H.O. 551

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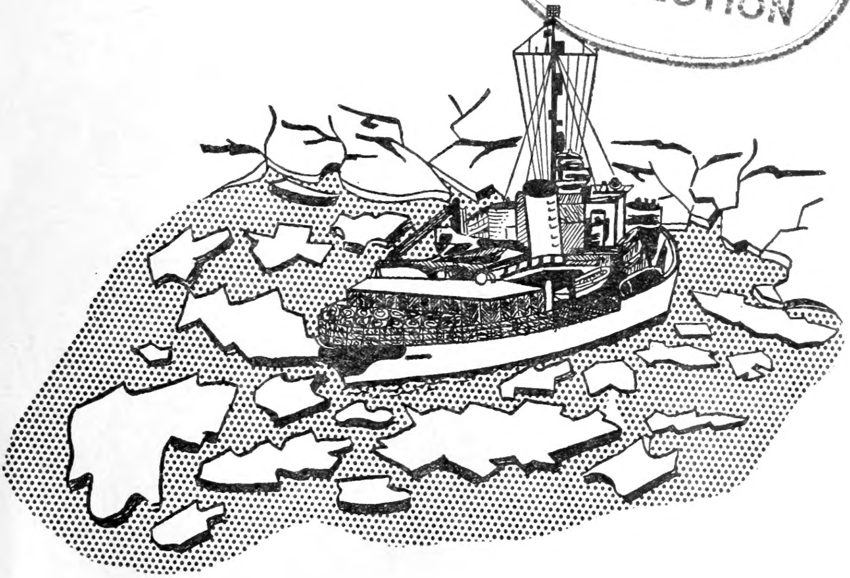
MANUAL OF ICE SEAMANSHIP

H. O. PUB. NO. 551



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U. S. NAVY HYDROGRAPHIC OFFICE
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FOREWORD

The interest of the United States Navy in polar navigation dates back over a century, to the voyage of the United States Exploring Expedition under Lt. Charles Wilkes, in 1838–42, which made landfalls at several points along the Antarctic continent. In 1855 the U. S. S. *Vincennes*, Commander John Rodgers, explored and charted the Arctic Ocean beyond Bering Strait.

Meanwhile, in 1850–51, the *Advance* and *Resolute* under Lt. E. J. de Haven, were engaged in a search for the missing British Arctic explorer, Sir John Franklin, and in 1853 the *Advance* was sent out again under Passed Asst. Surg. E. K. Kane. In 1855 the *Release* and *Arctic*, commanded by Lt. H. J. Hartstene, went to the relief of Dr. Kane in the Arctic. Capt. C. F. Hall's third voyage in search of Franklin was made under naval auspices in 1871 in the *Polaris*, and the *Tigress* and *Juniata* were fitted out with naval crews to go to his rescue in 1873.

The increasing interest in the Arctic brought about by the Franklin relief expeditions led to the commissioning of the *Jeannette* as a naval vessel in 1879 to explore beyond Bering Strait under Lt. G. W. de Long. The revenue cutter *Corwin* cruised in search of the *Jeannette* in 1880, as did the U. S. S. *Rodgers* and U. S. S. *Alliance* in the two following years. In 1884 a naval expedition under Commander Winfield S. Schley, comprising the *Thetis*, *Bear*, and *Alert*, rescued the survivors of the Greely expedition in Greenland waters.

Except to mention that the North Pole was attained by Commander Robert E. Peary of the Civil Engineering Corps in 1909, and that the first man to fly over both Poles was Rear Adm. R. E. Byrd, USN (Ret.), later naval operations in Polar waters need not be touched on here.

This publication has been prepared in an effort to make available the accumulated experience of past expeditions in a form convenient for use by present-day Polar expeditions, whether operating for military, commercial, or scientific purposes. It should be used in conjunction with the Sailing Directions for the appropriate coasts, of which the following have been issued by the Hydrographic Office:

H. O. Pub. No.—	*Sailing Directions for—*
75.	East Greenland and Iceland.
76.	Baffin Bay and Davis Strait.
77.	Northern Canada.
136.	Northwest and North Coasts of Norway.
138.	Antarctica.

H. O. Pub. No. 550, Ice Atlas of the Northern Hemisphere, should also be consulted for detailed information on monthly ice conditions in the Arctic.

Most recent expeditions which have spent only late spring, summer, and early fall months in the polar regions have reported some surprise at the relatively mild temperatures encountered. Long summer daylight and the heat-buffering properties of sea water combine to produce conditions far better than those experienced by the mariner operating out of Boston, Mass., or Portland, Maine, in winter.

A. Hobbs,
Captain, U. S. Navy, (Ret.)
Hydrographer.

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CHAPTER I

FORMATION AND GROWTH OF SEA ICE

An understanding of the formation, growth, and decay of sea ice is desirable for comprehension of many of the problems in ice seamanship. The climatic factors bearing on the formation of ice naturally vary from place to place and from season to season. However, a knowledge of the basic physics involved will be of great assistance to the mariner, enabling him to recognize certain salient features of ice and take advantage of its properties.

CAUSE OF FREEZING

In temperate and tropical latitudes, the ocean acts as a storehouse of radiant heat from the sun. The visible and infra-red wave lengths are largely absorbed in the surface layers, and the heat so stored is given off to the air at night and at other periods when the air is colder than the sea surface. In higher latitudes, however, as the nights begin to grow longer in the autumn, insufficient heat is stored in the short daylight period to compensate for the losses at night, and the temperature of the surface waters is therefore lowered. As the season progresses, the altitude of the sun becomes lower day by day; less radiation is received, and more is reflected from the sea surface owing to the low angle of incidence of the rays. Finally, the water reaches the freezing point and further loss of heat results in the formation of ice.

Conditions then become even less favorable for the retention of radiant heat from the sun since, as will be discussed more fully in a later chapter, ice reflects much more of the visible radiation than does water. Cooling of the air in contact with the ice is accelerated, and as this cold air spreads, more ice is formed.

INFLUENCE OF SALINITY

Fresh water freezes at 32.0° F., but the salt present in sea water causes it to remain liquid until a lower temperature is reached. The greater the salinity, the lower the freezing point. Ordinary sea water, with a salinity of 35‰ (35 parts per 1,000), does not begin to freeze until it has been cooled to 28.6° F.

Salinity may also affect the rate of freezing through its influence on the density of the water. Fresh water contracts on cooling and thus sinks below the surface until a temperature of 39.2° F. is reached. On further cooling it expands, so that its density decreases. If the cooling takes place at the surface with no other process of mixing at work, the coldest water stays there in a layer. It is then necessary for only this surface later to be cooled to the freezing point for ice to form. Water with a salinity of 5‰ has its greatest density at 37.2° F., so the entire body of water must be cooled to that temperature before density currents cease. The temperature of maximum density decreases faster than the freezing point with increasing salinity, as shown in figure 1. The two temperatures coincide at a salinity of 24.7‰. This means that with a salinity of 24.7‰ or greater, density currents operate until the freezing point is reached, and theoretically the entire body must be cooled to this temperature before ice can form on the surface.

In nature, however, rapid cooling of still water often occurs under conditions where heat is removed from the surface layers faster than

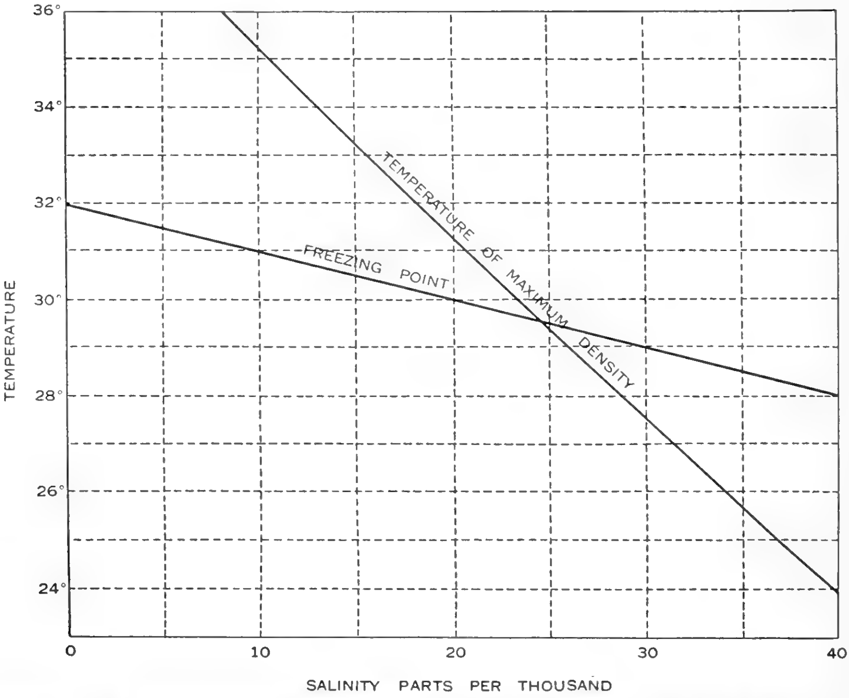

Figure 1.—Relationship between freezing point and temperature of maximum density for water of varying salinity.

it can be supplied from the deeper layers through convection currents, so that ice will form on the surface before the deeper layers have approached the freezing point. Salinity gradients in the sea may also diminish the thermal convection currents. If, because of discharge from rivers or melting of ice, the top layers have a lower salinity, the difference of density may be so great that the surface layer, although cooled to the freezing point, will be too light to sink below the warmer but more saline water underneath.

A practical outcome of the foregoing is that if a body of water originally of uniform density is losing heat at the surface, ice will be formed most readily in fresh water, less readily in sea water of low salinity, and least readily in sea water of high salinity. The greater heat removal required to freeze sea water is due not only to its relatively low freezing point, but also to the increased tendency of the cooled surface water to sink as the temperature of maximum density decreases.

THE GROWING PROCESS

On account of its fairly high specific heat and low thermal conductivity, water loses heat slowly, so that the surface temperature of a large body of water will lag behind the rise and fall of the mean air temperature. In the Murmansk-White Sea area (lat. 65° to 70° N.), rivers usually freeze about 3 weeks after the mean air temperature falls below 32° F. This phenomenon is probably representative of many similar regions.

Ice forms first in shallow water, near the coast or over shoals and banks, particularly in bays, inlets, and straits in which there is no current, and in regions with reduced salinity, such as those near the mouths of rivers. It spreads from these areas as centers. Such ice, broken up and carried seaward by winds or currents, starts further ice formation in deeper water, where floating ice that has not melted during the previous season also acts in the same way. Wave action ordinarily hinders the formation of ice to some extent by mixing the waters of the upper layers. Old ice damps sea or swell and, at the same time, by cooling and freshening the water and providing nuclei of ice crystals, assists the beginning of the freezing process. Quickly recurring fresh winds with raised sea will hinder ice formation, breaking it up several times. The greater the depth, with water of salinity greater than 24.7‰, the later is the time of freezing. As a matter of fact, complete freezing may never occur, as in the case of the central part of the White Sea; hence the necessity for following the deep-water route in order to reach high latitudes during the season of ice formation.

The first sign of freezing is an oily or opaque appearance of the water, due to the formation of needle-like spicules and thin plates of ice about one-third of an inch across, known as frazil crystals. These consist of fresh ice, free of salt, and increase in number until the sea is covered by slush of a thick, soupy consistency.

Snow, falling into water, aids freezing by cooling and by providing nuclei for ice crystals. Except in sheltered waters, an even sheet of ice seldom forms immediately; the slush, as it thickens, breaks up into separate masses and frequently into the characteristic pancake form, the rounded shape and raised rim of which is due to the fragments colliding with each other. The formation of slush damps down sea or swell, and if the low temperature continues, the pancakes adhere to each other, forming a continuous sheet.

RATE OF GROWTH

Sea ice may grow to a thickness of 3 to 4 inches in the first 24 hours, and from 2 to 3 more in the second 24 hours. Ice is a poor conductor of heat and the rate of its formation drops appreciably after the first 4 to 6 inches have formed; a snow cover, if present, still further reduces the conductivity, as shown in figure 2. Once a layer of ice is formed, snow falling on the surface retards growth

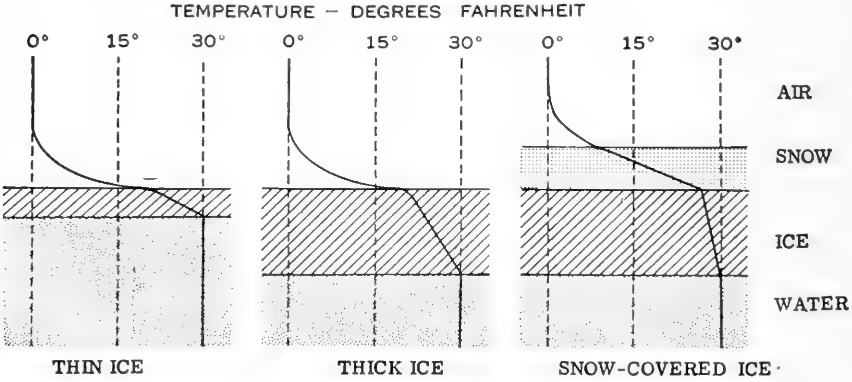

Figure 2.—Idealized diagrams illustrating the distribution of temperature with air at 0° F. and sea water at its freezing point of 30° F. The rate at which heat is conducted through the ice from the water to the air (which, neglecting radiation, is proportional to the rate of freezing of the water or the rate at which the ice increases in thickness) is proportional to the slope of the thermal gradient in the ice away from the vertical.

by its insulating power. This is particularly true of loosely packed snow.

A common assumption in the North is that heavy snow in the fall means a rapid break-up in the spring. With the subsequent decreasing rate of growth, ice which has grown steadily throughout the winter is seldom more than 4 to 5 feet in thickness by the following summer.

Perennial sea ice may grow in thickness during the summer by refreezing of thaw water. Snow on the surface melts, and the water runs down through cracks and holes to form a layer of fresh water under the ice. Since the temperature of the underlying salt water is usually lower than the freezing point of fresh water, a layer of fresh water ice is formed on the bottom of the sea ice. In summer, therefore, a floe melts away on top, but at the same time may be growing slowly on its undersurface. By this process, mud, stones, seaweed, or shells originally frozen to the under side of grounded floes may work right up to the surface. Diatoms frozen to the under side will similarly rise. An autumn period follows, with lower temperature but without ice formation, the supply of fresh water being no longer renewed and the sea temperature not being low enough for the freezing of salt water to begin again. In the second winter, growth continues by salt water freezing. If the ice is unbroken through the second winter, its thickness may reach 7 to 8 feet at the most. Ice in the Arctic polar basin is seldom less than 3½ to 4½ feet thick, and Nansen reports a maximum thickness of 13 feet 10 inches produced by about 4 years of normal growth.

The action of blocks and floes being forced over each other or turned on end by some form of pressure is called rafting. Ice of much greater thickness than ordinary floes can be formed by rafting, tidal overflow, or other types of flooding such as spray and splashing, but such areas will be of limited extent.

The approximate thickness of ice may be predicted from figure 3 if the temperatures at a specified locality are known. Even if exact temperatures are not available, estimates can probably be made from a general knowledge of weather conditions in the region. The only complication in using this graph lies in calculating the "degree days of frost." First it must be remembered that a temperature of 0° F., for example, is equal to 32° of frost. Secondly, the mean number of degrees of frost for each day, or group of days with the same mean degrees of frost, is to be used, not the mean degrees of frost for the entire period. Days on which the temperature was below freezing for only a part of the 24 hours can be ignored unless exceptionally

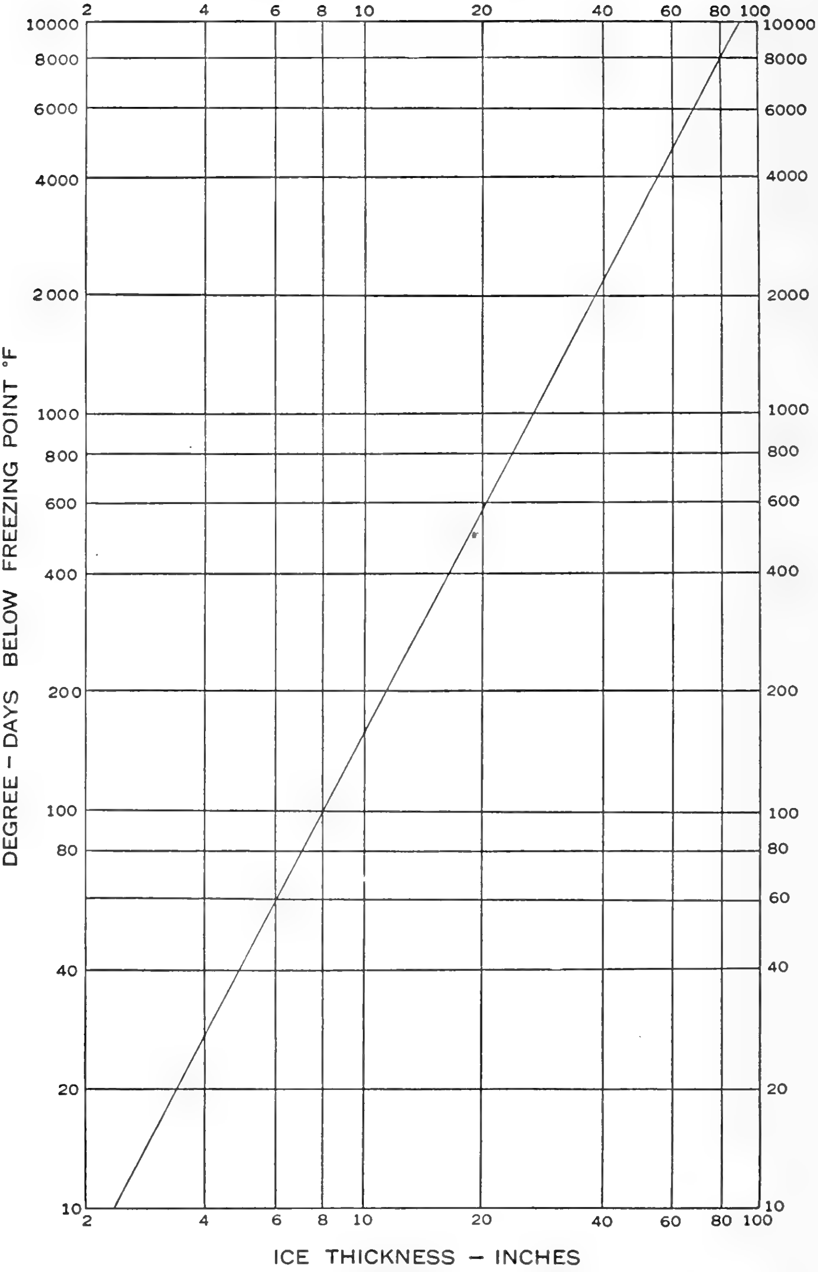

Figure 3.—Graph for prediction of approximate thickness of ice.

numerous. For example, assume a specified day had 8 hours below freezing, and the mean temperature for those 8 hours was 25° F. The degree-days of frost for that day are $\frac{8}{24} \times 7 = 2\frac{1}{3}$. Suppose the next day had temperatures below freezing for the entire 24 hours, and the mean temperature was 20° F. The degree-days of frost for this day are 12. If the next 10 days had approximately the same mean temperature, say $-20°$ F., and all hours were below freezing, the degree-days of frost for the 10 days are 520. The total degree-days of frost for the 12-day period described above would be $534\frac{1}{3}$. A glance at figure 3 shows that the curve permits considerable approximation in calculating degree-days of frost without seriously affecting the final results. Obviously other factors such as wind, snow, and currents introduce complications difficult to evaluate and not allowed for in the graph. The lowermost end of the curve is none too reliable because freezing weather may exist for a number of days before ice starts to form. In addition, the number of variable factors affecting cooling, mentioned heretofore, is difficult to evaluate. Once a layer of ice has begun to form, the curve is much more reliable.

The annual history of ice in far northern harbors is shown in figure 4. The size of such curves will differ from place to place, but their shape will undoubtedly be similar. The important things to note are the steady increase in thickness for two-thirds to three-fourths of the total period, the brief flattening off, and finally the sudden drop at the end.

COMPARISON OF ARCTIC AND ANTARCTIC ICE

Differences in underlying factors specific to the region develop corresponding differences in the features of the ice. An example of one of these agencies is the low mean annual temperature of the Antarctic. The warmth of the Arctic summer has no parallel in the far South and, mainly because of this thermal difference, the ice sheets of the northern polar regions are unlike those of the southern. The margin of the Antarctic cap, overflowing its land support, is free to spread over the sea until fracture detaches huge strips, sometimes including 10 to 20 miles of its front. In Greenland, by contrast, the edge of the inland ice ends on land, and icebergs irregular in shape are formed. The tabular or box-shaped berg is, therefore, in general, characteristic of the Antarctic while the pinnacled, picturesque berg is typical of the North.

The Antarctic sea ice surrounds the continent, while the Arctic sea ice is a central mass surrounded by land. The ice moves around and outward from Antarctica and gathers in a belt formed by the meeting of southeasterly and northwesterly winds in the vicinity of the 60th parallel. There is a close correspondence in the formation of this belt of ice with that formed in the Arctic which follows down Davis Strait and eastward off Greenland. In the Antarctic it is unusual for sea ice to be more than 1 or 2 years old. The drift in both the Weddell and Ross Seas carries the pack out into the open oceans in a little over a year.

In the Arctic, on the other hand, floes of great age are frequent. Ice formed off the Siberian coast takes from 3 to 5 years to drift across the polar basin and down the eastern coast of Greenland. Ice of this age, therefore, becomes pressed and hummocked to a degree unknown in ice formed in lower latitudes. The warmth of the Arctic summers also has its effect and the result is worn-down, more or less even, floes of great thickness known as "polar cap ice." During the summer, melting on the surface is considerable, as a rule about 2 feet, and pools of

Figure 4.—Course of thickness of ice formed in two typical sheltered harbors in the Northern Hemisphere at the latitudes indicated.

fresh water are formed on the floes. This is not a very marked feature off the east coast of Greenland, north of latitude 72° N., but in Baffin Bay the floes become covered with a maze of deep pools. In the Antarctic, surface pools on floes in the pack are almost unknown. The outstanding difference between Arctic and Antarctic ice, which is apparent to the navigator, is the softer texture of the latter.

PALEOCRYSTIC ICE

The extreme development of sea ice is found in the channel between Grant Land and the northwest coast of Greenland. Here the early explorers encountered ice masses so thick and irregular that they were assumed to be closely packed bergs of glacial origin. Later observations, however, indicate that this paleocrystic ice consists of remnants of Arctic pack that is blocked by the tip of Peary Land from drifting down the east coast of Greenland and instead is trapped along the north coast of Greenland and Grant Land. Intensive hummocking of this pack over a period of years produces tremendous floebergs.

CHAPTER II

CLASSIFICATION AND DESCRIPTION OF ICE

Ice met at sea consists for the most part either of icebergs originating from glacier and continental ice sheets, or of sea ice formed by the freezing of the top layers of the sea itself. Sea ice proper accounts for probably 95 percent of the area of ice encountered at sea, but bergs are important because of the manner in which they drift far from their place of origin, constituting grave menaces to navigation. A certain amount of ice may also originate in rivers or estuaries as fresh-water ice, but it is already in a state of decay by the time it reaches the open sea and its importance is no more than local.

With some risk of over-simplification, figure 5 outlines the relationships between the chief categories of ice, and gives an indication of the cycles of formation and disintegration.

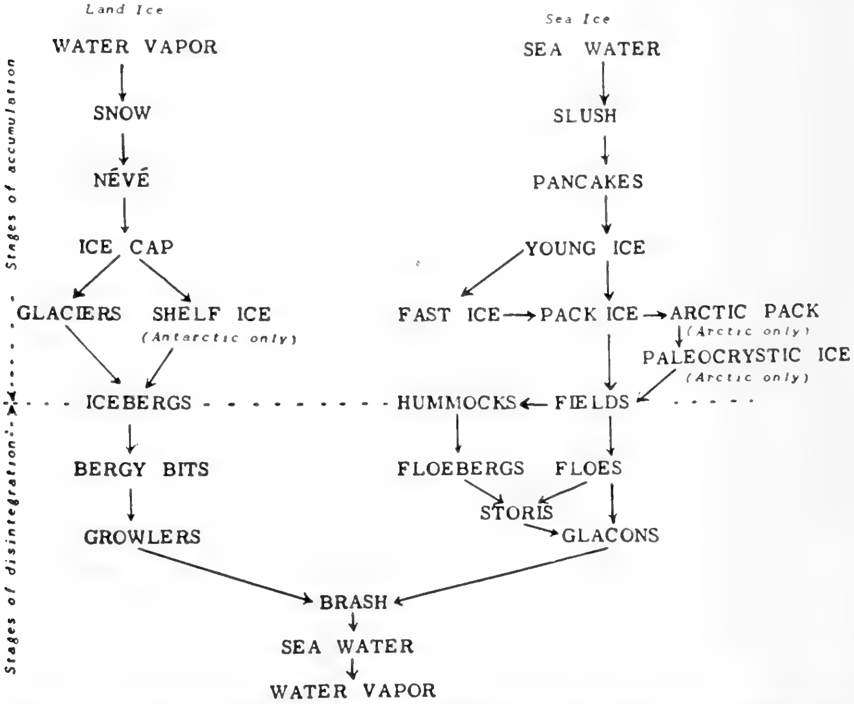

Figure 5.—Synoptic diagram showing the general relationships between the various kinds of ice occurring in the sea.

ICEBERGS

Icebergs are large masses of floating (or stranded) ice derived from the fronts of glaciers, from glacier ice tongues, or from the shelf ice of the Antarctic. They are products of the land, and not of the sea. Their structure, and to some extent their appearance, depend upon the source from which they are derived.

Arctic bergs originate mainly in the glaciers of Greenland, which has 90 percent of the land ice of the north polar region. Svalbard, Novaya Zemlya, and Ellesmere Land also produce a few bergs. Arctic bergs are irregular in form and take many varied shapes. Most common are the irregular dome-shaped bergs, produced by glaciers that have plowed across the uneven foreland on their way to tidewater which differ entirely from the flat-topped, straight-sided bergs originating where the ice sheet itself is thrust directly out into the sea.

In color, bergs are an opaque flat white, with soft iridescent hues of blue or green. Many show veins of soil or rock debris; others may have yellowish or brownish stains, probably due to diatom films. Under certain conditions of illumination, an iceberg will appear dark in contrast with the sky or with other bergs in the direct sunlight, and this phenomenon has often led mariners to report islands where none exist.

The higest berg yet measured in the Arctic stood 447 feet out of water; 230 feet is a common height for a large berg. These figures refer to bergs soon after calving; the highest so far observed to the southward of Newfoundland was 262 feet. The longest iceberg measured in those waters was 1,696 feet long, although one several miles long was reported in 1928.

The ratio of the mass of the submerged portion of a berg to its total mass is equal to the ratio of the specific gravity of the berg to that of the water in which it is floating. On account of the origin of glacial ice in compacted snow, berg ice contains up to perhaps 10 percent of trapped air and is therefore somewhat less dense than ordinary ice. Measurements of the specific gravity of ice in Greenland bergs have given values close to 0.90, while the cold sea water in which they float has a specific gravity of about 1.027, so that about seven-eighths of the mass is submerged. It is often erroneously assumed that a berg with one-eighth above water and seven-eighths submerged should be floating with a draft seven times its height above water; but these ratios hold good only for mass, and not for linear dimensions. Actual measurements on Arctic bergs show that the draft is seldom more than

Figure 6.—Tabular iceberg off Scott Island.

five times the exposed height for the blockiest bergs, and may be as low as one or two times the height for the pinnacled and irregular types.

Tabular bergs, the most common type in Antarctic waters, are derived by breaking off floating portions of the continental ice sheet. Bergs of great size, much larger than any found in the North, may be produced in this way. In January 1927 the whale-catcher *Odd I* sighted one off Clarence Island which was about 100 miles in length and width and floated about 130 feet out of water. There are numerous reports from the Antarctic of bergs 1,000 feet out of water and even higher, but these observations were made from sailing ships and have never been confirmed by a trained scientific observer. Poulter measured the average thickness of the floating ice barrier in the Bay of Whales as 760 feet with 94 feet out of water, or a draft of seven times the height. He determined that this ice was formed from compacted snow and frost, without glacier material from the highlands. Elsewhere in the Antarctic, névé bergs are encountered with a draft only about twice the height. These are formed at localities like Robertson Bay, where precipitation is at a rate greatly in excess of ablation. Where glaciers in the Antarctic lead across a sloping foreland to the sea, irregular bergs like those of the Arctic are produced.

On a clear day an iceberg can be seen at a great distance, owing to its brilliant luster; during foggy weather it may not be perceptible until dangerously close aboard. When the fog is dense but the sun is shining the first appearance of a berg is in the form of a luminous white object; while if the sun is not shining it is a dark, somber mass with a narrow streak of black at the water line. Diffusion of light in the fog will produce a blink around the berg that augments the apparent size of the ice mass.

Relieving stresses set up by temperature changes, and responding to vibrations from sound or wave action, bergs may at anytime calve off large sections of ice, which after falling into the water may bob up to the surface again with great force, often at a considerable distance away. Bergs are often so balanced that this calving, or merely melting of the under surface, will cause a shift in the center of gravity with consequent capsizing and readjustment of the mass to a new state of equilibrium. Vessels and boats should therefore keep well clear of bergs that give evidence of disintegrating or overturning. Bergs may also possess underwater spurs and ledges at a considerable distance from the visible portions, and should be given a wide berth at all times.

In fair weather, icebergs can be of great assistance to navigation in floating ice. They may mark shoals, break up consolidated pack, and afford reference points to assist in conning through ice. Having a relatively small "sail area" in proportion to their bulk, bergs are not affected by wind to the same extent as pack ice, and with a wind blowing the pack past a berg, the optical illusion may arise that the berg is being carried to windward, cutting a channel. Illusion or not, such a lee may be a desirable place for a vessel to lie to avoid heavy ice; there are cases on record of vessels laying out an ice anchor to a berg under such circumstances. A careful watch must be kept for growlers calved off from the berg under these conditions. Navigators are frequently alarmed by the presence of icebergs in an anchorage area. Unless the bergs are of mammoth size or disintegrating, there is little to fear. Small bergs that foul a handling area can easily be fended off with ice picks.

When navigating in fog, the presence of a large number of growlers bunched together may be a good indication of icebergs to windward. In calm weather, growlers may sometimes be found distributed in a curved line, with the berg on the concave side of the curve.

SEA ICE

Fast ice forms in sheltered bays, gulfs, and fiords, as well as among floating lumps of old ice. Developing along the shore and spreading into the sea, it joins the new ice formed around islands, grounded floebergs, and floating masses of old ice. Though then subjected to repeated fracturing, with the fall in temperature of the air, it spreads farther and farther into the sea, increasing in thickness and offering more and more resistance to breaking up. Finally in the first months of winter it reaches its maximum offshore extension, beyond which the region of the pack is found.

The development of the width of the fast ice belt depends upon the configuration of the shore, since the more rugged the coast line and the greater the number of islands in its vicinity, the greater is the width of the fast ice; it also depends upon the relief of the bottom, since the shoaler the sea, the less prevalent are strong currents and wave motion. Stranded hummocks in shoal water also assist fast ice development.

Assuming the height above water of floebergs to be 10 feet and their draft to be 70 feet, the average depth for their free motion is about 12 fathoms. The floebergs ground in shoaler water, and thus the whole area of fast ice is confined between the shore and the rampart of ice heaps which lie approximately along the 12-fathom contour.

The seats of fast ice are the broad continental shelves and their spacious embayments. The most striking example is the Siberian Shelf, which has a mean width of 400 miles and a depth of 12 to 50 fathoms, its outer edge falling abruptly to the greater depths of the Arctic Ocean. These regions produce a vast amount of fast ice, because the shallow depths favor early chilling, and the salinity of the sea has been lessened by the discharge of numerous large rivers. The Arctic coast of Eurasia, especially the shore of the East Siberian Sea, has more extensive shallow water than is found elsewhere in the Arctic Ocean. Here fast ice attains its greatest width, amounting to 270 miles at its widest place off the mouth of the Yana. It has an average thickness of 6½ feet and at times reaches a maximum thickness of 9 feet.

Another large area of fast ice, second only to that off Siberia, is the sheet covering the labyrinth-like waterways of the Canadian Arctic Achipelago. While small openings in some of the narrower channels and straits may be kept unfrozen in winter by strong currents for long or short periods, the stabilizing effect of the large number of islands promotes a maximum amount of stationary ice. This is held fast in the archipelago region longer than in many other localities because of the intricate channels and sounds. There are other types of ice present as well, since the 12-fathom curve is generally near shore.

Along open coasts the fast ice is liable at all times to break up and drift away. This break-up may not occur, however, in regions where the configuration of the land is such as to shelter the ice from the prevailing winds, and especially where offshore winds blowing in from opposite sides of an embayment are opposed to each other and so hold the ice firmly in place. Stranded bergs sometimes act as anchors to fast ice, preventing it from breaking out and drifting to the open sea.

Pack ice is composed of sea ice frozen in the open sea, of detached fragments of fast ice formed along the coastline, and to a lesser extent of disintegrated particles of land ice. These elements are not uniformly influenced by winds and currents; as a result there is a differential movement with a decisive effect upon the composition and stability of the pack. This conglomeration drifts under the influence of wind, tide, current, and the component due to the earth's rotation.

Pack ice is classified according to compactness of arrangement into *consolidated pack*, *close pack*, *open pack*, and *drift ice*. The ice masses themselves, according to size, may be *ice fields*, *floes*, *blocks*, or *pancakes;* according to surface, may be *level*, or *hummocked;* according to thickness, may be *light* (up to 2 feet in thickness) or *heavy* (more than 10 feet in thickness).

Figure 7.—Pancake ice. This is new ice formed after 2 or 3 days of freezing temperature.

Under the influence of variable winds the ice, in all seasons of the year, is torn apart in some localities forming lanes of open water, and elsewhere is crowded together. Where lanes are formed the ice always breaks along a jagged line, and when the ice fields move apart they may also be displaced laterally. In summer such lanes do not re-freeze. When they close due to change in wind direction, the two sides of the lane do not fit: corners meet corners and openings of different shapes remain between the corners. "Arctic sea smoke" may sometimes be noticed wherever cracks in the ice appear, particularly in areas where there is considerable open water.

The belts of pack ice usually lie perpendicular to the prevailing wind. Tongues may be formed in the belt by a wind blowing nearly parallel to the axis of the belt, resulting in a bend of the ice edge. In regions where currents augment the influence of the parallel wind, a vast bend may occur redefining the limit of the pack.

Bays or bights may be formed by wind in a belt of pack ice; the degree of openness and the physical character of the ice forming the belt greatly determine the resistance offered by the ice. Where wind produces this effect the embayment is usually small. Bays may also be formed in the pack under the influence of currents, sometimes of huge dimensions.

Often consolidated pack, the heaviest form of pack ice, will drift from shore or will separate, forming leads or passages through the ice area. Massive detachments of ice resulting from hummocking are called floebergs. These should not be confused with icebergs, or growlers, which are of glacial origin. Pressure ridges are formed by a very large external loose floe riding upon a fixed floe or upon the

Figure 8.—Tidal currents acting on grounded ice produce the mushroom-looking pieces of ice, whose shape is visible at low tide.

Figure 9.—Sea ice being subjected to great pressure.

shore, or by elevation of the ice above the normal level under the pressure of the wind or the current. They are higher near the shore and lower at the sea end.

The pack ice in the Antarctic consists of larger cakes and is less broken and piled up than in the Arctic. The pack is heaviest and most closely packed around the coast in summer, and is more open and scattered during the winter months. Antarctic pack ice will generally have a great number of icebergs interspersed throughout its entire area, whereas iceberg distribution throughout the pack ice in the Arctic is confined to areas draining active glaciers.

Sea ice when newly formed is highly plastic and readily conforms to stresses. It acquires brittleness with age, and reaches a state of strain where it may require but a slight impulse to break it. This impulse is usually provided by the wind. Strain cracks may be produced by a swell from the open sea moving under a sheet of ice. The sheet suspended between the crests of the swell will be unsupported over the trough, and a crack parallel to the wave front may result. If a family of cracks is produced, the cracks will lie parallel to each other. If a crack assumes the shape of a fan, it indicates the presence of torsion.

This tendency to crack is always present in an ice field, whether composed of young ice or hummocky floes. All cracks are due to the relief of strain produced by stresses set up by sudden differences of temperature, by unequal loading, or by pressure. Heavy snow deposits may, to a large extent, protect the underlying ice from sudden thermal changes.

Although cracks are due to the relief of stress within the pack, they also allow movement of the pack. Blocks and floes are the product of cracks and, under the influence of the wind, they constantly shift their relative position, thereby producing leads which make the pack navigable. Such openings, however, permit the production of pressure and formation of hummocks, which make the passage through pack dangerous to vessels.

Pressure set up in the pack produces bending, tenting, and rafting. The first stage, bending, occurs in thin and very plastic ice. In heavier floes, which are less resilient, the ice bends up until a crack is formed perpendicular to the direction of pressure, resulting in a tent-like structure. Other radiating cracks usually occur and, if the movement is continued, the blocks so formed pile up into a pressure ridge. Rafting is the overriding of one floe on another and is the most common effect of pressure.

Pressure ridges attain their greatest height when newly formed and before settling to a position of equilibrium. Ridges seldom reach a height above 20 feet; greater height indicates the existence of land which obstructs the free drift of the ice.

Pressure produces cracks in the pack which have been classified as hinge cracks, shock cracks, and torsion cracks. Hinge cracks are longitudinal fissures in front of a pressure ridge. Old ice, which is no longer plastic, will not bend under the weight of a heavy pressure ridge piled on top of it. The result, when the breaking strain is reached, is the formation of a crack where the ice is pressed down by this heavy loading. The crack opens like a hinge. Radial cracks will also develop in front of the pressure ridge, resulting in new breaking up of the floes which, in turn, creates favorable conditions for further hummocking. Between the pressure ridge and the hinge crack the surface of the ice is often depressed below the level of the sea allowing a pool of concentrated brine to form. Shock cracks are produced by the impact of a moving floe against a floe relatively inert and in a state of tension. These cracks are produced transverse to the advancing pressure ridge. Torsion cracks result from shearing and screwing and produce chains of pools and zigzag leads.

The age of floes may often be judged by the presence of colored bands at their edges. During the summer, diatoms adhere to the underside of floating ice, which, as already mentioned, may be slowly growing through the freezing of fresh water derived from melting of the upper side. In the winter, the ice grows more rapidly, and diatoms are absent owing to the lack of sunlight. Thus yellow strata of frozen diatoms mark the interval between two winter freezings and may be an index to the age of the floe.

CHAPTER III

EVAPORATION, MELTING, AND BREAK-UP

HEATING AGENTS

Ice and snow are evaporated and melted by direct absorption of radiation and by conduction of heat from the surrounding air, rocks, or water. The ultimate source of the heat energy is the sun in either case, but the relative importance of radiation and conduction in melting ice will vary with climatic conditions in different localities.

A large part of the visible radiation striking a white surface such as ice or snow is reflected away from the surface again without warming it, just as a white uniform keeps the wearer cooler than a dark one, even if both are made of the same material. The percentage of incident light reflected from a surface is called the albedo. The albedo of clean snow is about 80 percent, of sea ice about 50 percent, and of sea water only 3 or 4 percent. In the case of the longer wave lengths in the infra-red portion of the spectrum, which make up slightly over half the total radiant energy received from the sun, the proportion reflected by a snow surface is only 15 to 25 percent. The proportions reflected by ice and water are correspondingly less, and since water is opaque to infra-red radiation, the heat absorption by water in this region of the spectrum is concentrated in the surface layers where it is of most significance with regard to melting of ice.

It is obvious, therefore, that a surface interrupted with areas of water, either leads between the floes or pools of melt water accumulating on top, will absorb much more radiant heat than a continuous ice or snow surface. Once disintegration of an ice sheet has proceeded to the point where free water surfaces appear, the rate of further disintegration is very much accelerated. Likewise, lowering of the albedo of the ice or snow through other causes, such as accumulation of dust or a film of diatoms, will speed up disintegration. At the beginning of summer, ice generally disappears first in the coastal zone where it has become dirty from the proximity to shore.

EVAPORATION

The absorption of heat by ice or snow results in either evaporation or melting. Melting takes place as soon as the temperature of any

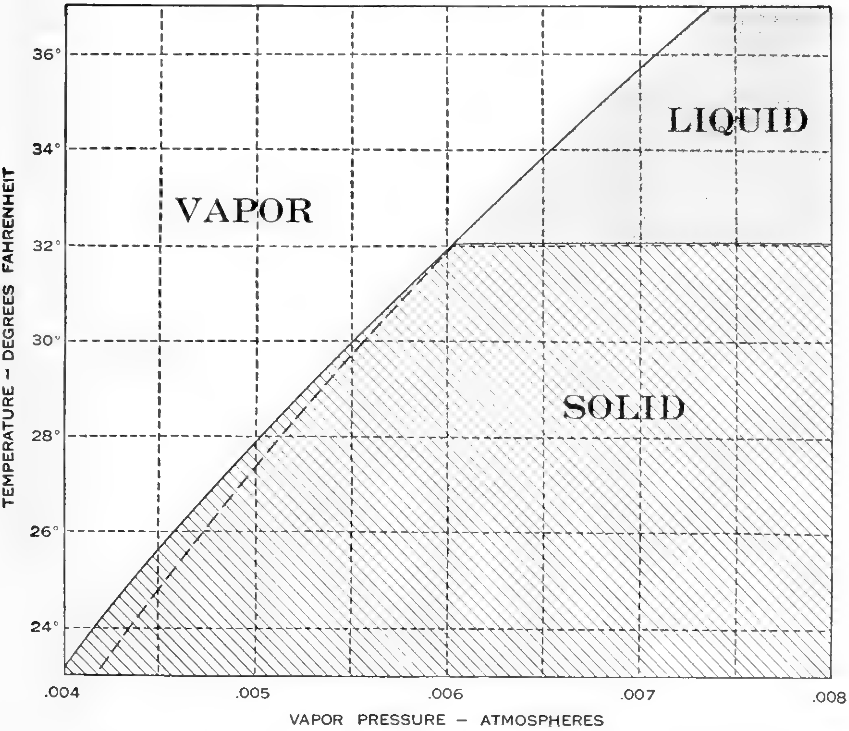

Figure 10.—Phase diagram for pure water in the vicinity of the freezing point. The intersection of the three shaded areas, near 0.006 atmospheres and 32° C., is the triple point, the only point at which equilibrium between water, ice, and water vapor can exist. Note that although the freezing point of water is exactly 32° F. at 1.0 atmosphere pressure, decreasing the pressure of the system to 0.006 atmosphere raises the freezing point to 32.013°, since the melting point of ice decreases 0.013° for each atmosphere increase of pressure. The solid line between VAPOR and LIQUID represents the vapor pressure of water; that between LIQUID and SOLID the freezing point of water; that between VAPOR and SOLID the vapor pressure of ice. The dashed curve below the triple point represents the vapor pressure of super-cooled water, which may exist in the absence of suitable nuclei to initiate crystal formation.

The phase diagram for sea water has the LIQUID-SOLID boundary shifted downward 3° or 4° to correspond with the freezing point of sea water, but there is very little shift in the vapor pressure curves.

superficial layer of the ice surface is raised above the freezing point, but evaporation may occur at any temperature. Figure 10, illustrating the equilibrium relationships between the solid, liquid, and vapor states for pure water, shows that vapor pressure, the tendency for evaporation, increases rapidly with increasing temperature, but that there is no appreciable change in this tendency in passing from the solid to the liquid state. Under still air conditions, the layer of air nearest the ice will soon become saturated with water vapor. Evaporation will therefore depend on the diffusion of water vapor from the surface and generally proceed at a relatively slow rate. Air currents increase the rate of evaporation by inducing turbulent mixing of the layers of air near the ice and by bringing new unsaturated air masses from drier regions. A brisk wind, under conditions of low relative humidity, may therefore result in the ablation of large quantities of ice or snow even though the air temperature never reaches the melting point and no melting occurs.

MELTING

Melting of ice, for the reasons already discussed, takes place mostly at the expense of the heat of the surrounding water. This heat may have been absorbed from solar radiation in the vicinity, or provided by currents originating in warmer latitudes. Melting also results from direct absorption of radiation by the ice and from contact with warm air. Ice will condense dew from warm, moist air on its surface, and each increment of moisture so condensed will melt several times its weight of ice in the ratio of the latent heat of evaporation to the heat of fusion.

Another factor tending to accelerate the rate of ice melting from solar radiation, once it has commenced, is the increased stability of the surface layers of the sea brought about by the freshening effect of the melt water. Mixing between the surface and deeper layers, already diminished by the wave-damping action of floating ice, is further decreased by the formation of a surface stratum of relatively low density. The normal transfer to greater depths of heat received as infra-red radiation in the top layers is retarded, and the melting of the ice is thereby speeded up.

The phenomenon of "dead water" is sometimes encountered by ships in areas where a layer of nearly fresh water derived from melting ice extends to about keel depth. Under such conditions, the propulsive power of the ship may be largely dissipated in generating internal waves in the boundary between the fresher water and the more saline water. The ship loses headway, answers her helm sluggishly, and appears to be "stuck" in the water. Fortunately, this state of affairs occurs only when the speed of the vessel is below the speed of propagation of such waves, which is not more than 2 or 3 knots. "Dead water" will therefore ordinarily affect only sailing vessels in light winds, or tugs with very heavy tows.

In regions where the spring melting of ice is brought about chiefly by atmospheric transfer of heat from lower latitudes, and where local fogs restrict the solar radiation reaching the ice and sea surface, the fresh surface layers of sea water may become greatly chilled, and the rate of melting will be reduced. Here vertical exchange of water caused by wind, sea, currents, and tides will contribute heat to the upper layers and expedite clearing of the ice. An example of melting due to tidal mixing occurs in the White Sea, where clearing of the ice takes place rapidly in the spring through overturn of deeper water with greater density than the surface layers but with temperature above the freezing point.

STAGES OF DISINTEGRATION

In spring, as the duration of daylight begins to increase and the mean air temperature at the sea surface rises, the snow cover of the sea ice and the top layers of the ice itself begin to thaw. Under conditions of low humidity, most loss on the upper surface of the ice will take place through evaporation imperceptible to the ordinary observer; where the relative humidity is higher, pools of dew and melt water will form on the surface. This fresh water, running down through cracks and holes in the ice, will freeze again on contact with the cold sea water, thus sealing the openings. On the other hand, cracks extended only part way through the ice will be widened by the expansion of this water freezing in them, and even though plugged at the top will now extend through to the water. On further rising of the air temperature and melting of the surface, these cracks open up again, and fresh water in a layer as much as 2 to 3 feet thick flows under the ice.

Sea ice less than a year old melts more readily than older ice because of its higher salt content. Fast ice usually melts first near shore, forming the so-called "offshore water." As melting progresses, the ice farther out from shore becomes honeycombed with cracks caused by tide, air temperature changes, temperature gradients in the ice, and ice pressure. Under the influence of wind and current this ice now commences to disintegrate. Then the increasing number of channels and polynyas brings about the motion of the larger areas. With the first strong wind these break into smaller pieces, and finally all the fast ice passes over into pack ice.

In the Antarctic, disintegration of pack ice is produced almost entirely by the sea. There, surface pools are seldom seen on the floes of the pack, but honeycombing may occur in the fast ice near the coastline where wind-blown sand and dust exist.

Decay of the pack is expedited by mechanical attrition from the swell. The physical erosion of the floes produces scaling, resulting in the formation of a quantity of small blocks and brash. The scaling process enables the sea to reach more extensive areas of ice where the comminution continues.

The final stages of melting vary with the type of ice. Ice of one winter's growth melts readily in low latitudes, if brine is still present. The internal melting due to variations in the salt content produces a honeycombed appearance with a much greater surface area. Since the rate of heat absorption through conduction is proportional to the area exposed, the rotten ice so formed quickly disappears. Fresher and firmer hummocky ice is longer lived. The old floes are heavily undercut at the water line, but honeycombing is rare, owing to the absence of salt. Underwater rams are produced by the melting back of the uppermost 2 to 3 feet of ice. The years-old hummocks of the Arctic pack, having a homogeneous structure of nearly salt-free ice, and having a minimum of exposed surface in proportion to their bulk, survive the longest in warmer waters. The *storis* of East Greenland waters consists of ice of this type.

Break-up on rivers usually occurs 3 or 4 weeks after the mean air temperature has risen above 32° F. Ice on lakes breaks up 2 or 3 weeks later, and sea ice may break up about this same time.

CHAPTER IV

PHYSICAL AND CHEMICAL PROPERTIES OF SEA ICE

STRENGTH AND HARDNESS

The mechanical properties of sea ice can be expressed only in very general terms, since they vary greatly with temperature, air content, and salt content of the ice, and depend to some extent on its previous history. Rough values for river ice near the freezing point can be taken as 150 p. s. i. for tensile strength, 500 p. s. i. for compressive strength, 100 p. s. i. for shear strength, and perhaps 50 p. s. i. for torsion. These values increase as the temperature decreases. It is stated that the compressive strength increases fourfold when the temperature is reduced from 23° F. to −76° F. Working values for ordinary sea ice are about one-third those just given for river ice. However, the increase of strength with temperature may be largely nullified by the strains set up by unequal cooling since, no matter how cold the upper surface of a floe may be, if afloat it is in contact with sea water at around 28° F.

The hardness of ice likewise increases with decreasing temperature. At 32° F. ice has a hardness of 2 on Moh's scale; this increases to 4 at −50° F. and 6 at about −80° F. The hardness of mild steel ship plate is about 5½ and of glass about 6 on the same scale.

Newly formed sea ice is weak and plastic in consistency, and does not acquire its strength and characteristic brittle nature until it has been cooled below 16° F.

THERMAL PROPERTIES

The freezing point of sea water and the temperature of maximum density are shown in figure 1. The specific heat of pure ice is only half that of water; but the addition of a little salt, as in sea ice, greatly modifies the heat content. Since newly formed sea ice will consist of a matrix of crystals of nearly pure ice surrounding cells of brine, further cooling results in freezing more water out of the brine. The apparent specific heat of the mixture will be made up of the specific heat of the existing ice plus the latent heat of fusion of the water newly frozen. This effect is illustrated by the following table.

SPECIFIC HEAT OF SEA ICE, B. T. U./lb./°F.

Salinity $^0/_{00}$	Temperature °F.			
	28. 4	24. 8	17. 6	10. 4
0	0. 50	0. 50	0. 50	0. 50
2	2. 57	1. 00	. 63	. 55
3	8. 76	2. 49	1. 01	. 68
15	16. 01	4. 24	1. 46	. 85

There will be a corresponding effect on apparent heat of fusion of the ice, as shown by the following table:

HEAT REQUIRED TO MELT 1 POUND OF SEA ICE, B. T. U.

Salinity $^0/_{00}$	Starting at temperature °F.	
	30. 2	28. 4
0	143	144
2	128	137
8	83	112
15	29	86

The heat of fusion of pure ice, the amount of heat required to melt one pound of ice at 32° F., is 142 B. t. u.

The coefficient of expansion of sea ice will likewise be affected. Since water expands nearly 10 percent on freezing, while ice contracts on further cooling, the net expansion or contraction of sea ice containing brine cells will be a complicated function of temperature and salinity, as indicated in the following table:

COEFFICIENT OF VOLUME EXPANSION OF SEA ICE, PER °F., MULTIPLIED BY 10,000

Salinity $^0/_{00}$	Temperature °F.			
	28.4	24.8	17.6	10.4
0	+0. 85	+0. 85	+0. 85	+0. 85
2	−12. 3	−. 59	+. 46	+. 77
8	−51. 9	−5. 17	−. 96	+. 25
15	−98. 2	−10. 51	−2. 63	−0. 35

A negative value in the above table means that the volume increases with decreasing temperature. The expansion of pure water on forming ice at 32° F. is equivalent to a coefficient of expansion of −900 in the units of the table.

The annual course of temperature in the pack ice of the East Siberian Sea, from measurements made in the *Maud* from 1922 to 1924, is given in the following table:

TEMPERATURE IN THE SEA ICE, °F.

Distance below surface of ice, inches	January	February	March	April	May	June
0	−18. 4	−23. 6	−20. 4	−6. 9	18. 7	29. 3
10	−11. 4	−16. 4	−14. 8	−4. 2	16. 5	26. 6
30	−2. 0	−6. 3	−5. 8	. 9	15. 3	24. 6
50	6. 8	2. 7	2. 3	6. 1	15. 4	23. 9
80	20. 3	16. 7	14. 7	15. 1	18. 7	25. 2

Distance below surface of ice, inches	July	August	September	October	November	December
0	32. 0	32. 0	23. 5	9. 9	−9. 4	−21. 8
10	31. 8	32. 0	29. 7	18. 3	0	−11. 9
30	29. 7	30. 6	30. 4	26. 1	10. 6	. 1
50	28. 9	30. 0	30. 0	29. 1	19. 2	10. 1
80	28. 8	29. 8	29. 7	29. 5	27. 7	23. 7

SPECIFIC GRAVITY

As indicated in discussing the thermal expansion of ice, the specific gravity of pure ice is about nine-tenths that of water at the freezing point. The exact value for water is 0.9921 at 32° F., and for pure ice 0.9168. Sea ice will contain a proportion both of salt or brine, which will increase the specific gravity, and of air, which will reduce the specific gravity. Malmgren found extreme values of 0.924 for newly formed ice, and 0.857 for the top of summered ice, in which the brine cells were replaced with air bubbles. He found that in general sea ice less than one year old had a specific gravity greater than 0.90, but that it fell below 0.90 after the ice had weathered a summer.

Glacier ice, such as makes up icebergs, has a fairly high apparent air content; but it is likely that the air is under considerable pressure and therefore does not lower the specific gravity as much as would be expected, since most determinations of the specific gravity of berg ice give values not far from 0.90.

SALINITY

When sea water freezes, the first ice crystals that form are practically salt-free, but they are surrounded by a brine that is saltier than the unmodified sea water and tends to sink below the surface. When the crystals cement together, some of this brine is entrapped among them, so that, on the average, a piece of newly formed ice will have an appreciable salt content. A microscopic examination of a section of such ice would show areas of nearly pure frozen water alternating with zones of brine. As the temperature decreases, the freezing point of the brine is reached, more water solidifies, and the remaining brine becomes more concentrated. This process may continue until the brine cells are so concentrated that they become saturated with respect to salt. At very low temperatures, crystals of salt will also be found interspersed in the mass of sea ice.

The faster the ice forms, the greater the salt content, since more of the brine will be trapped in the ice structure without a chance to sink. This fact is illustrated in the following table, from observations by Malmgren:

SALINITY OF SEA ICE AS A FUNCTION OF TEMPERATURE

Temperature of formation, °F	3	—18	—22	—40
Salinity, parts per thousand (‰)	5. 64	8. 01	8. 77	10. 16

The saltiest piece of ice encountered by Malmgren had a salinity of 14.59‰. The salinity of the sea water in which it was formed was around 30‰. Since the rate of freezing determines the salinity of sea ice, and the thicker the ice the lower the rate, the salinity of newly formed ice will decrease from the surface downward. The following table, again from Malmgren, illustrates this:

SALINITY OF NEW SEA ICE AS A FUNCTION OF DEPTH

Distance from surface, inches	0	2. 4	5. 2	18	32	37
Salinity (‰)	6. 74	5. 28	5. 31	4. 37	3. 48	3. 17

A snow covering over the floe will result in the formation of ice of lower salinity, since the rate of freezing, as illustrated in figure 2, is lowered.

Once formed, however, ice tends to freshen. It is well known that the freezing point of ice decreases as pressure increases; this is illustrated in figure 10, and is the phenomenon that makes ice skating possible. Since the brine cells in the ice have a greater specific gravity than the ice crystals, the ice in contact with the bottom of each brine cell is under a slightly greater pressure than the rest of the block, and the ice directly above each cell is under a slightly lower pressure. Each cell therefore is slowly melting the ice directly under it, while the ice is resolidifying over it. The brine therefore slowly travels downward under the influence of gravity, leaving the lighter ice behind. This process is greatly accelerated the following summer, when the temperature may not be low enough to refreeze the melting above the brine cells. The result is that air holes remain in the ice where the brine cells have been, and ice with a specific gravity under 0.90 forms.

CHAPTER V

MOVEMENT AND DRIFT OF ICE

FACTORS PRODUCING TRANSLATION AND DIFFERENTIAL MOTION

Sea ice, other than fast ice in sheltered bays or along the coast, is continually in motion as a result of the effects of wind, tide, and current. Although this motion may be the same for a time over a considerable area, there is a number of factors tending to produce differential motion of adjacent masses. Cakes, for example, vary in area and thickness, so that effect of wind and current differs on different masses of ice. Wind and current are also subject to continual local variations, wind from the usual meteorological causes and current from tidal effects.

The swinging or turning of floes is due to the tendency of each cake to trim itself to the wind when the pack is sufficiently open to permit this freedom of movement. In close pack this tendency may be produced by pressure from another floe; but since floes continually hinder each other, and the wind may not be constant in direction, even greater forces result. Thus wind produces rotation as well as translation. This screwing or shearing effect results in excessive pressure at the jutting corners of floes, and forms a hummock of loose ice blocks. Ice undergoing such movement is called *screwing pack*, and is extremely dangerous to vessels.

In its motion the ice opens and shuts like an accordion; there is always a certain number of lanes present, otherwise the ice could not move. In summer these lanes remain open, except in very high latitudes, but in winter they are soon frozen over with young ice. Swell also tends to break up the ice, as well as the vertical movement of the tide in narrow or shallow waters. As a result of all these agencies, the ice is alternately being broken up, even throughout the winter, and subjected to pressure. The onset of pressure or release of pressure may happen at any time of year, even during the lowest mid-winter temperatures.

HUMMOCKING

As moving floes are driven together or pressed against fast ice, bending, tenting, or rafting occurs, according to the degree of pressure and the composition of the ice. Definite ridges may thus be formed, the lines of which are at right angles to the direction of impact; or confused pressure areas of hummocky ice may be formed. The longer the pressure lasts, the greater the chaos produced. Pressure ridges may be as high as 50 feet where grounded against a coast, but in deep water away from land the greatest height is from 20 to 30 feet, although it is more usual to find ridges of 10 to 15 feet. A ridge is at its highest when first formed. A certain amount of settlement soon takes place, owing to the sinking down of the whole mass under the weight of the hummocks until hydrostatic equilibrium is reached. The weight of a ridge is ultimately supported by a downward extension of ice under water, which may be as much as 4 to 5 times the height of the ridge above. During summer, the pressure ridges change in outline and the sharper features soften to the form of rolling hillocks. Snowdrifts form against the ridges, the balance of the weight alters, cracks form due to differential loading, and the opening and closing process goes on.

The release of pressure gives rise to lines of weakness in ice fields in the form of cracks or lanes. These are often parallel to pressure

Figure 11.—Hummocky ice floes in Eureka Sound.

ridges, but owing to internal stresses an ice field does not necessarily crack in its thinnest part. Thus, cracks are frequently found passing through ridges and hummocks of considerable height. Thin half-melted ice may be left holding, but this is in many cases destroyed if the wind changes.

REGROUPING OF ICE

Any wind will tend to regroup ice that is more or less scattered over a considerable area. As the wind rises, the separate floes form lines in a direction at right angles to the wind direction. These chains break up when the wind changes, and after a time realign themselves at right angles to the new wind direction. When the wind blows from the shore, a channel of open water usually forms between the coast and the ice or increases in width if already existing. On the other hand, a wind blowing on to a coast or on to fast ice tends to reduce the

Figure 12.—Airplane photo of huge iceberg showing direction and effect of deep-water currents. Although the berg stands about 280 feet above water, it extends more than 1,000 feet below surface and is affected by currents which run too deep to move neighboring ice.

width of the channel previously existing. If the wind is strong enough, hummocks will be produced along a line approximately perpendicular to the wind direction.

The air temperature as influenced by the wind also has an effect on the grouping of ice. If the wind which has regrouped ice is a cold one, the lowered temperature may cause further freezing, so that the masses may become joined by new formation. In this case the ice would not be so readily broken up and regrouped by a change of wind. On the other hand, if the weather is mild, cakes brought together by a change of wind will not join together.

The rate at which the different floes travel is not so much dependent upon the size and depth of the floe as upon the nature of its surface. Since the pack is made up of a conglomeration of young ice, old floes which have been subjected to pressure, and icebergs, it varies radically in resistance to wind and current. Surface irregularities, such as hummocks and pressure ridges, act as sail areas, and the rate of movement of a floe depends to a certain extent on the amount of hummocking in proportion to the area and weight of the floe. As a result of previous pressure, hummocked floes in turn become the cause of still further pressure. When two floes are moving at different rates, either the distance between them is increased and a lane produced, or the distance between them is decreased and the floes brought into physical contact. In gaining momentum, larger floes will accelerate more slowly, but once underway, they will carry their way long after smaller floes have stopped moving. In the early stages, therefore, the large heavy floe will be charged by smaller floes overtaking it; in the later stages, it will itself be the attacker of smaller floes in its path. Because of their size and weight, the smaller floes will be disrupted and the floe surface materially modified, thereby creating new possibilities of further differences in speed.

LAWS GOVERNING DRIFT

While the general direction of the drift of icebergs over a long period of time is known, it may not be possible to predict the drift of an individual berg at a given place and time, for bergs lying close together have been observed to move in opposite directions. They move under the influence of the prevailing current at the depth to which they are submerged, which may often be in opposition to the existing wind and sea or surface drift. The International Ice Patrol has had considerable success in predicting the drift of bergs off Newfoundland by determining the surface current patterns through the methods of physical oceanography.

Pack ice drifts with the wind and tide, usually to the left of the true wind in the Southern Hemisphere, and to the right in the Northern Hemisphere. The speed of drift may not depend entirely upon the strength of the wind, since it is influenced greatly by the presence or absence of open water in the direction of the drift, even though the open water is somewhat distant.

Neglecting the resistance of the ice, Ekman's theory of wind drift calls for the ice to drift 45° from the wind direction. Observations show that the actual drift is about 30° from the wind direction on the average, or very nearly parallel to the isobars on a weather map. In winter, when the ice is more closely packed and offers more resistance, its drift deviates less from the wind direction than in summer, and tidal influences become more important.

The speed of drift of pack ice can be fairly closely determined from the wind speed. Observed average speeds of drift of ice in the Northern Hemisphere range from 1.4 percent of the wind speed in April to 2.4 percent of the wind speed in September.

There is a northward tendency in the drift of Antarctic ice, on which the left-hand component due to the earth's rotation is superimposed. The pack therefore travels westward and northwestward around the continent, and into and around the Weddell Sea in a clockwise direction.

The general circulation of the ice of the Arctic Ocean is determined by the direction of the ocean currents, which are the result of two chief factors: the circulation of the atmosphere above the polar basin and the surrounding adjacent seas, and the influx into the polar basin of water of oceanic and river origin, with a compensatory outflow of the water from the polar basin.

Above the central part of the polar basin, the cap of cold air has an anticyclonic (clockwise) movement which causes a movement of the polar cap ice in the same direction. Because of the deflecting influences of the earth's rotation, all movements in the Northern Hemisphere tend to incline to the right.

The ice moves slowly under the action of wind and current toward the opening between Norway and Greenland. The speed of the current increases as it approaches the opening, particularly its western mouth between Svalbard and Greenland, and great masses of ice (the *storis*) are carried swiftly southward along the east coast of Greenland. The ice that floats southward, east of Svalbard, soon melts in the warm waters derived from the Gulf Stream.

CHAPTER VI

VESSELS FOR OPERATING IN ICE

WOODEN SHIPS

The earliest vessels to be navigated in the ice of polar regions were the ordinary wooden sailing ships of the day. A strengthened version of this type of construction, with the addition of auxiliary steam engines and a feathering or hoisting screw, was favored until recent years by whalers and sealers, in whose experienced hands it proved highly successful. Compared with contemporary sailing vessels of ordinary type, they had heavier bow framing, usually with sheathing of ironbark or greenheart along the waterline to withstand the scoring action of ice, and with iron plating at the stem; but otherwise they were little modified in design or construction from the general shipbuilding practice of the period.

A notable example of this type was the auxiliary barkentine *Bear*, a vessel of 728 gross tons measuring 190.4 x 29.9 x 18.8 feet, built at Dundee, Scotland, in 1874 as a whaler and sealer. She was acquired by the United States Navy in 1884 to relieve the Greely Expedition at Cape Sabine, then was transferred to the Revenue Cutter Service (later the Coast Guard) and was operated in Alaskan waters until 1926. In 1933 she was acquired for the second Byrd Antarctic Expedition; next she served with the U. S. Antarctic Service Expedition in 1939–41; and finally she returned to Greenland waters for patrol duty in the early part of World War II.

The exploration vessel *Discovery*, built in 1901, which has also served in both the Arctic and Antarctic, represents perhaps the ultimate development of this type of craft. Her plans and description can be found in the article by W. E. Smith. A similar but smaller type of auxiliary wooden vessel has been evolved for the requirements of the Norwegian seal fishery, and these have also been used as expedition ships. The *Quest* of Shackleton's 1921–22 expedition, a vessel of 240 gross tons, 110 x 24.9 x 11.8 feet, is a typical example. Such sealers were employed in Greenland waters by the German Navy in 1940–41. More recently, a number of wooden auxiliary sailing vessels have been built as reparations in Finland for service in the Soviet Arctic.

The major drawback of vessels of this design in ice is their inability to withstand lateral ice pressure if they happen to become beset or are deliberately frozen in. Although the whalers successfully wintered in the Arctic by allowing their ships to freeze in at a location well sheltered from the open sea, a long list of ships lost through ice pressure when frozen in or "nipped" could be compiled. DeLongs' *Jeannette* and Stefansson's *Karluk* in the Arctic and Shackleton's *Endurance* in the Antarctic would be included.

As a means of circumventing this disastrous possibility, a few ships were designed with flaring sides and easy bilges so that there would be no vertical surface for ice to bear against. The horizontal pressure of the ice would thus have a lifting rather than a crushing effect. Nansen's *Fram*, built according to these principles, proved successful. The design was further perfected by Christian Jensen in 1917 in Amundsen's *Maud*, which spent several winters frozen in Arctic pack and successfully negotiated the Northeast Passage. The *Maud* was a wooden vessel of 392 gross tons, measuring 107.1 x 41 x 15.9 feet. She was built with double layers of planking and diagonal bracing in the hold, and had a 240-horsepower oil engine in addition to three-masted schooner rig.

ICEBREAKERS

With the development of powered vessels came the possibility of designing a vessel to cut or break through ice. Specially strengthened tugs or ferries were being used for this kind of work in harbors, both in the United States and abroad, shortly after the steamboat was introduced. In 1899 there appeared the first seagoing icebreaker, the *Ermack*, built in England for the Russian Government. Built of steel, with 1¼ inch plating along the waterline, this vessel displaced 10,000 tons and had engines of over 10,000 horsepower with three screws aft and one forward. Although without precedent, her design proved successful for her intended employment, and she may be regarded as the prototype of all later seagoing icebreakers.

The *Wind* class icebreakers of the United States Navy and Coast Guard, described in the paper by Rear Adm. H. F. Johnson, represent the latest development in United States seagoing icebreaker design. With over-all dimensions of 269-foot length and 63-foot beam, they displace 5,040 tons on 25 feet 9 inch draft. As originally designed they were powered with six 2,000-horsepower Diesel generator sets connected to motors on the shafts. The electrical arrangements permitted production of 5,000 horsepower on each of the two after shafts, or 3,300 horsepower each on all three. The bow propeller has been found to assist in penetrating ice when the tips of the blades are below the under surface of the ice, both by inducing turbulence to break up the ice and by washing it back out of the way after it is broken.

The double bottom of these vessels is carried up above the load waterline, the two skins being 15 inches apart. The outer plating is 1⅝ inch high-tensile steel at the waterline, tapering to 1¼ inches on the bottom. The pronounced flare to the underwater sections, resembling that of the *Maud*, is matched by considerable tumblehome in the topsides, for the purpose of reducing the fouling of top hamper when working around heavy ice or other vessels. The bow of the *Wind* class has the characteristic sloping forefoot of icebreakers, which acts to slide the bow of the ship up onto ice too heavy to break by the forward motion of the ship alone. The weight of the ship thus exerts a bending action on the ice, which is much weaker in tension than in compression and therefore breaks. Since icebreakers must at times back into ice, the shape of the forebody is reproduced in the afterbody.

In the *Wind* class there is a notch in the stern for towing. This is heavily padded to receive the stem of any vessel that has to be towed into ice, thereby eliminating the possibility of the tow running down the icebreaker should it be suddenly stopped by striking an unusually heavy piece of ice. The extra power from the vessel close-coupled astern can also be of assistance in breaking ice.

The vessels can be assisted in their attack on the ice by reducing sticking from static friction through the use of wing tanks and heeling pumps, which transfer 220 tons of water from one side to the other and produce a 10° roll in 1½ minutes. Ballast can also be shifted between fore and after peak tanks to change trim, to assist in backing off ice, or to present the most advantageous angle of attack under different loading conditions.

Vessels of this class can successfully maintain a speed of 4.8 knots in 5-foot thick ice, using the bow propeller, although there is some question as to value of such a propeller in heavy pack in the open sea. Without the bow propeller, they can open channels in 10-foot broken polar ice at a speed of advance of 1 knot, by backing and ramming.

CARGO SHIPS

Modern steel merchant vessels are not suited for unassisted navigation in any but the most open kinds of floating ice. The chief source of weakness is the bow plating, but other structural deficiencies can be gathered from the following extract from the rules of the American Bureau of Shipping:

(1) *General.*—Vessels constructed with special strengthening which is at least as effective as that described in this section will be distinguished in the record by the words "Ice Strengthening."

(2) *Special strengthening* for navigation amongst ice should cover an area which extends from the stem to the midship three-fifths length (i. e., one-fifth of the length from the stem) between lines which are respectively at least three feet above the load line, and three feet below the light load line.

(3) *Intermediate frames* having a strength of at least 75 percent of the strength of the fore peak frames should be fitted over this area; the intermediate frames should extend from the deck next above the strengthened area to a lower level than the top of the frame brackets or floor plate.

(4) *Side plating* should be of midship thickness forward to the strengthened area; the thickness of the shell plating over the strengthened area should not be less than 0.6 inch in vessels under 250 feet in length, and need not be more than 1 inch in vessels over 500 feet in length; the thickness for intermediate lengths may be obtained by interpolation.

(5) *Rudder scantlings*, rudder stock, steering gear chains, etc., should all be at least 10 percent above the ordinary requirements of the rules.

(6) *Tailshafts* in single screw vessels should have a diameter at least 5 percent and those in twin screw vessels at least 10 percent greater than required by the rules.

(7) *Propeller blades* made of cast iron should not be used.

(8) *Sea connections* should be so arranged as to minimize the risk that attends their attachment to plating which is subject to ice damage. Main injections should be provided with steam connections for clearing the strainers.

Arctic-constructed vessels with icebreaker assistance could penetrate any part of the Bering Sea, according to the experience of the *Burton Island* in January-February 1949. A 3:1 ratio of these vessels to icebreakers could be maintained, as compared with a 1:1 ratio necessary with unstrengthened ships.

A few cargo vessels, built with an ice-breaking bow, form a class intermediate between the sea-going icebreakers and the strengthened cargo vessels. One of these was the *Nascopie*, which was operated in northern Canadian waters by the Hudson's Bay Company from 1912 until her loss in 1946.

SUBMARINES

In 1931, Sir Hubert Wilkins published a book advocating the use of submarines in ice exploration, advancing the argument that a submarine could dive under ice that was impenetrable by the strongest icebreaker, and that even the densest Arctic pack contained leads in which a submarine could safely surface. He obtained an obsolete United States submarine, the *Nautilus*, in which he navigated to the edge of the pack near Svalbard in September 1931. At this point it was discovered that the diving rudders of the *Nautilus* had been lost, so that it was impossible to continue under the ice and test the practicability of the submarine for ice navigation. The experiment with the *Nautilus* has not been repeated by a civilian explorer.

In 1944 a German submarine navigated under the Northeast Greenland Pack, surfaced inside, and fired two torpedoes at the U. S. C. G. C. *Northwind.* The submarine escaped by submerging and running beneath the pack.

LST's

LST's may be used for transporting and unloading cargo in the polar regions with the assistance of LVT's carried along. To strengthen LST's in order to improve their serviceability in ice, Douglas fir wood sheathing 5⅝ inches thick should be installed from the turn of the bow forward and covered with ½-inch steel plate. Sheathing abaft the turn of the bow may be omitted. The bow doors should have ½-inch steel plate quilted over the wood sheathing mentioned above. Bracing timbers should be fitted between the bow doors and hull adjacent to bottom of ramp. The flaps on the bow doors should be welded shut and otherwise made an integral part of the door. The bottom plating in the way of the bow voids should be strengthened to prevent possible rupture from below. The hull forward of the propeller guards should also be strengthened to prevent puncture when the stern swings into ice.

In an experiment with two LST's on an expedition to Barter Island, a steel propeller was fitted to one shaft of each and the usual bronze propeller left on the other shaft for comparative purposes. It was found after the voyage that, except for minor pitting, the steel propellers were in almost new condition whereas the bronze propellers on both ships were bent.

An LST, even though specially strengthened, is not a suitable vessel to absorb the punishment entailed in following an icebreaker through the heavy, close pack of the type encountered between Point Barrow

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and Barter Island. The type of ice floes in this area requires it to make continuous approaches at steerage way. Moreover, icebreakers, because of their peculiar hull form, create a strong stern suction that swirls ice in behind them. Because of the running start required by the icebreaker in breaking heavy ice and the nonhomogeneity of the pack, it is impossible for an LST to follow closely enough behind the icebreaker to take advantage of the lane she makes. As it is necessary to make contact with the ice at bare steerage way in order to minimize damage to the LST, an average speed of only 1 to 2 knots can be maintained in heavy, close pack. Damage to LST's may be sustained by swinging into one piece of ice while trying to avoid another. It was found that the LST immediately behind the icebreaker is subject to more punishment than the last one in a column. From this fact, it may be concluded that a reasonable number of LST's could follow single file behind an icebreaker in the type of ice encountered in this area. However, when the icebreaker cannot maintain a straight course, the consequent twisting and turning of the LST's make their conning exceedingly difficult.

It is believed that convoying cargo ships through ice of the Alaskan coast presents certain features which may not hold in other Arctic areas and which are assuredly different from the task in Antarctic areas.

VESSELS FOR ALASKAN AND CANADIAN WATERS

The vessels used at present for navigation in the waters east of Point Barrow have evolved from many years of accumulated experience in that region, which began with the whalers in the 1850's. They commonly winter in the area. The desirable characteristics of such vessels are listed by a veteran navigator as follows:

1. *Strength.*—Strength of construction is of vital importance for obvious reasons. A wooden vessel should be sheathed for 4 to 6 feet abaft the fore edge of the stem with either plates or strakes of ½-inch steel, flush-fastened. Strakes are preferable to plates on account of the ease of renewing them if damaged. The hawsepipes should be constructed so as to allow the bower anchors to stow flush with the ship's side; otherwise, the projecting flukes will act as an obstruction in ice. Where this cannot be accomplished, anchors should be catted prior to entering the ice.

2. *Power.*—Diesel power is preferred because fewer engine personnel and no boiler feed water are required. Fuel supplies are readily available at Norman Wells, Fort Smith, and other points in the region.

3. *Speed.*—The short navigable season of the Western Arctic makes speed a necessity, in order to take full opportunity of every patch of open water.

4. *Endurance.*—Endurance is another quality of prime importance, in view of the large distances that often must be traversed through ice in making good a course between two ports.

5. *Maneuverability.*—A relatively short, beamy vessel is considered easiest to handle in ice. The trim of the vessel must also be carefully adjusted.

6. *Shallow draft.*—The necessity of taking shelter in the shallow bays and inlets, and the desirability of being able to work between grounded ice floes and the shore, imposes a maximum limit of 12-foot draft for vessels in this area. Even the *Maud* which, after weathering several years of navigation north of Siberia, was then bought by the Hudson's Bay Co., proved unsuitable for work in Northern Canada because she drew more than this.

The motorship *Fort Ross* of the Hudson's Bay Co. is a good example of this class of vessel. Built of wood in Nova Scotia in 1938, she measures 128.4 x 24.4 x 12.7 feet, registers 272 tons gross, and draws 11 feet 8 inches fully loaded. She has a single monel screw, driven by a 240-horsepower Fairbanks-Morse Diesel.

CHAPTER VII

PREPARING A VESSEL FOR ICE OPERATIONS

In the preceding chapter the design features which render a vessel suitable for operating independently in ice were discussed. The limited number of such vessels in existence generally makes it necessary to conduct operations in ice using vessels of ordinary type convoyed by icebreakers. Although in such cases it is impossible to make the structural modifications just described, proper care in preparing a vessel for work in ice will add greatly to the safety of the operation and the comfort and efficiency of the personnel.

When navigating in ice a vessel runs the risk of being damaged in various ways, so that both prevention and remedy depend largely on the extent to which she has been prepared for the voyage. The primary phase of preparation consists of the measures taken while in port and en route to the area of operations, since both facilities and time are limited in the frozen areas. The second phase comprises the precautions taken while in the operating area. Needless damage, delay, and work can be eliminated by a taut ship with an alert and energetic crew. However, regardless of all preventive measures taken, damage to the vessel is not always avoidable, so that the third phase of maintenance, that of making repairs to the vessel after it has been damaged, may be and usually is necessary. Remedial measures, anticipated or improvised, skillfully made, will in many cases be the salvation of the ship.

FITTING-OUT SHIP

The following check-off list of items to be attended to before leaving the home port for polar waters has been compiled from the combined experience of naval combatant types, naval auxiliaries, and merchant ships. Not every item, therefore, will be found applicable in individual cases, but careful consideration should be given to all.

1. *Screws.*—Equip the ship with steel propellers. Provide a spare propeller for each shaft. If propellers have removable blades, see that all blades are interchangeable. Test the spare bosses in drydock to see that they fit the shaft. Provide wrenches for boss and propeller nuts. Since the propellers are especially vulnerable when operating through ice, consideration should be given to fitting the ship with some

type of propeller guard. In small vessels provide suitable tackle to change propellers at sea; in larger ships see that docking plans are available.

2. *Rudder.*—Provide spare rudder assembly or temporary rudder and rudder stock. Fit steel-wire pendants from each quarter to after part of rudder blade; these will permit steering if the steering gear is damaged, and prevent losing the rudder if unshipped.

3. *Watertight integrity.*—Test all bulkheads, peaks, and tanks by hydrostatic pressure.

4. *Pumps and piping.*—Test all sounding pipes and bilge and tank pumping pipes for leaks and fractures. Check the operating condition of main drainage pumps, electric submersible pumps, and auxiliaries such as handy billies and P–500 pumps. Provide full allowance of spare parts. Renew any hose not in good condition. Clean all holds, scuppers, bilges, and rose boxes. After cleaning, take suction in each bilge well for an over-all operating test. In loading cargo, see that no sand, sawdust, or coal dust is introduced into the holds.

5. *Fire lines.*—Test all water-releasing equipment such as mains and cocks and renew any defective ones.

6. *Cargo stowage.*—For free passage of water to bilges and easy access to side plating in case of damage, stow cargo well away from the sides and tom in position. Load the ship so that she will be 3 or 4 feet down by the stern when in the ice. If in ballast, consideration should be given to the desirability of flooding the after hold most of the depth of the shaft tunnel in order to immerse the rudder and screws and minimize damage to them by ice.

7. *Underwater openings and projections.*—Inspect all inlet and outlet fittings in drydock. Remove all projections, such as scupper guards and ringbolts, on the ship's sides above and below the waterline; these catch ice and slow down progress.

8. *Wooden planking.*—If a wooden vessel is exposed to conditions where water freezes around her, the ice will adhere to the calking in the seams and pull it out, causing bad leaks. The preventive is to apply a second layer of uncalked wooden sheathing, breaking joints with the main bottom planking, with fastenings that penetrate only part way through the latter. This sheathing will also protect the bottom against the scoring action of ice along the water line. Fresh water ice, such as is found in river mouths, is harder than sea ice and is particularly severe in scoring action. Wooden vessels that operate in such waters are frequently sheathed with sheet steel along the water line, well nailed both through the middle of the sheets and

along the edges. Copper sheathing would similarly be used on a copper-fastened hull.

NavShips 250–336 gives the following particulars concerning wooden sheathing:

Wood sheathing, in order to give adequate protection to the hull against ice and marine organism attack, should begin at a point above the load water line when the vessel is at her deepest draft and completely enclose the hull, including the keel and all deadwood, the sternpost, the wood skeg, if any, and all other exposed parts of wood. The thickness of this sheathing varies from approximately one-half inch to 2 inches, according to the size of the vessel. The keel shoe should be sufficiently wider than the keel to cover the bottom edges of the sheathing fastened to the keel. If it is not, the shoe itself should also be protected by sheathing.

When sheathing is used for protection against ice alone, it should extend high enough up the sides of the hull to form a belt of sufficient width to afford adequate protection against floating ice at any draft. This may require spiling of the sheathing strakes. Sheathing for this purpose is secured to the shell of the vessel generally by means of screws, the heads being slightly below the surface of the sheathing. A metal cutwater should either be placed over the stem iron or butted and welded to the aft face of the stem iron. This cutwater should extend vertically across the width of the sheathing belt and sufficiently far aft to provide the proper cutting action when ice fields are entered, thereby protecting the forward edges of the wood sheathing. The portion of wood sheathing that is placed under this metal cutwater should be tapered.

Ice sheathing requires wood capable of resisting severe abrasive action and which can hold fastenings well. The species preferred for this purpose is Australian ironwood. White oak has given satisfactory service. Other species having the properties that indicate they could be used satisfactorily are red oak, hickory, pecan, and rock elm. Black locust and live oak also have the required properties but are not readily available. The properties of the foregoing woods responsible for their selection are high toughness and hardness. White oak is used almost exclusively for keel shoes for the same reason that it is used for protection against ice.

9. *Bracing in bow.*—If feasible, install timber bracing in the forepeak, using horizontal "ice beams" extending from side to side at the load water line and bearing on fore and aft planks placed between the frames. Additional support to the fore peak bulkhead on the

side toward No. 1 hold is also desirable. In small vessels, consideration should be given to reinforcing the stem with concrete.

10. *Repair materials.*—Provide a supply of timbers, shores, quick-setting cement, sand, hull plates, angle irons, clamps, wedges, jacks, canvas, collision mats, etc., for the temporary repair of holes and leaks. Stow these near vital places most likely to be damaged. As outboard repairs below the water line may become necessary, consideration should be given to carrying diving equipment with necessary accessories.

11. *Lookout stations.*—Build a shelter in the eyes of the ship for forecastle ice lookouts. Rig a crow's nest as high as possible on the mast and winterize with radiant heater and antiglare windows. Provide a protected conning station above the pilot house. Winterize the pilot house.

12. *De-icing gear.*—Provide a number of hardwood or nylon-faced mallets at least 6 inches in diameter for removing ice. Scrapers can also be used, but they are more likely to remove paint, with subsequent rusting.

13. *Sounding boat.*—Install a portable echo sounder in a small boat for use in leading the ship into uncharted coastal waters.

14. *Carrying animals.*—If dogs are to be carried, consult the paper by Surgeon-Commander Bingham on the care of dogs at sea. If wild animals or birds are to be brought back from the polar regions provide suitable cages, or the materials for making them, and obtain an ample supply of food. In installing the cages, consider whether warm weather will be encountered before returning to the home port and allow for the necessity of keeping the animals cool, of providing a place to thaw out frozen fish or seal meat, and of abating the sanitary problem involved.

15. *Mooring gear.*—Provide the following:

(*a*) "Dead men" made up of wooden planks (oak) of approximate dimension 3 x 10 inches x 6 feet. "Dead men" are expended each time the ship is unmoored. It takes at least four at each mooring, and the ship may have to be shifted as often as once a day while unloading operations are being conducted.

(*b*) Straps made up of 6- or 8-inch manila or 7/8-inch wire approximately 6 feet long with a large eye splice in each end. Straps are expendable with the "dead men" and an equal number should be provided.

(*c*) Toggles of hard wood similar to a 4-inch mallet head with trailing lines. Each mooring line is secured to a manila strap with a toggle. Normally the toggle will be recovered, but a good surplus should be on hand in order to provide for losses when freezing makes it necessary to cut lines on unmooring.

(*d*) Mooring lines of size normally used. There should be no losses, but one has occasionally to cut off the eye if a toggle is frozen and cannot be withdrawn.

(*e*) Picks, shovels, and buckets with lanyards attached to be used by line handling party in burying "dead men".

(*f*) A number of long wooden spars or telegraph poles for use as fenders and for construction of heavy temporary brows while alongside the ice.

The above gear is used for mooring to shelf ice or to bay ice in Antarctic operations, as well as for general Arctic service. Also provide ice anchors, which are stockless single-fluked hooks, and ice axes, which have longer handles than ordinary axes. In Operation HIGHJUMP to the Antarctic, the *Northwind* found ice anchors to be much more expeditious and efficient as holding gear than "dead men". She used 200-pound single-fluke anchors. On the other hand, Task Force 80 found that "dead men" have greater holding power than ice anchors in the Arctic.

16. *Main injections.*—Install steam lines on intakes to prevent clogging with brash ice.

17. *Electrical equipment.*—Add at least 25 percent to the allowance of 1.835 specific gravity storage battery acid normally carried. Thermally insulate below-water engine-room bulkheads behind and above the main switchboards to eliminate condensation with subsequent water dripping on exposed elements of the board.

18. *Gas bottles.*—Provide inside stowage for acetylene, oxygen, and other gas bottles in "stand-by," since if used directly from outside stowage in cold weather, up to 75 cubic feet volume is lost.

19. *Small stores, ship's store, or slop chest.*—Provide ample supplies of warm clothing, footgear, smoked glasses, face lotion, and antichap lipsticks. Allow 25 to 50 percent increase over normal consumption of cigarettes and candy. If tropics are to be crossed, arrange cool storage for candy bars.

20. *Recreational facilities.*—Provide an adequate ship's library, supplies of comic books, recent motion pictures, beer, and hobby-shop equipment.

21. *Personnel.*—Thoroughly screen men before sailing and eliminate psychiatric misfits. Give the rest complete medical and dental check-

ups. Carry a medical officer and dental officer if feasible. Require men using spectacles to equip themselves with a spare pair before sailing.

22. *Miscellaneous supplies.*—Provide poles and extra boat hooks for fending blocks of ice away from the ship's side and the screws in particular. Provide crowbars, which should be short, four-sided, and wooden-handled. Provide demolition charges, detonators, and fuzes or cable and blasting machine. Allow for the possibility of being forced to winter in the ice by loading provisions for all hands for 15 months, or providing sporting rifles, shot guns, ammunition, fishing gear, and vitamin supplies. Provide ice saws for cutting docks in ice floes, or freeing the ship if frozen in.

BOATS

Any ship operating in polar waters should carry boat capacity for 150 percent of personnel aboard, since life jackets, floater nets, and small rafts are worthless if men are not rescued within a few minutes. Unless this requirement is met, operation plans should be formulated so that two or more ships are always in company. The Navy standard 40- or 50-foot motor launches are considered to be practical lifeboats for such regions, if they are provided with sail and with a canvas weather-cloth covering in the waist.

Both the 40-foot motor launch and the Coast Guard 26-foot self-bailing surf boat have been operated satisfactorily under adverse conditions. The former has penetrated deep into pack ice with little difficulty. Motor whaleboats and LCVP's are also considered desirable for operations in which landings are to be made in ice.

Not only may the boats be damaged by contact with ice, but they may also be cut off from the ship by drifting floes brought in by a wind shift or tide, or by poor visibility. Therefore, all boats should contain emergency rations and survival kits including sleeping bags, firearms, a Very pistol, and medical supplies. In addition, all boats should be radio-equipped. Boat crews should have their full outfits of cold weather clothing with them at all times while in the boats.

Hoisting slings on all boats should be reinforced for handling in rough weather.

Wooden motor boats to be used in ice, particularly young ice, should be copper-sheathed forward along the waterline, as otherwise they may receive serious damage from ice cutting into the stem. Since this protection adds greatly to weight, it has been recommended that a new boat be operated in ice for a few hours, and then be sheathed only on the portions that exhibit signs of wear.

Boat engines should be cooled by fresh-water circulating systems or by air. A salt-water cooling system is likely to become clogged from slush drawn into the injection line, resulting in overheating the engine. Use a series-parallel circuit with four batteries instead of the usual two for starting boats. If temperatures below 20° F. are expected to be encountered, engine heaters should be provided for all boats to eliminate starting failures.

A water breaker filled to 75 percent capacity will not crack when frozen solid.

The paper by Commander Ryder cited in the bibliography describes a light boat specially built for use in polar regions. This paper should be consulted if it is planned to use small boats extensively around a base camp.

PREPARATIONS EN ROUTE TO POLAR REGIONS

The following check-off list covers items of maintenance and preparation that should be carried out before entering the ice zones.

1. *Painting and lubrication.*—Paint topsides and decks; regrease the rigging with a light coating; put winter grade lubricants in all the deck machinery.

2. *Antifreeze.*—Put ethylene glycol or alcohol in the cooling systems of motor boats and any other exposed internal-combustion engines.

3. *Batteries.*—Fill all storage batteries in boats with 1.280 specific gravity electrolyte. Keep batteries as near full charge as is possible at all times.

4. *Water tanks.*—See that no water tanks are over 90 percent full. Owing to the risk of contamination with sea water from leaks caused by contact with ice, use the potable water (if any) in the fore peak tank first. All water tanks adjacent to the outer skin of the ship should be equipped with heating coils.

5. *Towing gear.*—Rig towing bridle forward for immediate use in the event of necessity of being towed by the icebreaker. Break out towing gear and keep it available on the fantail for possible use in towing another ship.

6. *Mooring lines.*—Manila has a tendency to freeze or dry-rot in the center if exposed to cold for long periods. A line permitted to drag through snow and water becomes ice-coated immediately and is hard to handle, slipping in gloved hands and on winch drums and capstans.

Therefore, keep mooring lines dry by stowing below decks or under canvas covers.

7. *Instruction.*—Familiarize personnel with the operation of the main drainage system. Hold regular instruction periods on safety precautions in handling cargo, life and personal hygiene in frigid climates, survival, etc. If in the Arctic, indoctrinate personnel with regard to contacts with natives and compliance with game laws.

CHAPTER VIII

OPERATIONS IN POLAR WATERS

SHIPBOARD PRECAUTIONS

If the ship has been fitted out according to the procedure outlined in the previous chapter, the chief dangers to be met are those resulting from low air temperatures and from water freezing on the topsides, either through sleeting and snowing or from taking aboard spray or green water in cold weather.

Sweep decks clear of snow before it has an opportunity to form a crust or become trampled and hardened. This is particularly essential on the bridge and on the gangways. Extreme care should be exercised when using scrapers to remove ice close to electric cables and equipment because of the possibility of breaking them loose from switch boxes and other connections. Salt water hosing is a rapid means of melting snow and clearing decks but should be used only in nonfreezing weather after making sure that overboard deck drains are not frozen. It is not advisable to use mixed steam and water for ship de-icing since the ship will run out of steam too rapidly. A better method is to use the condenser feed as a source of warm water and by a heat exchanger raise the temperature to about 150° F. The water may then be used to cut into ice masses, making use of the weight of the ice to break them away. The worst ship icing conditions are said to be found in the Newfoundland-Belle Isle area when the water temperature is 30° F., the air temperature 20° F., and the wind force 4.

All running rigging that can reasonably be covered should be provided with canvas covers as previously recommended for mooring lines. Lowering a whale-boat with ice on the falls and cleats is a very dangerous operation. Canvas covers are considered a necessity for all deck winches and appliances. They are also essential for open boats if the bilges are to be kept dry. Cover the deck space or hatch used for helicopter operations with a tarpaulin so that the snow can be removed in a minimum of time.

Secure firemain cut-out valves on firemain risers to weather decks and drain plugs at lowest point between riser and plug. Drain fire hose on weather deck and dry in heated compartment before restowing in racks. Keep proportioners in heated compartments adjacent to a hatch or door where access to weather decks will permit rapid connection to be made with fire plugs. Drain them after use, and dismantle, dry, oil, and reassemble the chamber change-over valves.

In using fire hoses at freezing temperatures, satisfactory results can be obtained if good pressure is maintained; however, when the pressure is reduced or the hose is secured, the nozzle and plug become frozen, and the nozzle must be replaced.

Steam deck machinery should be carefully looked after to prevent clogging with ice. In extremely cold weather it should be operated daily, and condensed water drained out after use. If circumstances require that steam capstans and winches be ready for instant action in freezing weather, warm them up and leave them turning over at slow speed, taking care that they are not permitted to stop.

When operating in pack ice, keep the ship's main engines manned and ready for immediate use at all times. In steam vessels, take precautions to insure that no water of condensation remains in the main steam pipes or engine cylinders.

Ice anchors should be stowed under shelter to prevent icing-up.

ANCHORING

It may be advantageous to lie at anchor when in brash, but as little of the cable as possible should be paid out. The capstan should be kept ready for weighing in case of the approach of large masses of pack ice. When anchoring in rotten ice in shoal water, get into the ice as far as possible to avoid the swell; but if the water is deep and ice is present, anchoring should be avoided. It may be preferable to lie to and keep power available to move the ship as necessitated by the shifting floes. It is not recommended to anchor to the bottom while in pack ice, as in most cases it is useless and will probably result in the loss of the anchor and cable.

Having decided to ride to an ice anchor, choose a strong floe which can shelter the vessel from the surrounding ice. To insure as nearly as possible obtaining the shelter of a natural dock, it would be well in making fast to a floe to take a position where a bight is formed by two strong projections. Such places may often be found. They offer at least moderate security in the event of other ice setting toward the ship, the projecting angles of the floes receiving the first shock. If the ice is not too thick, a dock can be sawed out. With two or more ships in company, time is saved by employing all hands to cut one dock large enough to take in all the ships. However, the degree of safety will then be lessened, for the larger the dock the less likely it is to have strength to resist pressure without eventually breaking.

Figure 13.—Showing the effect of the propellers in keeping the stern of the icebreaker clear of ice while hove to.

Lay the anchor from the side of the floe where a patch of open water is formed, or where the surrounding ice is least packed. When riding to an anchor the movement of the ice must be continually observed. If there is a risk of the ice surrounding the ship, weigh anchor and move into a more open region off another floe. Therefore keep the engines ready for immediate action. If a small berg or larger bit drifts down on the ship, it can frequently be avoided and permitted to drift clear by judicious use of the engines while at anchor.

In selecting an anchorage in a bay or harbor which is open to drifting ice, the shallowest depths should be chosen, provided other conditions are suitable. A vessel should not select an anchorage too close to a glacier cliff since calving of the barrier may endanger the vessel or set up a heavy swell making the position uncomfortable.

In bays or fiords where fast ice exists, the tidal currents may cause this ice to drift in and out of the harbor, rendering the anchorage unsafe. Fast ice in a harbor usually moves along a tidal crack and, under the force of onshore winds, may acquire violent motion. Vessels should quit moorings at the edge of fast ice whenever onshore winds blow.

Vessels taking winter quarters in a harbor should select a site where protection from ice is afforded to seaward by islands, islets, rocks, or shoals. Moor in shallow water, allowing for the height of seas and tidal range which may be experienced in the harbor. Run out steel wires and anchor cables to shore moorings. Stretch and anchor cable across the seaward side of the anchorage to impede ice drifting down upon the ship. Unship rudder and propeller, if possible. Drain boilers and secure all sea connections at the hull.

MOORING AND UNLOADING

The following procedure for mooring alongside either bay ice or shelf ice not too high above the ship's deck is based on the experience of the U. S. S. *Bear* while serving with the United States Antarctic Service Expedition in 1939–41.

Although ice conditions in the Antarctic are seldom the same from one year to the next, it has been found that the general condition of the fast ice in the Ross Sea changes very little, particularly in regard to offering a clear "dock space" for mooring alongside.

The thickness of the fast ice in the Bay of Whales during the months of January and February was found to be approximately 12 to 15 feet, with an above-water height of 3 to 4 feet and with sufficient strength to hold the weight of the equipment unloaded.

Break-ups occur without warning, and ships moored to the ice edge must be prepared to get under way on short notice. Sometimes cracks will develop between the ship and the barrier, but the ice may not break up for several days. Prevailing winds and currents coming from under the barrier tend to cause the broken pack ice to drift to the westward. With this condition a starboard-side-to mooring has been found to be the most desirable.

Prior to arrival alongside the ice, all gear should be put on deck in order and line handlers instructed as to how and where to bury "dead men" and how to secure mooring lines. Secure manila strap and/or wire strap to each "dead man," depending on the use of hawsers and cables. Obviously if a "dead man" has both a manila strap and a wire strap, either wire or manila lines can be secured to it. At least four mooring lines should be ready to run with a toggle attached to the eye of each line.

The *Bear* made it a normal practice to place her bow head-on against the ice and to hold this position by steaming ahead slowly. Line-handling parties were disembarked onto the ice via Jacob's ladders. After passing over and securing the bow line and bow breast, the ship was warped around until she lay alongside the ice, and the stern lines were then put over and secured. This procedure of placing the bow against the ice may not be considered advisable for large vessels. If the commanding officer prefers, the line-handling party may be sent to the ice by boat and the ship held off until the "dead men" are planted and all preparations made to receive the mooring lines. Then the ship can be brought alongside in the normal manner of tying up to a pier.

Plant "dead men" well in on the ice shelf so that an almost horizontal pull will be made on the mooring lines when hauling the ship alongside. A trench for a "dead man" should be dug about 4 to 6 feet deep with sides at a slight angle as shown in figure 14 in order to give better holding power and to avoid the tendency to pull the "dead man" out before it is well frozen into place. The "dead man" with the manila strap attached is buried in the hole and covered over with ice. A few buckets of water thrown on top of the fill will help freeze it in place in a few minutes. The mooring line is passed

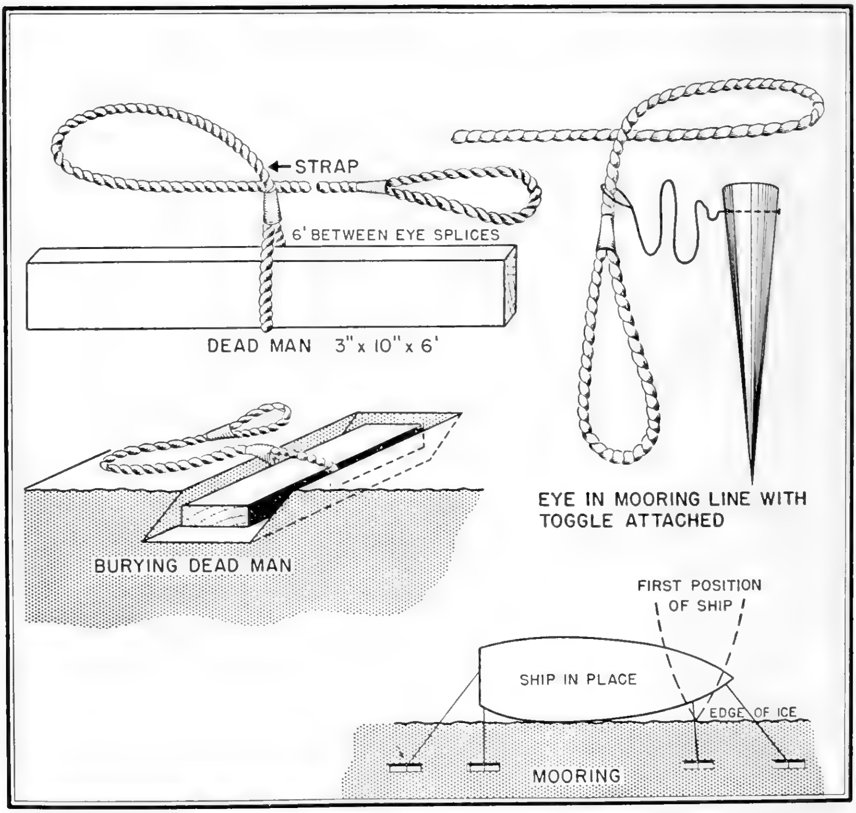

Figure 14.—Mooring ship to the Antarctic ice shelf.

Figure 15.—Unloading cargo from U. S. S. *Yancey* (U. S. S. *Merrick* in background). Lengths of telegraph poles hung vertically over side of ship are used as fenders.

through the eye of the strap that protrudes up through the ice from the "dead man," and is secured with the toggle passed through its own part for quick release. Check toggles frequently to see that they are free for easy slipping. If wet snow or sleet falls, they may become frozen in place.

Four mooring lines distributed as shown in the sketch are recommended. The number should be kept to a minimum to keep the ship safely secured but also to facilitate a hurried unmooring to clear the area during a break-up. The *Bear* found that many break-ups occurred at night when there was a limited number of men up and available to slip the lines. Lengths of telegraph poles 12 to 16 feet long, hung vertically over the side of the ship, make the best fenders. There is usually some ground swell in the Bay of Whales which will cause a vessel to work up and down. Cane fenders have a tendency to ice up and may catch on the edges of the shelf ice because of its height above water.

The use of ice anchors in mooring alongside the Antarctic shelf is generally not recommended. The surface of the ice is too soft to provide adequate holding power. Mooring to a timber with strap and toggle requires less manpower, makes weighing much easier and quicker, and eliminates the possibility of losing an expensive metal anchor.

Precautions

(*a*) To facilitate unloading, moor ship as close to the ice as possible.

(*b*) In unloading heavy equipment, land it as far inboard on the ice as booms and cranes will permit so as to avoid having heavy weights on the edge of the ice near the ship.

(*c*) Skidding of heavy weights from the ship to the ice is not recommended unless shelf ice conditions appear to be exceptionally good and no crevasses are observed between the ship and the barrier. When skidding is necessary, heavy cribbing made up of long telegraph poles should be used in order to distribute the weight as far inboard on the ice as possible.

(*d*) The ship must be kept constantly ready for unmooring and getting under way. A quick break-up may call for that action. If more than one ship is tied up in the same vicinity, the situation may be more complicated, and no time should be wasted in getting clear.

(*e*) Unless coming alongside to moor, a vessel should not steam too close to the barrier. Bergs frequently calve without warning.

(*f*) Men should not be permitted to wander over the ice away from the ship until a careful check has been made for crevasses.

Figure 16.—Ships moored to ice showing tracks left in the ice from unloading operations. Camp HIGHJUMP in the background.

(*g*) Material should be unloaded only as fast as it can be moved inland. Every effort must be made to reload material onto the ship if a break-up occurs.

In the Arctic, unloading cargo over the ice is considered practical over land-fast or land-locked ice, but not over ice in open areas. Fast, smooth ice would present no difficulties for trucks or tractors provided it was thick enough to support the weight. Rough, hummocky ice would be more difficult but could probably be traversed by careful selection of route and use of a small bulldozer. In the event the ice is covered with soft snow and there are large amounts of cargo to be landed, a metal landing strip mat would serve very well to make a smooth roadway to the beach. In land-locked areas during the winter months, natural slips for unloading can easily be cut out by an ice-breaker thus entirely eliminating the problem of mooring lines or "dead men." It is recommended that land-locked areas be selected and checked by aerial scout before planning large scale over-ice movements.

Tracked vehicles can carry cargo over most shore-fast ice shelves and onto the frozen ice or snow-covered beach with no prior road construction. Weasel (M29C) cargo carriers were found satisfactory over solid pack and were used extensively in tows with one or two 1-ton sleds. Cargo and passenger off-loading was conducted at King Island, Nome, and St. Lawrence Island onto shore-fast ice shelf with ease. Summer open water conditions at these ports, however, are hazardous and difficult, unloading being often delayed by high seas.

WATER SUPPLIES

It is important to a ship's economy to be familiar with various sources of water supply in polar regions. Clean snow, of course, is a source of pure fresh water; but if a large quantity is to be thawed, it will be more economical of fuel to use ice, on account of the poor heat-conducting properties of snow. Choose the clearest, most brittle ice, such as is to be found in hummocks and pressure ridges. This will be the oldest ice and most nearly free of salt.

Sea ice more than 2 years old is generally salt-free enough for drinking purposes. The pools that form on the surface in summer contain water suitable for cooking purposes, which can be pumped aboard with handy-billy pumps at a distance of 30 or 40 feet from the edge of a floe to avoid the admixture of salt spray.

Fresh-water streams can frequently be found on land in the summer. They generally occur in association with glaciers and are caused by thawing of the ice in contact with bare rock masses. There is generally an alluvial deposit at the mouth of glacial streams with steep shelving offshore. Such streams should be approached with caution. It is advantageous for vessels to carry 1,000 feet of fire hose with suction attachment and two portable pumps for use in shipping water. The procedure is to anchor a suitable distance off the mouth of the creek, plant an anchor on shore, warp stern in, and run the fire hose buoyed, if necessary, with damage-control timbers. A pump should be placed at the suction and another on deck.

In this manner, much time may be saved in taking on water, which is usually done at about 4,000 gallons an hour.

Although individuals vary regarding a taste for salt, water with a salt content of 1 or 2‰ will often be chosen in preference to distilled water. A salt content as high as 10‰ can be tolerated in emergencies without harmful effects, and such water can be used freely in cooking. The boiler-water kits carried by most modern ships can be used for water analysis. If the sample under test lies off the scale of the apparatus, dilute it one-half, four-fifths, or nine-tenths with distilled water, and multiply the salt content so found by 2, 5, or 10.

Ships making their own distilled water from sea water occasionally encounter concentrations of plankton that yield a volatile oil, which gives a somewhat fishy odor and taste to the water. No harmful effects have resulted from the ingestion of such water; but when the water was used to wash photographic negatives, the film became oil-spotted. This condition can be recognized by the deposition of green scale instead of the usual tan scale in the tubes of the distilling plant.

DAMAGE AND REPAIRS

Typical forms of damage to vessels by ice are:

(*a*) Breaking of propeller blades, rudder head, or rudder.

(*b*) Damage to steering gear.

(*c*) Damage to stem and perforation of plating, causing leaks in the forepart of the vessel.

(*d*) Buckling of plating and tearing out of rivets due to ice pressure, leading in extreme cases to crushing of the hull and breaking of frames.

As a rule, when a vessel receives damage under its stern, repairs should not be undertaken until the vessel is first trimmed well down by the head. This is accomplished by pumping the water out of the stern tanks and flooding the fore-peak and forward ballast tanks. If these measures prove inadequate, a suitable amount of cargo will have to be transferred forward from the after holds.

In the event that the steering gear breaks down, it is possible to steer with the aid of the two rudder pendants secured to the rudder and run to a stern capstan or cargo winch. If the rudder has been carried away a similar steering arrangement may be improvised with the jury rudder.

Repairs to damage in the forepart of a vessel are generally restricted to preventing water from getting into the ship. It may be necessary to transfer water or fuel aft, in order to raise the bow sufficiently out of the water to undertake repairs. If the damage is considerable and men cannot work from the inside because of the volume of water entering, it is advisable first to pass a collision mat over the torn plating before undertaking repairs from inside the ship. The best way of closing up small holes and parted seams is to use wooden plugs, wedges, and oakum. After the repair is dry a large cement box, reinforced with cross pieces, should be fitted over the damaged plates and be well shored into position. A well-placed patch will simplify this work. Damage-control parties should be trained and exercised as frequently as possible in making emergency repairs.

CHAPTER IX

HANDLING AN UNESCORTED VESSEL IN ICE

The first requisite of the embryonic ice pilot is to develop a healthy respect for the tremendous power of the ice. He must never permit the peaceful appearance of an ice field to lull him into a false sense of security. On the other hand, he need not fear the ice, since a great deal of progress through ice can be made by a vessel in capable hands.

In general, ice is an obstacle to the progress of any vessel, and is dangerous to vessels which by their construction were not intended for ice navigation. Nevertheless, it is possible for ordinary vessels to navigate through regions of open pack. The long periods of summer daylight in high latitudes greatly facilitate such operations, and the ability to see obstacles contributes markedly to the ease of ship handling.

ENTRY INTO ICE

When a vessel encounters ice lying on her course, a careful decision must be made whether to attempt to penetrate the ice, or to steam around it. If the boundaries of the ice are in sight, do not enter, but skirt it to windward. In the case of larger ice areas, unless they fill straits through which the vessel must pass or completely block access to her port of destination, the vessel will generally find it more economical of fuel and time to take the longer way around the ice zone.

When conditions make it necessary to enter the ice, the point of entry should be selected with great care. Make a thorough reconnaissance, using radar and aircraft (if available), put an experienced ice pilot in the crow's nest, and search for water sky. The following principles govern choice of the place of entry:

1. Consider the penetrability of the ice along the proposed course inside the edge of the ice field, with regard both to the thickness and the degree of consolidation.
2. Never enter ice where pressure exists, as evidenced by tenting or rafting.
3. If possible, enter the ice up-wind. The windward edge of an ice field is more compact than the leeward edge. Moreover, the individual pieces of ice in violent motion from wave action will be damped out on the leeward edge. If it is necessary to enter downwind,

use great care to avoid damage to the hull of the vessel through collisions with the ice cakes.

4. If the ice is thick and drifting rapidly, wait for a change in direction of the ice movement, which may be accompanied by an improvement in ice conditions. Take into account the time of ebb and flood: ice generally becomes more compact on the flood but begins to break up on the ebb.

5. The ice edge is usually not straight, but often has projecting tongues between bights. Enter at such a bight, for here the surge will be least.

6. Enter at the slowest possible speed, to reduce the force of the initial impact on the stern. Once the bow is in the ice and is cutting or pushing ice aside, increase power to avoid losing headway and adjust revolutions thereafter in accordance with the state of the ice.

7. Always enter the ice on a course perpendicular to its edge. Failure to observe this precaution may result in a glancing blow which will very likely damage the bow plating on the side toward the ice, and may swing the stern into the ice with resulting damage to rudder and propeller.

WORKING THROUGH ICE

Some guiding principles of working in pack are:

(1) Keep moving,
(2) Work with the ice, not against it,
(3) Do not rush the work,
(4) Respect the ice; do not fear it,
(5) Stay in open water or leads,
(6) Watch the propeller,
(7) Never hit a large piece of ice if you can go around it; if you must hit it, hit it head on.

The type, thickness, and area of ice which can be attempted depend on the type, size, strength, and shaft horsepower of the vessel employed. Ice covering up to five- or six-tenths of the sea surface is passable by all powered vessels, for a way can always be found around individual blocks or masses of ice. Independent navigation by vessels in ice covering more than six-tenths is more difficult; the master's experience in ice navigation, and the existence of leads or areas of open water are the things that count. Bearing in mind the contour of the coast, the position of islands, and the direction of the wind and permanent currents, one may form an idea of the direction in which the ice may be getting thicker or breaking up.

The state of the ice should be viewed from as great a height as possible, preferably with glasses from the crow's nest. Not only does the higher viewpoint increase the range of visibility, but it also enables distant leads and open waters that are invisible from the bridge to be seen. Constant attention is necessary, so that the most favorable direction in which to proceed can be determined by noting the presence and distribution of leads or polynyas near the line of the course. Pressure ridges should also be looked for so that they can be avoided and all movements of the ice noted. The thickness and character of the ice ahead viewed from the crow's nest may be roughly determined by comparing its aspect with that of the ice already passed through, the character of which is known. Arctic and Antarctic whalers consider that ice which has a greenish-blue color is the hardest and should be avoided where possible. The vessel should be piloted from the bridge, however, since from this point the character and thickness of the ice in the immediate vicinity of the vessel can best be ascertained.

When the services of an airplane are available, have the plane scout ahead of the vessel. By this means the nature and extent of the ice for miles around can be observed, and a vessel enabled to choose the most promising openings as well as those which lead in the desired direction. In some instances, such an aerial survey will indicate the advisability of the ship making a wide detour, skirting the pack and arriving in a stretch of open water, the presence of which would otherwise have been unknown. Helicopters have proved particularly useful in scouting the ice ahead of vessels and procuring information concerning leads, pools, and extent of pack.

The ice should be carefully scrutinized from the plane at a low altitude. Sometimes, particularly in the Arctic, pools about 6 inches deep form on top of the ice. From the air and even from a distance at sea level, this ice resembles open pack, but upon closer observation it is found that the ice is continuous under the pools and may in fact be unnavigable. Under these circumstances an erroneous report on the navigability of ice may be made, resulting in considerable loss of time and efficiency. It will prove helpful if aircraft observers familiarize themselves with the appearance of such ice either through actual experience or with photographs. Observers should be employed who are thoroughly familiar with the ice problems of surface vessels through actual experience aboard ships working in heavy pack. The same observer should be used in preliminary ice reconnaissance flights to provide continuity in the picture of changing ice conditions on successive flights and uniformity in the ice terminology used in the reports. Although open water and icefields can be seen a great distance from the air, the nature of the ice and its navigability often remain to be determined by the vessel itself.

When working in ice, the maneuverability of a ship is reduced. At the slow speeds often required, a vessel will answer her helm badly and be slow in turning. A short ship turns more readily and is thus easier to maneuver in ice. When the use of full power is limited, a kick at full speed after the helm is put over may be found of assistance. If the ship is down by the head, steering will be especially difficult. On the other hand, although some protection may be offered the propeller and rudder by trimming the vessel down by the stern, if overdone this impairs the maneuvering properties of the ship. The bow, because of its large sail area, will fall off in a moderate breeze. The result is that the stern will be brought up against the ice. Stopping the engines to protect the propeller results in losing headway and accelerating the falling off. If way is lost entirely, the ship will gather sternway in a

Figure 17.—U. S. C. G. C. *Northwind* breaking through ice in McClure Straits, showing upended ice cakes which present a danger of fouling the propellers.

moderate breeze, and drift into the ice, thereby endangering the rudder and propeller.

On impact with ice, the ship will move in the direction of least resistance without regard to the position of the rudder. With experience, a helmsman may be able to take advantage of this fact.

A twin-screw vessel is at a distinct disadvantage in ice navigation because of vulnerability of her propellers, although twin screws give much greater maneuverability. One successful expedient that has been adopted by such vessels to minimize propeller damage when in ice is to set a propeller watch. A man is stationed on each side of the fantail directly over the propeller guard, with phone communication to the bridge. He is instructed to report ice in contact with the side of the ship especially if the thickness extends to the upper side of the propeller blades. When such pieces have reached a point 30 feet forward of his position, the report "starboard (or port) foul" is made to the bridge, and the screw concerned is stopped until the report "starboard (or port) clear" is received. The U. S. S. *Edisto* found a preferable

Figure 18.—U. S. S. *Edisto* in drydock. Port propeller and external portion of shaft were sheared off due to contact with the hard ice of the Lincoln Sea. Shaft is 18 inches in diameter.

arrangement in having a watch on each wing of the bridge with authority to take action when a propeller is in danger. If signaling is necessary, ice-breaking vessels, because of their relatively short length and broad beam, lend themselves to a simple system of visual signals, such as hand motion or flashlight, whereas telephone communication may introduce an element of lag.

Go astern in ice only with extreme care; put the rudder amidships, and keep a sharp lookout for ice under the quarter. Again, a twin-screw vessel is at a particular disadvantage when backing in ice, owing to the great likelihood of pieces of ice being sucked in toward the ship and jamming between the propellers and the side. One system for working astern when breaking ice which has been found expeditious is to:

(1) Allow the screw to wash the ice astern for a few minutes before backing,
(2) Back full until just before contact with debris, then
(3) Stop and allow momentum to carry the vessel well into the debris.
(4) When all ice has surfaced, give a kick ahead and stop.
(5) Back full again, repeating the process until the ice canal is of sufficient length to ram it full speed on the next lunge.

The line of a crack or lead in an ice field is usually normal to the direction of the movement of the field. A new crack will thus form according to the direction of the wind and current, and either widen out into a lane or form a new hummock. A field of ice does not necessarily crack in its thinnest part; frequently cracks are found passing through hummocks, leaving thin, half-melted ice holding it together. However, in many cases this half-melted ice is completely destroyed when the wind changes.

When a crack in a floe is but partly made, it is sometimes possible for a ship, by ramming her way into it, to complete the crack and widen it into a lane. A vessel may also force her way through an ice field of young ice, or through a bridge connecting two floes, if the bridge is not too thick and heavy. Great care should be taken in such operations, for old and heavy pieces of ice can withstand the impact of the most powerful vessel; even fairly stout ships can then suffer damage, but vessels that have been specially constructed for use in ice are usually so strong that their engines cannot force them against the ice with sufficient force to injure them by a head-on impact. Ships so constructed can charge the ice again and again, backing away for each charge. Under such conditions, when it is a matter of seconds from going ahead to going astern, it is recommended not to stop the engines, but to reverse directly from ahead to astern. Care should be taken, however, to prevent undue torsional stresses being set up in the shafting which, owing to the low temperature, will have lost part of its safety factor.

A vessel may attempt to force a way through ice, but only in the absence of pressure from the ice due to the influence of winds or currents. Always avoid pressure ridges of any type. Such ridges are formed on a line roughly perpendicular to the direction of movement of the ice. Cracks may be formed in ice fields along the line of pressure, likewise perpendicular to the movement of the ice. Such a crack is usually covered with thin ridged ice from 1 to 3 feet thick. On the least change of wind the heavy masses may come together again, entirely crushing and grinding the thin ice between. A vessel should, therefore, in no circumstances proceed along through a pressure ridge. Other cracks often occur, cutting right through pressure ridges, which may be as much as 30 feet thick; these cracks are similarly covered with thin ice. Such a crack should not be entered, unless it is obvious that it will take the vessel quickly out of the whole area affected by pressure. The signs of the proximity of ice and open water given on page 107 must be looked for and used. For example, in a vessel in pack ice, signs of distant areas of open water might be discernible by reflection from the clouds; course should therefore be set in that direction, if possible.

Fine weather in the pack usually portends lowered temperatures, close pack, and little open water. Damp misty weather in the pack generally signifies the presence of a considerable amount of open water with the ice and better conditions for maneuvering, in spite of the poor visibility. The existence of swell or the presence of skua gulls and petrels are signs of more open pack near, with open water not far distant. Blowing whales usually travel in the direction of open water.

Weather and sea conditions in the pack are variable. Brilliant sunshine, cloudless skies, and light air may alternate with periods of gales, heavy swell, and grinding floes, when vision is obscured by driving wind and blinding snow squalls. Periods of calm may follow, bringing fog and fine mist which form a sheath of frozen rime over the running gear of the ship. Heavy clouds and overcast skies may produce a milky atmosphere in which shadows are nonexistent and distances become very deceptive.

Ice in the sea, other than fast ice, is in continual movement under the influence of wind or current, causing the various pieces or masses to gather together and move along, retaining the openings between. Heavy onshore winds and swell break up the ice, and if offshore winds follow, the ice will open out, making the waters navigable. Once broken up in mild weather, the pack ice will not recement if brought together again, and consequently will open more readily to light winds.

Proceed through the lanes thus formed, even if they do not lead in exactly the same direction as the vessel's course; by proceeding through weak patches in the ice from one lane to another, a ship can thus make good her course. To avoid ultimately taking the vessel far from its objective, it should be impressed upon conning officers that the compass must be closely watched while navigating leads and care taken to adhere within reasonable limits to the base course.

An offshore wind usually forms a channel between the coast and the pack ice which is frequently used by navigators, who must, however, be on guard against an onshore wind setting the ice back onto the coast. In such a case, shelter should be sought in a bay, behind an island, or even behind a floe. The alternative is to proceed out to meet the ice so as to work a way through it to clear water beyond, before the floes pile up on each other against the land. However, this can only be done where one is reasonably sure of finding open water well away from the coast; it must never be done on coasts like the north shore of Alaska, unless direct information of open water offshore has been received. Northward of western Canada, Alaska, and Siberia, the amount of ice to be met increases with the distance from shore.

Bergs in the pack should be given a wide berth as they are usually current-driven, while the pack is wind-driven. Owing to their depth below the surface, bergs travel with the current and are only slightly affected by the wind. In pack, bergs generally move at a different rate from the sea ice. In regions of strong currents they may travel up-wind, wrecking heavy pack in the way and endangering a vessel unable to work clear. Under these conditions open water will be found to leeward and piled-up pressure to windward of bergs. The same condition has been observed in regions where currents are weak. In a strong wind, the pack overtook the bergs and was heaped up to windward, while a lane of open water lay to leeward of the bergs. This condition produced the optical illusion that the bergs themselves were traveling in a direction opposite to the pack.

If it becomes necessary to lie-to in a polynya, it is not always desirable to choose the vicinity of icebergs since they do not move with the pack; the opening is therefore apt to close up. Furthermore, there are usually growlers in the vicinity of bergs. There is danger in making fast to bergs in bad weather, for they are often in motion and may carry the vessel upon a grounded mass, or heavy floes; there is also the danger of their overturning and calving. Unceasing watchfulness is necessary for eddies and currents, if fast to a floe, and a weather eye must be kept on any bergs or heavy ice that may be near, lest they approach without noise or perceptible motion.

The movement of a berg through a wind-compacted belt of ice creates a fair lead which may remain open for an indefinite period, depending on the size of the berg and the force and direction of the wind. In traversing pack, advantage may be taken of the leads so created by following the berg through the ice belt. In 1943, the Northeast Greenland Task Unit Cutter *North Star*, beset in close pack *storis*, managed to plant her ice anchor on a large berg which drifted close aboard. Because of the rapid relative drift of sea ice, as compared with that of the current-propelled berg, she was towed to open water. In order to save time and fuel, the *Eastwind* in 1944 resorted to the same tactics in working through a consolidated field of polar ice. It should be noted that both of the aforesaid operations occurred in northeast Greenland where low water temperatures insure the stability of bergs.

If entering a narrow strait or bay into which the winds blow directly, keep an alert watch on drifting ice, since the greatest danger from ice exists in an enclosed space.

If operating in an area to windward of a prominent point in the coast line, exercise caution: a sudden increase in the wind may bring the pack down upon the vessel which, if set toward a lee shore, may become quickly beset and subjected to pressure.

Care should be taken when operating in the vicinity of ice tongues which project seaward from the coast line without reference to the trend of the coast line. An ice jam along an otherwise clear coast may indicate the existence to leeward of such a tongue. Stranded bergs, shoals, islands, and seaward extensions of land may produce ice jams, and vessels finding themselves to windward of such features must be prepared to quit the vicinity upon the appearance of pack ice.

In slewing through pack ice there are two effective ways in which progress can be made through areas in which there are only cracks and narrow lanes between floes. In the first method the vessel charges the openings between the floes and, upon impact, puts the rudder hard over. When the forward motion of the ship ceases, the rudder is reversed and the engines placed on half-speed ahead. The effect is to widen the opening and let the ship gain easier entrance. This operation is repeated until the floes yield, forming a lead wide enough to allow the vessel to proceed ahead.

In close pack, the second method is employed when the first is not fully effective. In this operation the vessel is used as a lever to force a path between the floes. Upon gaining entrance of the stem of the ship by ramming, the bow is brought up against that floe which is to be forced to leeward or in such direction that space is made available for the vessel's movement. The engines are then placed on full speed, and with full rudder the vessel is pivoted with the bow hard against the floe. The ship then acts as a fulcrum and effectively overcomes the inertia of the floe in contact which slowly picks up motion in the direction impelled. Sallying is often helpful in working a small vessel through narrow leads. Vessels should always be kept clear of corners and projecting points of ice masses as such points become the foci of pressure. In working the pack by slewing, skillful use must be made of the rudder to prevent the stern from swinging into the ice.

Polar pack ice, if it exists in close pack of over eight-tenths coverage with small leads only, should be avoided. To traverse it when the coverage is seven-tenths or below, the second method above, which has been employed to break the field ice in Melville Sound, may be used. Thus, the tendency would be to keep small chunks from breaking off the pack and upending and decrease the danger to the propellers. The ice would tend to move away in a horizontal direction.

SPEED OF ADVANCE

Successful ice navigation is basically a matter of speed through the ice. Pack ice, unless very open, must be entered at the lowest possible speed, which should be increased only after observing the state of the ice and the extent to which it is possible to pass through it. The possible speed through ice is determined primarily by two factors, the amount of surface covered, and the possible force of impact with the ice without damage to the ship. When possible, maintain way on the ship at 2 to 5 knots so as to have some control of the rudder. Coasting into the ice with engines stopped results in the loss of effective rudder control.

Ships must be prepared to back down emergency full at all times. When a "stop bell" is rung up, the propeller must be stopped, by backing steam if necessary.

When ice does not cover more than six-tenths of the sea surface, the speed of a vessel passing through it without an icebreaker will depend on the distribution of leads and polynyas. If the distribution is suitable for navigation, the speed may even be increased to full from time to time. On the other hand, it must be reduced occasionally to examine the state of the ice and adapt the course accordingly.

Ice covering seven- to eight-tenths of the surface must be traversed throughout at slow speed, so that any impacts with the ice will not damage the hull.

Once inside pack ice covering eight-tenths or more of the surface, revolutions may be increased even to full with the object, not of increasing speed, but of forcing a passage through the ice by using the power of the engines.

When darkness descends, or the visibility becomes poor, a vessel working her way through leads or weak areas in close pack should heave to or ride to an ice anchor. Otherwise she may unwittingly enter thick ice from which it will be difficult to withdraw when the visibility improves. On the other hand, when navigating at night or with poor visibility through more broken ice, it is recommended not to stop, but to proceed with caution at very slow speed. Under such circumstances keep searchlights manned for immediate use. The *Edisto* used 24-inch searchlights to aid the conning officer in picking leads with some success. The main criticism against using these lights is that they are located behind the observer and the glare partially blinds him. As an alternative, two portable lamps similar to "sealed beam" automobile headlights can be rigged so that they can be installed on the forward bridge bulwark and operated as necessary by bridge lookouts. A portable damage control lamp has also been successfully tested.

HAZARDS IN THE ICE

The most serious danger is that caused by the pressure of the ice on a vessel, which may result in the crushing of the hull or the nipping off of the ship's bottom. This risk is greatest when navigating in pack ice covering seven-tenths or more of the surrounding sea. Apart from this hazard, a vessel beset by ice and therefore drifting with it, may be forced into waters which are dangerous to navigation. In the autumn there is also the risk of being forced to winter in the ice.

Another danger is the meeting of masses of thick broken ice, especially those that bear signs of erosion by the sea on their upper surfaces. Such ice masses often have underwater spurs. The submerged portions of such pieces are extraordinarily strong and are hardly affected by melting. These can be very dangerous on impact with the hull or screws of a fast-moving vessel. Dirty ice, broken away from coastal regions, may sometimes be encountered at sea. This ice may also be very strong. Furthermore, it must be remembered that the strength of ice increases markedly with the approach of frost and the fall of air temperature.

The danger of the fore part of the vessel striking against sharp corners of ice must always be guarded against. If collision with cakes is necessary, try to take the impact on the stem. Newly formed young ice is dangerous to wooden ships, as it may cut right through the hull planking at the waterline unless the vessel has been sheathed with ironbark or steel plating.

While working through the ice, a ship makes use of every weak spot en route and is, therefore, frequently required to make sharp turns. If in trying to save time, these turns are made at all possible speed, the stern may be thrown against ice edges. Sometimes the blows are very heavy and a broken blade or shaft results. Sometimes breakage results from metal fatigue caused by the propeller hitting the ice frequently over a long period of time. In such cases, the loss of the blade or the entire propeller may occur almost imperceptibly. When navigating in deeply submerged old ice, the conning officer should therefore endeavor to make slow turns and prevent the stern from striking sharply against the ice. When maneuvering astern, a lookout should always be kept on the fantail with direct communication to the bridge and a warning system worked out. Most damage to propellers and rudders happens at the end of the navigation season when ships are working at night in heavy ice.

When forcing a passage through the ice by ramming, it is necessary to pay strict attention to the loss of headway at the moment of running into the ice. If it is evident that as a result of the run taken the obstacle will not be overcome and the ship will stop, it is then necessary, to avoid being embedded, to go full speed astern even before she stops. At the moment when way is lost the engines should already be going full speed astern. It is not advisable to continue forcing a passage if the channel so made does not considerably exceed the beam of the vessel, so that she can move freely out astern. Moving forward in such a channel may cause the vessel to become beset or even eventually crushed.

A vessel may sometimes be beset and yet be saved from pressure. When the besetting ice has underwater spurs, due to the melting back of the uppermost 2 or 3 feet of ice, these may act as a cradle for the ship.

RELEASE OF A VESSEL

In endeavoring to avoid getting fast in ice it sometimes happens that taking a run at the ice may result not in the breaking of the ice, but in the vessel's bow sliding up on the ice edge, so that she becomes fast. This tendency to slide up on the ice depends on the lines of the forward part of the ship and on her loading and trim. One or more of the following methods may be used for releasing the vessel.

1. Go full speed astern. This may extricate the vessel, but it is not always successful. If it fails, stop the engines, put the helm over and go full speed ahead. By putting the helm over alternately from side to side and going full speed ahead, it is often possible to induce the stern to move a little to one side, so that the bow will move slightly; then by going full speed astern the vessel may slip off the ice.
2. Try to split the ice by striking it at the point of pressure with crowbars. This is one of the simplest methods.
3. List the vessel by transferring water in the ballast tanks.
4. Alternately flood and empty the fore and after peaks. First flood the fore peak, and then empty the fore peak and flood the after peak.
5. If the foregoing methods fail, try an ice anchor or warp attached to the ice astern. Pass the anchor cable through the mooring chock on the forecastle and lead it to the windlass. Take a strain while the engines are going full astern. An alternative of this method is to take an ice anchor abreast of a mast with the heaving line to the masthead.
6. Lay out ice anchors on each beam and heave first on one and then on the other, keeping the engines going full astern.
7. If all these means fail, try blasting. The usual position for placing explosive charges is about 35 or 40 feet from the ship, abeam of the bridge. If the ship is held only forward, good places are directly ahead and at each side of the bow, the idea being to break off a portion of the floe without enough buoyancy to support the ship. A blasting charge of 8 ounces of guncotton in a hole 6 inches deep will blow a hole either through the ice or deep enough to use an 18½-pound charge effectively, and this is the amount generally necessary. At the time of the detonation, the engines should be working full astern. It may also be helpful to hold a strain on ice anchors laid out astern.
8. When all else fails, a ship can be sawed out of the ice, provided the ambient air temperature is not below the freezing point of the sea water. The classical example of this feat was set by the *Belgica* of the de Gerlache Antarctic expedition. Dr. Frederick A. Cook who was later well known in connection with the North Pole, was ship's

surgeon. The *Belgica* was frozen in the pack off Alexander I Island in February 1898. After a number of months of aimless drifting in the Bellingshausen Sea, during which the members of the party underwent a physical and mental decline, Cook conceived the idea of working the ship into a polynya about half a mile away. All hands turned to with ice saws and attacked the ice. In a few weeks they had cut the channel, and the *Belgica* was again afloat; meanwhile their health and mental vigor were restored. In February 1899 a lead opened into the polynya, through which the ship worked clear of the ice.

PRECAUTIONS AGAINST BEING BESET

If a vessel is in danger of getting fast, especially if signs of pressure are evident, the master will be faced with the necessity of attempting to break through ice. The same problem arises if a floe which cannot be circumnavigated is encountered, provided no pressure is observed in the floe. Except in these circumstances, icebreaking should not be attempted by an ordinary vessel.

It will be possible to break only ice masses which have already been so weakened by thawing that the impact does not damage the hull. Head blows against the ice must be avoided. The impact should be taken on the stem perpendicular to the edge of the ice. A blow struck at any other angle will not break through. Instead, the vessel will graze with her bow along the edge of the ice and the forward plating may suffer as a result of the blow. In addition, the stern of the vessel is thrown violently to one side and, on coming into contact with the ice, the rudder and propeller may be damaged.

A blow against the ice can only be achieved by taking something of a run. The length of the run should be calculated in accordance with the hardness of the ice and the strength of the hull of the vessel. With a run, it is possible to open up a floe along the lines of narrow cracks and openings. It is necessary, however, to watch the ice very carefully to avoid hitting any projection that may buckle the plates.

PRECAUTION WHEN BESET

When a vessel is beset by ice, aground, or jammed between two ice blocks, the above measures should be tried in an effort to extricate her. If they fail, clear away the ice at the sides of the vessel, although it is not always the ice at the sides that is the cause of the stoppage. It is often the tongue under the water which cannot very well be reached.

In such a case it may be desirable to work on the opposite side of the ice masses, where possibly sufficient ice can be cut away to ease the pressure and permit the vessel to pass. Blasting by gunpowder or dynamite has been used to free ships that have been caught in the ice, or to open a passage when an intervening floe has blocked the way to open water. Passages opened by cutting or by blasting can sometimes be kept open long enough for the ship to pass through by placing some of the loose blocks of ice as wedges between the two floes, ahead and astern of the vessel. Men working on the ice at such times, or those crossing it on foot to look for a lead, should hold a boat hook or small ice pole in their hands horizontally, to guard against falling through a partly hidden crack. A strong plank drawn after one of the party can be very useful for crossing places too wide to leap across. One case of emergency rations for every man on board should be stowed under cover topside when operating in the pack in order that packed food can be readily tossed over the side if the vessel is nipped. Search and rescue equipment should likewise be assembled, packaged, and kept in readiness at all times.

No material injury is likely to occur to the crew of a beset vessel if they are on the alert and prepared beforehand, i. e., the boats furnished with provisions, clothing, and portable fuel. This simple precaution gives but little trouble and is well worth while. Boilers should be banked or fires allowed to die out and the boilers drained. In the event of being forced to winter in the pack, vessels fitted with propeller wells may find it advisable to unship the propeller and rudder. Slacking off the standing rigging is another precaution that should be observed, as ice pressure tends to squeeze in the sides and lift the masts. Serious damage to a vessel is not necessarily of sudden occurrence; it may be brought about by a gradual increasing of pressure on both sides, until the vessel's bottom is nipped off, leaving her sides, bow, and stern resting on the two floes, like a box without a bottom. When the pressure eases, and the floes part, the vessel founders between the two.

Unintentional wintering in the polar regions no longer presents the hazards that were faced by early explorers. Modern means of detection and communication assure that even a vessel with disabled radio will be located expeditiously and her personnel evacuated. Those who must stay with the ship for her security can be relieved and supplied at regular intervals. In the Arctic, at least, winter weather conditions in the pack ice are less severe than on land far to the south. Sverdrup reports a minimum temperature of −46° F. for the two winters that the *Maud* spent in the pack, and a maximum wind speed of 30 knots; in general the lowest temperatures were accompanied by the least wind.

OPERATING BOATS AND SEAPLANES

At reduced speed the standard Navy 40-foot motor launch and LCM are able to move aside ice 7 to 8 feet in thickness. The engine should be stopped when brash is encountered to eliminate the danger of having the shaft bent or the propeller fouled. Caution should be exercised that the stern of the boat does not drift on ice extending from floes below the surface of the water. If this occurs, difficulty in getting a boat off the ice may be expected. Boat hooks are the only means of clearing the stern.

For landings and take-offs seaplanes must have a seaway absolutely free of all types of ice. Even brash of small size hit at the speed of an aircraft will readily tear pontoon metal. In cases where seaplanes have been used in polar regions, records show that much time was spent searching for suitable areas for plane operations. Therefore, jet assisted take-offs would prove helpful. The necessary water space for operations may sometimes be found in long, narrow leads, bays in the pack, or inshore clearings, all of which must be carefully swept either by small craft or by aircraft taxiing over the proposed lane. Landing areas must likewise be scanned for floating ice before attempting to land. Long open leads may be found behind large bergs. During late summer it is possible that young ice will form as a transparent covering in smooth areas protected from the wind. This ice will cause damage to any planes attempting to taxi through it.

The use of boats and planes for scouting is discussed under other headings.

CHAPTER X

OPERATING AN ICEBREAKER

This chapter is based on the operating experience of the *Wind* class icebreakers, the characteristics of which are given on page 13. Seven of these ships were built at San Pedro by the Western Pipe & Steel Co. The first three were transferred to the Soviet Union under Lend Lease; two were taken over by the United States Coast Guard as the *Northwind* and *Eastwind;* and the last two became the *Burton Island* (AGB 1) and *Edisto* (AGB 2) of the United States Navy. They displace 6,465 tons on a full load draft of 29 feet, which places the propellers about 20 feet below the surface.

PROPELLERS

The propellers are of cast steel, with detachable blades bolted to the hub, and are about 1 inch thicker than standard blades. The *Burton Island* reported that many times while working pack in the Antarctic in 1948 the propellers were fouled to the point where the main motor would stall. As soon as they were clear, the ship would again resume normal operations without any apparant damage having been done the screws.

As already mentioned, this class was designed to have a bow propeller. The *Northwind's* propeller was damaged by grounding in the Arctic in the summer of 1946 and subsequent contacts with ice wrecked the thrust bearing and threatened damage to the motor. The bow propeller was therefore omitted from the *Burton Island* and *Edisto.* On Operation HIGHJUMP, later that year, one ship reported that the bow screw was unnecessary while the other, experiencing some difficulty in clearing the broken ice from the ship's track when traversing solid pack, expressed the opinion that a bow screw would help lay the broken ice back upon the adjacent ice, leaving a clear path.

The bow propeller has been successfully used on the winter ice of the Great Lakes, the St. Lawrence, and the Gulf of Bothnia. However, this is local winter ice with an average thickness of 3 to 4 feet, although rafted ice up to 30 feet is said to be sometimes encountered.

With the bow propeller going full ahead, pulling the water out from under the ice ahead, it was seen that the ice would break for a distance of 30 to 40 feet forward of the bow. It appears necessary to keep the bow wheel turning in water in order to get the best results. This practice is not always possible in polar pack ice where it frequently becomes necessary to use the ship to break the ice ahead of her in order to make headway. It is generally desirable, even in loose ice, to keep power on the bow screw for protective purposes even though the ship does not gain anything from its use. It has been the practice of the *Eastwind* not to hit ice with the bow propeller unless the wheel is actually rotating, in order that the impact of the blow will be taken on the leading edge of the propeller rather than on its face.

PERFORMANCE

Reports from the *Northwind*, *Edisto*, and *Burton Island* from operation NANOOK in Greenland waters in 1946, Operation HIGHJUMP in the Antarctic in 1946–47, Task Force 68 in Greenland waters and the Canadian Arctic in 1947, Task Force 39 in the Antarctic in 1947–48, and Arctic winter operations in 1948–49, indicate that the expectations of the designers with respect to these ships have been fulfilled. The hulls can withstand impacts against heavy ice at full power.

Heavily ballasted and using full power on two after-screws, these icebreakers can maintain headway through consolidated pack up to 6 feet or more in thickness. At thicknesses of about 8 feet they can penetrate such ice by charging, but there is a tendency for the broken pieces to remain astern in the ship's track. Backing down for a fresh forward run at the ice then becomes somewhat hazardous. The most vulnerable part of the ship is the screws. A simple system of signals is therefore recommended for use between flight deck or docking bridge and navigating bridge in order to avoid swinging the stern into ice with power on the swinging flank. The watch in both motor rooms must be alert for striking of ice by the propellers and, unless general orders to the contrary are received from the bridge, should stop the affected motor. There are times, however, when chances must be taken and the officer on the after-station relied upon to the exclusion of the motor room watch.

Pack consisting of detached blocks, even if they are large and the water spaces between them small, can be broken at thicknesses of 10 to 12 feet. With 35 percent and up of open water, floes as much as 25 feet thick can be broken through. Pieces of considerable surface area and 30 or 40 feet thick can be shoved aside as long as there is open water for them to be pushed into. The deciding factor as to navigation in ice more than 6 to 8 feet thick is whether or not there are any open water spaces for the broken ice to move into.

In a seaway, the icebreakers, lacking keels, are extremely lively. A 50° roll has been recorded off Nantucket Lightship. They are also reported to be wet in a head sea, although by virtue of their sturdy construction they can take a tremendous amount of punishment.

OPERATING IN ICE

The most expedient way to traverse ice is to find the open leads and polynyas even if it entails actually going much greater distances than intended. Too frequently ships that do not follow the above rule will find themselves back-tracking and looking for these open leads after having wasted many hours trying to bull their way through a short cut. The best means of finding leads, open water, and areas of ice that can be traversed is by use of the ship's helicopter. The HO3S type attached to the *Edisto* easily made reconnaissance flights up to 30 miles and with good visibility could pick out leads several miles ahead of her farthermost position. Navigating solely from its own observations, a ship can only proceed according to what it can actually see for about 7 or 8 miles around. Even this information is uncertain when the ice begins to get fairly heavy and thick because the appearance of the ice is frequently deceiving. However, there are numerous aids such as water sky, iceblink, and direction of prevailing wind that may be used with a great deal of success. The following up of water sky has proved quite helpful in navigating the ice fields; heading toward ice blink in an effect to short cut across the pack has almost always proved inadvisable in that the longer route had to be taken eventually anyway.

Therefore, the first recommendation for successful ice field negotiation is to use a helicopter to pick out the best patch to follow; in the absence of available aircraft for this purpose, follow the water sky and stay away from the iceblink. When the visibility closes down so that neither of the above methods can be used successfully, it is best to stop and lie to until visibility improves again. This advice presupposes, of course, that little or nothing is known of ice conditions ahead and that local ice conditions offer a navigational handicap.

Brash, slush, pancake, and new ice may tend to slow the ship but do not prevent her from maintaining a course. All these types are navigable by ordinary ships and are mentioned because they are quite frequently encountered. No particular skill or operating procedure is required except a good degree of common sense if these pieces of brash ice become heavy enough to throw the icebreaker off her course.

In open pack, where numerous big open leads are to be found, the progress of the ship will be determined by the conning officer's skill in spotting the best leads far enough ahead to keep his ship on the course nearest to the base course desired. Practically any speed desired may be used, provided caution is used in maneuvering around and between heavy floes in order not to strike the bow into these floes so as to cause the ship to be thrown off her course, possibly to such an extent that she will hit and rebound from floes on the other side. An experienced helmsman can maneuver the ship through this type of ice if the officer of the deck will merely point out to him which direction or lead to take and then let the helmsman use his own initiative. The passage of an icebreaker through this type of ice can be compared to an automobile driving through heavy traffic. The chauffeur can do better if back seat drivers are kept to a minimum.

In close pack or field ice the icebreaker literally runs into the real job of ice breaking. It is very serious business and must be approached with the highest degree of skill possible. First the ship should be ballasted properly, down as much as the ballast and trim tanks will permit, not only to protect the propeller but also to keep the engine injections low enough to avoid their being clogged with broken ice.

The bow should ride lower than the stern in order to present a sharp cutting edge for entering the ice. Because the center of gravity is moved forward under these ballasting conditions, more weight is concentrated forward to wedge the ship through the ice. As the bow comes up onto the ice, the ship's more buoyant stern is forced down; however, this extra buoyancy causes the stern to be pushed up again until it regains equilibrium with the bow. In effect, as the bow is lifted by the ice there is a constant lifting under the stern tending to force the bow back down again. The weight of the bow, of course, is what breaks the ice. Another advantage of keeping the bow low is that the ice is broken and forced out along the sides of the ship where it will slide clear of the screws and rudder. It has been observed that where extremely heavy floes were run upon by a high bow and low stern, if there was not ample room for a floe to slide to one side due to the heavy pack, then the floe would slide under the hull and come up aft in the way of the propellers. However, the bow should not be trimmed down to the extent where the screws are raised appreciably, further endangering them.

In working very heavy pack ice, all engines must be available for use as needed. The momentum of the ship, combined with proper ballasting and use of engine, is the greatest factor in breaking heavy ice. The full power revolutions for stalled conditions should be determined and the ship should make her approach to the ice at the predetermined number of turns. As the ship is slowed by the ice, more throttle should be applied to keep the shafts at the stalled condition full-load revolutions. This procedure gives the maximum power with the least possible strain on the power plant. There are times when the ship's progress is stopped completely and she must be backed down to take a new start and ram the ice. During this backing, caution must be used to see that the ship does not ram heavy ice that has drifted in astern endangering the screws and rudder. Use only enough power to gain stern way. The *Northwind* recommended limiting speed astern to 70 revolutions per minute to avoid clogging injection faster than the de-icing system can take care of it.

An icebreaker's progress can be slowed appreciably by relatively low snow-covered hummocks with a snow cover of 24 inches or deeper in drifts. If the temperature is not too low, the snow forms a cushion absorbing a large part of the breaking force so that only a small percentage is effective in actually breaking ice. Frequently, the fuel consumption for one-half mile in this type of ice can be equal to that in 340 miles of open water.

It is also imperative that the rudder always be in the amidships position while backing down. If it is necessary to force back heavy ice that has drifted in astern, the ship should be eased up to the ice as slowly as possible until contact is made, then power applied and backing continued. This method will allow more of the ice to move along the side of the hull at the water line rather than force it directly under the hull into the screws. One to three ship lengths is usually enough starting room for the next lunge at the ice.

In instances where backing down for new starts is necessary, the ship sometimes become wedged into the pack so tightly that she is unable to back out even with full power. This is a situation where the heeling system can help keep the ship on its way. On at least three such occasions the *Edisto* was broken free on the first roll so that she was able to move out. On Operation NANOOK II during the summer of 1949, the *Edisto* reported, "Ship stuck in heavy solid pack ice. Backing and attempted slewing failed to break her loose. Tried small charge of TNT in ice near bow—no results. Commenced heeling. Backed clear of the ice. Tried to get stuck again but with the heeling system in operation, she always backed clear." It is believed that the heeling system should not be used continuously while underway except in heavy pack that is rotten enough to give a mushroom effect. That is, the ice is unmoved except in the direct path of the ship and the ship acts as a wedge which is driven in but does not break its way through. If the ship is heeling under these ice conditions, every roll she makes has the effect of extra, small wedges assisting in relieving her for another strike at the ice. Another situation in which heeling would be necessary is where large bergs or land on either side will not permit the heavy floes to move out of the ship's way, causing the ship to become wedged in.

The necessity and importance of the heeling system cannot be overemphasized. It should be used only when it is necessary to keep the ship moving ahead or to break her out in the event she is beset.

During the heeling of the icebreaker, when beset and attempting to free her, keep a careful lookout for the results, so as not to miss the moment when the icebreaker falls through the ice. At this moment, all engines must be backed, since during the listing of the icebreaker the engines are stopped. The desired effect cannot be secured if they are left running. If they are not stopped they create a peculiar equilibrium between the holding force of the ice and the pulling force of the propellers, whereas a sudden jerk is needed to get the icebreaker off. This is accomplished by starting all engines simultaneously and operating them at full speed at the exact moment the icebreaker falls through the ice. If the heeling method does not achieve the desired results it can be supplemented by changing the draft forward and aft. For this purpose the fore peak tanks are filled and the after tanks are emptied; this process is then reversed, causing the stern to submerge and the bow to emerge. While operating the trimming and heeling tanks, the space in which the icebreaker is stuck is somewhat increased, enabling the ship to back up and run ahead.

It sometimes happens that an icebreaker wedges in so solidly that both these methods are insufficient. Additional help can then be given by working the engines in different directions. The ship may then swing a little and sometimes loosen herself out of the wedge. If all these methods used either separately or together do not produce results, ice anchors are used. The ice anchor is led out on the ice and placed about halfway between the bow and stern of the ship. The fluke of the ice anchor is put into a hole or crack in the ice and the line from it led through a bow chock to the drum of the windlass. When everything is ready, all engines are worked full astern. The icebreaker must at the same time be heeled to one side. The windlass takes a strain on the line secured to the ice anchor and with this additional pulling force the icebreaker moves astern. This maneuver usually brings good results and the icebreaker is released.

On the U. S. S. *Bear* in 1942 it was found to be of more advantage to take out an ice anchor abreast of a mast with the heaving line to the masthead. A slight force on the heaving line caused a slight list to the ship which was always effective in releasing it. Damage to the winch or gear usually resulted when it was attempted to free the ship by heaving on an ice anchor laid out astern or on the beam with the hauling line leading aboard at deck level. Explosives are also used to release an icebreaker.

In continuous sheet ice, even when the icebreaker is able to maintain speed through it, as she can in ice only 2 or 3 feet thick, the course is likely to be erratic. As the ship hits the sheet ice, cracks radiate from the point of impact, forming paths of least resistance. The ship is likely to start down one of these cracks making it extremely difficult to get the heading on the proper direction again. Often even with full rudder the icebreaker may go contrary to the desired course for a considerable period of time.

Steering with the engines may be of some help under these conditions, but slowing down one engine in order to swing the ship's head around also may result in the loss of headway and the stalling of the ship.

There appear to be two main methods in conning an icebreaker through the ice pack, both of which are dependent upon the degree of initiative allowed the helmsman. In the first method, much latitude is given the helmsman. Usually the officer of the deck points out a distant berg or some identifying mark in the pack which lies within a few degrees of the desired course. Also, he tells him the amount he may vary each side of the base course. Except for an occasional bit of advice the O. O. D. then generally allows the helmsman to follow his own bent. In the second method the onus is placed upon the O. O. D. He orders all changes of course and makes all decisions in following leads. In doing this he must make up his mind sufficiently well in advance to communicate an early decision to the helmsman so that the order may be understood and acted upon.

Both methods have their advantages and disadvantages, and the employment of either is dependent upon existing conditions, the temperament and experience of the O. O. D. and the helmsman, etc. Mainly because of the makeup of the *Burton Island's* bridge, her commanding officer in the Antarctic in 1948 preferred the first method. As no gyrocompass was available in the vicinity from which the O. O. D. was conning, it was continually necessary for him to ask the helmsman for the ship's heading in the absence of bergs or landmarks. In order to comply, the helmsman, who was wearing dark glasses, then had to look down and with difficulty read the heading from the gyro at one side of the wheel. He then had to readjust his eyes to the ice pack, impart the heading to the O. O. D., and get his mind once more on his steering. Helmsmen are rotated every 30 minutes.

Sometimes it is very difficult to decide whether to strike a floe squarely to enable the ship to penetrate the ice and keep closely to the present course, or hit it a glancing blow in order to help make a turn in following a lead.

Have the helmsman stand on a stool so he can look down on the point where the bow enters the ice. Keep your headway if possible. Take advantage of open water. Frequently the longest way is the shortest, all factors being considered. Steer toward the point where the dark "water sky" is highest in the heavens, provided, of course, it is not too far from your base course.

Ability to break ice is dependent on (1) degree of surface water between floes, (2) ice thickness, (3) ship's weight, (4) ship's power, (5) thickness of ship's plates, (6) ship's shape, and (7) snow cover of ice.

Remain clear of bergs in heavy pack. Especially avoid passing between two adjacent bergs in heavy pack as the ice you break has no place to go except to clog up the ship's wake. Also, the ice pack resists advance because of side pressure from the bergs.

In ballasting down *Wind* class icebreakers before entering the pack, a drag of about 6 inches is the best trim for a general situation, particularly in ice escort where maneuverability is an all-important factor. The peak tank arrangement of the *Wind* class permits altering the trim in a few minutes.

ANCHORING

During all of the operation in the Antarctic in 1948 there were only about three points at which the *Edisto* stopped that the water was shallow enough to anchor in. This problem was taken care of elsewhere by merely wedging the bow of the ship into the pack at full power until she became stuck and held fast, or by mooring to the ice shelf with regular mooring lines to "dead men" sunk in the ice. The more successful and easier method was lying to with the bow wedged in the ice. This, however, would apply only to the icebreaker class of vessels because others would not be able to force themselves into the ice sufficiently. It was found that the successful mooring to ice depends on weather conditions and wind direction and speed. On an average, the *Edisto*, out of 6 days mooring to ice, had to renew the "dead men" and shift position about every 36 to 48 hours when the ice would break up and start drifting out.

EXPLOSIVES

Icebreakers should carry about two hundred 54-pound wrecking mines with at least six mines on deck, forward, together with the wrecking mine outfit. A rigid ladder lightly constructed, must be secured to the forward bulwarks for instant use. If possible the demolition team should be trained before getting into heavy pack. Mines should be lowered to approximately 6 feet below the lower surface of the floe. One mine is generally sufficient to crack a floe 100 feet across and 30 feet thick. Great care should be exercised in using mines abaft the midships section if the icebreaker carries aircraft, because of damage resulting from falling debris. If such mines are used to liberate the beset vessel or provide swinging space, the aircraft must be covered with a tarpaulin. TNT demolition blocks may be substituted for the wrecking mines but at least six are required to loosen even young ice. In order to place a charge properly, the ship must have an ice drill to place the charge deep enough to be effective. The icebreaker's demolition team should practice blasting as soon as practicable after reaching the pack. The team of the *Northwind* was so trained that it required only 3 minutes and 36 seconds from the time of nosing into the ice until the charge was exploded.

ENGINEERING PROCEDURES

The following engineering notes are based chiefly on the report of U. S. S. *Burton Island*, operating in the Antarctic in 1948:

(*a*) Ice-breaking operations usually call for full power except when in column astern of another icebreaker. Under these conditions four main generators will generally carry the load, with the two remaining generators on 5 minutes' notice and a full steaming watch maintained in the standby generator room. The main engines are started once each 4-hour watch and run until the lubricating oil of the engine is between 120° and 140° F. (The *Northwind* found it necessary to limit shaft speed to 100 revolutions per minute when breaking ice with only four generators on the line to prevent overheating.)

(*b*) While the engines are secured the warm-up system is cut into both main engines and the fresh water is continually circulated at 120° F.

(*c*) When the standby engines are put on 30 minutes' notice they are started once each 12 hours and brought up to temperature.

(*d*) With the insulation and construction of this class of vessel, it was found that a cold engine could be started and warmed up to operating temperature in approximately 20 minutes.

(*e*) There were several periods during the operation when the ship lay to in the ice, either due to poor visibility or during operations ashore. At such times the ship was either wedged between the ice floes or had her bow jammed into the bay ice. The main plant was secured, but put on short notice, the main motor control boards and exciter sets being completely secured. The latter was feasible because the main motor set-ups could be made much faster than the main engines could be made ready.

(*f*) The pitometer log and sound gear are kept secured at all times while working pack or making passage through brash ice. Speed under such conditions may be ascertained by use of radar on bergs lying near the course line.

The U. S. S. *Edisto* offers the following suggestions:

(*a*) Main engines and lubricating oil are kept warmed up during standby operation by the water jacket heaters.

(*b*) All holding down bolts on engine base, shaft bearings, fittings, and attachments are frequently checked for tightness against the heavy shocks and vibration constantly encountered in ice breaking operations.

(*c*) When the maximum 10,000 horsepower is not needed during operations, an engine combination should be selected whereby the engines will be operated at or close to 80 percent of designed horsepower rating. Failure to do this results in inefficient engine-fuel combustion, high-carbon deposits on pistons, stuck piston rings, carbon deposits on exhaust ports, unburned-fuel deposits in exhaust stacks and mufflers, sometimes a serious stack fire, or increased maintenance cost and renewal of engine parts.

CHAPTER XI

CONVOYING IN ICE

An ice convoy consists of one or more ordinary ships, whether or not strengthened for ice navigation, accompanied by one or more icebreakers. Either the icebreakers or the escorted vessels may be naval craft. When naval icebreakers are escorting merchant vessels, most of the problems that accompany ordinary ocean convoy operations will be present in an accentuated degree, although they fall out of the scope of the present discussion.

It is highly desirable that a convoy while in ice be under the direction of the commanding officer of the leading icebreaker. If circumstances require that the senior officer of a naval force be embarked in a vessel without ice-breaking qualities, it is recommended that he delegate tactical control within the ice zone to the icebreaker.

Most of this chapter is based on Russian accounts of ice convoy operations. Beginning 50 years ago in the Baltic, later operating in the White Sea, and finally opening the Northern Sea Route, the Russians have accumulated a large body of experience in operating icebreakers jointly with merchant vessels.

TYPES OF CONVOY

There are three possible types of ice convoy:

(1) Single ship convoy.
(2) Simple convoy: one icebreaker escorting a group of ships.
(3) Composite convoy: two or more icebreakers escorting several ships.

A simple convoy consists of several transports or other vessels and one leading icebreaker. The captain of the leading icebreaker decides upon the number of vessels he can take through. His decision depends on the type of ships which are to follow the icebreaker and the condition of the ice en route. If the ships to be convoyed are reinforced for ice navigation and have sufficiently powerful engines, an icebreaker can take an average of four of them through an ice coverage of 70 to 80 percent. If the condition is favorable, only 50 to 60 percent ice, the number of ships can be increased. If there is close pack with over 80 percent coverage, the number of ships must be limited to one or two. In conducting a large number of ships in such heavy ice, it will be necessary for the icebreaker to keep falling back in order to break the ships out, thus losing more time than if piloting two vessels.

The arrangement of the convoy should be carefully worked out. The varying ice conditions in the areas along the route and the variety of ships forming the convoy must be taken into consideration. The first factor to be considered is the power of the ships. The weakest, as a rule, are placed immediately after the icebreakers, so that they can avoid striking ice obstacles and be able to move in a comparatively clear channel. The most powerful and beamiest ships are so placed in the convoy that less powerful vessels can proceed in their wake. Consideration must also be given to whether a ship is loaded or in ballast. Finally, it is essential that one of the most powerful ships in the convoy be placed in the last position in line.

A composite convoy consists of two or three simple convoys. The number of ships to each icebreaker and their place in column is determined in the same way as for a simple convoy. The difficult of controlling from a position in the front is an important drawback to this type of convoy, which frequently stretches out over a distance of 1½ to 2 miles. The first icebreaker is designated the leader; the others are placed according to orders of the leader's captain, either in column or in line of bearing for breaking out.

The operating procedure is for the most powerful icebreaker to lead the convoy breaking a channel in the ice without stopping to break out other ships. Following the leader at a distance decided upon by the leader's captain are two or three ships, the weakest and beamiest in the entire convoy. The second icebreaker proceeds astern of the first group followed by two or three ships, and so on.

The assignment of the second icebreaker is to break out the ships ahead of her so that the leader will not have to return to them and thus detain the convoy. The second icebreaker, on receiving a signal "Stuck" from any of the preceding ships, increases speed, leaves the column and breaks out the ship. When the latter is freed and moving, the icebreaker resumes her previous position in column. The same

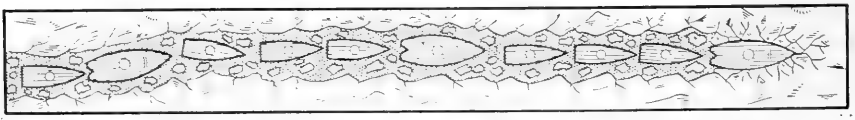

Figure 19.—A composite convoy in column following an icebreaker.

action is taken by the second icebreaker upon hearing the same signal from one of the ships astern, provided there are no more icebreakers in the convoy. If there is a third icebreaker, she breaks out the ships following the second icebreaker. Ships must be broken out while proceeding, in order not to delay the progress of the entire convoy.

When several icebreakers are present in line of bearing for breaking out, they follow behind the leader at a set distance to leeward in such a way as to thin out the ice in the channel made by the leader, and remain always in readiness for breaking out or towing any ship that gets stuck or lags behind.

DISTANCE BETWEEN SHIPS

Prior to entering the ice, the captains of all ships must be carefully briefed as to the order in which they are to follow the icebreaker. They must understand the importance of maintaining the distance between the ships and the icebreakers and between the other ships as ordered by the leader while moving in ice. Accurate station keeping is essential for the safe and speedy progress of the convoy.

If the condition of the ice is not too bad, say less than 70 percent coverage, the ships can follow the icebreaker without much difficulty. The beaminess of the latter makes it especially easy for the ships closest to her, but as the channel closes in farther astern, the ships at the end of the convoy encounter greater difficulties than those in the van. It is, therefore, unwise to have the convoy strung out in too long a line. At the same time, the distance between ships should be great enough for way to be checked and collision averted if a "Stop" signal is given by the icebreaker. As a rule, way can be checked in clear water by going astern over a distance of 3 to 3½ ship lengths, provided a full back bell is given. This distance should therefore be

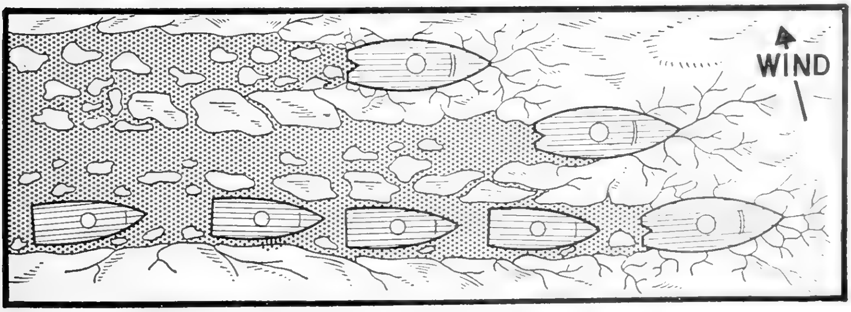

Figure 20.—Line of bearing for breaking-out.

the minimum between ships when navigating in ice with less than 70 percent coverage. At the same time, it should be fully appreciated that if this distance is increased the speed of advance of the whole convoy is reduced.

The channel made by the icebreaker quickly fills with broken pieces of ice. The pressure exerted by this ice on a ship in a narrow channel naturally increases when the distance between ships is increased, and even powerful ships find their speed greatly reduced. This is another argument for maintaining the minimum prescribed distance apart. A sharp lookout must be kept for signals from the leading icebreaker and these must be executed promptly and correctly. The ships ahead and astern, as well as the condition of the ice, must be carefully watched.

When navigating in thicker ice, the distances suggested above must be decreased. In order to avoid damage from the ice floating in the channel, the engines must work slowly and the ship must carry little headway. If the ice is completely unbroken and under considerable pressure, the distance must be reduced to a few yards. Under these conditions the channel will be quickly covered with ice, leaving only a small lead astern of the icebreaker, narrower than the beam of the vessel. If a ship should follow at a distance of 2 to 3 ship lengths

Figure 21.—Wake left by U. S. C. G. C. *Northwind* after making her way through the ice. Note consistency of the ice left in the channel and the tendency for the channel to fill up after passage of the icebreaker.

from the icebreaker, the influence of the icebreaker would hardly be noticed. The vessel would therefore either stop or be stuck in the ice.

Piloting a ship in convoy at reduced distances requires a certain amount of experience on the part of both the icebreaker's company and the personnel of the other vessels. It often happens that in heavy ice, there are obstacles which the icebreaker cannot overcome on the run. She may suddenly stop and give the signal "Full Astern" to the following ships. In order to avoid collision, the ships must go astern immediately. When moving in such close formation, the thickness of the ice ahead must be carefully observed by the icebreaker so that probable fluctuations in speed can be anticipated, and the necessary warning passed to the ships astern in plenty of time. The danger resulting from a sudden stop on the part of the icebreaker is obvious. The importance of maintaining the correct distance applicable to the ice conditions is therefore clear. This distance should never be greater than 3 to 3½ ship lengths, and is usually a matter of only a few yards. To assist the conning officer in keeping the ship in position, it is advisable to establish a "stadimeter watch" who can furnish readings as frequently as may be required. The spacing must be changed with the varying condition of the ice, and great stress must be laid on accurate station keeping. When navigating in ice, disregard of these rules can result in very serious consequences.

By virtue both of his experience and of his position in the convoy, which enable him to assess as well as sample the ice conditions ahead, the captain of the leading icebreaker must estimate the correct distances apart to be maintained by the ships. He must signal any changes required due to altered ice conditions, etc. It is absolutely necessary that the officers of the piloted ships should be thoroughly acquainted with all the signals used for convoying in ice. It should never be necessary for the icebreaker to repeat a signal due to slowness of execution.

COURSE AND SPEED OF CONVOY

Before entering the ice, captains of the icebreakers and masters of the piloted ships must clearly visualize the conditions of the ice in the various sectors along the prospective route, consulting (if possible) ice charts based on air reconnaissance observations and statistics of winds and currents in these sectors. The track to be maintained is decided upon by the operating staff or captain of the leading icebreaker, as the case may be, after a careful study of the ice charts and the synoptic forecasts, as well as the coastal topography, depths along the route, areas of permanent ice pressure, etc. The longest route in open water is generally shorter than the more direct one in ice, and the selected track should pass through areas of thin ice or open water, regardless of the length of the voyage, provided the depths along the route are adequate. Consideration must also be given to the assistance which may be forthcoming from the prevailing wind and current. In some areas, even in heavy ice, such help is pronounced. Course changes must be gradual, if practicable, since most cases of ships getting stuck occur when sharp turns are made by the icebreaker. The speed of the convoy must be decided upon by the captain of the leading icebreaker. Speed through the pack varies from 4 to 7 knots. The higher speed is desirable due to the better maneuverability of large ships, but the ice conditions will govern.

In a convoy composed of vessels reinforced for ice navigation, a speed of 6 to 7 knots can be maintained if the route lies through open pack of about 50 percent coverage with leads of clear water and if the captain of the leading icebreaker is certain that the ships following him will not meet with heavy ice. It must be remembered that frequently the ice on the surface thaws under the sun's rays and is washed away, whereas the submerged part lasts much longer, thus forming underwater projections of ice protruding for several yards. Ships following the icebreaker must be aware of the danger of passing close to large floes. If a vessel cannot keep off the ice, it should request the icebreaker to widen the channel.

When navigating in close pack of 70 to 80 percent ice coverage, speed must not exceed 5 knots. In such ice, the convoy follows the channel, which does not remain open long after the passage of the icebreaker. Therefore, the spacing must be decreased to 1½ to 2 ship lengths to enable the ship to move in as clear a channel as possible. Higher speeds not only increase the danger of hitting the ice but also the possibility of colliding during sudden stops of the icebreaker or other ships in the convoy. In the channel itself, danger from underwater ice projections decreases somewhat as these are destroyed by the icebreaker, although this hazard reappears on entry into areas of thin ice. If a single-screw vessel must back down suddenly "full astern" without warning while passing through an ice-covered channel, the stern will kick to port and the bow to starboard. Such action will probably cause damage to the propeller, rudder, and starboard side of the ship. To avoid collision with the ship ahead, it is preferable to ram the ice to one side of the channel, bow foremost, rather than to risk damage to the rudder and propeller by backing down on heavy ice.

CONDUCTING THROUGH ICE

In following the icebreaker, a convoy must keep dead astern of her. If the icebreaker alters course, all ships must turn in succession to the new course. By looking for independent channels, the ships break up the convoy and may get stuck. Thus, the icebreaker is compelled to return and break out each ship separately, thereby delaying the whole convoy.

Since passage through floes and ice fields is more difficult, the icebreaker increases her speed, and by striking the ice, crushes or breaks it ahead of her. The ships astern must then watch their distances carefully and try to enter the channel made by the icebreaker before it closes again.

If the icebreaker should encounter a solid ice obstacle where a glancing blow is struck by the stem, she will be thrown backwards and sideways in the direction of least resistance. The ships following close astern will be unable to make a quick enough turn and may receive damage through striking the heavy ice. This is particularly true of single-screw ships. This sudden change of direction or zigzagging must be expected when proceeding through ice of varying structures and strength. Under such circumstances, the icebreaker should not make too rapid a return to the original course and should avoid aggravating the zigzag.

Young ice is often covered with snow and, at first, all young ice seems exactly the same. However, an experienced eye can sometimes detect obstacles such as snowdrifts which probably indicate the presence of concealed hummocks. Such ice will be more difficult to overcome, not only for the icebreaker, but for the entire convoy. Though the ice is seemingly even, the route must be chosen so as to avoid this hummocky ice. The absence of hummocks and unevenness, in general, is the only sign of passable ice in winter.

When it is necessary to pass through ranges of hummocky ice which cannot be outflanked, the hummocks must be crushed in a direction at right angles to their crests. If, however, the hummocks have cracks at an angle to the general line of the crests, the cracks should be followed. It is much easier to maintain the course in close pack consisting of small blocks than in a floe or ice field.

In summer there are many signs indicating the passability of the ice. Observe whether the ice has been softened by the sun, or if it still retains its winter hardness, and the number of hummocks en route. Experienced icebreaker captains and ice pilots consider that greenish or greenish-blue ice is the hardest to crush. Such ice should be outflanked. This type of ice is sometimes covered with pools of clear water formed during the thaw of snow on the surface of the ice. There are also oval holes caused by the water trickling down the ice after the snow has thawed. If there is a considerable number of these holes on a field of greenish-blue ice, the field will be weakened and the ice can be forced. It will not be necessary to break the entire field, but only the portions separating the holes. The condition as well as the color of the ice must be considered, and an occasional test at slow speed by the icebreaker is well worthwhile. If sections of dirty looking ice occur in areas of light colored ice, the former should provide the easier route, since the darker object absorbs more sun and melts sooner. Even heavy blocks of dark ice are found to be spongy inside and much less compact than the surrounding ice. On impact by the icebreaker's bow, such ice will crack in spite of its thickness.

The most passable ice is considered to be brash, even though it is completely devoid of leads. Although this ice usually closes up as a result of action of tides and winds, it consists of separate cakes and therefore does not present a serious obstacle for the passage of the icebreaker or the conducted ships. When the pressure is great, however, even though an icebreaker can get through, the ships astern are usually hindered as the channel behind the icebreaker closes up immediately. It must be remembered that in brash, even during pressure, ships are in less danger than if they were being pressed by larger and heavier forms of ice.

When many hummocks are encountered, the icebreaker must first attempt to outflank them. The outward characteristics of the hummocky ice indicate to what extent it is navigable. If the hummocks consist of loose blocks not fused together into one solid piece, they are easily destroyed; but if they are composed of larger masses of ice many feet thick, they are impassable even to an icebreaker.

For ice navigation the axiom that "the straight line is the shortest distance between two points" is not necessarily true. Ships must often be taken along tracks unrelated to their general course; for example, a section of difficult or impassable ice may be dead ahead, while at the same time ice and synoptic charts, plus the information of the ice reconnaissance, show that better conditions are found either to port or starboard of the course. It is clear that in such a case it is necessary to deviate until the section of easier ice is reached, and then afterwards return to the original course. Sometimes, cracks and narrow leads at right angles to the course of the convoy are encountered. If the ice belts between the leads are very heavy and wide, it is better to follow the crack and seek easier ones than to attempt to break the heavy ice and proceed directly into the next lead. While the convoy is often led on a directly opposite course, going from lead to lead, it should proceed in the required general direction.

In zones of close pack, there are places where an icebreaker cannot penetrate. The great amount of friction created by the ice against the icebreaker's sides may hinder her advance causing her to stop. The power of the engines in these cases is insufficient and the ship gradually loses way. Such ice can be broken only by backing and ramming.

From the thickness and compactness of the ice, the captain of the icebreaker determines the distance from which he must start the icebreaker in order to attain sufficient momentum required for the initial blow. The momentum must be added to the power of the engines, since they alone cannot overcome the obstacle. Usually an icebreaker backs up a distance of from 1 to 3 ship lengths, then goes full speed ahead until her stem is pushed into the ice. It must be remembered that the ice must be struck only by the stem and not by the turn of the bow; in the latter case, the ship's hull might be damaged. If the obstruction is strong and extends over a great distance, the blow must be repeated for many hours in succession.

If the ice has not been broken after one blow, the icebreaker upon losing its momentum stops. As soon as the icebreaker slackens speed, the engines should immediately be reversed to full speed astern. If this moment is lost and the icebreaker stops in the ice while the engines are going full speed ahead, the ship will invariably wedge in and time may be lost in releasing her. When the engines are going astern, the rudder must be amidships. Once clear, the icebreaker backs the required distance and repeats the blow. It may be necessary to make either a simple channel, equal to the width of the beam of the icebreaker, or a double or triple one, depending on the strength and character of the ice. After making a channel, the icebreaker returns to the ships, and if the channel remains open, the icebreaker will be able to lead two or three ships at a time. If there is much ice in the channel and several ships cannot pass unescorted, the ships are taken through the ice one by one.

If the condition of the ice gets worse en route, and a convoy of three or four ships becomes too large, the assistance afforded by the icebreaker will be lost on the rearmost ships, which will have to be broken out continually. If, in such circumstances, a radical and rapid change in the condition of the weather or ice is expected, it is better to wait for an improvement and then proceed with the whole convoy. If, however, such a change is not anticipated, the ships must be conducted ahead one by one, eventually resulting in the speedier advance of all the ships. In this case precautions must be taken to prevent the ships left behind from being damaged by the ice. A more or less homogeneous mass of slush pressing against the ship creates a kind of cushion, with equal pressure along the ship's entire length. If the ship is near a heavy floe or an ice field, the pressure developed may result in serious damage or perhaps loss of the ship. Heavy ice under pressure creates a strain at certain points or over certain sections of the hull. Forced by the closing ice, large blocks of ice in the channel may be crushed against the hull, denting or even penetrating the ship's side. Under these circumstances, the icebreaker must make a few trips around the ships so as to break the large pieces. Then it can take the ships on one by one without fear that those left behind will be damaged or crushed.

The most difficult work for an icebreaker is to conduct ships in motionless young ice with no leads or cracks. Broken ice remains in the channel with the exception of a small amount which goes under its edge. If the channel is to be of considerable length, this brash not only hinders the convoyed ships but also makes the progress of the icebreakers more difficult. If small hummocks are encountered, the icebreaker often becomes wedged in. To avoid wedging and to facilitate the movement of the ships, it is necessary to break a channel considerably wider than the beam of the icebreaker. Under such circumstances, the width of the channel must be sufficient for an ice breaker to turn, 100 to 150 yards. To achieve this, a double or triple channel is broken. The double channel is made by the "herringbone" method.

To break a channel by this method, the icebreaker first strikes the ice at a small angle to port, then backs up and strikes again at an

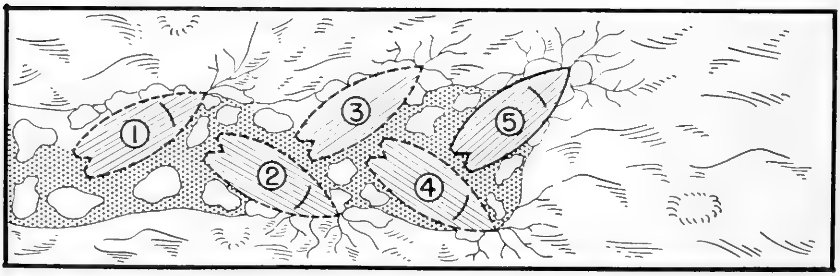

Figure 22.—Herringbone method of breaking ice.

angle to starboard of the course, and so on, alternating the direction of the blows. Breaking the ice in this way leaves the greater part of the icebreaker free, since only the stem hits the ice. The hull from amidships to the stern is in clear water, thus preventing it from being wedged in. If a double channel is too narrow, a triple one is made. The same method, though a bit more complicated, is used.

One blow is made to port, but at a greater angle than for a double channel. The second blow to starboard is also at a greater angle. The third blow is directed against the tongue of ice which protrudes in the middle. In this way the triple channel is broken. The time taken to break a channel in young ice about 4 feet thick is considerable, and it has required 40 working hours, on occasion, to break a 7-mile channel in such ice.

While navigating in heavy ice, there is danger of damaging not only the escorted vessels but the icebreakers as well, though they are well equipped for fighting ice. In the forward part of the ship the most vulnerable place is the curved plating of the bow. This may be damaged by striking the ice if the blow is not taken on the stem. The draft of the vessel is also of great importance, since the plating at the water line is usually strongest. Vessels should therefore be so loaded and trimmed that only this strongest plating will be in contact with the ice. In the after part it is the propeller that is exposed to danger. In fact, while in ice it is the most vulnerable part of the ship. It is often assumed that blades are damaged only when a vessel is going astern. This, however, is not always true. The blades can be damaged or lost while going ahead as well. Sometimes large blocks of ice pass under the ship's hull and turn on edge. Such ice is very dangerous and may damage the propeller. If the captain or watch officer observes a heavy block of ice on edge, close

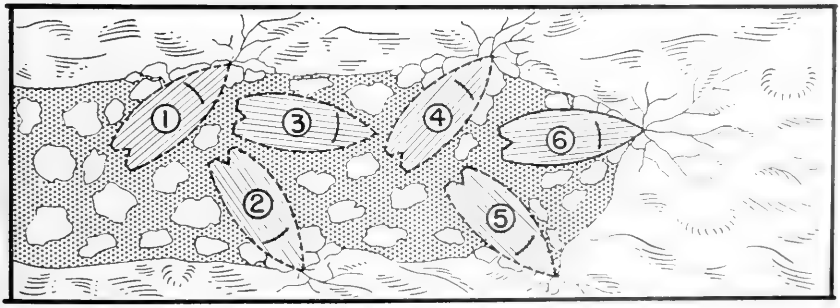

Figure 23.—Modified herringbone method of breaking a wide lane.

aboard one side of the ship, he should immediately take precautionary measures.

Explosives are used as an auxiliary means for getting the ice breaker through difficult obstacles. The heretofore accepted opinion that channels of various lengths could be made by using explosives has been proved to be impractical. Nevertheless, an ample supply of dynamite or demolition mines should always be carried by the icebreaker to destroy ice belts separating one lead from another which cannot otherwise be forced by the icebreaker. Before a charge is placed, the ice must be examined for a spot which would offer the least resistance. The explosion creates cracks in the main part of the ice belt and weakens the ice sufficiently to facilitate breaking by the icebreaker.

When forcing heavy fields, the icebreaker sometimes encounters pressure ridges stretching a great distance. Explosives can also be of help in such cases. The ridge must be examined before placing the charge so that the maximum effect is obtained from the explosion. From the experience of the icebreaker *Krassin*, the best location for placing explosives is abeam of the forward stack of the icebreaker at a distance dependent on the weight of the charge. The charge is placed in a deep hole almost at the lower edge of the ice. At the time of the explosion the icebreaker should be going full astern on both engines. The concussion of the explosion plus the work of the engines free the icebreaker and enable her to run astern. Even if cracks fail to appear, the ice between the hummocks will nevertheless be weakened. Mines are usually used to liberate the vessel when beset or to provide swinging room. To follow up the advantage after the explosion, the icebreaker must immediately go forward into the ice. If the ice is motionless, results usually are good. If the ice is under pressure, all the above measures might fail. In such cases it is necessary to wait until the pressure of the ice diminishes and start anew.

TOWING IN ICE

When piloting vessels in close pack of medium thickness, it is sometimes necessary to take them in tow on account of ice pressure, engine trouble, or propeller or rudder damage. All icebreakers are provided with necessary towing equipment. The latter consists of a tow winch and towline reeled on the winch drum; the end of the towline is provided with a large strap which is led through a specially constructed block at the stern indentation. The towing drum should be located as far forward as possible in order that the vertical angle of tow be minimized. In other words, the icebreaker should have a long fantail so as to permit snubbing of standard-type vessels into the crotch of its stern.

A 2¼-inch plow-steel wire bridle and a towline swivel are recommended equipment for all ships. Towing arrangements must be in full readiness before the convoy sails. Just before entering the ice, the ship's anchors must be secured on deck to prevent them from striking the ice while passing hummocks and thereby damaging the hawsepipes, as well as to enable the ship to take the towlines from the icebreaker through the hawsepipes at any time. It is not necessary, however, for a vessel with a high bow and considerable freeboard to cat her anchors; it is sufficient for such a vessel to rig a towing bridle forward with a shackle of size to mate with the towing cable of the icebreaker. Although a bridle should be used for towing in pack ice, the towing hawser should be shackled to the anchor chain for towing in the open sea.

The ship's personnel must know how to take aboard a heavy towline as quickly as possible and to secure it so that it can be slipped with minimum delay, when so signaled by the icebreaker. Wire rope messengers must be led through the hawsepipes in advance, to which the straps of the icebreaker's towlines are to be secured. The wire-rope messengers are then brought to the winch and the straps of the towlines hauled up on deck and secured. Figure 24 shows two methods of securing the towlines in the towed ship. One is to pass a manila line through the two straps, the two towlines being thus secured on deck by several turns of manila. When ordered to slip the tow, the turns are cut and the two straps released. The disadvantage of this method is the rapidity with which the manila rope wears out, resulting in the parting of the tow. Therefore, when towing in very heavy ice where jerking is unavoidable, the best method is to secure the straps to a wooden beam. When the straps are brought up on deck through the hawsepipes, the timber is passed through both eyes. To cast off, the straps are eased up, the beam is pushed out of the eyes, and the towline is cast off. If soft wood is used for securing, the wood is scored during the stretching of the towline and the towline eats into it. In such a case, when casting off it is necessary to cut the wood until the ends are free.

A large slip can be used for joining the eyes of the two towlines, but if incorrectly secured it may get twisted and deformed, making a quick release difficult. There are other methods of securing towlines, but on no account must the tow straps be made fast to the bitts. The

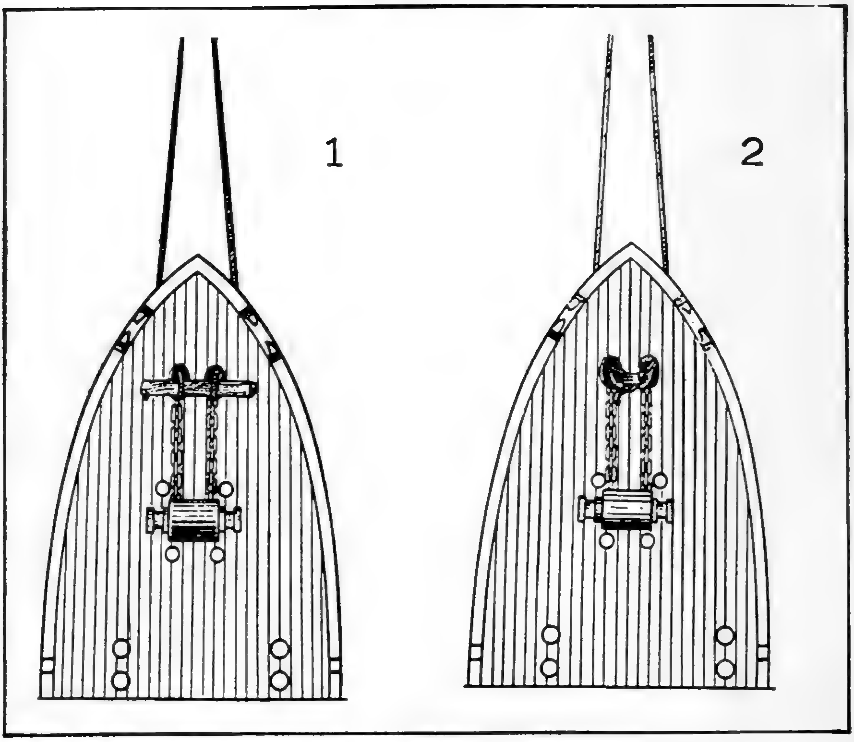

Figure 24.—Methods of making fast the towlines when towing in ice.

latter will invariably break, as they are not strong enough to take the great strain necessary when towing a vessel through ice.

In drift ice or open pack, a ship is towed by the icebreaker using a long towline. In this case, the entire towline is paid out with the exception of a few turns. Such towing is used when a ship has been damaged and cannot proceed under her own power.

When navigating in close pack, with moderate pressure, a short tow is used if the piloted ship cannot make headway unassisted. In this case the towline is eased off to 35 to 50 feet and the vessel will advance in the icebreaker's wake, where the propeller wash prevents the ice from closing up immediately. If the icebreaker slows down, the towed ship, which is being held back by compact ice, has enough time to go astern, provided the signals for reducing speed and going astern are given by the icebreaker in sufficient time. If the icebreaker stops unexpectedly when using the short tow, collision and damage are almost inevitable. Therefore, the captain of the towed vessel must be fully aware of, and prepared for, such an eventuality. Icebreakers with a stern indentation use this method of towing only in exceptional circumstances, and when the shape of the piloted ship's stem is not adapted for close towing. If collision between the icebreaker and the tow is unavoidable, the former should go full ahead on her engines so that her wash will throw the towed vessel's bow to one side and make the blow a glancing one instead of a direct bow to stern collision. This action is recommended in all cases (even when not towing) when the ship astern creeps up on the icebreaker.

When the ice pressure is great, the channel closes up immediately astern of the icebreaker. In such circumstances, it is necessary to tow the ship close under the icebreaker's stern. To do this, the stem of the towed vessel is secured as close as possible to the indentation at the icebreaker's stern by means of the towline. The winch, backed by additional stoppers, is secured so that the tow cannot ease off. The icebreaker and the tow move as one unit. Advance is possible in the heaviest ice, as long as the icebreaker can use her engines. The control of the icebreaker is, however, more difficult as the towed vessel tends to act as an uncontrollable rudder. When the icebreaker stops, it is almost impossible to go astern, as the towed vessel's rudder will be endangered.

BREAKING OUT SHIPS

If a ship fails to make headway in the ice, she must signal without delay, "I am stuck in the ice." Upon receiving the signal, and if conditions permit, the icebreaker signals the other ships to proceed on the course without her. Then she returns to, and breaks out, the icebound ship.

Ships are broken out of the ice in various ways, the method depending on the condition of the ice. If the ship is stuck in comparatively thin ice, the icebreaker, to save time, goes astern without turning, keeping her bow on the original course, and passes the ship close to one side. After coming alongside, the icebreaker backs as far as the stern and then goes ahead, simultaneously signaling the ship to follow. If this maneuver is performed at a distance of from 5 to 10 yards from the ship's side, the vessel as a rule can follow the channel as the ice astern of the icebreaker is considerably thinned out.

The direction of the wind must be carefully noted, and for breaking out, the lee side is chosen. If the icebreaker approaches to windward, the ship is blown towards the unbroken ice, and even after being broken out will be unable to move. When the icebreaker comes up on the lee side, a certain weakening is observed even in heavy ice, and the ship is pushed by the wind in that direction. The friction of the ice on the sides becomes less, and by using her engines the ship can follow the icebreaker. During calm or light winds, and with head winds

Figure 25.—U. S. C. G. C. *Eastwind* employing tactics of backing down on the bow of the U. S. S. *Wyandot* to break her out of ice.

or winds from aft, the ship must be broken out from the side on which there are fewer ice obstacles.

The above applies when the icebreaker breaks out a ship with her stern. In heavy ice conditions this method is not practical since when going astern the ice is piled up under the counter and fouls the propellers. This condition may cause the engines, which are turning at full speed, to stop suddenly. The same happens when a propeller gets caught against a chunk of ice, which in turn presses on other chunks of ice. Since the propeller is unable to overcome this obstacle, a broken blade or loss of the entire propeller may result. Going astern in heavy ice may also disable the icebreaker's rudder. Therefore, the above method of breaking out ships should be employed only when there is no danger of damage to the propeller and rudder, or when there is no other solution.

Another method of breaking out a stuck vessel is to approach on the windward side, with the target angle of approach varying according to the heaviness of the ice. Generally this will be about 155° or 205° (135° or 225° if the ice is heavy). The icebreaker's stern should be swung so that it is as close as possible to the stem of the other vessel and directly ahead thereof when the movement is completed. Between the icebreaker's stern and the beset vessel's stem there will inevitably be a floe fragment, which may be cracked by backing down on it. As soon as backing is commenced, the beset vessel should be instructed to go ahead with all possible speed consistent with safety. This will keep her bow into the propeller wash as the icebreaker's engines are turned ahead after the floe is cracked. It is advisable for the escorting icebreaker to have a pudding over the sheer of her stem since she may frequently be called upon to push the bow of the escort around. In this event it may be necessary to break the ice on the quarter toward which her stern will swing to minimize possibility of damage to rudder and propellers.

Ships can also be broken out by the icebreaker making complete bow turns. This takes a great deal of time as the icebreaker first turns toward the ship and then makes another turn astern of the ship. On making the turn toward the ship, the icebreaker approaches her on the lee side and passes along her close aboard. Astern of the ship the icebreaker turns again to the original course. Moving ahead the second time along the ship's side, thinning out the ice, she at the same time signals the ship to follow. The heavier the ice, the more time is required by this method, but in exceptionally heavy ice this is the only suitable way of freeing vessels. Objection is sometimes made to the bow turn method because it piles ice about the rudder and screw of the beset vessel.

Sometimes a vessel gets stuck in a floe of such heavy ice that the icebreaker cannot reach her. In such cases, before releasing the ship, the icebreaker is compelled to force the entire floe on one side or the other. By thus thinning the ice and by forcing it, the icebreaker eventually breaks out the ship and enables her to proceed. Often when such a floe is freed, there is a great separate grinding movement called screwing. Screwing pack should be avoided at all costs, because a ship caught in it may receive damage to her hull before the icebreaker can break her out.

It is sometimes necessary to break the ice around the same ship several times before she is freed. This situation usually occurs during ice pressure, or when the ship's engines are very low-powered. The above are the principal methods of breaking out single ships. However, it should be remembered that the other ships, left without assistance, are usually blocked by the ice and unable to proceed on their own.

When the ships are in column, the icebreaker can sometimes pass the entire convoy on the lee side along its course at the greatest possible speed, breaking it out entirely. The ships can then proceed along the channel broken by the icebreaker.

Usually if one vessel in the convoy gets stuck, they all get stuck. Also, it is not always possible for the vessels in a convoy to maneuver into parallel tracks. Therefore, it is necessary for the icebreaker to maneuver ahead of each ship, back down on the vessel's bow, then run toward the stern of the next vessel, swerving out in time to parallel her, and then repeat the process. This procedure requires rapid handling of the icebreaker because each vessel, as soon as the ice is cleared ahead of her, must start moving. By the time the icebreaker reaches her station ahead of the column, the entire convoy is in motion.

While the icebreaker is breaking out a ship, the ice often cracks toward the ship's sides. If the icebreaker passes her at a great speed the icebreaker's bow will turn along the crack toward the ship. This danger should be carefully guarded against, otherwise collision with resulting damage is probable.

In general, when passing close to a ship, the icebreaker must make an estimate of the character of the ice between it and the ship. If there is weak ice close to the ship, the icebreaker may be thrown against the ship. Likewise, when breaking a ship out, the strength of her hull must also be taken into consideration, since the icebreaker presses the ice against the ship's sides with great force while passing close aboard her. The speed of the icebreaker must therefore be regulated with great care.

CONVOY SIGNALS

Some system of signals must be agreed upon in ice convoy work. The following one-letter whistle signals have been arbitrarily chosen and are actually being used by the U. S. S. R.:

Signal	Made by leading icebreaker	Made by conducted vessel
G (— — .)	Am going ahead, follow me	Am going ahead, follow the icebreaker.
N (— .)	Reduce your speed	Am reducing my speed.
S (. . .)	Go full speed astern	Am going full speed astern.
M (— —)	Do not follow me, stop where you are.	Am stopping where I am.
5 (. . . . .)	Stuck in the ice, attention	Stuck in the ice, attention.
K (— . —)	Prepare to take tow line	Am prepared to take towline.
	If the vessel is already in tow	
	Cast off the tow line	The tow line is cast off.
C (— . — .)	Go ahead, follow the channel	I am going ahead, following the channel.
J (. — — —)	Shorten the interval	I am shortening the interval.
O (— — —)	Proceed on your voyage	I am proceeding to my destination.
R (. — .)	Pay attention to the radio, or, listen to the radio.	I am paying attention to the radio, or, I am listening to the radio.
X (— . . —)	Attention; look out for the signal.	Attention; I am looking out for the signal.
P (. — — .)	Anchor	I am anchoring.
0 (— — — — —)	Work stopped until morning or until more favorable circumstances.	
	If made while work is stopped signifies	
	Get ready	I am getting ready.

The signals (siren or steam whistle) used when vessels are scattered in the ice are the same as in Rules for Preventing Collisions at Sea.

One short blast	"Am going to starboard."
Two short blasts	"Am going to port."
Three short blasts	"The engines are going astern."

Between ships using air-driven sirens rather than steam whistles, the effectiveness of these signals is largely lost since there is no visual portion of the signal. In this case, they can be simultaneously supplemented by hoisting the corresponding International Code flag, or the cone, ball, and drum distant signals of the old International Code. A voice radio reserved for such traffic might prove more satisfactory, while ships close aboard can use loud speakers to advantage.

CHAPTER XII

NAVIGATING IN POLAR REGIONS

The art of piloting and navigating in the polar regions has generally been considered to present numerous difficult problems. Actually, apart from the special hazards offered by growlers and bergs during periods of low visibility and fog, the basic problems remain essentially the same as those encountered when operating over extended periods in lower latitudes.

SIGNS OF PROXIMITY OF ICE

When passing through open water where no ice is visible, it is sometimes possible to detect the presence of ice in the neighborhood by certain signs, as follows:

1. The receipt of a return signal (pip or echo) by a vessel employing radar or sonar will usually give positive indication of the proximity of large icebergs.
2. Iceblink, the reflection of ice on the lower clouds, is the indication that has been most used by experienced pilots. As mentioned previously, the albedo of sea ice or a snow surface is much higher than that of a water surface. Much more sunlight is therefore reflected upwards from snow or ice and diffused by haze, dust, or water particles in the lower atmosphere. Iceblink thus appears as a diffuse white patch, more or less bright, on visible clouds, or as brilliant scintillating strips on the horizon. There is no iceblink on a sunny day with a clear blue sky. Slight snow flurries cause a more definite iceblink.
3. The appearance of isolated fragments of ice often points to the proximity of larger quantities of ice.
4. In late spring and summer, fog often indicates the edge of the ice.
5. In fog, white patches indicate the presence of ice at a short distance.
6. Icebergs cracking, or pieces falling into the sea, make a noise like breakers or distant gunfire. However, the sound is faint and one must usually be quite close to the berg to hear it.

7. Absence of swell or motion of the water in a fresh breeze is a good sign of ice to windward, if the vessel is not in the vicinity of land.

8. Lowering of the temperature of the surface layer of sea water, or the lowering of the air temperature, may indicate that the ship has entered waters where ice is likely to be encountered. The converse does not apply; nor should maintenance of sea and air temperatures be taken to mean that no ice is about.

9. The presence of walruses, seals, or birds may indicate the proximity of the ice, if far from land. The Antarctic petrel is normally seen only within about 400 miles of the ice edge. The appearance of the snow petrel is an almost certain indication that pack ice is within a few hours' steaming.

SIGNS OF OPEN WATER

1. Dark patches on low clouds, sometimes almost black in comparison with the clouds in general, indicate the presence below them of open water. This is known as water sky. Like iceblink, this phenomenon depends on the greater absorption of sunlight by water than by ice or snow, and the subsequent diffusion of the reflected light in the lower atmosphere. When the air is very clear, it tends to be suppressed.

2. Dark spots in fog give a similar indication, but are not visible for as great distances as reflections on clouds.

3. A dark band on a cloud at a high altitude indicates the existence below this line of small patches of open water which may connect with a larger distant area of open water.

4. The sound of a surge in the ice indicates the presence of large expanses of open water in the immediate vicinity.

The best weather conditions for navigating in the ice are fine days with a clear horizon and atmosphere, but with the sky covered with an even layer of clouds. Then, as stated previously, the iceblink appears in light markings on the under surface of the clouds above it. Where leads of open water occur in the pack, the iceblink is sharply broken, with water sky appearing almost black by contrast.

If when approaching ice there is darkness on the horizon beyond a light sky, it indicates that there is open water or land beyond the ice, in some cases 40 miles or more beyond the visible horizon. If thin, dark streaks on the sky are observed, the existence of leads is indicated. If there are no dark streaks, a vessel should steer for the place where the iceblink is dullest. The clarity of the blink is increased after a fresh fall of snow, since the reflection on the sky will be whiter from snow than from ice. With a cloudless sky there can be no iceblink, though there may be a yellow or white haze or glare to indicate the presence of ice. However, with a cloudless sky there may be abnormal refraction, which raises the horizon and enables the observer to see the ice at a greater distance than would normally be possible. The image of the ice or areas of open water, or a mixture of the two, may be seen as an erect or inverted image, or both images may be seen at once, one above the other. In this case the erect image is the higher of the two, which are usually in contact. Allowance must be made for the fact that refraction causes the apparent dimensions of ice to increase, sometimes so as to make bergy bits appear like icebergs. Where there is open water there will be seen a dark blue color, toward which the vessel should steer.

ABNORMAL REFRACTION

Deceptions of vision at sea are produced by abnormal refraction of light which in the more extreme cases gives rise to false images of land, ships, or other objects. Generally speaking, abnormal refraction at sea is due to an inversion of temperature in a layer of air, the variations in density thus produced causing the light rays to be bent considerably in excess of normal conditions.

The most frequent and most favorable conditions for excess refraction, under which most of the more fantastic forms of mirage and distortion take place, occurs when a layer of warm air is in contact with cooler water. The air next to the surface of the sea is cooled, and consequently the upper layers are warmer than the lower so that instead of the usual decrease there is an increase of temperature with height. Most refraction phenomena are formed at the boundary between this cold, dense layer of air at the surface of the sea and the less dense warm air above. This condition is identical with that which is responsible for the formation of most sea fog; therefore, the presence of fog is an indication that excessive refraction is likely to be encountered.

Similar inversions may be caused by the presence of cold air over warm water. A marked difference between air and sea temperatures is therefore another guide to the presence of excessive refraction.

Although abnormal refraction is not restricted to particular geographical areas, certain regions of the globe are so situated with respect to general meteorological conditions as to be more favorable than others for the occurrence of abnormal refraction phenomena. The polar coasts are among the most favorable of these regions because of the frequently prevalent marked difference between sea and air temperatures. In polar regions excessive visibility or some form of mirage is often manifest when comparatively warm and light winds blow over the cold ice surfaces or when cold winds blow over open water. A milder temperature over open water than over the ice-clad adjacent shore also leads to refraction phenomena.

In the polar regions the most common forms of abnormal refraction are *looming* and *superior mirage.* Looming is the apparent raising of an object above the horizon. It is quite common at sea, especially in high and middle latitudes, and results in the appearance of distant objects which in many instances may actually be below the normal horizon at the time of observation. There are two types of looming. In one case, the object (island, iceberg, ship) is seemingly increased in elevation though not in size; in the other case, the object appears to be enlarged and brought much nearer to the point of observation.

The atmospheric condition that produces looming is one in which there is an abnormal decrease in the density of the air from the surface upward and hence a greater than normal downward curvature of the paths of light rays. The more rapidly the density decreases with elevation, the more unnatural and impressive becomes the phenomenon. If the rate of this decrease is variable at low elevation, the shape of the looming object is distorted, and strange bulging, thinning, flattening, or pointing may occur. Thus, a distant rounded peak might loom in its natural shape, appear with perfectly flat summit, or with a misshapen summit drawn much nearer the observer than the base. Likewise, the appearance from the masthead may be different from that at deck level.

Superior mirage is the apparent reflection from a more or less mirror-like atmospheric condition where there is a pronounced temperature inversion at a distance of several feet above the surface. This inversion introduces an abnormal change in density, and extraordinary refraction results. Its most frequent appearance is that of an inverted image above the object, but under suitable conditions a second mirage is seen erect, close above the inverted one. Sometimes the object is not observed directly and the inverted image or the upper erect image of an object below the horizon may be seen.

The formation of superior mirage is illustrated in figure 26. It is best and most frequent in Arctic and Antarctic regions but it may be observed down to middle latitudes. As with looming, the condition requisite for its formation is a warm layer of air existing over the sea at a suitable height; that is, an inversion of temperature. The only difference between this and the condition necessary for looming is that for superior mirage there must be a more sudden change from cooler to warmer air at a certain height.

The observer on a ship near land usually sees mirage as an unnatural image of the coastline, single, double, or triple, or as an appearance of the coast much nearer to him or farther from him than it actually is.

At sea, ships and icebergs are the mirage subjects more generally seen. Ocean fog is also associated with mirage since the temperature and humidity variations which favor condensation of moisture as fog in the air are often factors in causing mirage. An attendant mirage is, of course, not observable while dense fog actually obstructs the vision, but mock fog or the typical refraction band is often seen under such conditions and may lead to the recording of damp, or true, fog which does not exist.

The not uncommon phenomenon of mirage has been responsible for many false estimates of remoteness of newly discovered land features which have been seen by explorers within the polar regions, combined as it has been with the underestimates of distance due to the unusual clarity of the atmosphere. In many cases of snow-covered lands, there is not enough individual character in the coastal features to permit identification from different ship positions, and in such cases coasts have frequently been placed upon charts on the basis of the direction and estimated distance from positions offshore. These estimated distances are often as much as 40 to 50 miles too low because of atmospheric clarity alone, and can be as much as 300 miles too low as a result of the existence of a superior mirage.

As already indicated, abnormal refraction can be recognized only by its effect on the appearance of land, or such objects as ships, or icebergs. Temperature inversions may also give rise to abnormal dip of the horizon, which may seriously affect the accuracy of sextant observa-

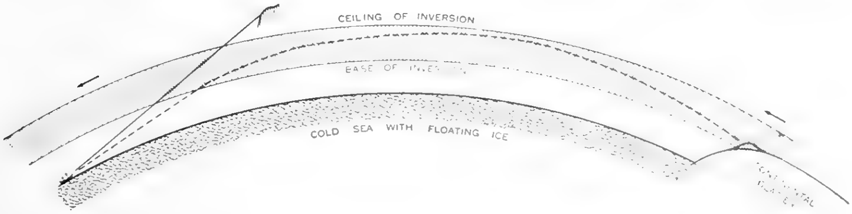

Figure 26.—Diagram illustrating the conditions under which superior mirages may be formed off large ice masses. The inversion layer has been warmed adiabatically in descending the glacier surface. The dust-free nature of the air leads to great underestimation of the distance of the coast.

tions. The navigator should therefore always be on guard against such a possibility whenever there is a chance that a temperature inversion may exist. If the motion of the ship permits use of a bubble sextant, it can be quickly determined whether the apparent horizon is appreciably displaced.

PILOTING

Piloting in polar regions is very uncertain. There are few established aids to navigation and almost no cultural features. Moreover, the land areas shown on many charts are not dependable either as to location or feature. Perpetual snow and ice cover many of the features and result in a monotonous sameness of the visible landscape over large areas. On approach to waters where ice has been observed in past years, lookouts should be stationed on forecastle head to watch for growlers or drift ice.

On dark, clear nights, icebergs may be seen at a distance of 1 to 2 miles, appearing either as white or black objects. Under such conditions of visibility, growlers are a greater menace to vessels, and speed should be reduced and a sharp lookout maintained. The moon may be an aid or hindrance to ice detection, depending upon its age and bearing. With the moon ahead, bergs are difficult to see; with the moon astern, a blink is thrown up by the bergs rendering them visible from a great distance. A clouded sky at night, through which the moon appears and disappears, renders ice detection difficult; heavy passing clouds may dim or obscure an object sighted ahead. Fleecy cumulus and cumulo-nimbus clouds often give the appearance of blink from icebergs.

Radar equipment can easily pick up large bergs in ample time to avoid collision. However, small bergs or growlers capable of inflicting serious damage to vessels may go undetected even with moderate conditions of wind and sea. As the state of the sea increases, so does the minimum size of berg that can be detected. On very rough seas, bergs as high as 50 feet cannot always be detected in the sea return. Only in exceptionally smooth seas can radar be depended upon to pick up growlers. It is, therefore, unsafe for any vessel, because of radar, to assume immunity to ice hazards.

Air temperature is not a reliable guide to the presence of icebergs; nor can sea temperatures be depended upon to give warning of their approach. It is true that a small increase in water surface temperature can usually be detected within a mile or so of an iceberg. This increase is due to the freshening of the surface layer of the sea by the melting ice, causing a reduction in vertical mixing as a result of greater density stratification, and hence a retention in the upper layers of heat absorbed from the sun's radiation. Variations of surface temperature of the same order of magnitude are frequently encountered, however, in the total absence of icebergs.

In fog, the use of the steam whistle or foghorn for detecting ice by echo is of little value. Sound waves will be reflected only by a high vertical wall, and are not always discernible. The absence of echo is by no means proof that no bergs are near.

During daylight, in the absence of fog, a vessel may usually proceed through berg-infested waters without deviating materially from her course and with a minimum loss of time; but in darkness or fog, extreme caution must be used. In a thick, low-lying fog, especially with a clear sky and during dark autumn nights, it is well for vessels not equipped with radar to anchor or heave to temporarily, as under such conditions there is no warning as one approaches bergs. A procedure that has been found helpful under these circumstances is to locate all the bergs visible at sunset, and to lay down their position relative to the ship on a maneuvering-board diagram. From time to time, while lying-to in the darkness, the ship is steamed to windward enough to make up for the estimated wind drift that has occurred. Ship and bergs (which because of their deep draft are virtually unaffected by wind) thus keep their relative positions. The navigator by referring to his diagram can so regulate his allowance for drift as to maintain a safe margin of distance from all the bergs.

There are few things more dangerous than threading a fleet of bergs in thick weather. The ship may suddenly encounter one of these masses of ice, unseen through the fog and rain until it is close aboard. There is danger in making fast to them in such weather, for they themselves are often in motion, and may carry the vessel upon a grounded mass or a heavy floe; there is also danger from an overturn of the berg, or a break-up or from the fall of overhanging pieces. A position may be taken in the lee of large icebergs where a clearing may be found, but a sharp lookout must be kept to leeward.

When working through a berg-studded sea in low visibility, a full-powered ship should reduce speed to a minimum compatible with quick maneuvering. A sailing vessel or low-powered auxiliary will drive rapidly to leeward if hove-to; these vessels should head-reach and endeavor to hold a weather gauge on the berg last sighted until the weather improves. If icebergs are sighted ahead in thick weather, sailing vessels and low-powered ships should go about and retire to the area of clear seas and wait for fair weather. Care should be exercised when approaching icebergs and soundings should be continuous, since submerged projections caused by overcutting may endanger the vessel.

If hove-to in pack ice in heavy weather, always place the vessel with the stem against a floe and use the engines to hold the vessel up into the wind. If the vessel falls off or drifts, serious damage may be sustained from grinding, surging floes. Sometimes there is no polynya or channel in which to heave to. Often in the pack, old ice is integrated by a film of young ice. Under such circumstances, it is prudent to heave to in the young ice where its soft texture will buffer the vessel against encroachment by old ice.

On approaching snow-covered land from ice-free waters the yellowish landblink is usually observed before the land is raised above the horizon. On many of the coasts of Antarctica a belt of pack ice is found from 20 to 60 miles off the shore, with a belt of ice-free water along the shore. When coasting inside this belt the mariner must maintain an alert watch on its movements. An onshore wind will drive the pack in quickly and place the vessel in danger of being set on to the land. Under such circumstances it is usually better to put to sea so as to meet the ice as far off the land as possible. If local conditions are favorable, it may be possible to seek shelter in a bay or behind an island or stranded berg.

An accumulation of icebergs offshore invariably marks a shoal. The water off a shore from which a line of icebergs extends is almost certain to be foul. An island with a nearly continuous line of icebergs between it and the shore is connected to the latter by shallow water or a submerged ridge. If, on the other hand, the icebergs are concentrated on the island and on the shore, leaving a wide space free of ice, this space is probably clear of shoals. A shore fringed by glaciers or studded with bergs inshore but free of ice to seaward, is considered to be safe for a distance of about one mile from the shore.

A bay in which icebergs are found has a channel leading into it. A channel, the sides of which are bordered with icebergs with the center clear of ice, may invariably be considered safe.

Open water will usually be found during the summer months along a coast where offshore winds prevail.

The ship's Fathometer will not give a reading when ice is under the ship or when the water beneath the ship is disturbed by backing down or by the turbulence caused by ice floes being shoved around. A vessel proceeding in uncharted coastal waters may minimize the risk of grounding by having a boat equipped with a portable echo-sounder scout ahead.

FIXING POSITIONS

High latitude Mercator plotting sheets should be used by vessels operating in polar waters for convenience in laying out courses even though distortion is great. The polar plotting charts are generally too awkward to handle in actual navigational problems although of great value as a geographical guide and for planning purposes. Nevertheless, the advantages and disadvantages which each projection offers should be understood, and an analysis of these factors as related to the particular problem at hand made as the best guide to the kind of projection to use.

When navigating in ice, it is necessary to get astronomical or land fixes as frequently as possible in order to check the course and speed made good. The resultant takes into account the ship's course and speed and the drift of the ice. During summer in the polar regions, the long days and short nights limit the number of stellar fixes. Running fixes from sun sights offer the best means of determining the vessel's position. The large amounts of cloud cover and of fog add to the difficulty; therefore, no opportunity to take observations should be missed. A routine schedule for navigation is out of the question after entering an area where bergs, growlers, pack ice, fog, and overcast are the rule rather than the exception. As the sun frequently appears through the fog only for a short time, sextants should be kept ready. Electronic aids to navigation, where they exist, should be utilized as fully as possible.

Sights must be taken with great care, for while in the pack false horizons may frequently be observed. If the horizon is covered with ice, it may still be used for astronomical observations by subtracting the height of the ice above the water from the actual height of eye. The possible error due to this cause is less than 4 minutes. It may be preferable to make astronomical observations by using a sextant with an artificial horizon. Excellent results have been obtained with the bubble sextant by vessels operating in pack ice when there was no excessive motion.

Navigators usually avoid observations of bodies within 15° of the horizon because of the significant variations in refraction in this band of the sky. In polar regions the only available body may not exceed an altitude of 10° for several weeks; in practice, therefore, there is no lower limit to observations. Because of the low temperature in polar regions the refraction correction for sextant altitudes should be adjusted for temperature (Table 25, Bowditch).

Even a celestial fix cannot be depended upon to guarantee the safety of a ship in Arctic or Antarctic waters. The inaccuracy of charts, which in many instances may be several miles, makes it necessary and more important to keep a ship's position plotted in reference to adjacent land rather than in reference to true latitude and longitude.

MAGNETIC COMPASS

The directive force on the ordinary mariners' magnetic compass is derived from the horizontal component of the earth's magnetic field. Although the total intensity of the earth's field remains fairly constant in all latitudes, the horizontal component decreases as the magnetic poles are approached. Within about 20° of the magnetic poles, the directive force is so weak that the compass is sluggish and unresponsive. Conversely, the vertical component increases and may give rise to large heeling errors. Although the horizontal component of the earth's field, and hence the induced magnetism in horizontal soft iron, decreases as the magnetic poles are approached, the field of subpermanent magnetism of the ship's structure retains its absolute value, and therefore becomes relatively much more important in causing deviation. Small uncompensated deviations due to subpermanent magnetism thus may attain very large values in high latitudes.

To obtain the best performance from the magnetic compass in polar waters, the ship should be swung and the compasses adjusted in high latitudes, preferably just before entering the pack ice. If the Flinders bar has not been permanently set at the magnetic equator, it should at this time be adjusted to the position indicated by computation, and the horizontal and heeling magnets should be carefully placed to produce minimum deviation. On completion of the adjustment, the ship should be swung again and a new deviation table constructed. This procedure will provide the navigator with a more satisfactory instrument than if he attempts to use a compass compensated in low latitudes.

Even if this recommended procedure is followed, changes in magnetic latitude may cause large deviations to reappear. Likewise the magnetic variations will change rapidly with locality and may undergo large diurnal changes, particularly if auroral activity is present, so that the navigator must undertake frequent azimuth determinations. If large compass errors are found, and if it is uncertain whether these are due to variation or to deviation, swinging the ship again to see whether the error persists on all headings will establish the cause.

The flux gate compass has proven less sluggish and has given fairly accurate and reliable results. In high latitudes the gyrocompass performs satisfactorily if properly adjusted but, since it is always subject to mechanical failure, two gyrocompasses should be installed in addition to the magnetic compasses.

During the voyage no opportunity should be missed to observe the errors of the compasses, particularly by azimuths of the sun. An azimuth attachment for a telescopic alidade is recommended; it may be of value in obtaining accurate azimuths for determining gyro error when the sun is not brilliant enough to obtain an azimuth by the use of an azimuth circle. The present azimuth tables for high latitudes can be used only during a certain portion of the day but computed azimuths for any time may be taken from H. O. Pub. No. 214.

DEAD RECKONING

The Dead Reckoning Analyzing Indicator (DRAI) is designed for use below latitude 70° and above this will not function. For ease in navigation it is suggested that a ship planning to operate above latitude 70° have its DRAI factory-adjusted to perform in latitude up to 85°. On Operation NANOOK the *Atule* was equipped with a DRAI which, although not adjusted for high latitude operation, was made to work satisfactorily by the application of a few well thought out corrections.

Two systems were devised for using the DRAI above 70°. In both systems it was set back some number of degrees of latitude. Between 70° and 75°, for instance, it was set back 5°. This made the DRAI read 65° when the latitude was actually 70°; 66° was 71°, etc. The DRAI latitude was then corrected by adding 5° to it, but the longitude was in error because the distance between meridians is a function of the cosine of the latitude, and the DRAI latitude was 5° in error. The problem therefore became that of determining the correct longitude.

One method of correcting longitude is to determine the mean latitude between the last DRAI latitude and the present DRAI latitude. These are the actual readings of the DRAI, not corrected by adding 5°. The mean DR latitude equals the mean DRAI latitude plus 5° in this case. The correction to the DRAI longitude can then be computed by using the following formula:

$$\text{Corr. to long.} = \frac{(\text{long}_1 - \text{long}_2)\ \cos\ (\text{mean DRAI lat.})}{\text{Cos (mean DR lat.)}}$$ where long_1

and long$_2$ represent the last and the present DRAI longitudes, respectively. The correction is added to or subtracted from the original DRAI longitude to give the corrected DR longitude.

In the second method of correcting longitude, the Dead Reckoning Tracer (DRT) is used. When a fix is obtained the DRAI is set as before and the table of the DRT is marked: the fix is also placed on the chart. When the ship's latitude and longitude are required, a 0°–180° line is drawn through the fix on the table. Then a 90°–270° line is drawn through the present position on the DRT. The distance measured in miles from the fix to the 90°–270° line gives the difference in latitude between the two positions. The intercept measured on the 90°–270° line between its intersection with the 0°–180° line and the DRT position is the difference in longitude measured in miles. With the difference of longitude and difference of latitude it is then quite simple to determine the DR position on the chart by consecutively stepping off these vectors in the appropriate directions from the fix.

It is difficult, when navigating through ice out of sight of land, to establish the ship's DR position. The fundamental factors, speed and course, change continually and do not lend themselves to accurate calculation. Even if a gyrocompass and automatic pilot are on board, the distance run must be known. No device has yet been invented which can measure continuously the speed of a ship in ice. While maneuvering in ice, where the course changes almost continually, the average course should be noted over a relatively short period of time during which deviations from this mean course are inconsiderable (2° to 3°) or of short duration, e. g., when passing round small floes. The ship's position must be kept up to date while navigating in ice, otherwise after spending some time in ice she will be out of position on reaching the open sea.

For this purpose a careful record should be made of all alterations of course and the corresponding times at which they are made for subsequent plotting on the chart. For the continual noting of frequently changing courses and speed, it is recommended that a special notebook be kept, compiled in the following manner:

Time in hours and minutes	Compass course	Compass error	True course	Duration on the course	Speed	Distance	Notes

During frequent alterations of course it is extremely difficult to plot on the chart, especially if it is of small scale. It is therefore recommended to plot the general course and the distance made good on the chart once during every watch. To obtain these data it is necessary to carry out subsidiary plotting, for which squared paper should be used if a large scale chart is not available. When navigating in ice it is desirable to compute the speed as often as possible, in any case not less frequently than several times an hour.

For determining speed in ice the navigator must fall back on the method probably used by Columbus, which is as follows:

The lookout, standing in the bow of the ship, throws to one side onto the ice ahead of the vessel a chip of wood, a piece of clinker, or a similar object. At the moment when this object passes abreast the stem, the lookout gives a signal by hand whistle and the navigator starts a stop-watch. A third hand in the stern of the ship notes the passage of the object past the stern post and at that instant gives a signal on which the navigator stops his watch. By this means the time during which the vessel covers a distance equal to the length of its hull between the stem and the stern post (or between any two widely separated frames of the ship) is determined.

Suppose for instance, that this distance is 325 feet. The stop watch shows that the distance is passed in 66 seconds. The distance covered in one hour (3,600 seconds) or the speed, would be:

$$\frac{325 \times 3{,}600}{66} = 17{,}727 \text{ feet per hour} = 2.9 \text{ knots}$$

It is not necessary to make this calculation every time; a table should be prepared in advance for the ship, by which after determining the time as above the corresponding speed can be obtained at once.

A second method of determining the speed is to use a variant of the chiplog, by attaching a weight to a line on which any length, say 100 feet, may be marked. Having thrown the weight overboard onto the ice, determine with the stop-watch the time taken to pay out the measured length of the line. If this is 20 seconds, the speed of the vessel is shown to be:

$$\frac{100 \times 3{,}600}{20} = 18{,}000 \text{ feet per hour} = 3.0 \text{ knots}$$

By actual determinations of this kind, the navigator can calibrate his revolutions vs. speed curve. Thus, one ship found that her speed in pack ice could be found by deducting 1 knot from the revolutions per minute speed curve, except in the heaviest pack when 4 knots should be deducted.

Plotting the positions of large icebergs by radar ranges and bearing and using these relative positions to compute the ship's speed have been reported to give good results. However, this method assumes the iceberg to be motionless in the water, an assumption not believed to be justified in most instances.

In depths where it is possible to sound, drift may be determined with some accuracy. If the vessel is surrounded by ice, a hole can be cut, the deep-sea lead dropped through it, and the trend of the drift of the ice thus obtained. To determine the drift it is recommended to make use of all enforced stops and even to stop the vessel especially to carry out the necessary observations.

Some navigators ignore such methods of reckoning because they require too much time and are too detailed. They estimate by eye, both the general course and the distance made good. As a result, there have often been cases where a ship has found herself a considerable distance from the position estimated by the navigator. When steaming in dangerous regions, the ship can easily run aground or expose itself to other unexpected hazards. Because of insufficient information on tides as well as other factors, the most accurate dead reckoning navigation will not result in giving the exact position of the ship, but good and careful reckoning in accordance with the above methods helps reduce errors.

RADAR IN ICE

The reliable detection of ice with radar is dependent upon the following factors:

(*a*) Condition of the equipment. The importance of keeping the radar at top operating efficiency for ships operating in ice areas cannot be stressed too highly. It is possible, without adequately trained personnel, for a radar set to be 25 decibels down without the fact being noticed. In calm to slight seas the detection of bergy bits or growlers in time to avoid collision can safely be expected only when equipment is operating at peak performance.

(*b*) State of the sea. As the state of the sea increases, so does the minimum size of berg that can be detected. On very rough seas, bergs as high as 50 feet cannot always be detected in the sea return. Only in exceptionally smooth seas can radar be depended upon to pick up growlers.

(*c*) Weather conditions. For radar of both “S” and “X” bands, the echo from certain weather features such as rain clouds may at times obscure returns from ice. Meteorological conditions in certain areas affect radar propagation in a manner that may under certain conditions reduce range in fog where radar is most needed.

(*d*) Operator's ability. The best equipment known today can give maximum performance only in the hands of well-trained and experienced operators. The performance and interpretation of radar may differ as much as 33 percent according to whether the operator is skilled or unskilled.

Ice does not have the microwave reflection properties of metals and is therefore a poorer reflector of radar waves than are ship-type targets. Even ships of moderate size give greater target range than the largest bergs encountered.

Over-water return from ice targets follows the same type echo-strength-to-range relationships as have been found for ship targets.

During rough weather, representations on PPI and A-scopes may become momentarily blurred but should clear in 1 or 2 sweeps of the antenna.

It is quite possible that a target may be lost due to the ducting effect of the beam caused by air conditions. This happens occasionally but not to the extreme that the target is completely lost.

The blending of the sea return and the echo from growlers offers the greatest problem of detection, but an alert operator can reduce the hazard. In moderate seas the growlers alternately appear and disappear from the scope in approximately the same position each time, whereas the sea return will fail to appear in the same relative position; likewise, the sea returns are not as strong as those reflected from the ice.

Caution is essential during periods when ships are navigating in consolidated pack during low visibility. Large bergs can be distinguished from adjacent pack ice returns at ranges of 4,000 yards or more, but these are obscured by pack ice echoes at lesser ranges and what actually are shadows of large bergs can be very easily mistaken for open water. Antijam controls are of some value in differentiating between pack ice and large bergs at reduced ranges but should not be relied upon.

Floes up to 6 miles from the ship are well patterned on the PPI: radar may therefore be of considerable assistance in picking leads through the ice. It should be remembered, however, that ice less than 1 foot out of water cannot be detected by radar.

In no case should the radar be accepted as 100 percent accurate, resulting in the relaxation of safety precautions dictated by the rules of good seamanship. It is a valuable and essential aid in ice navigation which, when judiciously used, safeguards the ship from many of the hazards presented by ice.

SONAR IN ICE

During the 1947 Antarctic Development Project (Operation HIGHJUMP), sonar proved invaluable in detecting ice targets and assisting in navigation. The value of sonar in navigating ice-laden waters, when visibility was restricted, lay not in its ability to classify targets, but in the positive warning it was able to give the conning officer of the ship's approach to ice.

In the cold waters of the Antarctic, ranging in temperatures from 34° to as low as 29° F., conditions were found to be excellent for propagation of sound, and very good results in the use of sonar with all kinds of targets were obtained. The excellence of sonic conditions produced very nearly 100 percent reliability in sonar to detect obstruction within dangerous ranges.

Ice targets were found to give solid echoes at moderate ranges. Growlers, which constitute a hazard in radar navigation in rough seas, were detectable well in excess of hazardous ranges, even when swells up to 6 or 8 feet were encountered. Observed sound ranges and those predicted from the temperature data were coincident.

High water noise and heavy rolling of the ship had a decided effect upon the range. Best results were obtained when the vessel was making less than 10 knots. Some difficulty was reported in detecting growlers when bearing between 170° and 180° relative, due to the interference caused by the noise of the screws.

On Operation NANOOK the *Atule* reported that bergs could best be detected by sonar listening. They gave off a loud noise similar to high-speed screws on a ship, possibly caused by the release of air bubbles under fairly high pressure. Echo ranging in the Arctic was not dependable, often failing to indicate bergs at ranges where they were a distinct hazard. The U. S. S. *Edisto* found sonar of little value during summer Arctic operation as the ice shield had to be closed upon entering ice to avoid certain damage to the sound dome. Nevertheless, sonar gear is regarded as a valuable aid to navigation in polar waters.

APPENDIX A

A PROPOSED ICE DOCK

(From article Ice Dock by Engineer K. Zhukov in Tekhnika Molodezhi (Technics for the Young), 1944)

The crew of the Russian vessel *Temp* (drawing 13 feet) carried out repairs to the ship using an ice dock they had built themselves.

In Tiksi Bay, where the crew of the *Temp* was carrying out its work, the thickness of the ice cover reached 8.2 feet. Such a thick

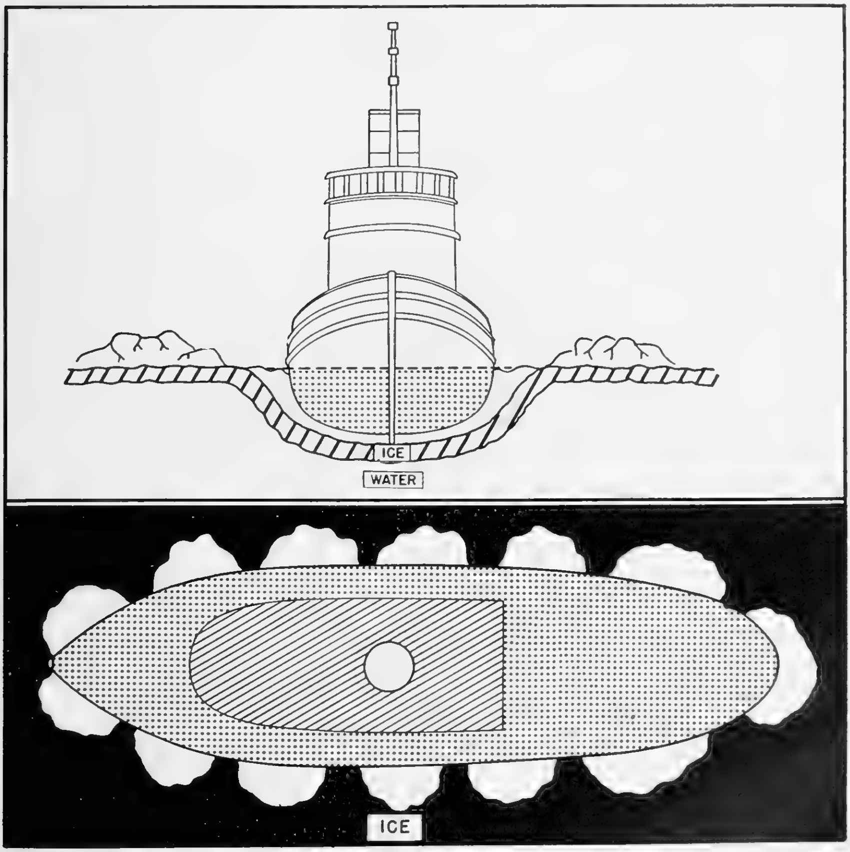

Figure 27.—Immense ice cup serving as a drydock. The ship is supported by ice buttresses. While wintering in Tiksi Bay, the crew of the S. S. *Temp* carried out repairs of the underwater part of the ship, using a similar ice dock.

coat of ice becomes an obstacle to further freezing of the water and serves as an insulator between water and air. The temperature of the air is below freezing, while the temperature of the water under the ice is above freezing. This equilibrium may be upset by reducing the thickness of the ice cover, i. e., by removing a layer of ice. The thinner ice layer will allow the water adjacent to its lower surface to freeze, bringing the layer back approximately to its original thickness.

Work on setting up the ice dock started in autumn, before the sea became covered with ice. The vessel was placed with its axis along the direction of predominating winter winds so that it would not become surrounded by large snowdrifts. The surface of ice surrounding the ship must be as thermoconductive as possible and must be cleared of everything that may delay freezing, such as snow, rubbish, wood chips, etc. When the ship had frozen into the ice, the dock was mapped out on the surface of the ice. The workmen then began digging under the ship, grooving out recesses at a great depth.

The ice dock has a number of sections separated by ice buttress-partitions, from between which the ice is removed. This arrangement allows the weight of the ship to be equally transmitted through the ice onto the water. Should the water break through a thin layer of ice, which may happen if too thick a layer is inadvertently removed, only one section would be flooded, which is but a small part of the entire dock. A dock may be set up for the entire ship or only part of it.

As the size of the ice pit is larger than the vessel, the pressure on the walls of the ice dock will not be fully balanced and will be considerably more than the weight of the ship. The ice will bend out some-

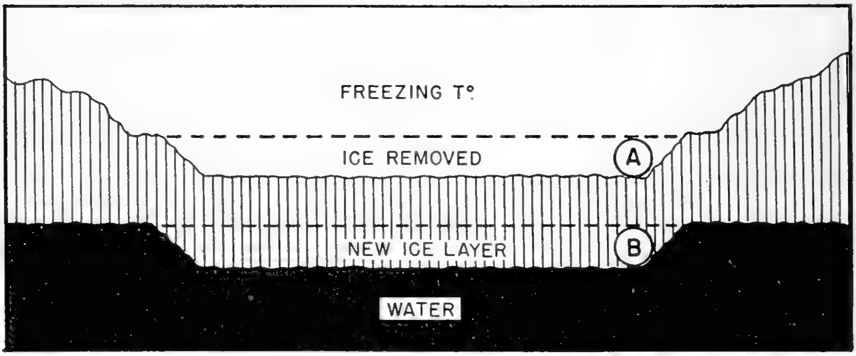

Figure 28.—After the ice has been removed from (A), a new layer of ice (B) forms below the ice layer, constituting the bottom of the future ice dock.

what and the dock will rise above the level of the ice. The entire ice cup of the dock will, so to speak, be pressed out above the surrounding field. During the repair of the *Temp*, the dock rose 44 inches.

The repairs on the vessel were carried out simultaneously with the building of the dock. As the workmen dug deeper and deeper into the ice, they repaired whatever defects of the ship's hull they encountered. The *Temp* underwent the following repairs: replacement of a worn-out screw, repair of a bent rudder, and setting of a new false keel. During the second wintering in the ice dock, a complete repair of the underwater part of the ship was carried out.

As the ice cup was being hollowed out, the vessel was placed on wooden cross-beams, while the ice buttresses dividing the sections were being cleared away. It was then possible to paint the hull and tar the underwater parts.

Shifting of the ice in spring is very dangerous and may damage a ship caught in the midst of drifting ice fields. If, after completion of repairs, the ice dock is flooded, the ship floats in a basin with exceedingly thick walls protecting it from shocks and pressure. When the ice thaws out and the ring encircling the ship finally breaks, the vessel will find itself in water more or less clear of ice. If the ice ring fails to break up in time, it may be blown up with explosives.

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