MICRORELIEF PRODUCED BY SEA ICE GROUNDING IN THE CHUKCHI SEA NEAR BARROW, ALASKA*

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IT HAS long been known that sea ice and glacial icebergs ground in shallow water (Transehe, 1928, p. 102) and can deform the bottom (H.O. 77, 1951, p. 31; United States Coast Pilot, 1947, p. 594). Small-scale microrelief has been noted on the inner shelf of the Beaufort Sea off the Colville River by Carsola (1952, pp. 22, 64; 1954, p. 159) who suggested that it is caused by ice grounding. Pressure ridge ice is often the last fast ice to break up and float free in the summer. Frequently the inner fast ice in water of 20 to 30 feet depth will break up while pressure ridge ice remains grounded in deeper water. Boat observations at the time of break-up are extremely hazardous and little accurate information is available as to the depths of ice groundings. In the summer of 1954 the writer studied the microrelief off Barrow, Alaska, to determine the effective range of grounding of the polar pack ice.[1] The Barrow area of the Chukchi Sea was chosen because it is the northernmost shoal area of Alaskan waters and the site of the Arctic Research Laboratory.

Method

Numerous short echo sounding traverses were carried out in a boat to establish confidence in the instruments, procedures, and the reality of the microrelief, then 6 bathymetric traverses were made, all together consisting of 14 legs. These traverses and a summary of the results obtained are shown in Fig. 1. The microrelief studied here is not the same as that described by Carsola (1954) for deeper waters of the outer continental shelf to the northwest of the Barrow area.

Depth determinations were made with a new Bludworth Model NK-6 echo sounding recorder operating at 14.25 kilocycles, for which the power supply was 12 volts from the boat's batteries. The echo sounder was the only power drain on the batteries during the period of its operation. Frequent checks from a moored boat showed that no measurable changes in depth were recorded by the instrument at any engine or generator speed encountered

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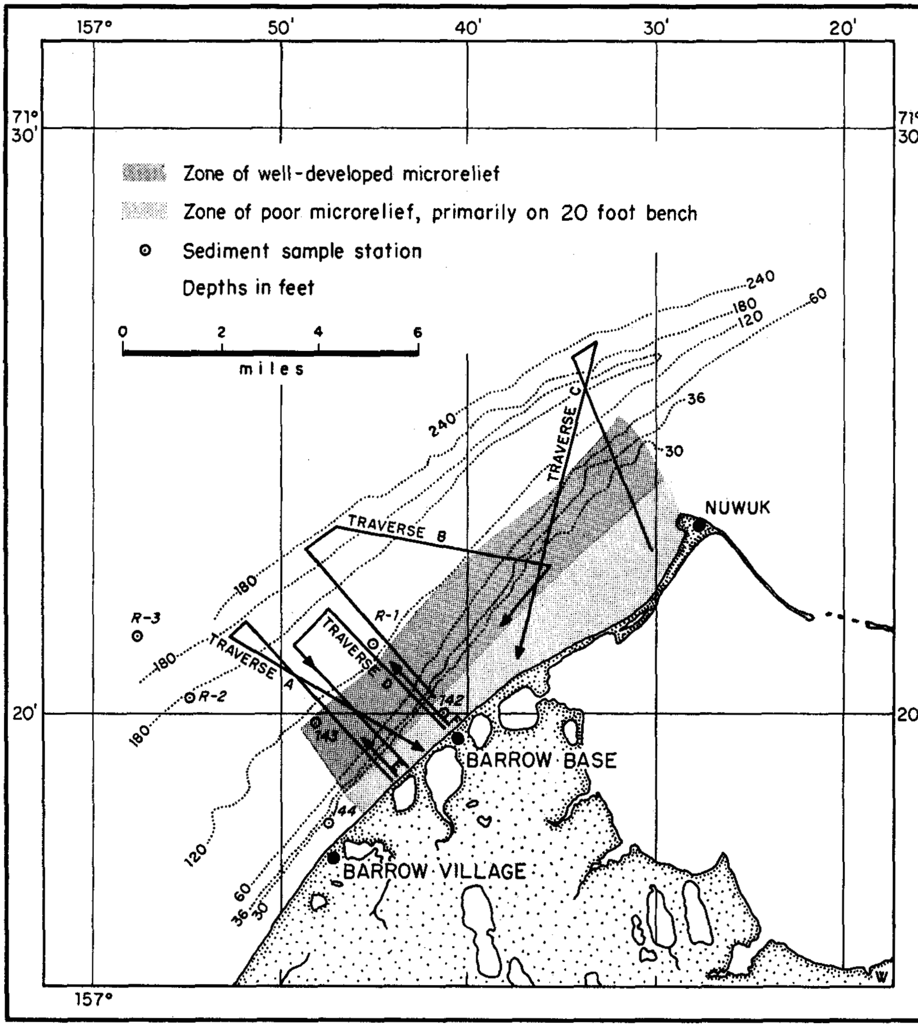

