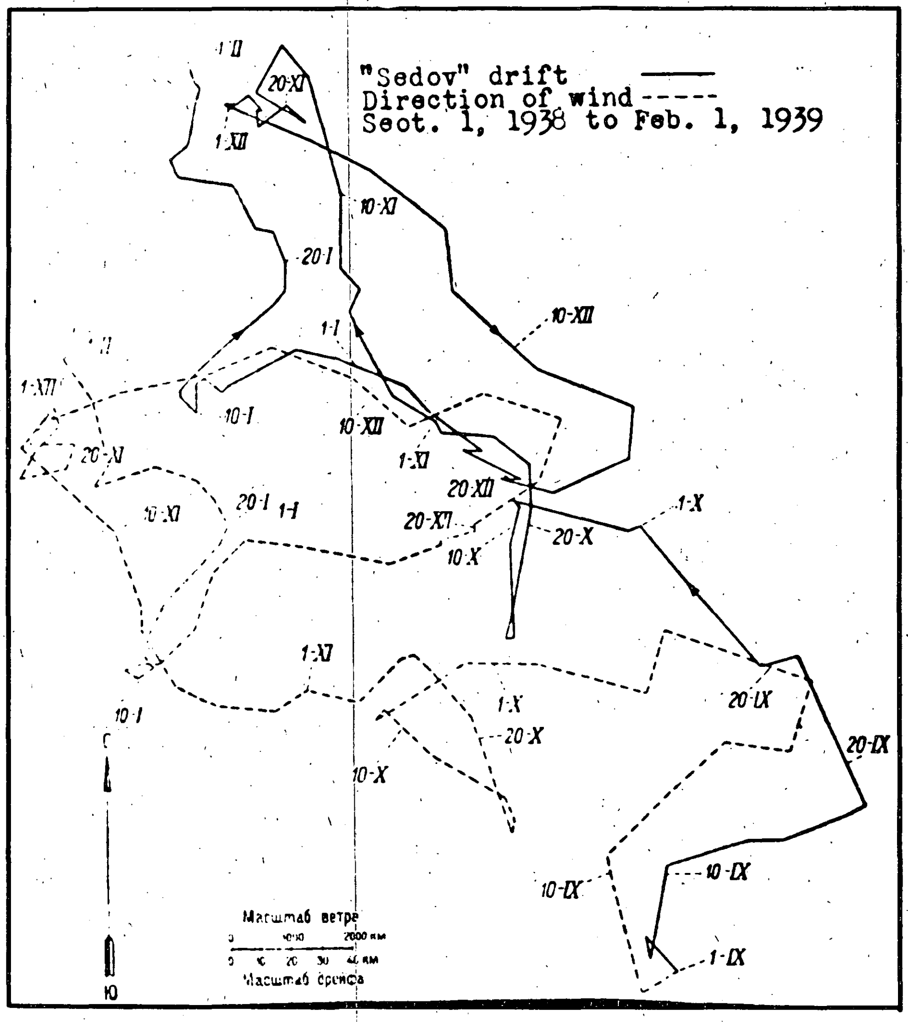


Fig. 30. The scheme of the drift of the Sedov and the direction of the wind from September 1, 1938, through February 1, 1939.

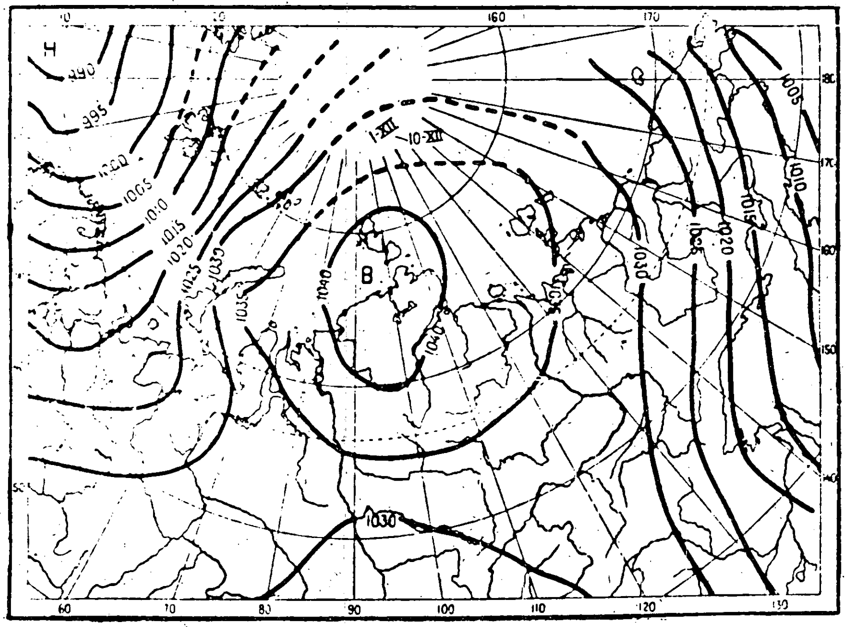


Fig. 31. A chart of distribution of pressure in the Arctic for the first ten days of December, 1938

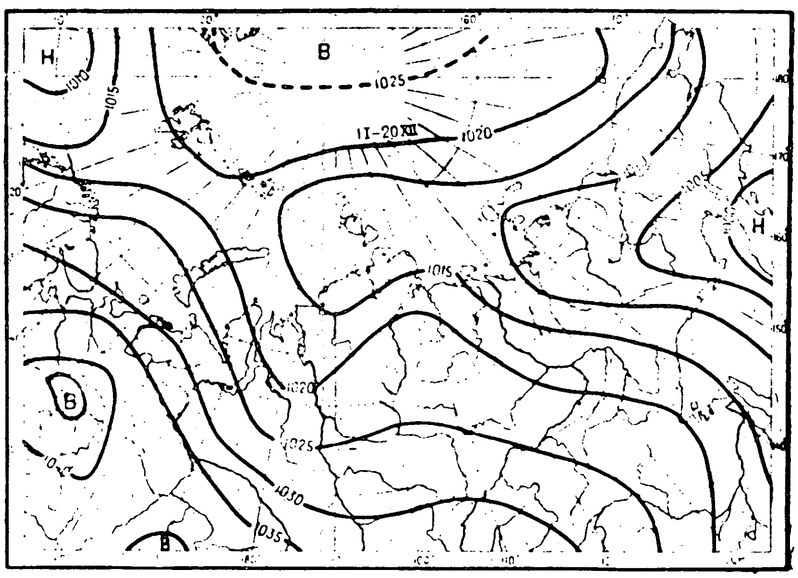


Fig. 32. Chart of distribution of pressure in the Arctic for the third ten-day period of December, 1938

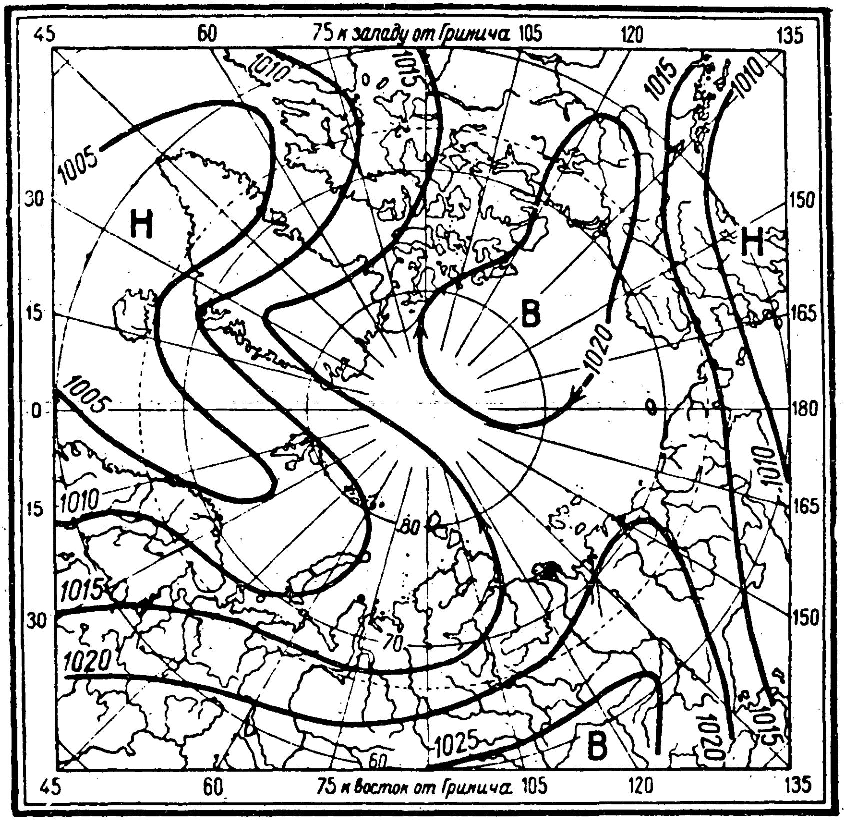


Fig. 33. Chart of the distribution of mean atmospheric pressure, in millibars, during winter in the Arctic. The arrows show the basic movement of the ice

