ATLAS OF SEA ICE

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Introduction.

The present Atlas of Sea Ice was prepared in order to serve as a guide to ice observations at arctic or antarctic stations or on board ships navigating in The Arctic or The Antarctic. For this purpose it is necessary to introduce a uniform terminology, because many of the ice terms which are now commonly used among sealers are vague and incomplete (in all languages) and since the terms which are used in scientific literature are not always given the same meaning. This terminology must be logical and the terms must be selected as far as possible such that they can be translated into corresponding existing terms in other languages. In the following, a terminology will be discussed, which can supply complete information as to character and appearance, thickness and arrangement of ice. In chapter V is given a brief account of the life cycle of the sea ice. Special attention has been paid to conditions in the arctic but the terms are applicable to antarctic ice as well.

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Alf Maurstad.

I. GENERAL REMARKS

The ice in the sea originates from glaciers, — *glacier-ice*, or rivers, *river-ice*, or is formed in the sea — *sea-ice*.

With respect to age the sea-ice can be divided into two groups, *winter-ice* (including young ice) and *polar-ice*.

1. Winter-ice is ice frozen all through during the last autumn, winter or spring, and is, therefore, not more than one year old.

Ice which has been formed during the spring is called spring-ice and in the autumn, the newly frozen ice is called autumn-ice. The latter name is used also for the ice which was formed during the preceeding autumn. Ice which is less than 20 cm (8 inches) thick is called young ice.

2. Polar-ice is more than one year old.

Ice which was formed during the last winter (or the last winter if the observations are made in the autumn) is called last year's-ice. Ice which is 2 to 3 years old is called young polar-ice.

With respect to location and state of motion the sea-ice can be divided in two groups, *fast-ice* and *drift-ice*.

1. Fast-ice represents stretches of unbroken ice which on one side is limited by the shore line.

The fast-ice is formed in bays, fjords, sounds, and in shallow water where stranded hummocks give protection. (Parts of the coasts of Siberia and Alaska.) It consists mostly of winter-ice and, as a rule, it remains undisturbed during the whole winter, but in exposed localities it may break up several times during the winter. In summer the fast-ice opens along cracks, and is transformed to drift-ice or it melts entirely where it lies.

2. Drift-ice[1] is all sea-ice which is not fast-ice.

The drift-ice in the arctic regions can be divided into three main groups:

a. Extensive fields of polar ice (Arctic pack).

b. Broken fields (floes, etc.) of polar ice (Pack-ice).

c. Winter drift-ice.

II. DEVELOPMENT OF SEA-ICE AND ICE TERMINOLOGY

1. Forms of newly frozen Ice.

Ice Crystals. When sea water is cooled to a sufficiently low temperature, (—1.8° C. at ordinary salinity) ice crystals are formed in the upper layer. The crystals are pointed, thin plates, a few centimetres long, and consist of purn ice without salt.

Slush. Slush is the term for accumulations of ice crystals, which are not, or only slightly frozen together, forming a thin layer. The slush gives the sea surface a greyish or leaden tinted colour and the wind ripples disappear (fig. 1).

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[1] It should be noted that the term "drift-ice" is used in a meaning which differs from the older English use: "very open pack-ice".

[2] In this chapter the development is described only to the extent which is necesary for the explanation of the ice terminology. Further information is contained in chapter V.

Snow slush. Slush of a somewhat different appearance is formed by snowfall in sufficiently cooled water (see chapter V).

The further development of the slush depends on temperature, wind and waves. If the air temperature is relatively high and there is some motion in the water the slush can increase in thickness without freezing together. The upper centimetres are, however, soon loosely bound to *sludge-ice* (see below).

Ice-rind. In calm waters and at low temperature the slush can freeze to harder ice, *ice-rind* (fig. 2). This type of ice is especially formed where the surface layer has a low salinity e. g. in bays and fjords, and between floes of old ice, where fresh melting water freezes when it spreads on top of the colder sea water. The ice-rind is less than 5 cm (2 inches) thick, thinner than young ice, and comparises all transitions between thin fresh water ice and slush-ice. A ship which passes through ice-rind makes a noise, but when it passes through slush-ice no noise is made.

Pancake-ice. When there is some motion of the water and the air temperature is low, the slush congeals to small lumps, which increase and take the form of round discs with raised rims. The raised rims are developed partly because the discs rollide with each other, and partly because the slush adheres to the rims. This form is called *pancake-ice* (fig. 3).

At very low temperature pancake-ice can form directly without passing the stage of slush and can then occur scattered. In calm weather and with quiet sea the raised rims may be lacking.

Pancake-ice can also be formed from ice-rind, when this is broken by waves to uniform pieces, which by rounding, due to increase in size and collisions, take on the pancake form (fig. 4).

In some cases pancake-ice can be formed under the sea surface (see chapter V).

Pieces of small pancake-ice can freeze together and form *compound pancake-ice* (fig. 3). This type is also formed when pancake-ice has frozen completely together to young ice and then has been broken up in greater pieces. Thus, no definite limit exists between pancake-ice and cakes of younger ice. Pieces of ordinary pancake have a diameter of 0.5 to 1 meter ($1^1/2$ to 3 feet). Pieces of large pancake ice have a diameter 1.5 to 3 metres (4 to 10 feet).

During strong wind the slush, as a rule, congeals to small irregular lumps, *sludge-lumps* (fig. 5).

Sludge. Sludge is the general term for accumulations of small pieces of soft ice mixed with slush and sludge ice. It has a wider meaning than the term slush which should be applied only to accumulations of ice-crystals. As a rule it is formed at moderate temperatures, when slush grows in thickness and is subjected to the action of waves and currents, but it is also formed by the grinding of ordinary, or of rotten ice (*spring sludge*, fig. 6) or by snowfall (*snow sludge*). The most common types of sludge are intermediate between these former and occur usually together with sludge-ice.

Sludge-ice. This term is used for all kind of soft ice the pieces of which cannot carry a man or a seal (most pancake-ice is sludge-ice). The sludge-ice is mostly formed by freezing, but it can also be formed when winter-ice is crushed. In most cases it depends upon the general impression whether the ice shall be termed sludge or sludge-ice. At low temperatures accumulations of sludge or sludge-ice can congeal on the surface to *sludge-cakes* or small *sludge-floes*, which carry a man.

Slob-ice. Sludge or sludge-ice which has been pressed together to a thick layer through which small sealing vessels cannot pass, is called *slob-ice* (figs. 6 and 7).

Young-ice. In calm and cold weather ice-rind, pancake-ice etc. freeze to young-ice. This term is used for newly frozen stretches of level ice, which is thicker than 5 cm

(2 inches) and thinner than 20 cm (8 inches). The appearance of young-ice depends upon the process of its formation. In most cases it is formed from pancake-ice, and the surface shows a pattern of round rings (fig. 8). The young-ice is of a greenish blue colour and is moist on top (fig. 9), it is tough and flexible and is not easily broken by as slight swell.

2. Winter-ice.

Because of its considerable content of salt, winter-ice is relatively soft compared with polar-ice (see chapter V).

Winter-ice within which the single ice pieces are so big that they can be called small floes or big cakes (see page 10) is subdivided into

Level-ice
Ordinary winter-ice
Hummocky winter-ice

When the single ice pieces are so small that they cannot be called small floes or big cakes the following terms are used:

For a single piece:[1]	For accumulations:
Big growler	*Big growlers*
Growler	*Growler-ice* (or *Growlers*)
Cake	*Cake-ice*
Bit	*Brash ice*

Level-ice. Level-ice (fig˙ 10) is of uniform thickness, with a flat and smooth surface, and is more than 20 cm thick. As a rule it is formed by continued growth of young ice. In sheltered locations the level-ice soon reaches such a thickness that it remains unbroken for long periods, often during the entire winter. In the open sea newly formed areas of level-ice are soon broken up (fig. 11). A swell breaks the ice into small floes of regular form, whereas wind and tidal currents break it in more irregular floes. During the further development the level-ice floes collide and soon lose the character of level-ice because wells of crushed ice or sludge form along the rims (margin crushed, or margin hummocked floes, fig. 12).

Hummocky-ice. If the floes are pressed together they are broken to smaller pieces, and (especially when the ice is drifting) the smaller are showed upon, or underneath the greater (*rafted* or *tented ice*)[2]. Under violent pressing the cakes and pieces are piled up in a irregular way to a thicker layer with mounds and ridges, *hummocked ice* (fig. 13).

In calm weather the hummocked ice masses freeze together to areas of *hummocky-ice* (fig. 14). The appearance of hummocky-ice depends upon whether the ice is hard or soft, and whether the ice has been hummocked on one occasion only or several times. In many cases quantities of sludge and brash-ice are accumulated underneath the hummocky ice. Therefore, and also because of the presence of many hollows and spaces which are only filled with snow and air, the hummocky-ice floats high in the water.