Fig. 1. Barrow area, showing zone of sea ice grounding and location of echo sounding traverses A–F.

during the traverses. In addition, depth checks were made with a hand line. Therefore the depth fluctuations recorded are assumed real for values ± ½ foot.

Sediment samples R-1, R-2, and R-3 (Fig. 1) were obtained with a Dietz-LaFond snapper and samples 142 and 143 with a 1⅜ inch I.D. gravity corer.

Results

The traverses generally showed irregular depth fluctuations of 8 feet or less over distances of 25 to 50 feet, superimposed on a very gently sloping bottom. These depth variations occur both parallel (Fig. 2) and perpendicular (Fig. 3) to the depth contours. Figure 2 was made at a speed of ¼ knot drifting with the current parallel to the depth contours. Depth fluctuations

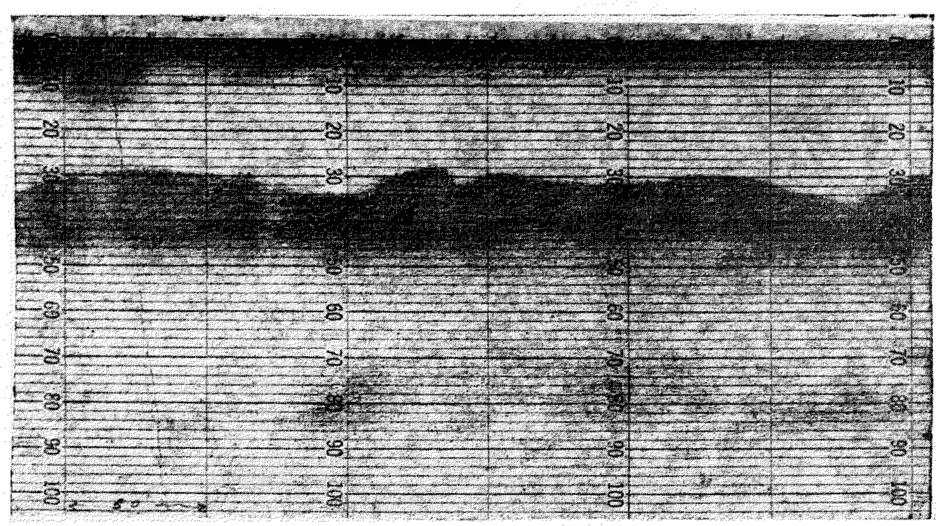

Fig. 2. Echo sounding traces, parallel to contours near Traverse F. Depth in feet. Add 2 feet to depths for transducer depth correction. Distance between vertical lines approximately 25 feet.

were determined simultaneously with the echo sounder and a hand line and agreement was ± ½ foot.

Microrelief is best developed between depths of 20 and 80 feet, where it is often 6 feet, and in one case reached 12 feet (Fig. 3). Moderate microrelief usually extends to a depth of 100 feet (Fig. 4).