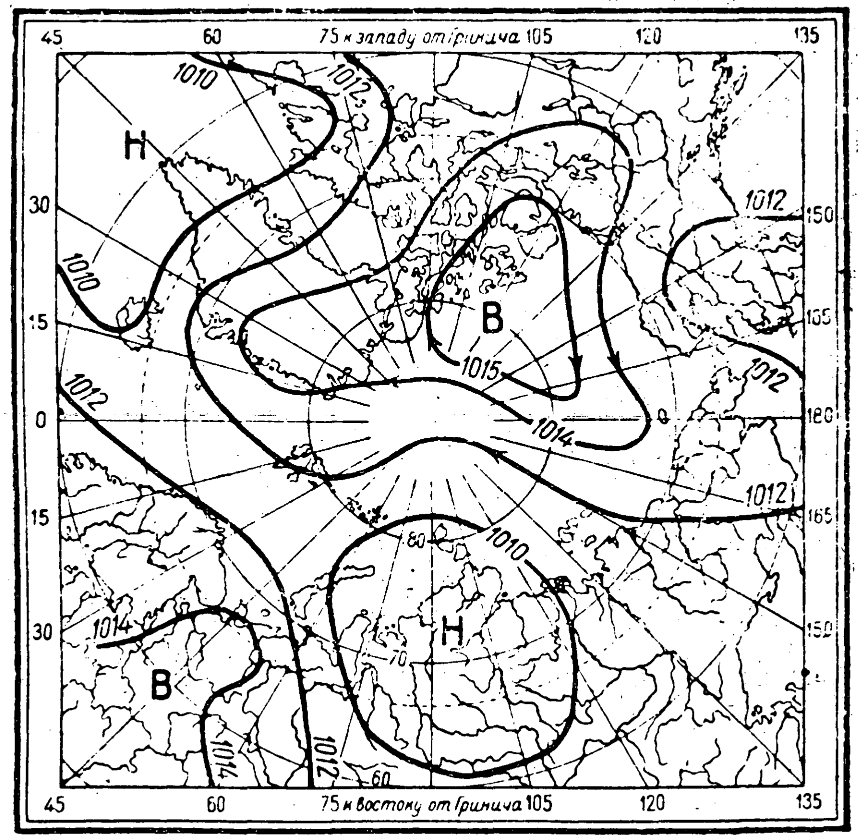


Fig. 34. Chart of distribution of the mean atmospheric pressure, in millibars, in the Arctic during summer. The arrows indicate the basic movement of ice.

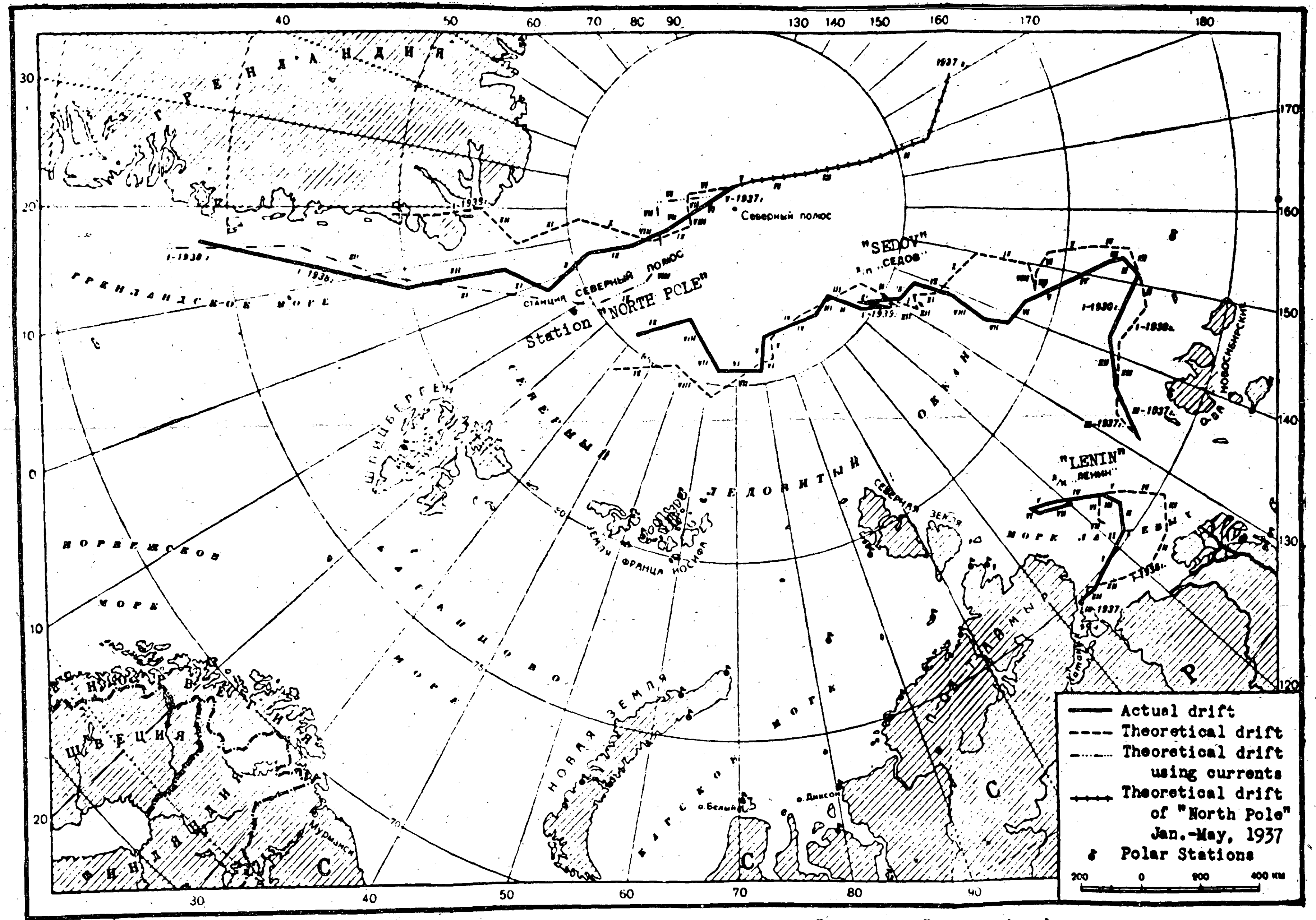
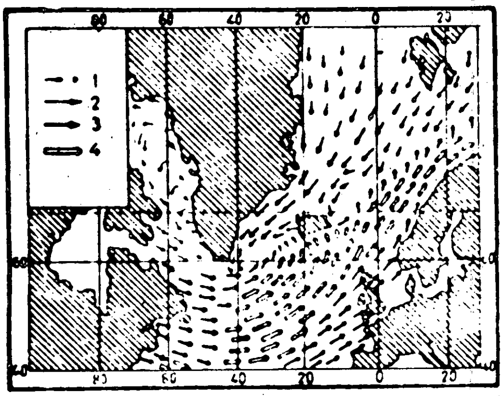


Fig. 35. Actual and theoretical drifts of the station "North Pole" and icebreakers <u>Sedov</u> and <u>Lenin</u>

Jan. & Feb.



July & Aug.

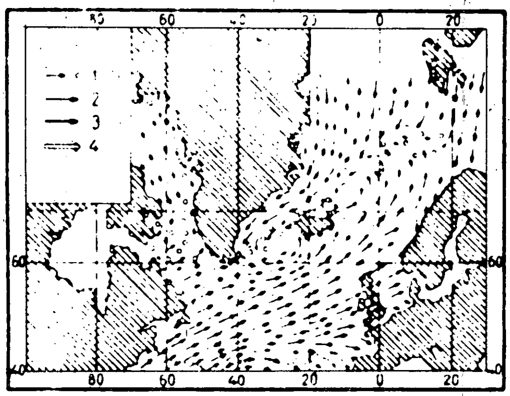


Fig. 36. Distribution of winds, according to their force and direction, over the northern part of the Atlantic Ocean and the North European (Greenland) Sea in January and February. The thickness of the arrows corresponds to verious speeds of wind: 1 - less than third degree; 2 - from third to fifth degree; 3 - from fifth to sixth degree; 4 - higher than sixth degree*.