The heaps or mounds of the hummocky-ice are called *hummocks.* Very often the hummocks are arranged as long ridges and are then called *pressure-ridges.* Enormous

[1] The term *floeberg* is used both for great accumulations of ice and for icebergs. It has been omitted here in order to avoid confusion.

[2] The terms rafted and hummocked can also be used for describing the amount of ice (close, compact, rafted, hummocked).

pressure-ridges, up to 20 m thick can be formed when the ice is pressed against shores (*stranded pressure ridges*).

Ordinary winter ice. This term comprises all transitional forms between level-ice and hummocky winter-ice. It can be formed in many different ways: By margin-crushing of smaller bay-ice floes, by the freezing together of growler-ice, by formation and further growth of ice between floes etc. It can, furthermore, consist of hummocky winter ice which has been smoothed by drifting snow.

There exists, of course, no definite limit between level-ice ordinary winter-ice and hummocky-ice. Within a given area, two or all of these forms are mostly present. The term which is to be used, depends upon the general impression.

The three terms mentioned above can only be used when the single ice pieces are large enough to be called small floes (or cakes for level-ice). (The limit depends upon the thickness and flatness of the ice, e. g. one meter (3 feet) thick level-ice piece must be at least 5 metres (15 feet), and one meter (3 feet) thick hummocky-ice at least 10 metres (30 feet) wide to be called a small floe.

Big growler. A big growler is a piece of ice of hummocky origin, reaching at least to 1 to 1.5 meter (3 to 7 feet) above sea level (fig. 15). Accumulation of big growlers is called *big growlers* or *big growler-ice.*

Growler. Smaller pieces of hummocky origin, more than 1/2 meter (2 feet) in diameter. Accumulation is called *growler-ice* (fig. 16).

Cake. Cake is a relatively flat piece of ice and it forms the link between growler and small floe. Big and small cakes. Areas of cakes may be called *cake-ice.*

Bit. Brash-ice. A *bit* of ice has a diameter less than 1/2 meter (2 feet). Accumulations of bits is called *brash-ice* (fig. 17). If brash-ice is mixed with sludge the mixture is called sludge-ice or slob-ice according to its density (see p. 7).

The growlers are mostly formed by scattering of hummocky ice, and by melting and pressing together with subsequent scattering of hummocky ice. A compact layer of growlers forms a type of hummocked ice. Cake-ice is especially found near the ice edge, where the swell acts. Brash-ice, sludge-ice and slob-ice is often found at the ice-edge where wind and waves are most active.

3. Polar-ice.

Contrary to the winter-ice the polar-ice contains little salt and is, therefore, hard (see chapter V).

The terms *big growlers*, *growler*, *cake* and *brash-ice*, *hummocked* and *rafted* can also be applied to the polar-ice (fig. 18 to 23). Big growlers which are washed by the sea so that they look like glacier-ice are occassionally called *bergy bits*, but this term ought to be reserved for glacier-ice.

By the term *hummocky polar-ice* one understands areas of polar-ice which have been subjected to pressure after the preceding summer (fig. 23). No definite limit exists, of course, between hummocky polar-ice and other polar-ice.

When the surface of hummocky polar-ice is subjected to melting processes during the summer, the sharp forms of the hummocks and pressure ridges are rounded, and the surface attains the *moutonnée* appearance which is characteristic of many old ice fields (fig. 24).

In winter and spring the ice in polar sea consists minly of compact fields of polar-ice which is several years old. The fields are lined by pressure ridges. The average thickness is about 3 metres (9 to 10 feet). The pressure-ridges rise to 5 or 6 metres

(15 to 20 feet) above sea level and isolated hummocks may reach to 10 metres (30 feet). Considerably thicker polar-ice is found where the ice is pressed against a shore where the water is not too shallow, and where the ice can attain a thickness of up to 50 metres (160 feet). Such ice was called *paleocrystic ice*, but this term should not be used any longer, since it may give a misleading impression of the history of the formation in question.

Some other Ice-Terms.

Ice-foot is a border of ice which is frozen to the beach and takes no part in the tidal motion. The ice foot is, as a rule, formed in the manner that ice freezes at a thin layer on the stones on the beach. The layer increases during the winter at especially high flood tides, and can reach a thickness of several metres. The ice-foot can also be formed in other ways, by spray for instance, or when sea-ice is pressed ashore and freezes to the beach. A *permanent* ice-foot does not melt completely in summer.

Stranded ice is ordinarily formed by pressure ridges, or big growlers which are carried into shallow waters (fig. 25). Where shoals extend to great distances from the shore, big floes may strand. (Parts of the Siberian and Alaskan coasts).

Anchor-ice (or *ground-ice*) is ice which is attached to the bottom (at river outlets).

Sikussak is a term used for many years' old ice which is found where the ice does not drift away (e. g. in fjords on the north coast of Greenland). It is to a great extent formed by snow-fall and snow-drifts and has, therefore, great similarity to glacier-ice.

Drift-ice and **pack-ice.** The term drift-ice is here used only for describing the freedom of motion of the ice (contrary to fast-ice), but is by several authors used for describing the arrangement of the ice and the possibility of navigation. Drift-ice then means ice occurring as small floes, which are scattered if they are thick but can be closer if they are thin. Pack-ice means close ice consisting of thicker floes. The limit between the terms is very varying and arbitrary. They, therefore, give little information and should not be used in ice reports.

III. TERMS FOR DIMENSION, QUANTITY AND ARRANGEMENT OF THE ICE

A. Dimensions.

Width. According to the width a piece of ice is called:

a. *Field* or *giant-floe* if the limit cannot be seen from the crow's nest (figs. 23). The width is, thus, at least several kilometres (miles). The term giant-floe is mostly applied to fields of polar ice. Fields of winter ice are generally formed by hummocky ice or by fast-ice and seldom by unbroken ice in the open sea.

b. *Floes*, if the width is more than 200 metres (1/10 mile) (fig. 28). Big floes are more than 1 000 metres (1/2 mile) wide.

c. *Small floes*, if the width is less than 200 metres (1/10 mile) but greater than ca. 10 metres (yards) (figs. 26. 27).

d. *Growler, cake, bit* etc. if the pieces cannot be called small floes.

Thickness. The common terms for describing the thickness of the ice are: *thin, medium, thick, heavy, huge.* The actual thickness which corresponds to these terms differs with the different types of ice (young ice, level ice, hummocky winter-ice, polar-ice etc.), varies from one region to another, is dependent upon the size of the ship from which the observation is made, and so on.

Thin young-ice is 5 to 8 cm (2 to 3 inches), thick 12 to 20 cm (5 to 8 inches). Thin level-ice is 20 to 40 cm (8 to 16 inches), thick level-ice is about 1 meter (3 feet). Ordinary winter-ice is considered thin when the thickness is between 0.5 and 1 meter ($^1/_2$ and 3 feet) and heavy when it is more than 2 metres (6 feet). When the terms are applied to hummocky winter-ice the thicknesses must be more than doubled. Ordinary polar-ice is considered medium when the thickness is 2 to 3 metres (6 to 10 feet).

B. The Amount of Ice.

Within the area of observation the distribution of the ice can be approximately even or very uneven. In the former case the amount can be described by the terms

Very open:	The ice covers	less than $^2/_{10}$ of the sea surface	(fig. 40)
Open:	» » »	between $^2/_{10}$ and $^7/_{10}$ » » »	(figs. 15, 26, 27)
Close:	» » »	» $^7/_{10}$ and $^9/_{10}$ » » »	(fig. 11)
Very close:	» » »	» $^9/_{10}$ and $^{10}/_{10}$ » » »	(fig. 12)
Compact:	» » »	$^{10}/_{10}$ » » »	(figs. 14, 23)

When the ice is unevenly distributed it is, furthermore, necessary to state the arrangement of the ice.

C. The Arrangement of the Ice.

Ice-edge. The term ice-edge is applied to the limit between open water and ice which can be seen from the crow's nest (figs. 5, 16, 17). (Ice-limit means the limitation of an ice area along a distance of hundreds of nautical miles). The appearance of the ice-edge depends mainly upon the wind. When the wind blows towards the edge it becomes straight, without tongues and bays, but often a belt of brash-ice lies outside of the edge. When the wind blows from the edge, the ice becomes scattered and often arranged in streams. The edge itself becomes blurred.

Tongues. When the wind blows almost parallel with the ice edge or somewhat away from it, tongues are formed which may be several nautical miles long. On the weather side ofthe tongue the ice is closely packed, but on the lee side it drifts off to the next tongue.

Tongues of greater dimensions are formed at bends of the current, in which the ice floats. In some instances they are met with where the cold water branches off and forms part of a whirl between a cold and a warm current (the Jan Mayen tongue). The main reason why a tongue is formed under such conditions is that young ice forms and grows on, and not that ice is carried along by the cold current (the wind-drift is dominating). Within such permanent giant tongues, therefore, one encounters mostly young-ice and level-ice. One may say that the ordinary tongues which are formed by the wind represent bends of the ice-edge, whereas the giant tongues, which are due to currents, represent bends of the ice-limit.

Strips (or streams). Strips of ice are often formed when the wind blows away from the ice-edge, because tongues are torn off and carried away. Several parallel strips often lie near each other. When a strip is so broad that the limit cannot be seen from the crow's nest (in clear weather) it is called a *belt*.

Belt. A belt isbroader than a strip and it is not possible to see across it from the crow's nest. A belt often lies off a coast. There exists often a marked difference between the drift of strips and belts. A strip is generally carried by the wind in a direction at right angles to its axis, whereas a belt drifts in the direction of its axis. The term belt is often applied to the ice within broad stationary currents (e. g. The East Greenland current).

In the case of fast-ice the terms *fast-ice* or *shore-ice belt* are used.

D. The Opening in the Ice.

Crack. A crack is formed when floes or fast-ice are broken (fig. 28). It is too narrow to be navigated. A crack can be *open* or *closed.* Cracks are mostly formed during packing when the ice becomes unequally loaded or is torn asunder. They may be formed by temperature changes. Between the fast-ice and the shore one or more *tidal-cracks* occur, representing the limit between the fast-ice and the ice-foot.

Lead or Lane. A lead or a lane is an approximately straight opening in the ice, which is wide enough to be navigated. An *open lead* is at least about 100 metres wide (fig. 29). A *shore-lead* is a lead between the drift ice and the shore, or the drift-ice and a narrow belt of fast-ice, or the fast-ice and the shore. In the former two cases the shore lead is most often present with off-shore winds, and may develop in any season, whereas the latter type is present in summer only when the fast-ice has melted away on the inside of stranded ice.

Clearing. A clearing is a rounded opening in the ice, up to a few hundred metres wide (figs. 30, 31).

Big Clearing. A big clearing is a larger opening in the ice and must be more than a few hundred metres wide.

Bay. A bay is an inward bend of the ice-edge or the ice-limit and can, in the same way as the tongues, be formed either by wind or currents. The latter are much larger than the former.

E. Ice Blink and Water Sky.

The whitish glare on the clouds produced by the reflection of the light from wide areas of ice is called *ice-blink*, and by means of this, ice areas beyond the visible horizon can be perceived. *Water-sky* means the dark patches, or streaks on the clouds which appear as contrast when light is reflected from areas of ice and water. When low stratus clouds are present, details in the arrangement of the ice can be plainly visible.

IV. GLACIER ICE IN THE SEA

In the sea glacier ice is present as *icebergs* or *calved ice.*

Icebergs rise to more than 5 metres above the water. *Calved ice* rises to less than 5 metres. Great pieces of calved ice are also called *bergy-bits* and small pieces (less than $^1/_2$ meter above the water) are called *growlers of calved ice.*

The form of the icebergs. According to their appearance the icebergs are divided in two groups, *blocky* and *pyramidy.* The blocky icebergs have a nearly horizontal surface and steep sides (figs. 32, 33, 38). Pyramidy iceberg is a common term for all bergs which are not blocky, but they may vary much in form: domeshaped, triangular (turned-over blocky icebergs) pinnacled, valley-typed, double, or twin bergs winged and horny and so on (figs. 34, 35, 36, 37).

Colour and appearance. The colour of the glacier ice is bluish-green. A surface which is melting attains a grainy appearance, and the single grains of the glacier can be seen (diameter about 1/2 cm (1/8 inch)). Glacier-ice which lies awash in the sea may assume the colour of the sea and is not easily discerned (growlers, fig. 39). As a rule, icebergs appear white and snowlike since the surface becomes porous because the enclosed air bubbles escape when the surface is exposed to heating by incoming radiation. Icebergs are occasionally coloured by diatomes, and often show bands of mud or of blue, clear ice.

V. ON THE FREEZING AND MELTING AND ON THE PROPERTIES OF THE ICE IN THE SEA

Freezing point of sea water. Saline sea water has a lower freezing point than fresh water. The difference increases with increasing salinity of the water. Thus, sea water of a salinity of 7.5 ‰ (Baltic water) freezes at a temperature of — 0.4 ° C, whereas water of salinity of 35 ‰ (Atlantic water) freezes at a temperature of — 1.91 ° C.

Maximum density of sea water. Fresh water has its maximum density at 4 ° C. Sea water of salinity 7.5 ‰ has the greatest density at 2.55 ° C. Ordinary sea water of salinity 35 ‰ has its greatest density at — 3.52 ° C. At salinity 24.7 ‰ the maximum density is reached exactly at freezing point — 1.8 ° C.

Freezing at salinity greater than 24.7 ‰. These conditions are of importance during the processes of cooling and freezing of sea water. When the sea surface is deprived of heat and the salinity of the surface layer is greater than 24.7 ‰, the cooled water gets heavier than the underlying, it sinks and is replaced by warmer water from some depth below the surface. This, in turn, is cooled, it sinks, and so on. In this manner the water down to a considerable depth becomes cooled to freezing point of the very surface layer before formation of ice begins. The most rapid cooling takes place on shoals and banks where ice freezes first.

Freezing at salinity less than 24.7 ‰. If the salinity is less than 24.7 ‰ a corresponding exchange of masses takes place within the upper layer until it has attained its maximum density. When the cooling continues the density of the surface layer decreases, and no convection takes place (in quiet weather). Ice freezes rapidly as slush or ice-rind. In the presence of waves the upper layers become intermixed, and a longer time passes before freezing begins. It happens that slush, which has formed in quiet weather, melts rapidly when a wind has been blowing for some time, since the wave motion brings warmer water to the surface.

Near the ice-edge in the Arctic a very thin surface layer of low salinity is present in the late summer. This surface layer is formed by the melting water from the old ice, and favours the ice formation in the autumn.

Formation of ice below the sea surface. Ice can form below the sea surface if a layer of water of low salinity (melting water from the ice, river water, Baltic water) spreads over a layer of more saline water which is so cold that the temperature lies below freezing point of the low-salinity layer. Under such conditions the formation of ice often begins suddenly because the lower part of the relatively fresh layer becomes undercooled before freezing commences. The ice rises to the surface as long ice needles, or, even as pancake-ice if the undercooling has been considerable. At the surface such ice may melt or continue to grow according to the temperature conditions.

Slush. Slush consists of pointed, plate-shaped ice-crystals of varying size. As a rule, they are 2—3 cm long, 0.5—1 cm broad and 0.5—1 mm thick. Slush (and any other type of slush) of a thickness of a few centimetres is more difficult to pass than young-ice (ice-rind) of a corresponding thickness. The most compact (toughest) slush is formed when snow falls on slush.

Snow-slush. When snow falls in sea water which has been cooled to freezing point, snow-slush is formed. As a rule the snow slush becomes mixed with ordinary slush because ice crystals are formed around the snow crystals. The appearance of the snow slush depends upon the weather and the state of the sea. Lumps are formed under the action of wind and waves.

The growth of the ice and the salt contents of the ice. The formation of young-ice in the sea has been described previously (Chapter II). The further increase takes place on the lower side, where a network of ice crystals is formed. Between the ice crystals (which consist of pure water fresh-ice) sea water is enclosed. When the crystals grow, pure water is extracted from the enclosed sea water, the latter attains a higher salinity and a greater specific gravity for which reason it sinks and trickles out of the ice. By this process which is favoured by slow freezing the salt contents of the ice decreases and the ice becomes harder. Ice which has frozen rapidly has a great salt contents and is soft. The rate of increase in thickness of young ice, and the salinity which the ice attains, depends upon the air temperature. Young ice which freezes at an air temperature of — 40° C has a salinity of 10 to 20 ‰, whereas young ice which is frozen at — 10° C has a salinity of 4 to 6 ‰. The thickness of the ice increases more rapidly when the ice is thin and more slowly when the ice is thick, as heat must be conducted through the ice which is a poor conductor. As a consequence the ice is more saline in the upper part. In the upper 20 cm the salinity may be 4 to 6 ‰ when it at 1 meter's depth is 2 to 3 ‰.

A snow cover reduces the cooling of the ice surface. Ice which grows in thickness below a snow cover, therefore, increases slowly and attains a lower salinity than ice of the same thickness without a snow cover.

The brine which is enclosed in the ice has a higher salinity than the sea water, because the single ice crystals contain no salt. The freezing point of the brine is, therefore, lower than the freezing point of sea water. When the temperature of the ice sinks, part of the brine freezes to pure ice crystals, the brine becomes more concentrated, and the network of crystals more solid, the ice becomes harder.

At a given temperature the enclosed brine has a certain concentration and occupies a certain space. The space which is occupied by the brine depends upon the salt contents of the ice. At — 4° C the enclosed brine occupies about 1/3 of the total volume of the ice, provided that this consists of ordinary, quickly frozen winter-ice. At — 8° C only 1/6 of the total volume is occupied by brine. At this temperature the brine is so concentrated that part of the salt (sodium sulphate) begins to crystallize. At — 23° C the major part of the salt (sodium chloride) crystallises and at — 55° C the last remnants of the originally dissolved salts solidify. At this and lower temperatures the sea ice consists of pure ice and enclosed solid particles of salt.

Owing to its great density the enclosed brine has, as mentioned above, a tendency to sink through the pores in the crystal network (and be partly replaced by rising sea water). As the network is relatively dense at low temperature (below — 7° to — 8° C) only a small amount of salt escapes when the ice is cold. The salinity of the ice, therefore, decreases little during winter.

The melting of the winter drift-ice. In spring and summer, heat is supplied to the surface of the ice by incoming radiation from sun and sky and by warm winds. When the ice temperature increases in spring the volume of brine in the ice increase and the structure of pure ice crystals is weakened: *The ice melts from within.* At a few degrees below zero the network of ice crystals has been weakened to such an extent that the ice becomes porous (*rotten ice*). The brine in the upper layers runs off and these, therefore, become almost free from salt. The surface becomes honeycombed and at greater depth the ice becomes sodden. Thus, contrary to fresh-water ice (pure ice), the sea ice does not melt at a definite temperature but the melting takes place gradually as soon as the temperature increases. Sea water has, on the other hand, a definite freezing point; the temperature at which the first ice crystals begin to form.

Rotten ice is easily crumbled to spring sludge, when subjected to pressure. Pressed (hummocky) ice first falls asunder to growlers and then to sludge-ice or brash-ice. Drift ice which is carried into warm water by wind or currents disappears in a short time (1 or 2 days).

The incoming radiation melts the ice in two different ways, either directly by melting the surface or indirectly by heating the sea water which in turn wears the ice away in the water line. The lower parts of glaçons and growlers may jut out below the water as *rams*. Such rams occur, however, more frequently within poler-ice (see later).

Part of the winter-ice melts completely during the summer but another part survives the summer and is transformed to polar-ice. The transformation takes place especially on the broad Siberian shelf where great quantities of polar-ice are produced. Within this region the temperature of the sea water remains so low in summer that the fresh melting water, which in summer runs off the ice and spreads underneath, freezes when it comes in contact with the cold sea water. The decrease in thickness of the ice is, thus, considerably reduced.

The melting of the fast-ice begins, as a rule, near the shore under the action of melting water from the land incoming radiation and warms off-shore winds. In certain circumstances the condensation of water vapour on the surface can accelerate the process. Near the shore spaces of open water are formed (*shore clearings*). At some greater distance from the shore the melting begins somewhat later and the water runs down into the cracks, which furrow the ice, where it freezes and blocks up the cracks. During the continued melting the water, therefore, accumulates in numerous pools on the surface and for a short period the ice may be completely covered by water (*off-shore water*). Later on the ice melts in the cracks and in a short time the greater part of the water runs down and spreads below the ice, which now is said to have *broken up*, and wind and current have free play. This development is especially characteristic within wide, open areas (e. g. the Siberian coast). In fjords and bays, where rivers disembogue, these will, during the flood season, break up and partly melt the fast ice over wide areas. The ice can be carried out of the fjord by the relatively fresh surface current (*running* of the ice).

The annual cycle of the polar-ice. In the Polar Sea the polar-ice remain for several years until it is carried to the south, especially through the wide opening between Spitsbergen and Greenland. During one year characteristic processes of melting and freezing take place.

In spring and summer the snow-cover melt in the first place and afterwards the melting of the ice begins. The top parts of pressure ridges and hummocks melt most rapidly. The heat for melting is supplied mainly by the incoming radiation, but the heat which is transported by warm winds may occasionally accelerate the process. The melting water flows down through cracks and holes and spreads under the ice where it freezes on the underside when it comes in contact with the cold sea water. It also accumulates in pools on the ice. On hummocky ice such fresh water pools can be extensive and deep. Owing to the rapid melting of the higher parts, the surface forms become rounded (*moutonnée*). Each summer about 1 meter of the surface melts and during winter, spring and summer a corresponding amount freezes on the lower side, By this process mud, clay, small stones and shells which have frozen fast to the lower side of grounded ice floes, are gradually transported towards the surface (*muddy* ice).

In summer cracks, newly formed lanes and clearings remain open and the ice fields, therefore, decrease in size and the ice becomes less compact. Considerable hummocking of the ice is not frequent in summer except in the vicinity of the coast.

In the autumn the water in the fresh water pools freezes to clear ice. In the lanes and clearings young ice is formed, which is hummocked and rafted until the ice masses during the winter have been cemented together to compact ice fields. In the autumn and during the first part of the winter, cracks are formed where the ice is weakest, but, later on, long straight cracks may open across the fields. During hummocking, pressure ridges are often formed along these cracks and in the late spring the ice-fields are, therefore, lined with pressure ridges. In some areas these are arranged in parallel lines, especially in the vicinity of land.

The ice which in summer forms at the underside of the floes, has the character of slush. During the autumn, when the ice is cooled off this slush solidifies, but the freezing is slow, the brine in the ice can trickle down and the ice attains a small salt contents. During winter, ice continues to form on the underside but the freezing is slow and the salt contents of the ice is small. Owing to these processes the polar-ice contains less salt than the winter-ice and is, therefore, harder. The surface layers which have been exposed in summer, are practically free from salt and give drinkable water when they are melted.

In a region the amount of ice which during summer, autumn, and winter freezes to the underside of the floes, corresponds to the amount which in summer melts at the surface. The thickness, which the ice can reach by freezing only, is, therefore, limited, but probably it varies somewhat from one region to another, as the freezing depends upon the winter temperatures and the thickness of the snow cover, and the melting depends upon the amount of incoming radiation in summer. At the beginning of the melting the maximum thickness is, on an average, 3 to 4 metres.

The drift of the polar-ice. The ice in the Polar Sea is carried back and forth by the varying winds, but owing to slightly predominating easterly winds and a surface current which increases towards the Spitsbergen regions, it drifts in 3 to 5 years from the Siberian-Alaskan side to the region between Spitsbergen and Greenland. From there it continues along the eastern coast of Greenland. The East-Greenland current also carries ice from the region to the north of Greenland (to the north of Peary's "big lane").

During the drift the ice is in certain regions subjected to especially great pressures, and there it is very hummocky (the region off the north-west coast of Greenland, the region to the north of the New Siberian Islands). In other regions the ice is, on the other hand, not much subjected to pressure. In such regions a tendency to scattering of the ice exists in summer and autumn, and navigation becomes possible (*regional clearings*).

The polar-ice is, as already mentioned, carried out of the Polar Sea by the East Greenland current. Near the open water the fields which float out from the Polar Sea are broken to small floes by the swell. The outer part of the ice is called the *broken belt*, or the *broken ice*, and may be many nautical miles broad. Near the sea, the floes are smallest and at the edge growlers and brash ice are met with. Inside of the broken belt lies the *floe-belt*. The further the polar ice is carried to the south, the smaller are the floes, and at last only small floes and hard growlers are present.

The melting on the water line is considerable since the surface layers of the water are heated by the incoming radiation. On the water line a deep furrow can develop and growlers can be completely cut off. The lower part of floes jut out under the water (*ram*). A ram can also be formed by telescoped ice within which the lowest floe juts out. Rams are most common in summer, far to the south in Denmark Strait. Here one meets nothing but polar-ice and glacier-ice, since the winter-ice, which melts quicker and is thinner, has disappeared. Polar-ice which by the wind is carried out of cold water and into warmer, melts very rapidly, especially if the waves wash over it.

Specific gravity of the ice. The specific gravity depends upon the consistency of the ice. Pure ice has a specific gravity of 0.916. Young ice and level ice have a maximum sp. gravity of 0.925 but, as a rule, the sp. gravity is less (about 0.90) because the ice contains air bubles. It floats with about $^{9}/_{10}$ below the water. Winter-ice and especially hummocky ice floats higher because it is more filled with air and snow. As much as $^{1}/_{4}$ of the volume may be above the water. Pointed hummocks can reach higher above the water than the glaçon, upon which they rest, reaches below water. The water-filled rotten ice reaches deep down. Polar ice is, as a rule, more compact than winter-ice. In summer it floats higher because the higher parts have been filled with air after the escape of the brine. When such ice is carried into warmer water it becomes heavier because it melts from below and the air spaces in the upper part are filled with sea water.

Destruction and melting of icebergs. Iceberg decrease in size in three different ways:

1. By calving. 2. By melting. 3. By erosion.

An iceberg calves when a piece drops off. When this happens the equilibrium of the iceberg is disturbed and the iceberg may turn over (*capsize*). One calving is often followed by one or more successive calvings.

In cold water the melting takes place mainly on the water line where a cutting is formed. The number of such cuttings may show how many times the iceberg has capsized. In warm water the iceberg mainly melts from below and calves frequently. In addition, melting above the water takes place due to the effects of incoming radiation and warm air.

Erosion is caused by waves and rain. The waves are more effective in wasting the icebergs. Crevasses in the bergs are widened and a valley can be eroded across the berg. When the washing continues the bottom of the valley can disappear below the surface and a double (twin) iceberg result. One of the protruding parts of the berg is often washed away or melted more rapidly than the other, but a submerged ledge may jut out a hundred feet or more beyond the visible contour of the berg. Such icebergs are especially dangerous to traffic.

Specific gravity of iceberg. Glacier-ice is formed from snow which in the course of time is recrystallised to ice-grains. A considerable amount of air is enclosed in the ice (up to 20 to 30 % of total volume) and the density of the glacier ice, therefore, varies within wide limits (sp. gravity between 0.6 and 0.9). On an average an iceberg has a specific gravity of 0.8 and floats with about $^{1}/_{5}$ of its volume above the water (from $^{1}/_{4}$ to $^{1}/_{6}$). The most porous and lightest glacier ice comes from glaciers of low temperature. This ice is often loosely knitted together and the bergs fall easily asunder. Such bergs are called "sugar bergs" by Norwegian navigators.

Bibliography.

Instead of giving a list of the literature which has been consulted, reference is here made to two treatises, which contain comprehensive information as to ice literature:

1. Smith, E. H.: The Marion expedition to Davis Street and Baffin Bay under the direction of the U. S. Coast Guard 1928. Scientific results Bulletin no. 19, Part 3. Washington 1931.
2. Transehe, N. A.: The Ice cover of the arctic sea . . . Problems of Polar research. American Geographical Society. Special Publication no. 7. New York 1928.

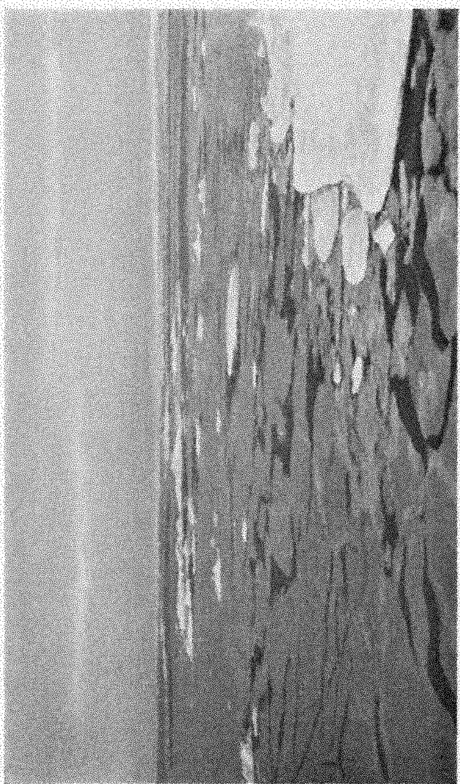

Fig. 1. Slush. This slush is barely frozen together.

Fot. Alberto Fumagalli.

Fig. 2. Ice-rind.

Fot. Thor Iversen.

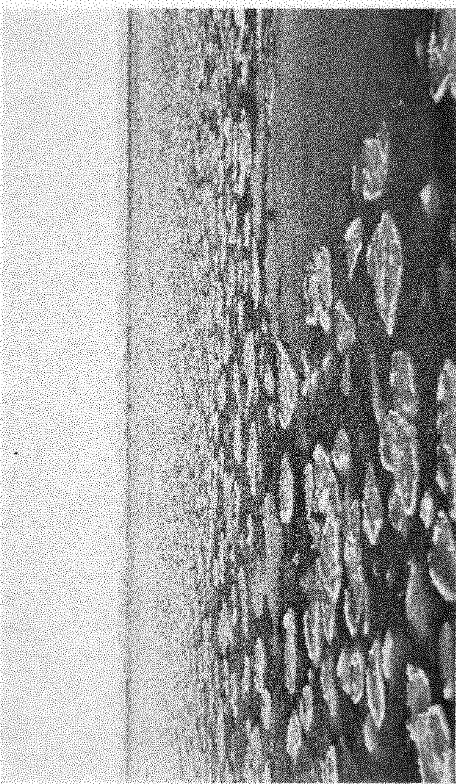

Fig. 3. Pancake-ice. Single and compound pancakes mixed with slush.

Fot. Fumagalli.

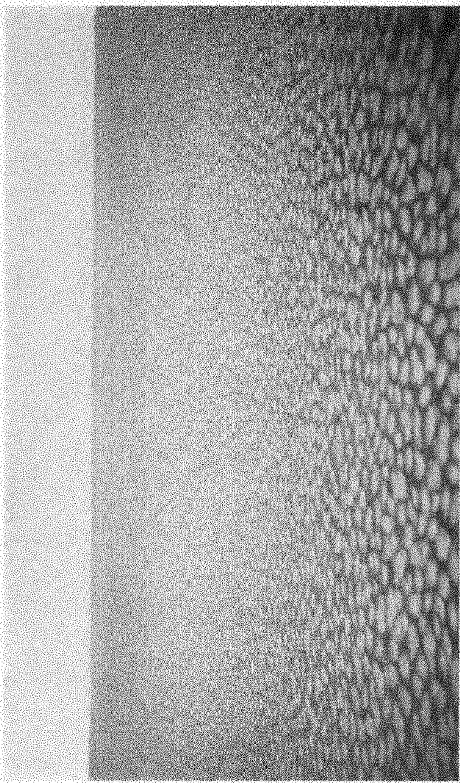

Fig. 4. Pancake-ice. Formed by breaking up of ice-rind.

Fot. Fumagalli.

Fig. 5. Sludge. A mixture of sludge lumps and slush.
Ice-edge in the background.
Fot. Fumagalli.

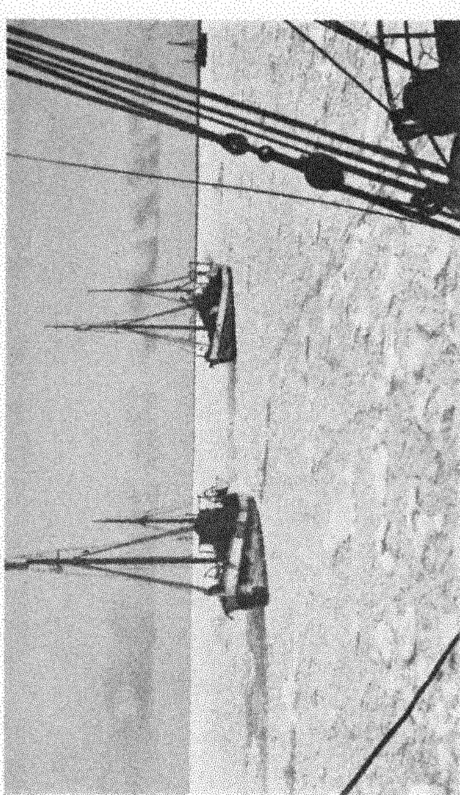

Fig. 6. Sludge. (Spring-sludge) or brash-ice. Formed by crushing of soft winter-ice. If the sludge is so dense that the vessels cannot pass, it may be called "*slob-ice*".
Fot. Fumagalli.

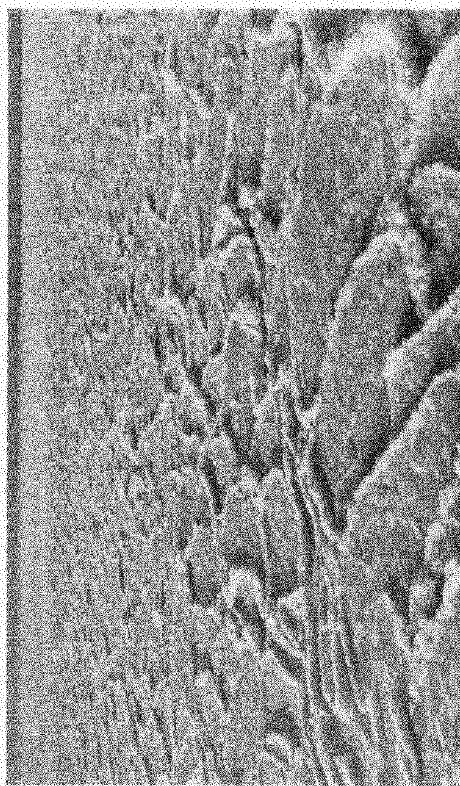

Fig. 7. Sludge-ice. Formed by pressed (telescoped) big pancake-ice. The term *slob-ice* may be used if it is very dense.
Fot. Thor Iversen.

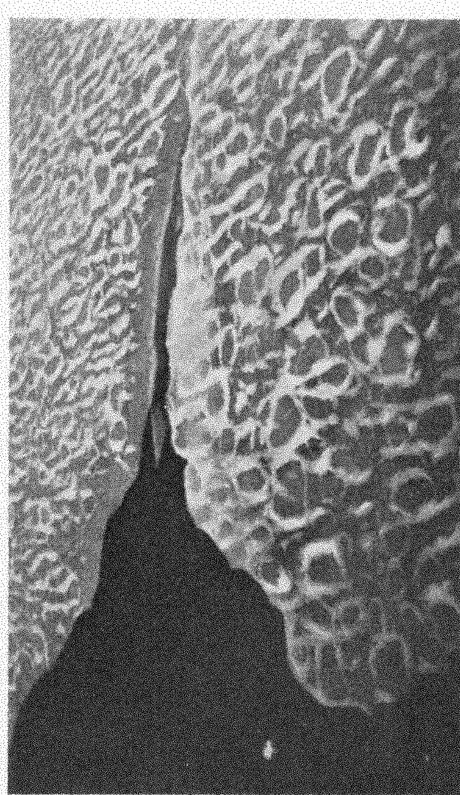

Fig. 8. Young-ice. Formed by freezing together of pancakes.
Fot. Fumagalli.

Fig. 9. Young-ice. Seal tracks are seen in the snow cover on the moist surface.

Fot. Thor Iversen.

Fig. 10. Bay-ice. Level-ice, occurring as *fast-ice*.

Fot. Thor Iversen.

Fig. 11. Level-ice. Recently broken to small floes or big cakes. "Close ice".

Fot. Thor Iversen.

Fig. 12. Winter-ice. Margin-crushed small floes of level-ice. "Very Close ice".

Fot. Thor Iversen.

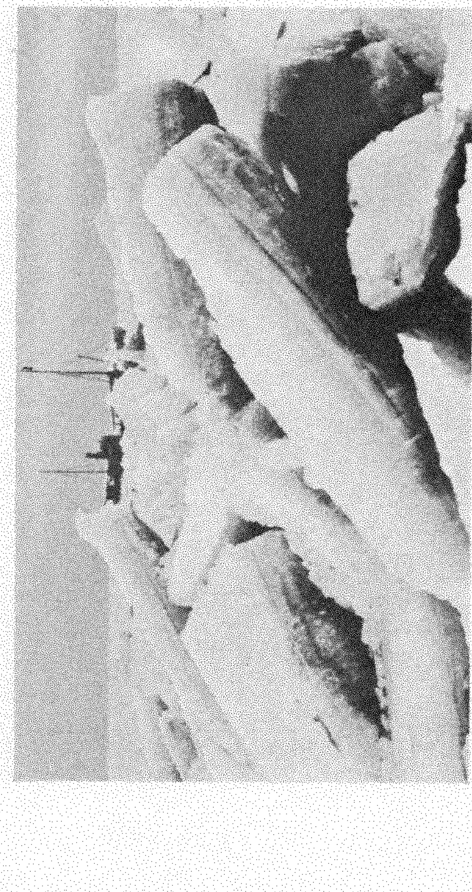

Fig. 13. Hummocked winter-ice. Fot. Lindberg.

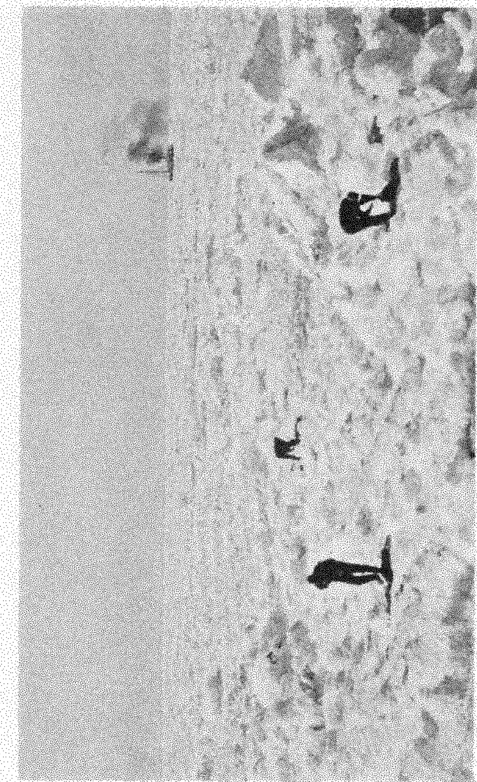

Fig. 14. Hummocky-ice. Fot. Thor Iversen.

Fig. 15. Growlers of winter-ice. In the centre two or three *big growlers* of "Open ice" Fot. Fumagalli.

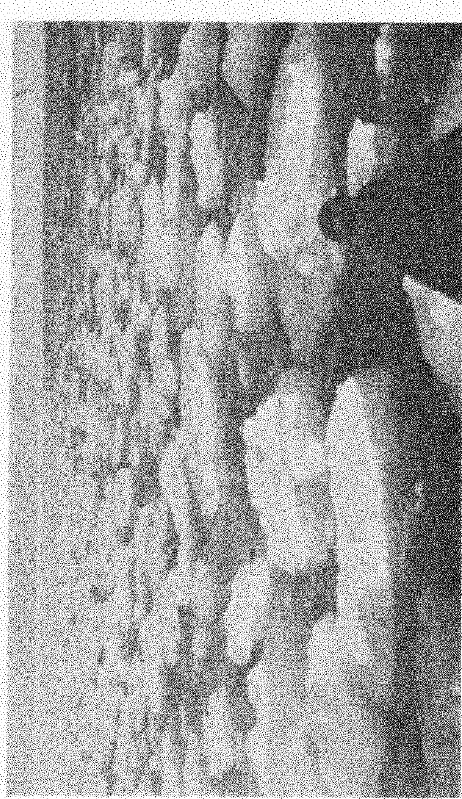

Fig. 16. Growler-ice. Growlers of winter-ice. Ice-edge in the background. Fot. B. Villinger.

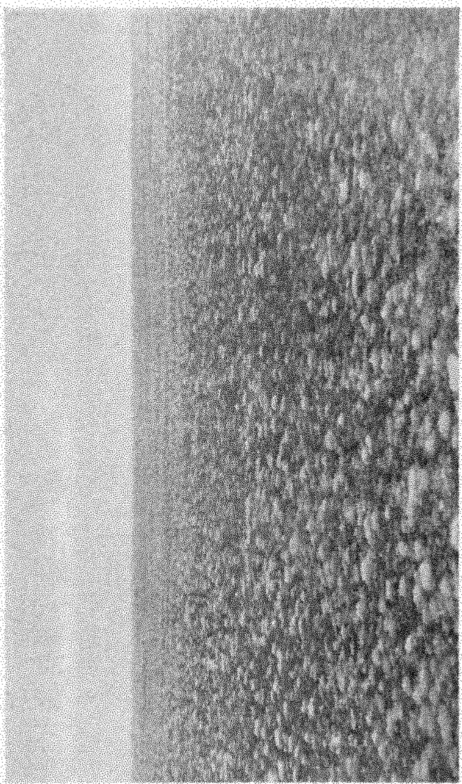

Fig. 17. Brash-ice outside the ice-edge (in the background).

Fot. B. Villinger.

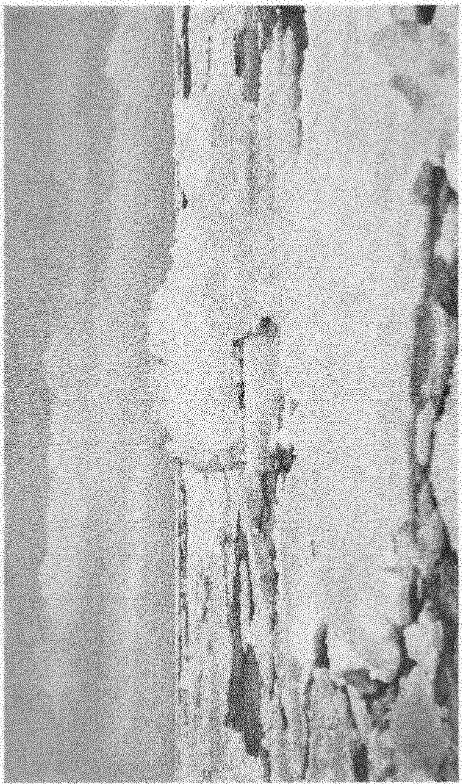

Fig. 18. Big growlers and cakes of polar-ice.

Fot. Dr. Sutton.

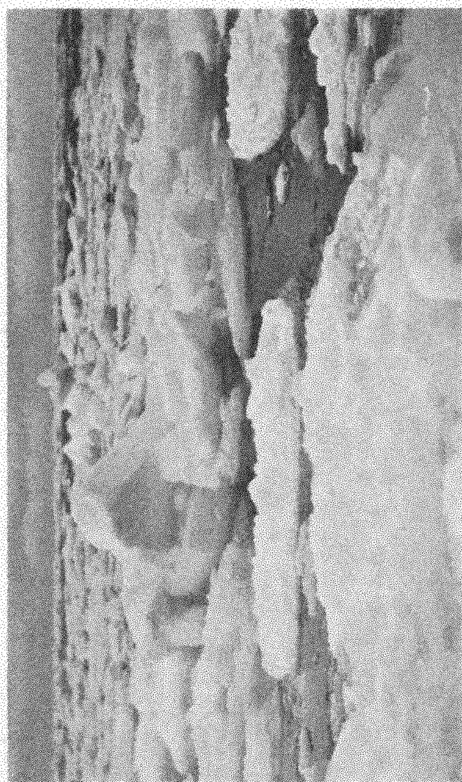

Fig. 19. Growlers of polar-ice.

Fot. Dr. Sutton.

Fig. 20. Polar-ice. Edge of a *floe* of huge polar-ice during melting. *Sludge* in the foreground.

Fot. Dr. Sutton.

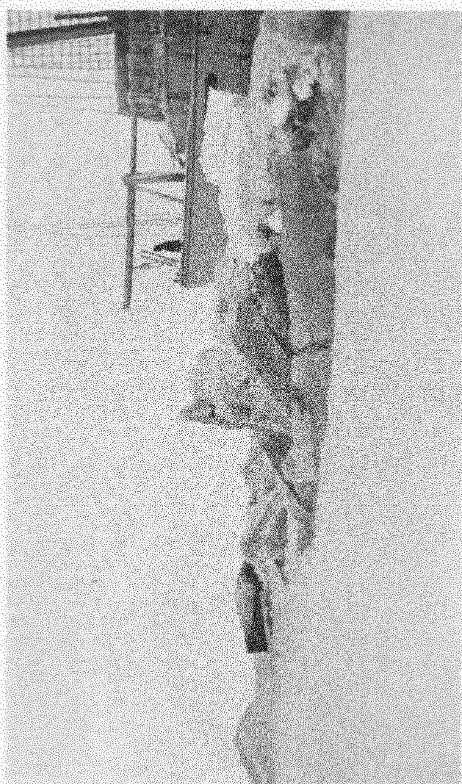

Fig. 21. Polar-ice. Hummocked.

Fot. O. Dahl.

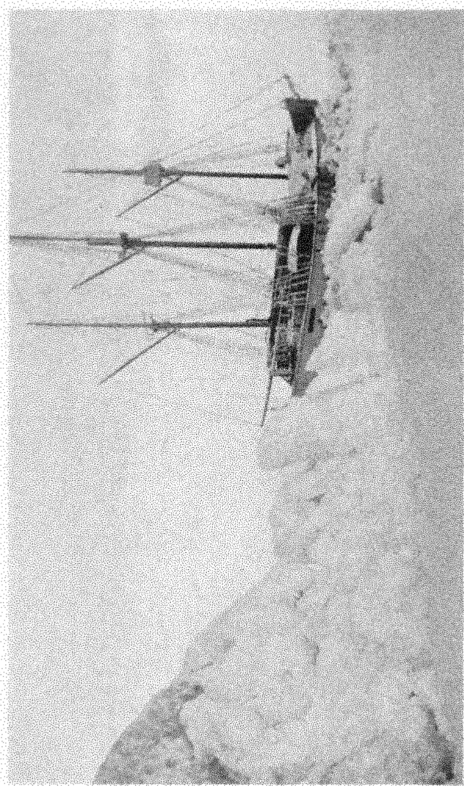

Fig. 22. Polar-ice. *Pressure ridge* or *hummock.*

Fot. O. Dahl.

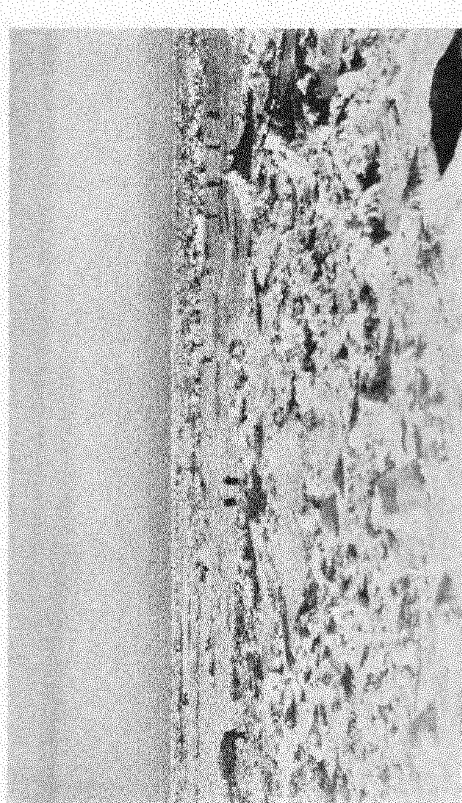

Fig. 23. Polar-ice. A *field* of *hummocky polar-ice.*

Fot. A. Hoel.

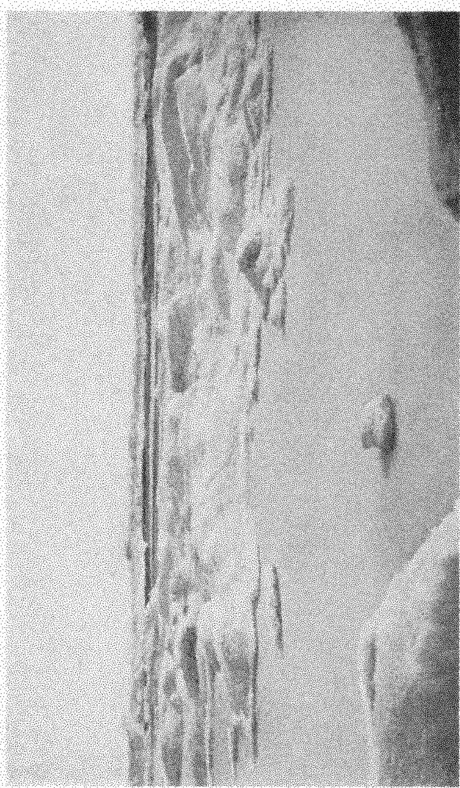

Fig. 24. Polar-ice. *Moutonnée* ice-field. In the foreground a *frozen pool.* In the background a *clearing* and behind that an old *pressure ridge.*

Fot. O. Dahl.

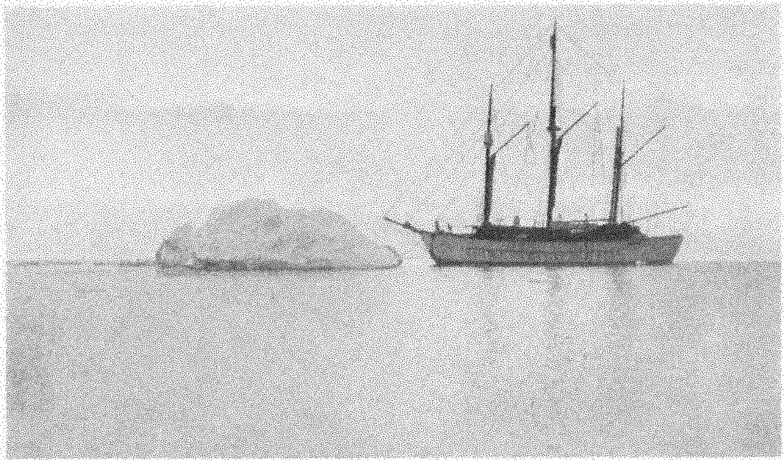

Fig. 25. A big growler of polar-ice. *Stranded.*

Fot. O. Dahl.

Fig. 26. Small floes of polar-ice. "Open ice".

Fot. Nils Foldvik.

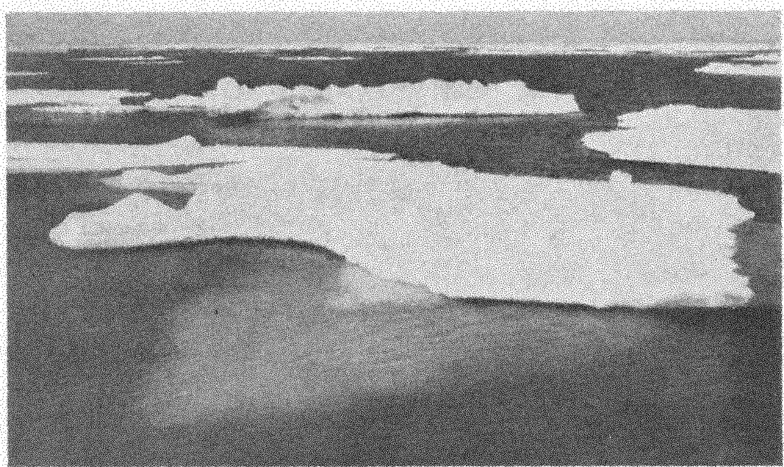

Fig. 27. Cakes of polar-ice. In the foreground the *ram* is observed under water.

Fot. B. Villinger.

Fig. 28. Cracks and small clearings in hummocky winter-ice.

Fot. Thor Iversen.

Fig. 29. Broad lane. In the foreground a *floe* of polar-ice which has melted off a great deal and is filled by *pools*. Fot. O. Dahl.

Fig. 30. Small clearing in hummocky winter-ice. Fot. Thor Iversen.

Fig. 31. Clearing. In the foreground *margin-crushed* floes of winter-ice. Fot. Thor Iversen.

Fig. 32. Iceberg of the blocky type west of Spitsbergen Fot. B. Villinger.

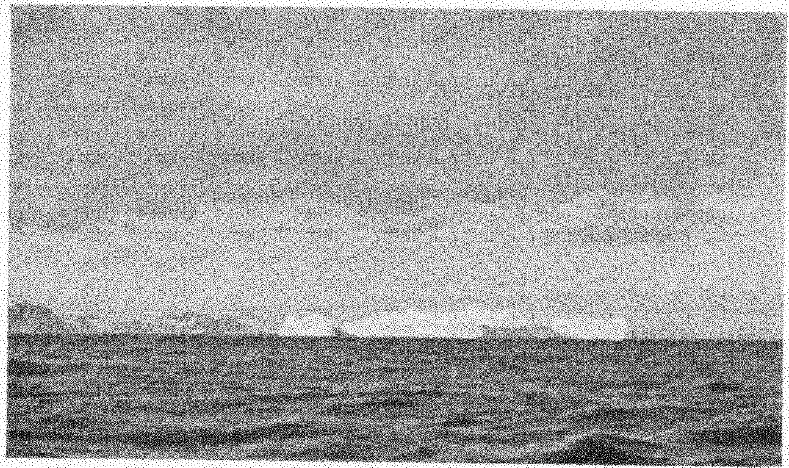

Fig. 33. Iceberg. A big *blocky* iceberg in the Denmark Strait.

Fot. Thor Iversen.

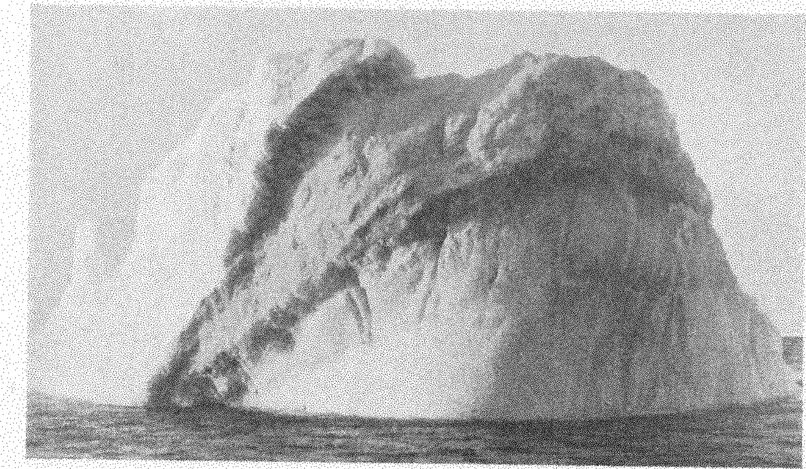

Fig. 34. Iceberg. Pyramidy iceberg with furrows showing that it has calved and capsized several times.

Fot. Lindberg.

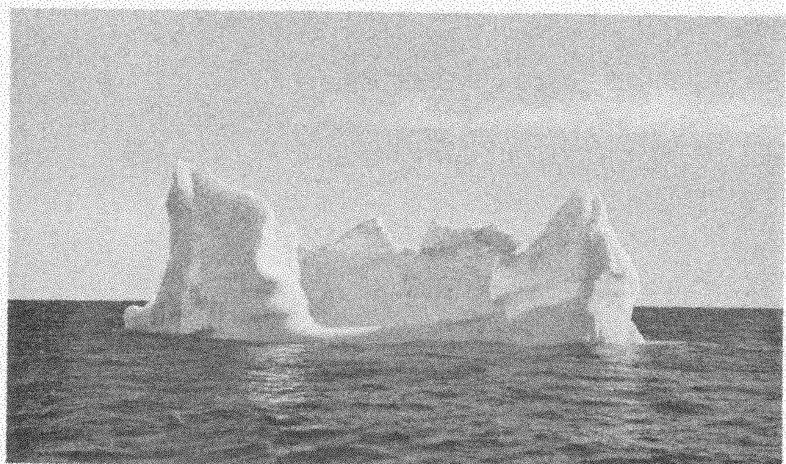

Fig. 35. Iceberg. *Valley-shaped* iceberg. The berg is of "sugar" consistency and will soon fall asunder or calve.

Fot. Thor Iversen.

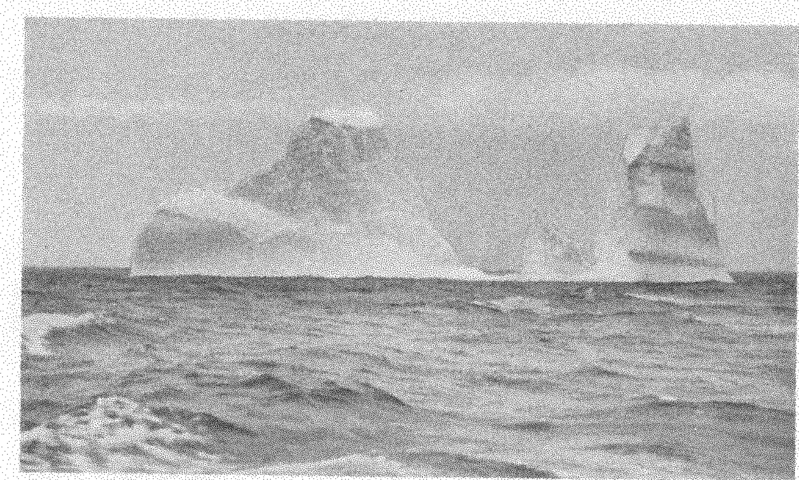

Fig. 36. A big pyramidy iceberg eroded to a twin berg. The right hand one shows blue-band structure. From Davis Street.

Fot. Olav Mosby.

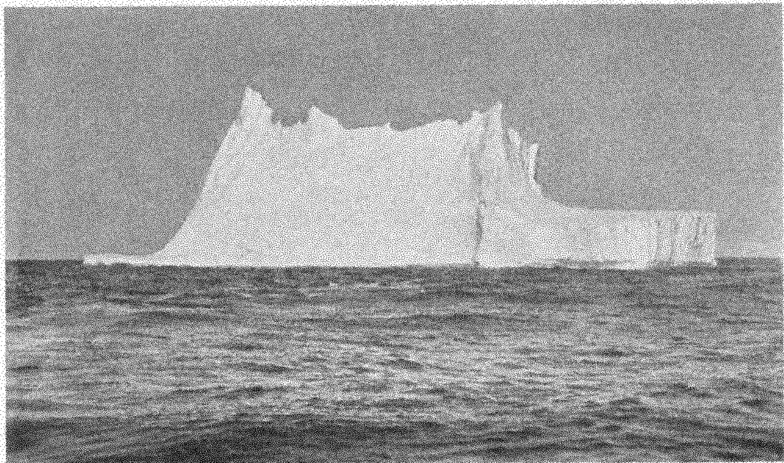

Fig. 37. A very big *pyramidy* iceberg from Davis Street.
Fot. Olav Mosby.

Fig. 38. Blocky iceberg from the Antarctic.
Fot. J. K. Eggvin.

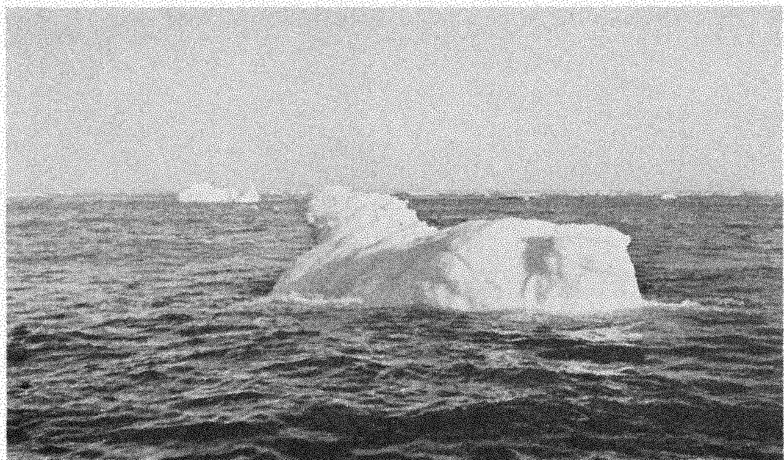

Fig. 39. Bergy bit or big growler of glacier ice. The sea washes over it during storm.
Fot. Thor Iversen.

Fig. 40. Bergy bit or big growler of glacier ice or hard polar-ice.
Fot. Thor Iversen.