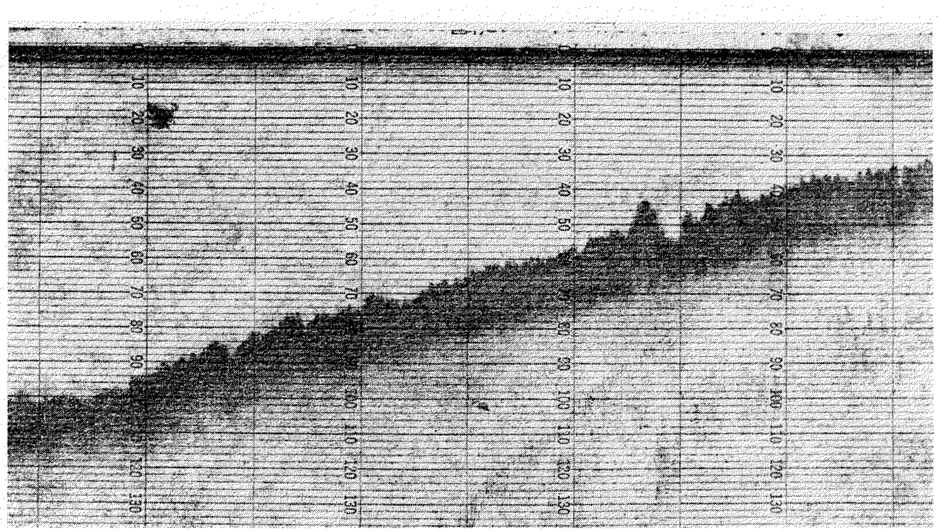

Fig. 3. Slope from 35 to 100 feet showing development of microrelief perpendicular to contours. Depth in feet. Add 2 feet to depths for transducer depth correction. Distance between vertical lines approximately 200 feet.

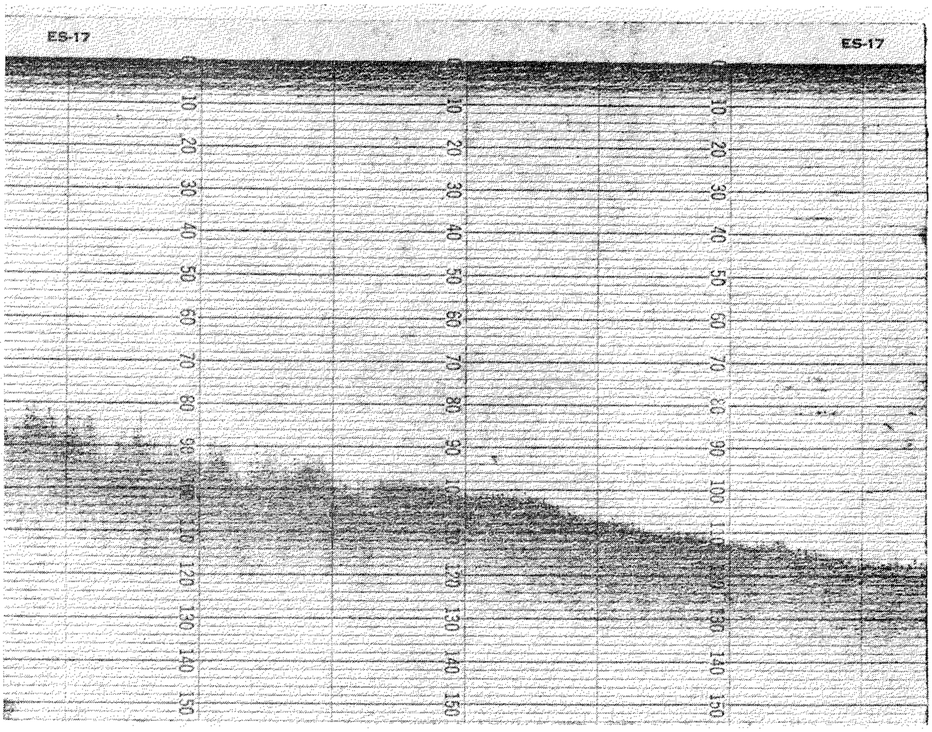

Fig. 4. Traverse D, leg 1, from 80 to 120 feet, showing the transition from microrelief above 100 feet to microrelief-free slope below. Depth in feet. Add 2 feet to depths for transducer depth correction. Distance between vertical lines approximately 80 feet.

A submerged shoreline marked by drowned river and stream valleys and a broad bench from 20 to 30 feet in depth (Fig. 5) characterizes the northern Alaska coast of the Chukchi Sea. Pack ice impinges against the outer portion of this 20-foot bench or terrace in the Barrow area and forms pressure ridges. Brash ice,[1] some pack ice, and young pancake ice fill the area above the 20-foot bench. The ice is grounded in places and remains as part of the fast ice in the spring. Moderate microrelief is developed on the 20-foot bench (Fig. 6) and pressure ridge ice extends seaward from it. Aerial photographs indicate that the main series of contiguous pressure ridges occur in water depths between 20 and 100 feet, coinciding almost exactly with the depth distribution of the microrelief. Pressure ridges also occur in various patterns in the open pack, but not as a continuous zone of crumpled ice over a mile in width and hundreds of miles in length, as is true of the fast pressure ridge ice. Fast pressure ridges have in general an arcuate pattern with overall lineation very roughly parallel to the depth contours. Pressure ridge ice forms the

[1]All sea ice terminology is in accord with the definitions given in the U.S. Hydrographic Office sailing directions for arctic waters, for example H.O. 77, 1951.

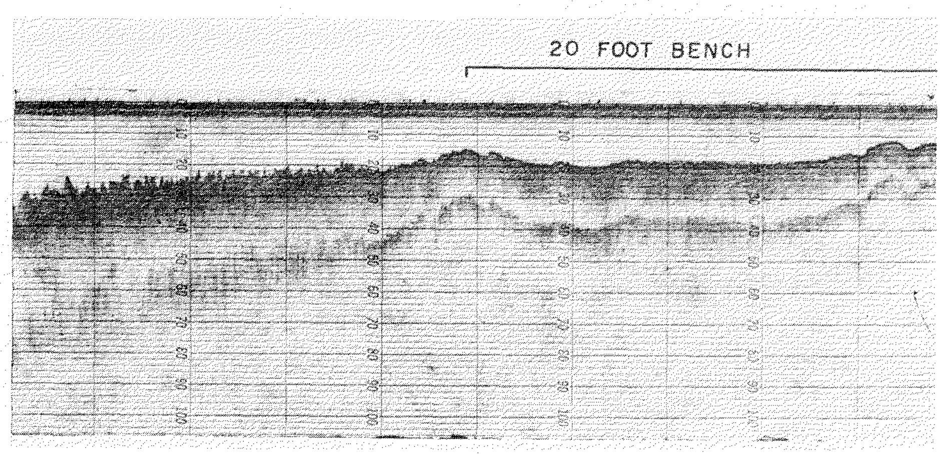

Fig. 5. Traverse from near shore bar (right), across 20-foot bench to ridge where inner pressure ridge ice grounds, downslope to 30 feet in the zone of microrelief (left), in the vicinity of Traverse F. Note relative absence of microrelief from 20-foot bench. Depth in feet. Add 2 feet to depths for transducer depth correction. Distance between the vertical lines approximately 200 feet.

principal body of fast ice in spring and early summer, sometimes containing large quantities of silt and fine sand, and occasionally it contains some mollusc shells.

Before accepting the hypothesis of pack ice grounding to explain the microrelief a number of alternate hypotheses were considered. These were: residual features of thawed permafrost, slump topography, current scouring, and sand waves.

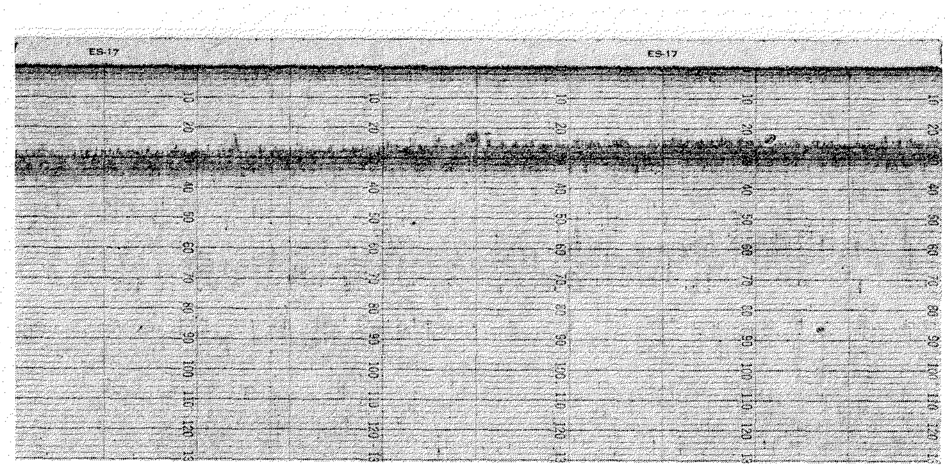

Fig. 6. Traverse C, leg 2, microrelief developed on the 20 to 30-foot bench in a level area. Depth in feet. Add 2 feet to depths for transducer depth correction. Distance between vertical lines approximately 150 feet.

Thawed permafrost as described by Hopkins in the Imuruk Lake area of the Seward Peninsula (1949) may be an explanation for some of the microrelief found in the Chukchi Sea. The thaw lakes in the Imuruk Lake area are up to several hundred feet in width and 30 feet in depth. Carsola (1954, p. 1598) suggests that possibly the microrelief observed to the northwest of the Barrow Sea Valley resulted from the thawing of Pleistocene permafrost by a rising sea. Relict thawed permafrost topography is readily buried under prograding continental shelf sediments and can be expected only in areas free of sedimentation from the time of their submergence to the present day. The East Chukchi Sea-Alaska Coastal Current carries sediments northward on and near the bottom of the shelf to the north-northeast trending Barrow Sea Valley. It therefore appears probable that Carsola's area of microrelief, to the northwest of the Barrow Sea Valley, lies in a sediment "shadow" thereby meeting the requirement of non-deposition of sediments for the present day preservation of thawed permafrost topography.

The microrelief studied in the Barrow area by the writer differs in a number of important ways from the microrelief studied by Carsola. The Barrow microrelief is of smaller dimensions; the relief is 6 feet compared to a maximum of 30 feet, and 100 feet in length compared to a maximum of 1,000 feet. It lies on the southwest side of the Barrow Sea Valley, between the valley and the present shore line, within a zone of sedimentation; and it occurs at depths between 20 feet and 100 feet, whereas Carsola's microrelief occurs at about 300 feet.

The sediments on shore consist of 150 to 200 feet of Recent and possibly Pleistocene unconsolidated silts, sands, and gravels of the Gubik formation (Payne, 1951; Gryc and others, 1951). A stratigraphic study (Rex, 1953) indicated that the upper portion of the Gubik formation in this area consists of prograding marine sands and silts overlain with littoral deposits of beach sands and gravels. A series of uplifted beach ridges (Rex, 1953) extends inland from the Barrow area. Black (1952) estimated from the growth rate of ice wedges that the age of the uplifted beach deposits near the coast is approximately 3,500 years, supporting the concept of recent sedimentation in this area at a time when sea level was within 10 to 20 feet of its present stand. Sediments forming the beach and shallow water deposits can certainly be expected to mask any residual permafrost topography in some cases less than 1,000 feet away and in water only 20 feet deep. Extensive movement of silt occurs in this area during summer storms when the water is extremely turbid. Therefore thawed permafrost is rejected as an explanation of the microrelief observed by the writer.

Slump topography described by Shepard (1948, pp. 195–8; 1955, p. 1479) is characterized by irregular undulating or hummocky relief and slump scars or valleys in the source areas. The presence of microrelief on the broad and flat 20-foot bench cannot be explained as slump topography, because slumps must have a source and slump scars are not evident in association with the microrelief on the 20-foot bench. Gravity cores, Samples 142 and 143 (Fig. 1), taken in the area of microrelief disclose a compact grey silt beneath 2 to 5 feet

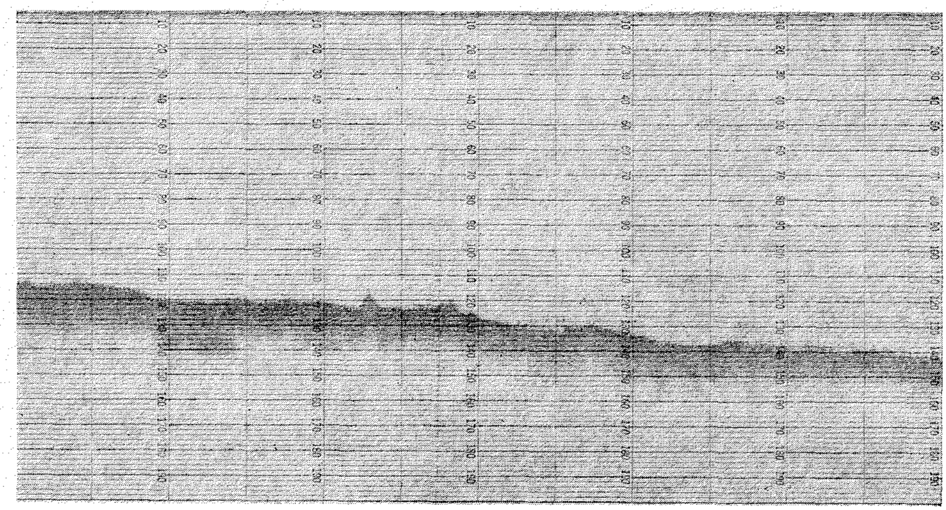

Fig. 7. Traverse B, leg 1, gently undulating relief, more like slump topography than is the shallower microrelief attributed to sea ice grounding. Depth in feet. Add 2 feet for transducer depth correction. Distance between vertical lines approximately 80 feet. Compare with Fig. 4 for scale of microrelief.

of soft grey silt. The compact sediment contains a fine structure that is usually destroyed in slump material. In addition, the extreme sharpness of the microrelief is not characteristic of slump terrain. Handline soundings show this sharpness better than do echo soundings which tend to smooth bottom irregularities. It is possible that some of the deep undulating relief below 120 feet may be slump topography (Fig. 7), but this deeper topography differs from the shallower microrelief in being of greater width and lesser relief, suggesting that a slump origin is an unsatisfactory explanation for the shallow microrelief.

Current scouring occurs in the Barrow area. Deep scour channels result where large quantities of water pass through the inlet between Elson Lagoon and the open sea at speeds sometimes exceeding four knots. The East Chukchi Sea-Alaska Coastal Current flows to the northeast over the microrelief area with an average speed of one knot and occasionally attains two to three knots with a favourable wind. This current is sometimes reversed temporarily by strong winds from the northeast and then flows to the southwest. In midsummer after ice break-up and before the first summer storm, the waters of the Chukchi Sea at Barrow are unusually clear permitting white objects on the bottom to be observed at depths of 50 feet. It was evident that no bottom veil or cloud of sediment was being moved across the 20-foot bench at times when the current flow was two knots. Microrelief disappears relatively abruptly below a depth of 100 feet. To create microrelief by current scouring a two-layer water mass is necessary, with fast moving water above 100 feet and slow moving water below. Temperature, salinity, and paravane current data do not support the presence of a two-layered system with an interface at 100 feet depth. On the contrary, the data indicate nearly isothermal water with irregularly varying salinity related to sea ice melt water and river runoff. Traverse E, made after a strong storm late in the summer, lies about 300 feet to the northeast and parallel to Traverse A (Fig. 1). The effect of the storm was very slightly noticeable in Traverse E and tended to diminish the microrelief on the 20-foot bench, not increase it. These observations effectively eliminate the possibility of current scour as a mechanism of microrelief formation.

Fig. 8. Fast ice near Barrow, looking northeast from 1,500 feet, 28 June 1952. The dark puddled area near the shore (right) overlies the 20-foot bench. Two weeks later the fast ice broke up and floated free.

Sand waves cannot explain the microrelief because it is developed in an area of predominantly silt sediments and shows no symmetry, a characteristic feature of any ripple mark.

Pack ice grounding could cause the development of microrelief in a way that explains all the observed features. