The Ice of the Southern Ocean

A. F. Treshnikov

The Arctic and Antarctic Research Institute, Leningrad, USSR

Abstract: Regular sea ice observations off the coasts of Antarctica in the Mirny Station area have been made by the Soviet Antarctic Expedition since 1956. For eight years air ice reconnaissance over the Davis Sea has been made from Mirny Station during all the seasons of the year from the shore to the ice edge. During the voyages of the d/e ship Ob special observations on sea ice and icebergs have been made in the coastal zone of Antarctica. Physical properties, formation and desintegration of sea ice have been studied.

The data obtained on sea ice peculiarities may be spread over a vast water area of the Southern Ocean.

For many years the author has studied sea ice in the Arctic Ocean. The paper deals with general features of sea ice existence in the Antarctic and with differences.

The formation and growth of ice from sea water both in the Arctic and Antarctic depend mainly upon air temperature and heat content in the sea. Disintegration and melting of ice in the Antarctic occur differently. Solar radiation, a great amount of diatoms included in the ice thickness and currents carrying ice out to the north into more warm waters play most important part here.

The amount of old ice remaining in the Antarctic waters after the summer season is considerably less than in the Arctic waters.

In the coastal zone of Antarctica due to ice cooling from ice cliffs, ice shelves and icebergs a great amount of intra-water ice crystals are formed. The crystals, coming to the surface, increase ice thickness.

Due to great depths the width of the fast ice at the coasts of Antarctica is 20–30 miles, the width of the fast ice in the Arctic is hundreds of miles.

A characteristic peculiarity of the Antarctic waters is the existence of icebergs. The icebergs have irregular spreading over the water area of the Southern Ocean.

Soviet investigators have made an attempt to calculate the volume of fresh water in icebergs. It has been established that the annual runoff of fresh water from melting of icebergs is negligible and does not play any important part in the hydrological regime of the Southern Ocean. But icebergs have great influence on water temperature at coasts, on sea ice distribution and, consequently, on the conditions of the ship navigation in the Antarctic waters.

The early explorers, such as Captain James Cook and F. Bellingshausen, circumnavigating the globe in the Antarctic waters, noticed that drifting sea ice extended farther north in the Indian and Atlantic Oceans, than in the Pacific Ocean.

The small wooden sailing boats of the nineteenth century encountered the belt of the floating ice and could not force their way through it to the Antarctic coasts. And the navigators came to think that the sea ice of the Southern Ocean is a powerful and impenetrable barrier. Severe storms, gloomy sky with low clouds, fogs and poor visibility near the edge of the sea ice only strengthened this impression.

But even then it became known that there are narrow canals of open water in this outer girdle of ice in summer time. Through such a passage the vessels of DNMONT d'URVILLE's Expedition approached the coast of Antarctica, thus discovering Terre Adelie Coast.

Deliberately JAMES CLARK ROSS entered this notorious ice belt on his ships EREBUS and TERROR, and then reached again open water. During this Expedition JAMES CLARK ROSS discovered Victoria Land and the barrier of the Ross Ice Shelf.

A large majority of the expeditions in the beginning of the XXth century with larger steam vessels had the objective of approaching some points in the Antarctic (SCOTT, SHACKLETON, AMUNDSEN) or of exploring the coastal areas (MAWSON, DRYGALSKI, CHARCOT, OTTO NORDENSKJÖLD and others).

As a result of the voyages of the ships of these expeditions the water areas with the largest ice coverage were discovered, they were: The Weddell Sea, the Bellingshausen Sea. But there are other areas, where ice completely disappears or has a very small concentration, presenting no special obstacles to ships approaching the Antarctic Coasts during southern summer. These regions are: the western portion of the Ross Sea, the d'Urville Sea, the Davis Sea, Prydz Bay, and Zero Meridian area, east of the Weddell Sea.

Summarizing the data of en route observations of numerous expeditions the information on the seasonal variations of the sea ice northern limit was obtained.

In the majority of the foreign papers, the official pilots including, any drifting sea ice is called PACK ICE. This term does not give the full idea of the origin of the ice and the degree of its concentration. The Soviet scientists in their classification of the sea ice of the Arctic Ocean use the term "pack ice" to denote heavy old ice (about 3–5 years old), the main obstacle to navigation. There is no pack ice in this sense in the Southern Ocean, since the sea ice here is constantly exported to the north, that is to warmer water areas, where the ice melts.

Moreover, the brief fragmentary ice data, obtained in different seasons and years can scarcely be compared, since the navigators used to denote the degree of ice strength and concentration in a very general form, that is the ice was either light or heavy. This characteristic, however, depends essentially on the class of the ship. Any ice seemed heavy for the sailors of the sailing boats, and this explains the false opinion of an impenetrable barrier in the way to Antarctic coasts. Actually, the sea ice of the Southern Ocean is not so strong as the Arctic sea ice.

In the present report I shall review in brief the data on the sea ice in the

Southern Ocean obtained by the Soviet scientists for the period beginning with the IGY.

Experienced scientists, ice specialists, are usually taking part in the Soviet Antarctic Expeditions; they carry out en route ice observations from board of the ice — strengthened d/e ships Ob and Lena. They employ the technique developed by the efforts during many years in the Arctic.

In addition to ship observations aerial reconnaissance of the ice is made from the coastal stations. The aerial reconnaissance flights were flown once a month during 8 years from Mirny over the area of the Davis Sea, and over the area of Soviet stations Novolazarevskaya and Molodezhnaya in summer time.

Ice observations from board of the ship depict ice conditions only along the ship's track within the visibility zone from the captain's bridge or from the mast, which stretches for 10 km. While short period aerial ice reconnaissance permits to characterize ice conditions along vast water areas.

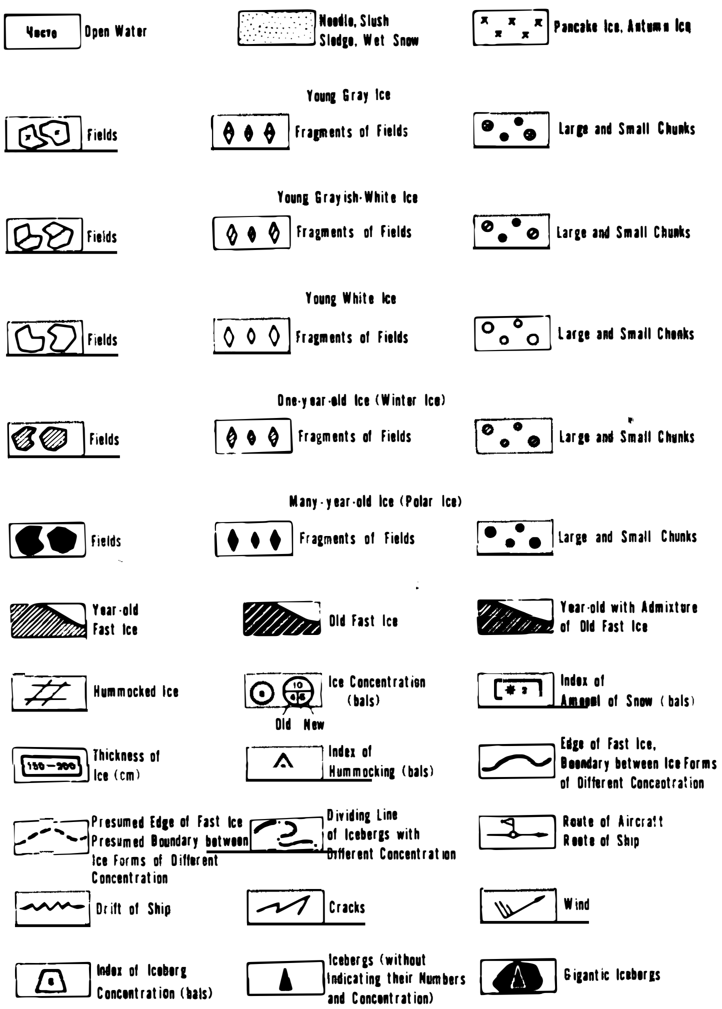

Fig. 1. Legend for the Soviet ice maps.

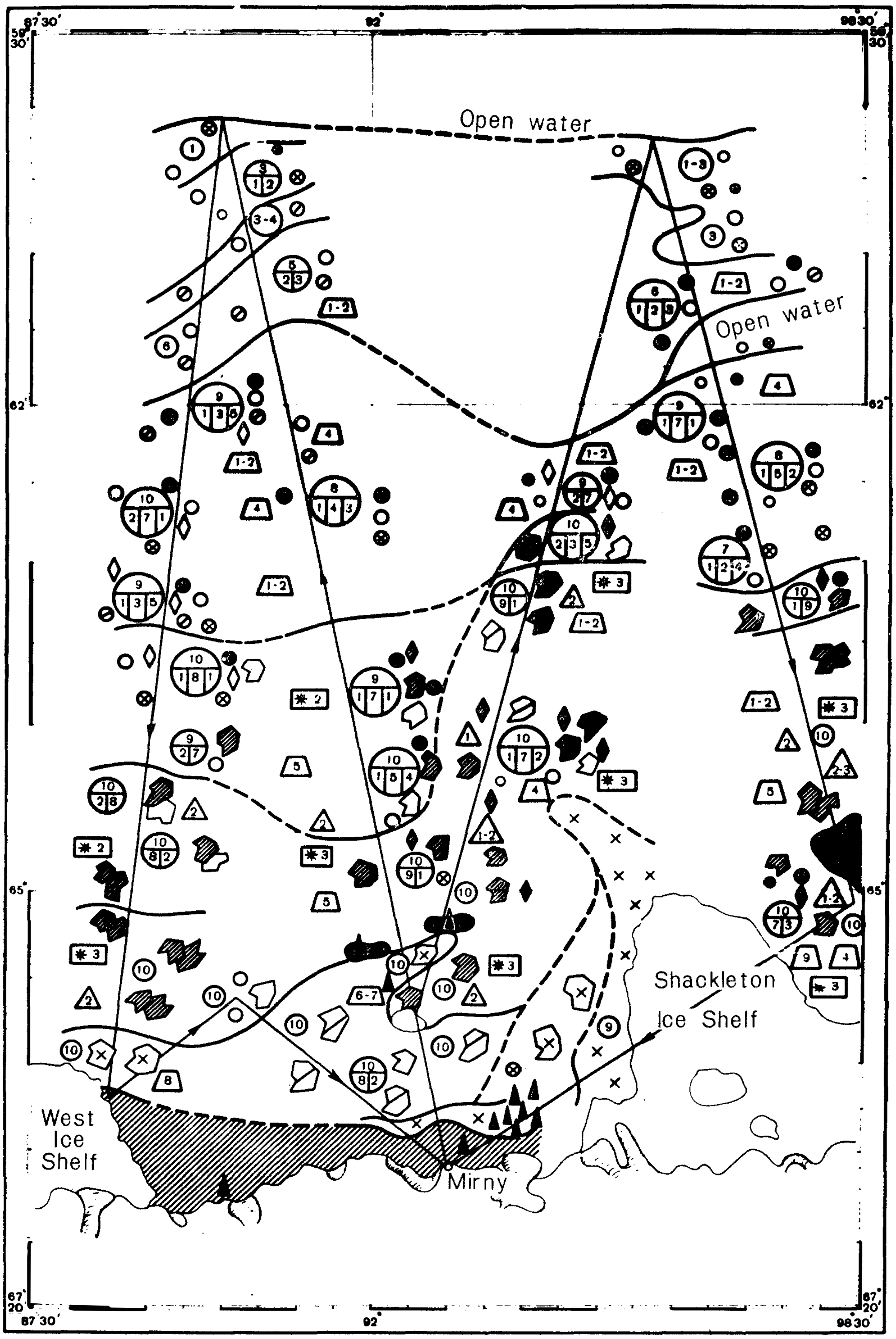

Fig. 2. Ice condition according to the air reconnaissance on October 8 (west route) and October 13 (east route).

On the basis of many years of work in the Arctic the Soviet scientists have developed methods of ice reconnaissance from the aircraft. The aircraft route is worked out so that the distances between the direction changes should allow to chart the distribution and the type of the ice in the observed area. These maps allow us to analyze the ice conditions and to choose the right course for the ship.

Figure 1 shows the table of the symbols used by the Soviet scientists to compile the ice maps of the Arctic Seas.

The ice age is considered an important factor, since the age of the ice fairly reliably conveys the strength of the ice, therefore different colour shades in the table show the age differences.

Six age categories are accepted:

1. New ice, a general term which includes grease ice, slush and pancake ice.
2. Young gray ice.
3. Medium-winter ice (belo-seriy lyod or grayish-white ice).
4. Thick winter ice (beliy lyod or white ice).
5. One-year-old ice.
6. Polar ice.

Ice floes according to their size are divided into ice fields, fragments of fields, large and small chunks.

The fast ice has three age categories:

1. One-year-old fast ice (winter fast ice).

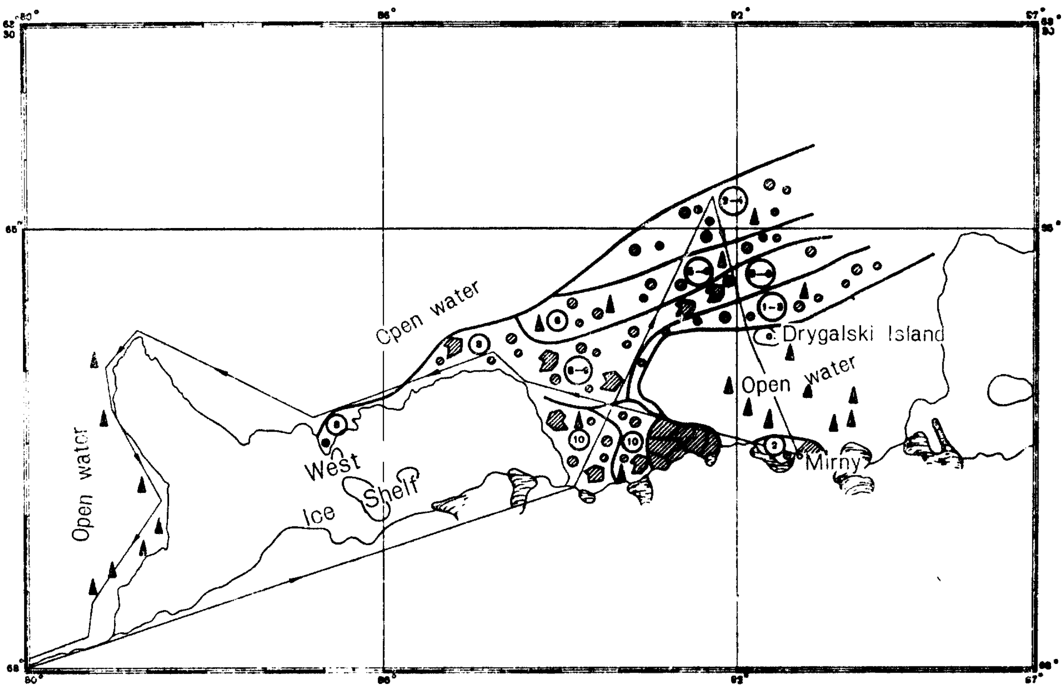

Fig. 3. Ice condition according to the air reconnaissance on February 6, 1957.

2. Polar fast ice.
3. Winter fast ice mixed with polar fast ice.

The amount of sea ice encountered (the concentration of ice) is measured in the scale of 10 bals. The concentration bal is shown by the figure in a circle. If ice of different age is observed, then in this circle the numerator of the fraction shows the total ice concentration in the area, and the denominator shows the amount of young and old ice.

This table may seem to complex, but it is not so and the map is simple to deal with. Not only ice specialists, but captains of the ships read the map easily and choose the right route through the ice. Figures 2 and 3 show the aerial ice reconnaissance maps for the Davis Sea, winter and summer.

Soviet observatory Mirny is situated on the coast of the Davis Sea, therefore this sea appears to be best studied. The aerial reconnaissance was flown to the limit of the open water even in the winter months.

The following is the ice conditions at the Mirny Meridian in late winter.

A shore lead and a zone of young ice extend beyond the fast ice of width varying within 12–20 km. The predominant south — easterly winds push the young ice north, but new ice is formed here again.

To the north of this zone the ice consists of hummocked snow covered with fragments of ice fields, formed last autumn, mixed with the old ice of the last year. This ice constitutes a zone 100–150 miles wide, farther north medium-winter ice (belo-seriy lyod) and thick winter ice (beliy lyod) prevail.

Small pieces of young grey ice, predominantly pancake ice, are spread near the ice edge, while at the ice water junction new ice (grease ice, slush, shuga) appears, which soon melts and then forms again.

The northernmost limit of the ice edge at the Mirny Meridian is observed in October, when this limit extends north for almost 400 miles from the Coast (up to 60°S). In late October, when air temperatures rises to 0°C in the vicinity of the ice edge, the ice formation stops, due to solar radiation increase, surface water layers are heated and the young ice of winter origin starts melting. The northern limit of the ice rapidly retreats south (Fig. 4). The rate of this retreat reaches 10 miles per day in the period of November-December.

Beginning with October, the number of clear days rapidly increases with the consequent increase of direct solar radiation. Ice formation in the shore lead ceases, rapid melting of the young ice begins in the shore lead.

After young ice melting both from the south and the north, there remains a zone of the autumn ice, 100–150 miles wide in early December, which is separated from the fast ice by a stretch of open water.

During the period from December to March the area covered by sea ice remains fairly unchanged; it is the concentration of ice that reduces, in some area reaching 1–3 bals.

During the early part of March new ice formation begins in a zone of old ice, left from the last winter. And until July the position of the northern limit of sea ice varies very little. In July ice formation progresses rapidly to the

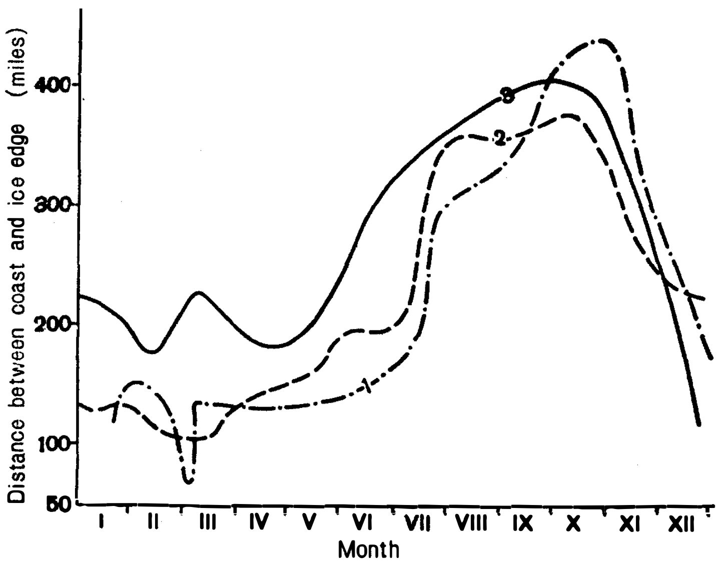

Fig. 4. The rate of ice edge change.

north (Fig. 4) and by the end of October the ice limit approaches 60°S.

Unfortunately, the data of long-period ice observations are available only for the Davis Sea, but judging by fragmentary observational data of different expeditions we may conclude that the general characteristics of ice formation and destruction are typical of other areas of the Southern Ocean.

This conclusion permits us to construct the map of ice distribution during the maximum extension of the ice cover of the Southern Ocean (Fig. 5).

The most northern extension of the ice limit is observed in the western part of the Atlantic sector of the Southern Ocean, where this limit reaches up the south parallel of 55°. The southernmost position of the ice edge is observed in the Pacific sector, in the area of the Ross Sea and the Bellingshausen Sea, where it locates south of 65° south parallel.

It is more difficult to denote the summer ice distribution, as it varies more extensively from year to year.

The map of ice distribution for the late February of 1957 is given in Fig. 6, when the largest number of ice observations from board of the ships of different countries were made in the Southern Ocean.

It is seen from this map that the ice belt was less than 100 miles in width for late summer in the majority of areas, except the Weddell Sea. Three definite areas with the most permanent ice conditions can be distinguished, and the Soviet scientists suggest to call these areas similarly to those in the Arctic Seas, that is ICE MASSIVES, namely the Atlantic Ice Massive in the Weddell Sea, the Pacific Ice Massives in the Bellingshausen Sea and in the Amundsen Sea, and the Balleny Ice Massive in the area of the Balleny Islands.

The ice limit location for every month of the year is given in the Soviet Atlas of the Antarctic. Using the maps of this Atlas the area covered with sea

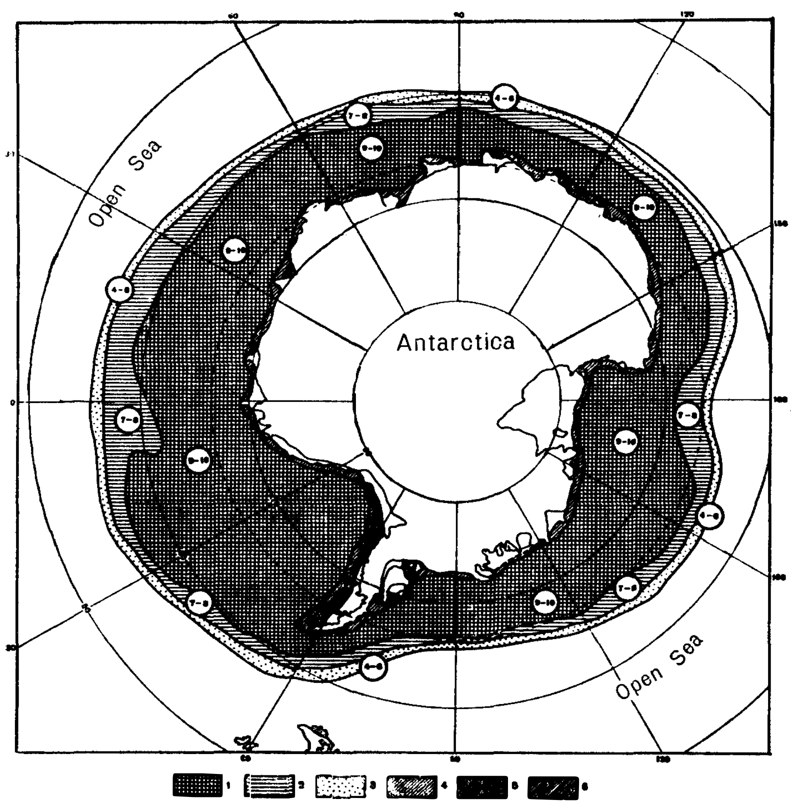

Fig. 5. The map of ice distribution during the maximum extention of the ice cover over the Southern Ocean.

ice in different months was estimated by the scientists of the Arctic and Antarctic Research Institute. These values are given in the following table.

Table 1. Area covered with sea ice.

Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Area in mln. sq. km	6.8	4.3	2.6	6.4	9.2	11.0	13.9	15.7	18.8	17.8	15.2	11.4

It is seen from this table that the main bulk of the sea ice formed in the cold period of the year melts in summer.

The presence of the shore lead in the ice belt of the Southern Ocean is a characteristic feature of the Southern Ocean ice conditions, this feature being an important factor of both the hydrological and ice regime of the Ocean.

In winter, due to permanent southeasterly winds the shore lead is formed between the fast ice and floating sea ice near Antarctic coasts. Near ice shelf barriers, where there is no fast ice, the shore lead develops near the barrier itself. All the coastal research stations observed the existense of the polynya beyond the fast ice of the ice shelf barrier.

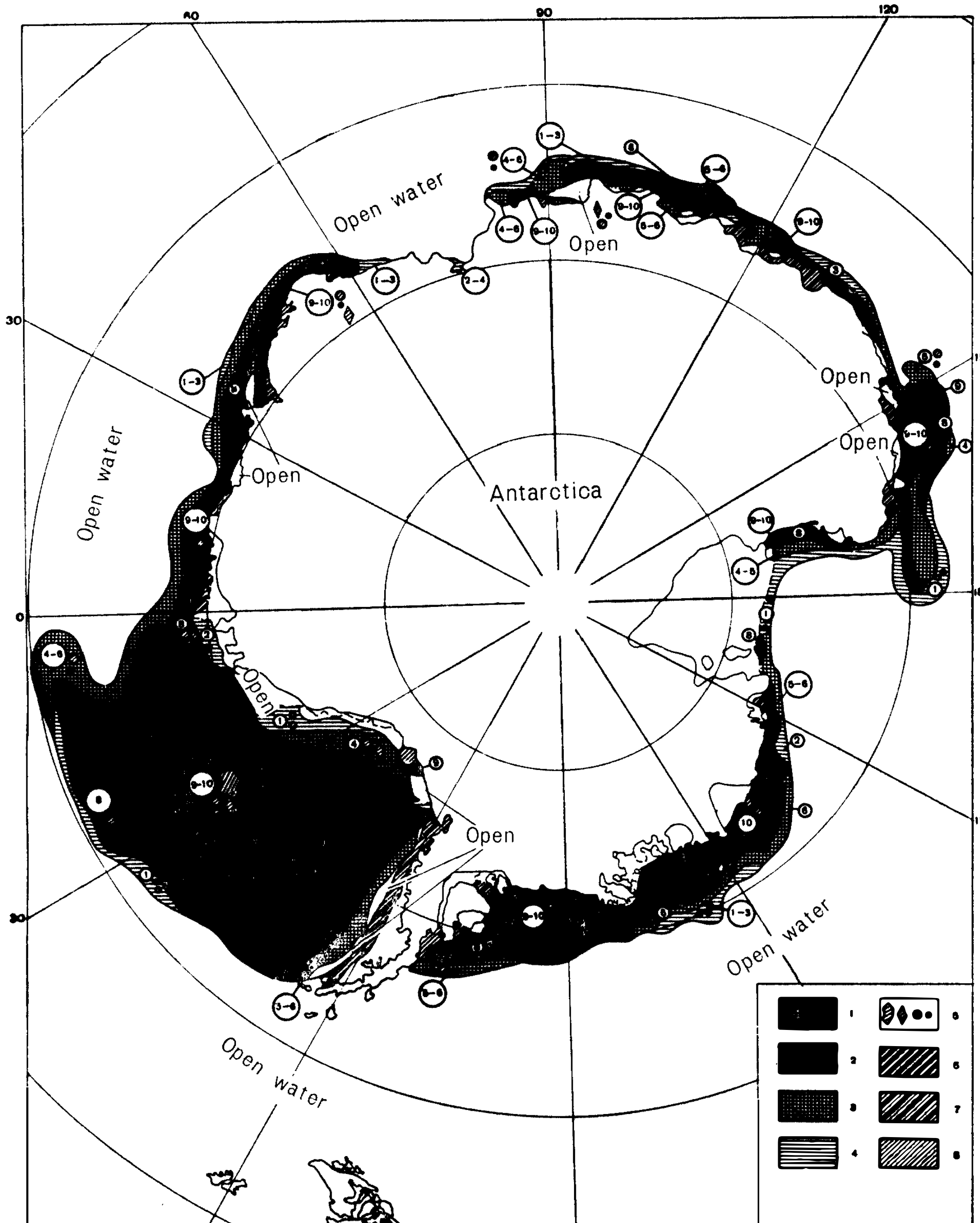

Fig. 6. The map of ice distribution for the late February, 1957.

In winter, when air temperatures are below zero, young ice is regularly forming and in the polynya it is being carried north by the wind. It is here that the process of winter vertical circulation is the most intense. Some authors believe that the large amount of cold Antarctic water is formed in the shore lead.

In summer this shore lead accumulates solar energy. Albedo of the young ice and the water itself due to their dark surface colour is considerably less than that of the old ice covered with snow. Therefore the water is heated and the new ice rapidly melts. Water waves accelerate the melting of sea ice to the north and break the fast ice to the south.

The fast ice near the Antarctic coasts unlike that of the Arctic is less extensive. The Arctic fast ice is hundred kilometers wide, while in the Antarctic its width is less than 30 km and this fast ice is not formed at all near the ice shelf barriers.

This difference in the width of the Arctic and Antarctic fast ice is determined by the water depths near the coasts. In the Arctic seas vast shallow water areas extend along the coasts, while in the Antarctic the depths near the coasts are large almost everywhere.

In spite of its comparably small width the Antarctic fast ice is a serious obstacle to the ships approaching the continent in summer.

The fast ice finally settles in March-April and in the years with favorable conditions (with frequent autumn storms) the fast ice is formed in May. The fast ice, as a rule, breaks up late in summer, that is either in January or in February.

The structure of the Antarctic fast ice is not homogeneous. In winter after its formation, it is covered with a thick layer of snow, blown from the Continent. Under the weight of this snow cover the ice sinks below sea level, the water shows through ice cracks, then this water mixed with the snow freezes up, forming a layer of infiltrating ice.

Moreover, the coastal Antarctic waters are characterized by the formation of interwater ice. This interwater ice was found in winter on the instruments lowered under the ice cover. Usually, a large amount of flat crystals rapidly grow on the instruments and cables, these crystals in appearance reminding us of the oak leaves. It was noticed that the interwater ice formation takes place where strong under ice currents are observed.

It is known that interwater ice is formed in the rivers and other water basins in cold sunny weather, in areas with rapid currents and with no ice cover.

But in the Antarctic the interwater ice is formed under the ice cover and in any weather.

The formation of this interwater ice seems attributable to the influence of the supercooled water which washes up the ice shelf barriers and icebergs.

This interwater ice coming to the surface freezes up to the fast ice bottom and forms a layer of loose ice, with the density smaller than that of the ice layer of natural accretion.

Thus, the fast ice of the Antarctic has a three-layer structure: the layer of infiltrating ice, the layer of crystal ice, and the layer of loose, small density ice. In a number of places where interwater ice formation is especially intensive, the layer of loose ice may be several times larger than that of the crystal ice. The thick ice (the fast ice) may be erroneously considered to be old ice, which is actually one-year-old fast ice, with a thick layer of interwater ice portion.

For instance, fields of broken fast ice more than 4 meters thick were encountered in 66°53′ S, 47°26′ E at the entrance of one of the Enderby Land Sounds during the voyage of the Soviet d/e ship LENA in 1958. This ice might have been taken for the old ice by its appearance. But the ice floes were easily broken by the hull of the ship. The study of the structure of this ice showed that the thickness of the dense crystal ice layer was only 30 cm, and the loose water saturated ice constituted the remaining 4 meters. The ice appeared to be the one year old ice, with the lower portion of interwater ice.

The fast ice is often used for the unloading operations from the ships to the coast. And it is absolutely necessary to remember that the loose ice is not so strong as the dense crystal ice in estimating the load capacity of the fast ice. It is difficult to notice the signs of summer thermal disintegration of the Antarctic fast ice. Unlike the fast ice in the Arctic, there are no puddles on the Antarctic fast ice due to the large thickness of the snow cover. The infiltrating ice, however, becomes like slush under the snow cover as a result of the penetrating solar radiation.

The Antarctic fast ice is interesting because of its other peculiarity. This ice is rich in mineral salts which results in the development of a large amount of diatoms in its thickness. They are frozen within the bottom layers of the ice. And in spring-summer period due to their dark colour they absorb the incoming penetrating solar radiation, transferring it into thermal energy. And V. BUYNITSKY, Soviet scientist, believes that the role of this biogenic factor is very important in the melting and disintegrating process of the Southern Ocean ice.

It is difficult to characterize all the peculiarities of the ice regime of the Southern Ocean. I dwelt only on the main features of their structure and behavior and compared them with the Arctic ice. More detailed data are regularly published in the reports of the Soviet Antarctic Expeditions.

And finally I would like to draw your attention to the well known fact. The sea ice of the Southern Ocean is limited by the the Continent only from one side and therefore the ice is exported to the warmer latitudes where rapid melting occurs, while the Arctic sea ice is encircled almost everywhere by the earth's massives and is carried to colder latitudes where this ice becomes heavy pack ice. And this is the main reason for regime differences of the sea ice of the two opposite polar regions.