*These degrees, or grades, may refer to the Beaufort Scale of winds. (Note by Stefansson)

Fig 37. Scheme of currents on the surface of the Greenland Sea. (Nansen)

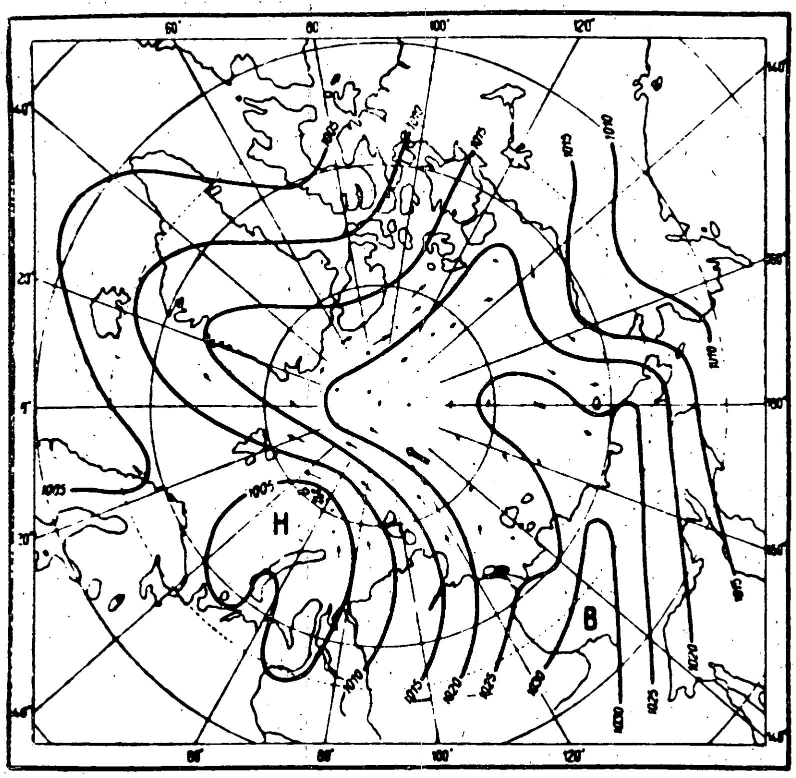


Fig. 38. A map showing the average monthly atmospheric pressure over the Arctic basin in January 1939.
The arrows indicate the drift of the ice; double arrow - the actural drift of the Sedov.

AIR EXPEDITION TO HIGH LATITUDES OF THE ARCTIC IN 1941

by D. B. KARELIN

Izvestia Vsesoyuznovo Geograficheskovo Obschestva,
No. 3, Vol. 77, 1945, P. 164 ff.

Translated At The Stefansson Library

FOREWORD

The following article is especially important in that it indicates the type of flying and landing conditions (with respect to operation of a moderately heavy plane) which may be encountered near that central area which is the most inaccessible part of the Arctic Sea. This area is well described by words and map in Stefansson's "The Friendly Arctic", pp. 8-9 and 757 - 762.

AIR EXPEDITION TO HIGH LATITUDES OF THE ARCTIC IN 1941

The vast unexplored area with the "Pole of Inaccessibility" in its center, occupies about 2.2 million square kilometers, the equivalent of 25% of the entire surface of the Arctic Ocean.

An air expedition headed by the flyer Cherevichy was organized by the Glavsevmorput in 1941 for a survey of the unexplored area. The following scientists of the Arctic Institute took part in it: Hydrologist Y. S. Libin, in charge; magnetician-astronomer M. E. Ostrekin, and hydrologist-actinometrist N. T. Chernigovski. The plan of the expedition was worked out by the Arctic Institute in conjunction with the Administration of Polar Aviation. The scientific equipment was prepared by the Arctic and Astronomical Institutes, and consisted of 50 different pieces of apparatus weighing a total of 460 kg. The expeditional and other equipment and food supplies weighed 1,280 kg. The flying weight of the plane totaled 24.5 (metric) tons. By order of the Glavsevmorput, in addition to special tasks, the expedition was to do high latitude ice scouting.

The flight stages were:

March 5, 1941: Flight from Moscow to Archangel

March 6: Flight from Archangel to the Kara Sea coast.

March 7: Crossing of the southwestern part of Kara Sea and landing on Cape Zhelanya, Novaya Zemlya.

March 9: Flight from Cape Zhelanya to Franz Josef Land. Beyond the narrow strip of landfast ice bordering on Novaya Zemlya, there lay a 100-mile area of rather scattered ice. There was clear water and scattered ice in the vicinity of Rudolf Island (most northerly of the Franz Josef Group).

March 14: The plane crossed from Rudolf Island to Cape Molotov, northernmost extremity of Severnaya Zemlya. Part of the sea was packed with last year's ice; part of it was covered with young ice, which had not yet formed so as to close all leads. The ice conditions turned out to be varied. There was no polar pack, characteristic of high latitudes of the Arctic, which was evidence that local ice was being driven northward out of the Kara Sea. Were the drift in the opposite direction, from north to south, the expedition would have encountered old ice.

Upon reaching Cape Molotov, the plane headed southward along the eastern shores of Severnaya Zemlya. No winter observations had ever been made before in this region. The limits of the extension of landfast ice were determined for the first time; the average number of icebergs forming from local glaciers was also determined. The greatest number of icebergs was found in the Strait of the Red Army, where there were up to 80 in an area a mile square. Beyond the landfast ice was a wide lead, apparently of recent formation, as no young ice had as yet formed over it.

Landing on Cape Chelyuskin proved very difficult owing to the rough surface of the airfield, which was covered with large, hard snow sastrugi. A take-off with full load therefore seemed dangerous. So, on March 17, the plane took off with a part load of fuel, landing in Kozhevnikova Bay, where it filled up to capacity and took off for Kotelny Island on March 18.

In the course of this hop, icebergs were encountered around meridians 114°-116°, i.e., 100-130 miles east of Severnaya Zemlya. These icebergs may, to a certain extent, yield information as to currents and ice drift in the western part of Laptev Sea.

Numerous and wide leads were seen around meridian 132°. Their location coincided with the borderline between the continental shelf and oceanic depths, which goes to confirm the theory that ice is sparser over the continental shelf than over the deep sea.

On March 20th the plane covered the longest stretch, from Ketelny Island to Wrangel Island, 1,500 km. Its course lay partly across a previously unexplored area. A strong head-wind lowered the speed to 150 km. per hour. A great amount of pack ice was seen between latitudes 76° 30' - 76° 00' and meridians 164° 30' - 166° 00'. On parallel 75° 30', between meridians 164° 30' and 166°, there was observed a curious strip of ice broken into small floes; in places there was even finely crushed ice, conspicuous amongst the large fields that are typical of this area. Small icebergs were also seen.

The results of these observations may be far more significant than seems at first sight. Small floes and crushed ice could have formed in the event that land or a shoal was forming an obstacle across the path of drifting ice fields. Only as a result of the pressure of the fields against such an obstacle could the ice have been broken up and crushed over so wide an area. More significant still is the presence of icebergs, which means that glaciers have slid down from some neighboring land. Judging by predominating winds and currents, the icebergs could have come drifting from southeastward, i.e., from the area of the "white spot" around latitude 74°. This may lead to the re-emergence of the theory of "Andreev's Land", which appeared about 200 years ago (1763-4) and was discarded in recent times after numerous flights into the region.

In view of this recent discovery of crushed ice and icebergs, it is necessary to explore the "white spot" before definitely discarding the existence of Andreev's Land. It can be argued that what may have been mistaken for icebergs by the observers were iceberg-like formations of paleocrystic ice, old shoal ice (stamukhi), or floebergs. But, even in such case, one should infer the presence in this area of an extensive shoal hampering the free movement of ice.

On the return flight, by order of the Arctic Institute, the course of N-169 lay across the "white spot"; but poor visibility prevented extensive observations. In 1940, Cherevichny had also been hampered in his observations by fog when flying over the same "white spot".

After landing in Rodgers Bay, Wrangel Island, the Cherevichny expedition was held up by a severe snow storm lasting 10 days. They finally took off on April 3, and after a flight of 6h. 55m. they landed on a drifting ice floe in Latitude 81° 04' N. and Longitude 178° 20' E., after penetrating 800 km. deep into the unexplored area. Pack-ice was first encountered near latitude 73° 55', and the border of predominating pack-ice around Latitude 75° 20' N. Large leads extended throughout the ice fields which were up to 10 km. wide and 45 km. long. These were covered with thin young ice.

The very first observations yielded unexpected results; the ice floe was only 196 cm. thick. This meant that the ice was no older than 1-1/2 to 2 years, and that this floe was not yet actually old pack-ice. (It may be mentioned for comparison that, in Rodgers Bay, ice of autumn formation was (by spring) 165 cm. thick.) This, in turn, refutes the theory advanced by a number of scientists, that in the region of the Pole of Inaccessibility, ice takes part in an enclosed circular movement, remaining in high latitudes for a long period of time (many years), therefore acquiring considerable thickness and changing into paleocrystic ice. According to the observations of the expedition, the fact is that the ice is being rapidly carried out of the region, and apparently takes part in the general drift out of the polar basin into the Atlantic. This is also evidenced by the extensive leads, encountered almost everywhere by the expedition.*

The expedition measured a depth of 2,647 m.; later, when the floe had drifted 25 miles northward, they got 2,427 m. Greater depths had been expected here, for Wilkins, sounding 360 km. to southeastward, had obtained a depth of 5,440 m. (in 1927). The observations of the N-169 expedition lead us to doubt the Wilkins results, but are not sufficient for refuting them.**

Upon comparing all depths registered by the N-169 expedition, the conclusion may be reached that the sea bottom inclines to southeastward about $1/4^{\circ}$. Taking this angle as a basis, it may be presumed that, at the point of the Wilkins airplane landing the depths were about 4,800 m. If this angle is allowed to increase to $1/2^{\circ}$, a Wilkins depth of 5,440 m. is probable enough. It may be observed that such an allowance is within the limits of a grade usual for the ocean bottom. The observations of the ice-breaker Sedov, which drifted in the Polar Basin, showed a number

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* The view expressed by Stefansson has been that if there is the discussed eddy then it will lie between the Point Barrow meridian and the Banks-Borden Line of island coasts (therefore perhaps near 76° or 78° N., 135° or 140° W.), not at the Pole of Inaccessibility. (Note by Stefansson).

** The Wilkins-Eielson sounding was taken by the echo method and so presumably was open to error. (Note by Stefansson).

of sharper changes of depth, as well as an increase of the angle of inclination to as much as 1-1/2° or even 2°.

The plane spent more than 4 days on the first floe. During this time hydrological work was done at 2 stations, a round-the-clock station observing the currents in connection with 2 horizons. Magnetic, gravitational, meteorological and hydrobiological observations were carried out and samples of water were collected for chemical analysis. Observations of water temperature revealed the presence of a layer of warm waters of (doubtless) Atlantic origin at a depth of 275-900 m. Thus was confirmed the hypothesis of the extension of these waters over the entire deep area of the Polar Basin. The drift of the ice-floe during the 4 days may be traced by the coordinates (Table 1).

Table 1 - Location of Ice Floe No. 1

Date	Coordinates Latitude	Longitude	Depth in meters	Wind (Force in points)	Temperature of air
Apr.3	81° 04' N.	178° 20' W.	2647	SSE 3	-28°
Apr.5	81° 17' N.	179° 58' W.		E 4	-27°
Apr.6	81° 29' N.	178° 30' E.	2427	E 5	-19°
Apr.7	81° 37' N.	179° 00' E.		ENE 4	-21°

On April 7 the plane took off from the floe and, after a flight of 7h 52m. it landed on Wrangel Island, where it unloaded part of its equipment and left Ostrekin and Chernigovski for the computation of collected data. The plane then took off for the base on Cape Schmidt.

A second flight was carried out April 13th, when the plane returned to Wrangel Island to pick up Ostrekin and Chernigovski, together with their equipment. It flew northward for about 6 hours. Upon nearing the area decided on, the plane spent 40 min. hunting for a floe suitable for landing. The coordinates of the landing spot were 78° 26' N. and 176° 40' E. Owing to a quartering head wind and low ceiling, which prevented astronomical observation, the plane had deviated 40 miles from its course, westward.

All scientific observations were repeated on Floe No. 2. The depth was 1,856 m. which testifies to the considerable extension of the continental shelf in the region of Wrangel Island. A polar bear and a white fox were seen in the vicinity of the floe. Meteorological conditions were very similar to those on Floe No. 1. The second floe was located in the zone of the polar maximum, which accounted for calm weather, the consequence being that the drift was very insignificant. (See Table 2)

Table 2 - Location of Ice Floe No. 2.

Date	Coordinates Latitude	Longitude	Wind (Force in points)	Temperature of air
Apr. 13	78°26' N.	176°40' E.		
Apr. 14	78°30' N.	176°40' E.		
Apr. 15	78°27' N.	176°00' E.	NNE 1	-21°
Apr. 16	78°27' N.	176°03' E.	NE 4	-19°
Apr. 17	78°27' N.	176°00' E.	ENE 2	-24°

High atmospheric pressure was registered, over 1,040 mb (as against 1,020 on shore).

April 17 the N-169 left the floe and returned to Wrangle Island, the flight lasting 6h. 10m.

April 23 the expedition started out on its third flight. When they reached the desired area the search for a landing spot took 2 hours and the plane landed after 9 hours in the air. The ice was about 1.50 m. thick. All scientific observations were again repeated. Depths were 3,451 m. The drift of Floe No. 3 is shown on Table 3.

Table 3 - Location of Ice Floe No. 3.

Date	Coordinates Latitude	Longitude	Wind (Force in points)	Temperature of air
Apr. 23	80°00' N.	170° 00' W.	N 4	-19°
Apr. 24	79°54' N.	169° 48' W.	N 4	-20°
Apr. 25	79°53' N.	169° 35' W.	NNW 3	-18°
Apr. 26	79°53' N. (?)	169° 35' W. (?)	N 2	-20°
Apr. 28	79°53' N.	171° 44' W.	N 1	-23°

Much time had to be spent by the crew to smooth a path for the take off.

The plane returned to Wrangel Island on April 29th. Ostrekin and Chernigovski remained there while the plane flew over to Cape Schmidt. Thus ended the expedition to the Pole of Inaccessibility. Seven thousand kilometers had been covered and 15 days had been spent on drifting ice in the central Arctic basin.

May 2 the N-169 flew over to Anadyr and back to Cape Schmidt. May 3 she visited Wrangel Island and took off for Kotelny Island on May 5th. The ceiling was low, there was fog from time to time, and snow. Between meridians 171° and 165° E., in the "white spot" area of polar pack, leads were encountered; on meridian 155° table- like icebergs were seen. The origin of these remains just as mysterious as that of the icebergs seen on March 20 north of the "white spot." It is hard to believe they came from the De Long Islands, as in that case they should have drifted 200 to 300 km. against the wind and current.

May 6 the N-169 took off and reached latitude 79°, skirted the shores of Severnaya Zemlya, crossed Vilkitski Strait twice, and landed at the mouth of Taimyr River. In the Laptev Sea much pack ice was encountered, testifying that there recently had been a drift from north to south instead of the usual northward drift. This circumstance was significant for a long-range ice prognosis.

May 7 the plane landed on Cape Zhelanya; after a 12 minute stop it took off again and reached Matochkin Shar the same day.

May 8 the N-169 was in Amderma, thus beating the record for speed along the Northern Sea Route.

In Amderma skis were changed to wheels. On May 9 the N-169 was in Archangel, on May 11 back in Moscow. 8,500 km. had been covered on this part of the journey, of which 5,500 km. were over Arctic seas.

In 68 days the plane had covered a total of 24,000 km. of which 19,000 km. were over Arctic ice. Altogether 22 days had been spent in flying, 15 on drifting floes; 31 days were used up in waiting for good weather conditions, in preparations and in the preliminary study of observations.

The unexplored area of the Arctic sea is now a quarter of a million square km. less than previously. There are numerous other scientific results. The Arctic Institute's plan of surveying the Arctic by means of a "flying laboratory" has proved feasible and successful.

AIRFIELDS ON ICE

by G. Volkov

"Morskoi Sbornik", No. 3, 1940, p. 77-88

Translated At The Stefansson Library

Footnotes and some parenthetical material have been supplied by the translator and by the editors.

AIRFIELDS ON ICE

In winter, when the aquatoria* freeze, hydroplanes may change their water-landing gear to skis, allowing them to pursue their work using an ice airfield as their base. The use of an ice airfield brings up the question of determining the thickness of the ice which may ensure the safe landing and take-off of hydroplanes. This depends on the weight of the plane, on the strength of the ice and on the weight per square cm of the runners.

The study of the mechanical qualities of ice has been taken up but quite recently in connection with the building of ice crossings over rivers for railroad trains (HTY HK C, Ice Crossings, Transpechat, M. 1929; A. N. Komarovski, The Structure and physical properties of the ice cover of fresh water. State Energetics publications, M.-L. 1932) As regards ice airfields, experiments were carried out on the solidity of ice by the "HUU" of the Civil Air Fleet. The results were published in a book by engineer N. N. Kashkin "Investigation of the work of Ice Airfields when under the load of a plane". We shall borrow his methods to aid us in our computations.

Conditions of Ice Formation.

The formation of ice is a consequence of the freezing of water. Fresh water solidifies (changes into ice) at a temperature of 0°,; sea water freezes at lower temperatures. This phenomenon is due to the degree of salinity of the water. It has been discovered that:

a) The more salty the water, the lower will the temperature of freezing be below 0°C.; the maximum density of salt water occurs at a temperature below -4°C.;

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* "Aquatoria" = Water areas used as landing places for airplanes.

b) When ice forms, not all of the salt is included in the ice; part of the salt remains in the water increasing the density of the upper layer of water and thereby provoking intensive convection.

In addition, the swell, which is very frequent in winter, also delays the formation of continuous ice.

From the data supplied in Table I, showing that the temperature of freezing and of maximum density depend on salinity, it is apparent that, as the salinity of water increases, the temperature of maximum density approaches the freezing temperature and, when salinity reaches 24.7 0/00, these temperatures coincide.

Table I

Salinity 0/00 (Parts per 1000)	Temperature of freezing °C	Temperature of maximum density °C
0	0	3.98
5	- 0.3	2.9
10	- 0.5	1.9
15	- 0.8	0.8
20	- 1.1	- 0.3
24.695	- 1.332	- 1.332
25	- 1.35	- 1.4
30	- 1.6	- 2.5
35	- 1.9	- 3.5
40	- 2.2	- 4.5

Thus, when salinity is below 24.7 0/00, freezing is similar to that of fresh water: while the temperature of the water is falling, there occur convection currents, which cease the moment maximum density is reached; only in the upper layer does the temperature fall to the freezing point and ice forms on the surface of the water. When salinity of water is 24.7 0/00 or more, convection currents continue up to the moment of freezing; consequently, down to the very bottom the water cools down to freezing temperature.

The de-salting of the upper layer of the sea by waters from the rivers flowing into the sea, and the snow, falling onto the sea, both contribute to the freezing of seas.

When water which is in the process of cooling has reached a definite temperature (depending on the degree of concentration of salt in it), it produces crystals of ice, or ice needles, which contain fresh water as it is the pure solvent alone that freezes; whereas the salts dissolved in the water are ejected, increasing the density of the water which has not yet frozen. The crystals of ice are distributed on the surface of the water, or may penetrate to a certain depth.

The further formation of ice occurs by means of the freezing together of the ice needles into thin films floating on the surface of the water; these may also form patches of a gray-leaden color which are called "salo", slush (or lard ice).

On calm water, slush (salo) freezes together, forming a translucent, ice crust called "nilos". This ice crust is hard and sharp, and breaks easily in the wind.

On a sea rocked by a swell, but in the absence of a strong wind and of considerable waves, the freezing of slush (salo) occurs simultaneously in several centers, which are so to speak foci of further freezing (centers of crystallization). This results in the appearance of discs of ice, 50 cms or more in diameter, which are termed pancake ice.

When the wind and swell are strong enough, the slush (salo) breaks up into young ice (shuga). If snow falls on the cooled water, there forms a pasty ice called "snezhura".

In low temperatures, and even in the presence of wind and swell, and as a result of crushing and continued freezing, "shuga" and "snezhura" also form pancake ice. Its edges are turned up, they have a fringe of small ground ice, resulting from friction.

The further formation of ice occurs as a general rule by way of freezing together and of thickening of pancake ice, of shuga and of snezhura. There then forms "molodik" - young ice: it is of a light color, grayish, several cms thick, and humid with brine. Smooth ice forms both at sea and near shores. In the latter case it freezes to the shore in the guise of landfast ice ("zabereg"); thereafter, spreading seaward, it forms stationary level ice, denominated "pripai" -fast ice. The thickness of level ice depends on physico-geographical and hydro-meteorological conditions in the given area.

After the formation of a continuous ice cover, the further growth of ice occurs from below, by way of yielding heat to the atmosphere through the thickness of the ice. In consequence of the low thermal conductivity of ice (its coefficient is 0.005), and of the increased salinity of the water (pro duced by the salts ejected in the formation of ice) the growth of ice pro ceeds very slowly. Even in polar regions ice reaches a thickness of no more than 2 - 2.5 ms (6-1/2 - 8 feet) in the course of winter.

In the beginning, while the ice is still thin, its presence does not affect the amount of heat, which the sea yields to the atmosphere (given a certain determined difference of temperature between them.) However, when the layer of ice reaches a thickness of about 15 cms (6 in.), the situation changes; the amount of heat which, in the given difference of temperature between air and water, might have been yielded by the sea, cannot pass through the ice, even if the thickness of ice is but slightly above the limit figure mentioned.

Under the action of wind, swell and currents, level ice is broken up, forming fragments which vary in size and character.

Large areas of floating ice, whose length surpasses 2 kms (1 - 1/4 miles), are termed ice fields. In the course of further destruction of an ice field, there result fragments of ice fields extending to 200 - 2,000 ms (1/8 to 1 - 1/4 miles). Direct destruction of stationary ice or of an ice field, and the gradual destruction of fragments of ice fields results in the formation of large broken ice from 20 to 200 ms (65 to 650 feet) in breadth, and of smaller broken ice, less than 20 ms (65 feet) in breadth.

Large broken ice may also form by way of the freezing together of considerable enough fragments of ice.

When mixed with slush (snezhura) and young ice (shuga), small broken up ice forms ice kasha (sludge). At the ice brink (edge of ice) sludge (kasha) accumulates in a layer which may reach several ms.

The destruction of level ice by the forces of wind, swell and currents is not limited to its breaking into small fragments. The constant shocks and pressure (of floating ice on stationary ice and of separate ice fragments on each other) result in the piling up of accumulations of various aspect and character, namely: "ropaki" - separate ice fragments standing upright on the level surface; "torosy" - hummocks, which are accumulations of ice fragments frozen together, extending in ridges or in the guise of seperate massifs; "stamukhi" - accumulations of large fragments considerable in size and grounded on a shoal or on land; "sikozak" - the result of several raftings of ice floes lying flat on top of each other.

The elevation above the water surface of the floating part of the ice is of considerable interest in the case of air operations. For hummocky ice, the above-water height as a general rule corresponds to 1/3 - 1/4 - 1/5 of the total thickness of ice. On an average, the above water parts of hummocks rise to 2 - 3 ms (6-1/2 - 10 feet), but may also reach a height of 10 - 12 ms (33 - 39 feet), and sometimes even more.

The character of the snow-cover depends on the amount of fallen snow, on the winds, and on the relief of the surface.

Very often, the snow-cover is rough and uneven, and only in rare cases is it level and smooth. Sometimes there is no snow at all on the surface of the ice.

In regard to configuration, the unevenness of the snow covering may be divided into "zastrugi", "sugroby" (snow drifts and "nadduvy".

"Zastrugi" (Fig. 1) rise above the surface of the snow blanket in the form of mounds, rising in the direction of predominating winds, and sloping towards the horizon (at an angle of several degrees). On the lee side these mounds have extending tongues and end in rounded ravines. When the extending tongues reach a considerable size, they break off. They may be several decimeters in length. Usually, the height of a "zastruga" does not surpass 0.5 meters (20 in.). With "zastrugi" on a field, a plane should not attempt a landing against the tongues, as it is dangerous and may end in capsizing.

"Sugroby" -snow drifts, are regular and sloping mounds rising above the surface of the snow cover. Their formation results from the considerable unevenness of the ice surface. Encountering an obstacle, the wind-driven snow is held up and thickens on the windward size of ice massifs. On the lee side, the particles of snow which have lost their speed, accumulate immediately behind the hummock, forming a heaped up snow drift. In time, the uneven parts fill with snow both to windward and leeward, and the snow drifts acquire a streamlined shape, with slopes varying in height and steepness.

"Nadduvy" are formed in the hollows between upright ice fragments, filling the hollows and uneven parts with snow. In the process of their formation "nadduvy" may remain empty; this depends on meteorological conditions and on the character of the ice massif which is being filled with snow.

A smooth surface of the snow covering occurs on level, smooth, young ice, when no strong wind is blowing during the snowfall. The thickness of the snow covering may reach 20 to 30 cms (8 to 12 inches) in the vicinity of the shore.

Bare surfaces occur on level ice as an exception, and only on separate spots; usually the surface of the ice is covered with crystals of salts and, consequently, by a thin film of brine. The snow is therefore not blown away, but covers the ice with a layer of insignificant thickness and intermixes with the brine. A landing on ice, which is covered with crystals of salts, may result in the capsizing of the plane owing to the increase of the coefficient of friction between the runner (ski) and the ice surface.

On open, level spaces, subjected to the action of predominating winds, the snow blanket is densified, as though it were compacted. On an intersected surface (one crossed by ridges), in the midst of hummocks, the snow is protected by the latter and is therefore not being compressed by the wind-it remains fluffy to a certain extent, particularly on the lee side of the ice massifs.

River ice forms in rivers and in their estuaries during the winter season. In consequence of the rising of water, thin ice "nilos", may sometimes form on the surface of the ice - it breaks easily under the skis of a plane.

Sea ice differs in structure from river ice, mainly by its viscosity and plasticity. Crystals of salt and bubbles of air are contained in it.

The specific gravity of sea ice is about 0.9; given a regular geometrical shape, the ratio of the above-water part and the submarine part equals 1:7.

Ice melts and becomes water at the temperature of 0°C., provided however, that the atmospheric pressure equals 1 atmosphere; with a rising pressure, the freezing point of ice falls. Thus, given a pressure of 1,000 atmos., the freezing point would drop to -7.5°, and to -22.5°, given a pressure of 3,000 atmos.

The connection between the change in specific gravity at the time of melting, and the change of the freezing point, is conditioned by the fact that, if a body expands when freezing, an increase of pressure necessarily hampers this expansion. It is therefore necessary to cool the body further in order to bring the molecules closer together and provide space for expansion. This is achieved by a lowering of temperature.

The variation of specific gravity is dependent on pressure, and on pressure too depends the density of ice. When thawing (melting?), ice reduces its volume, and consequently, increases its density; on the contrary, when hardening (forming?), it increases in volume and correspondingly loses in density. In consequence, ice is lighter than water and therefore floats on its surface. At a temperature of 4°C., the volume of water equals 1; at a temperature of 0°C. it equals 1.00012; at a temperature of 0°C, the volume of ice equals 1.09082. The difference is 0.09070, i.e. above 9%.

The Ice Cover When Subjected to the Action of a Dynamic or Static Load.

In order to ensure the safe use of an ice airfield, the latter must satisy the following requirements:

1) The working surface of the airfield should not be subjected

to hummocking and neither to the formation of "nadduvy";

2) The ice cover must possess sufficient solidity to stand the frequent dynamic load of the shock from the skis of the plane when landing, as well as the static load of the plane itself when it is grounded on the ice.

The study of the methods of computation is based on the following premises; ice is taken as an elastic body, subject to Hooke's law in the event of minor tension (strain), and possessing definite physical and mechanical properties. These premises are based on:

1) The fact that the dependence of deformation and tension on the load is subject to a certain law of proportion;

2) The insignificance of the length of the curve of deflection caused by the load, as compared to the size of the ice surface of large rivers and lakes;

3) The reestablishment to a certain, but not complete degree, of the deflection, after the load has been withdrawn.

However, the idea that ice, being an elastic body, possesses properties of solidity, is purely conditional, and necessitates the acceptance of a considerable coefficient of reserve of solidity (factor of safety), and this derives from peculiar physical properties which distinguish ice from other materials.

These properties are:

1) Considerable variation of the elasticity of ice, depending on its temperature;

2) The plasticity and viscosity of ice which allow considerable residual deformations without its destruction;

3) The peculiar fact, that spring ice is capable of standing much lesser loads than winter ice, and computation must therefore be based

on a minimum norm.

When determining the forces of tension in ice floating on the water, we consider: either a centralized load (Fig. 2), or a load distributed on a more or less limited area and producing local deflection in the sheet of ice (Fig. 3).

The weight of the ice itself and the weight of the snow covering the ice are not taken into consideration, because these represent a load regularly distributed over the entire area of the ice, and resulting in a uniform immersion of the entire sheet of ice deeper into the water (following the law of Archimedes), without producing any deflection of the ice-sheet (Fig. 4).

The fall of the load G from the height h, hits the surface of the ice with force P. The force of the shock provokes the deflection **f**. As action equals counteraction, the force of reaction of the ice, R, is equal in magnitude to force P and bears a contrary sign (Fig. 5):

$$R = r_1 + r_2 = -P,$$

r_1 being the inertia of the water mass, and r_2 the force of action of the internal elastic forces of the ice sheet. Similarly to force P, forces r_1 and r_2 increase with deflection from zero to the maximum. Thus, in usual conditions, part of the force of the shock is assumed by force r_1, and part by force r_2.

If the water, in which the ice floats, were enclosed in a hermetic container, no deflection f would occur in consequence of the incompressibility of liquids; the pressure of the ice would be transmitted through the liquid to the walls of the hermetic container in the way it occurs in a hydraulic press (Fig. 7).

In natural water basins of considerable size (rivers, ponds, lakes), let alone seas, no tightly enclosed masses of water are ever encountered (there are openings between the ice and the shoreline, cracks in the ice, etc., through which the water may emerge from under the ice). Therefore, the mass of water subjected to the action of a shock on the ice, is speeded up; the pressure of water on the ice from below surpasses the hydrostatic pressure and the water spouts up through an opening in the ice, as shown on Fig. 6.

The growth of the force, acquired by the mass of water under the ice, brings about the emergence of a certain force of inertia, which depends on the mass of water receiving acceleration, and on acceleration itself. This force of inertia is represented by r_1.

The movement of water below the ice enables the ice to bend. Up to the moment when the water spouts up through the openings at the time the shock is delivered, the ice works only towards compression and adherence (shear); after the mass of water has come into motion, the ice works toward deflection, accompanied by the corresponding work of internal forces of elasticity r_2.

Therefore, the more considerable is r_2, the less will be the reaction of the ice at the moment of landing, the softer will the plane land, with the least shock for its construction, but the stronger the tension (tensile stress) endured by the ice from deflection at the moment of landing.

Would it be possible to regulate the relation between r_1 and r_2? Regulating is possible to a certain extent by means of providing or closing off apertures in the ice. For example, in order to ensure the possibility of landing a plane on thin ice, it is necessary to seal up all neighboring ice-holes in order to utilize the inertia of the water for facilitating the task of the ice. On the other hand, when the ice is thick, it is necessary to increase the size of ice holes in order to alleviate the shock of the plane at the moment of landing.

The height of the column of water ejected from small apertures in the event of a dynamic load may serve as an indicator of the force of inertia of the water.

When a dynamic load is applied to it, the ice undergoes a gradually diminishing fluctuating movement.

In the event of deflection from a shock, not exceeding the limit of elastic proportionality, the elastic forces r_2, which tend to return the ice to its previous position, are proportionate to the deflection or to the distance from the stationary center.

The experiments carried on have revealed that the fluctuations of the ice decrease very rapidly from the resistance of water and air, the result being that the third deflection is almost unnoticeable (Fig. 8).

As regards the action on ice of a static load, it results in deflections; the magnitude of the deflection increasing in proportion to the load. A comparison of the results of deflections from static and dynamic loads has revealed that a dynamic load which, in magnitude, is three times greater that a static one, produces deflections of ice which are considerably smaller than in the case of a protracted static load.

Therefore, the maximum deflection, and consequently, the maximum tension (tensile stress) at the time of bending, will occur in the event of a static load, which should be considered as the least advantageous.

At the moment of landing, and depending on speed, on the work of shock absorbers, on the angle of landing and various other factors, the overload (or load?) is usually expressed by the weight of the plane multiplied by the coefficient of the overload, which equals 2-3, and only in exceptional cases 6. Therefore, taking into consideration the elasticity of the ice sheet which mitigates the shock, it may be presumed that deflection from this dynamic load will be less than deflection from a protracted static load, even in the event of an exceptionally awkward landing with an overload coefficient reaching 6.

We know that, following the growth of pressure on ice, the temperature of melting falls, and therefore a load concentrated on one spot will very rapidly sink in the ice owing to the later's melting. Protracted, concentrated loads on ice should therefore not be allowed (for example that of the tail crutch of a plane). Anyway, mats made of boards should be provided for the stationing of planes on snow and ice airfields.

As regards concentrated* loading, this may be safely applied to ice for a more or less long time.

Mechanical Properties of Ice.

The mechanical properties of ice are not constant and vary, depending mainly on temperature.

As the result of a whole series of experiments, the average tension (tensile strength) of ice undergoing deflection has been determined to vary between 22 and 5 Kg/cm^2 (313 and 71 psi). For the static (load) computation of ice, discounting a certain reserve of solidity (factor of safety), it is advisable to take the lower limit, namely 5 kg/cm^2 (71 psi), and the corresponding modulus of elasticity $E = 5,000\ kg/cm^2$ (71,100 psi).

The magnitude of destructive tension (breaking stress) from adherence (shearing) along (parallel to) crystals varies from 6 to 12.5 kg/cm^2 (85 to

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* Russian original uses term "concentrated" but it is considered that this is an error and that it should read "non-concentrated".

178 psi). As regards contact tension (tangential stress) to be allowed, it is advisable to take 6 kg/cm^2 (85 psi). The transversal force Q, which induces contact tension (tangential stress) in the ice sheet, produces a deformation in the form of an infinitely minimal side shifting of the ice layer in the plane of the vertical section without deflection; at the same time, it does not provoke the reaction of the elastic foundation underlying the ice, namely of the water.

Therefore, at the moment of landing on ice, the dynamic action of the plane's load, which provokes a threefold overloading of the plane together with the corresponding transversal force Q, is assumed (in the presence of adherence (shearing)) in full by the inner forces of ice elasticity, without any alleviation being afforded by the reactive action of the water layer (Fig. 9).

Method of Static Computation of the Ice Cover.

If the winter aquatorium of the hydro-airport has an even, smooth ice surface covered with a more or less thick layer of snow, it may be utilized as a winter airport for the takeoff and landing of hydroplanes fitted with ski landing gear. However, to allow the use of the ice aquatorium it is necessary that the ice reach a certain thickness, requisite for assuming the load arising at the moment of landing as well as at the time of parking of the plane.

The ice surface of the airfield may be considered as a sheet resting on an elastic foundation. The load of the hydroplane is not transmitted to the ice as a weight concentrated at one point, but in the form of a load transmitted to the ice at three places corresponding to two working skis and one tail ski.

Engineer Kashkin therefore uses the method of computation of an equivalent loading in the form of a continous load, distributed over the area of the circle which has radius A. The magnitude of radius A of the circle is determined by the distance between the points of support of the place (see Fig. 10):

$$A = \frac{2a_1 + 2a_2}{2} + a_1 + a2^{*}$$

One may dispense with magnitude a_2 provided there is small load on the tail ski.

Accepting such a distribution of the load, discounting the action of the neighboring sections of ice on the area under consideration, and introducing Poisson's coefficient of transversal contraction (m), we discover the characteristics of ice ( ):

$$\sqrt[4]{\frac{m^2Eh^3}{k\,(m^2 - 1)\,12}} \text{ Meters} \quad ***$$

h - thickness of ice in meters; E - Modulus of elasticity (in metric tons per square meter); k - specific gravity of the liquid (= metric tons $/m^2/m$ = foundation modulus);

m - Poisson's coefficient (m = 2 to 4).

We discover the magnitude of , in the function of which are expressed the magnitudes of the moment and of the adherence effort (total shear)

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* This equation apparently in error in Russian original. Perhaps should read: $A = \frac{2a_1 + 2a_2}{2} = a_1 + a2$

** Original Russian text shows square root symbol, but has been corrected to fourth root here.

*** For derivation of the formula see "Ice Crossings" by Engineer Bernshtein and consequently of the corresponding tensions (stresses).

Then, the maximum deflection of ice under a load will be:

$$W(\alpha)_{max} = \frac{G}{b^2} B(\alpha)$$

The maximum bending moment in the ice sheet under the load:

$$M(\alpha)_{max} = \frac{G(m+1)}{2m} C(\alpha)$$

The maximum tension (tensile stress) at bending:

$$\sigma(\alpha)_{max} = \frac{6M}{h^2} = \frac{3G(m+1)}{mh^2} C(\alpha)$$

The maximum shear along the perimeter of the area of distribution of the load:

$$T(\alpha)_{max} = \frac{G}{\lambda} D(\alpha)$$

and the maximum shearing stress

$$\tau(\alpha)_{max} = \frac{3}{2} \cdot \frac{T(\alpha)_{max}}{h} = \frac{3}{2} \cdot \frac{G}{\lambda h} D(\alpha)$$

In these formulas, $B(\alpha)$, $C(\alpha)$ and $D(\alpha)$, which are functions of $\alpha = \frac{A}{\lambda}$, are represented in the diagram (Fig. 11).

The method expounded may be applied in the computation of ice aquatoria in cases when the ice is considered as a sheet floating on water, no discount being made of the influence of shore supports. As mentioned above these conditions are also satisfied by ice aquatoria, whose minimum size is twice the length of the curve of deflection occurring under the weight of a plane.

It appears that, in low winter temperatures, the size of a region with positive deflections of ice, and whose border is determined by the condition $W = 0$, is an extremely constant (stable) quantity, close to the circle of radius 40-50 m (130-165 feet) and independent of either the magnitude of the load, or of the thickness of ice; this quantity depends exclusively on the elastic properties of the ice.

A zero deflection of the sheet or an elastic foundation, is located at the following distance from the center of loading: $x = 0.75L$, L being the length of the half curve of the deflection.

Knowing from experience length $x = 50$ m, we get the length of the curve of deflection:

$$2L = \frac{2 \times 50}{0.75} = 133 \text{ m}$$

whence we conclude that, at the time of the lowest water, the dimensions of the ice airfield (from one shore support to the other) should be no less than $2 \times 133 = 266$ m (approximately 875 feet). Given the small magnitude of the modulus of elasticity of spring ice, the length of the curve decreases correspondingly.

Considering the run of the plane following its landing, we come to the conclusion that not all ice airfields are of a sufficient size to allow computation without taking into account the influence of supports. As the behavior of the ice - similar to that of a beam on two supports - cannot be calculated due to the cracks existing in it, the landing and stationing of planes on narrow river-airfields, is possible only in the event of considerable thickness of ice, to be determined by investigation.

Example of Computation.

Let us determine the tension of ice. The given thickness of ice is $h = 0.25$ m (9.84 inches); the hydroplane equipped with skis, has a flying weight of 5.5 tons (metric). The distance between the axles of the skis,

$2a_1 = 5$ m (16.4 feet).

We consider the ice layer as a large sized sheet, without allowance for the action of coastal supports, and we consider it as placed on an elastic foundation, i.e. as floating on water.

We obtain the characteristics of the ice from the formula:

$$= \sqrt[4]{\frac{m^2Eh^3}{k\ (m^2 - 1)\ 12}},$$

Taking the following quantities; $E = 50,000\ t/m^2$ (modulus of elasticity - metric tons/m^2); $h = 0.25$ m (thickness of ice); $k = 1\ t/m^3$ (specific gravity - metric tons /m^2 /m = foundation modulus); $m = 3$ (Poisson's coefficient), we obtain:

$$= \sqrt[4]{\frac{3^2 \times 50,000 \times 0.25^3}{1\ (3^2 - 1)\ 12}} = 2.93\ m$$

We obtain the quantity:

$$\bar{\ } = \frac{\bar{a}}{l} = \frac{2.5}{2.93} = 0.84$$

We determine the average tensile stress on the curve in the presence of a static load. The magnitude of the maximum moment will be:

$$M(\ )_{max} = G\ (m + 1)\ C\ (\ )$$

G - weight of the plane; C ( ) - coefficient, whose magnitude depends on and is determined from diagram on Fig. 11; in the given case C ( ) = 0.014.

Thus:

$$M\ (\ )_{max} = \frac{5.5 \times 4}{6} \times 0.014 = 0.049\ tm$$

The average tension (tensile stress) will be:

$$(\sigma)_{max} = \frac{6M}{h^2} = \frac{6 \times 0.49}{0.0625} = 4.7 \text{ kg/cm}^2 = 5 \text{ kg/cm}^2$$

The obtained average tension (tensile stress) during deflection is less than that allowed, i.e. 5 kg/cm^2.

We determine the shearing stress τ. The shearing stress is determined, not from the static, but from the dynamic load, i.e. by three times the weight of the airplane:

$$G_p = 3 \times 5.5 = 16.5 \text{ t.}$$

In a normal landing of a plane on ice, contact with ice takes place simultaneously for the surface of both skis. Owing to the hinge connection of the skis with the fuselage, it may be assumed that the contact occurs over the full surface of the ski, and not only with its edge.

However, in exceptional cases, a landing on one ski is not excluded. In such case, the full weight of the airplane with the threefold load is transmitted onto the surface of contact with the ice by means of one ski only. This is an example which should be considered as the worst for the computation of the ice layer and the shear.

Given the size of the plane's skis at 3.10 x 0.70 m, the mean radius of distribution of load will be found to be the geometrical mean of the distance from the axis of the skis to the axis of the airplane*:

$$a = \sqrt{\frac{3.10 \times 0.70}{4}} = \frac{1}{2}\sqrt{217} = 0.74 \text{ m}$$

* This sentence is confusing but it is taken to mean that distances are taken parallel to and perpendicular to the long axis of the loaded ski.

We then determine the value of:

$$\alpha = \frac{a}{\ell} = \frac{0.74}{2.93} = 0.253$$

and the magnitude of the maximum shear:

$$T_{max} = \frac{2G_P}{\ell} D(\ )$$

where $G_p = 16.5$ t (metric tons), is the weight of the plane with the overload, while $D(\alpha)$ is the coefficient, which may be found from diagram Fig. 11 and depends on the magnitude of α; in this case we have $D(\alpha) = 0.065$.

Thus:

$$T_{max} = \frac{2 \times 16.5}{2.93} \times 0.065 = \frac{2.14}{2.93} = 0.72 \text{ m}$$

whence

$$T_{max} = \frac{3}{2} \times \frac{T_{max}}{h} = \frac{3 \times 0.72}{2 \times 0.25} = 4.32 \text{ kg/cm}^2$$

Consequently, the shearing stress obtained is less than the one allowed, i.e. 6 kg/cm^2.

Taking consecutively different magnitudes for h (thickness of ice), and obtaining by the above mentioned method the magnitudes of σ and τ, we can obtain h, corresponding to values close to the one allowed, and thus determine the minimum thickness of ice which may be accepted for an ice airfield.

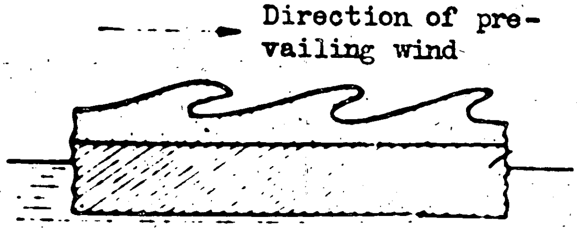

Fig. 1

Fig. 2

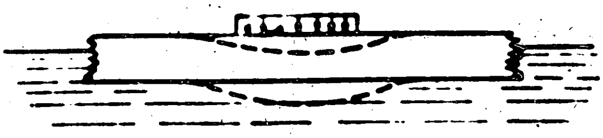

Fig. 3

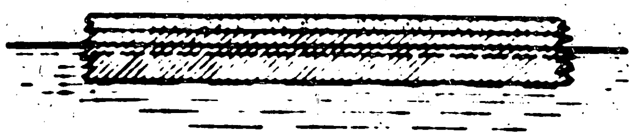

Fig. 4

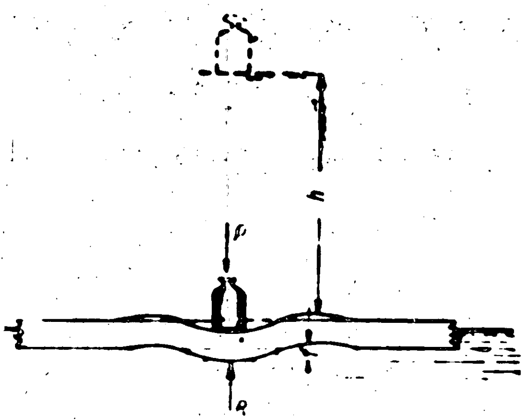

Fig. 5

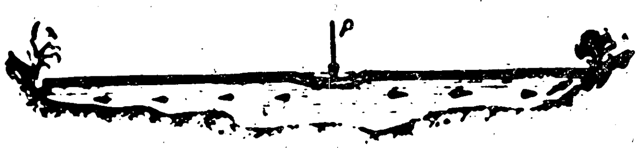

Fig. 6

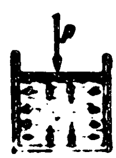

Fig. 7

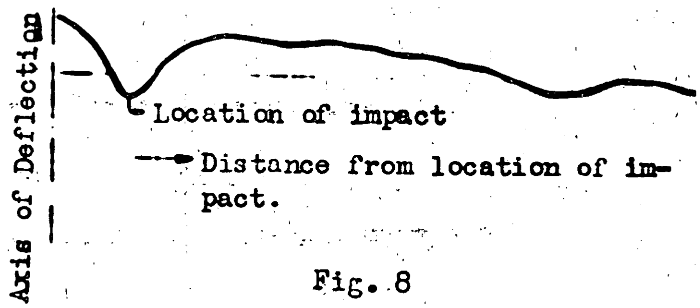

Fig. 8

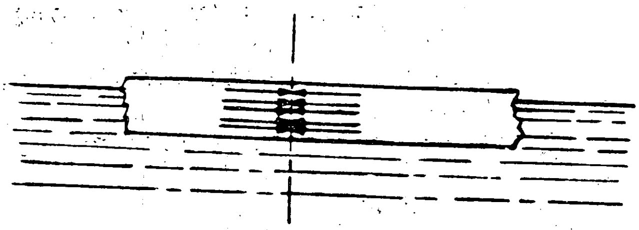

Fig. 9

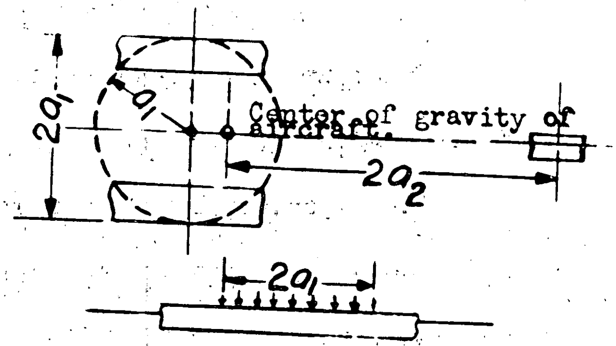

Fig. 10

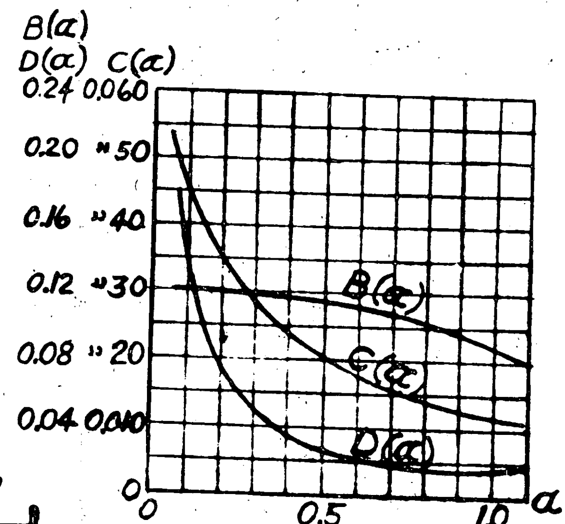

Diagram of values for functions. $B(\alpha)$, $C(\alpha)$ & $D(\alpha)$

Fig. 11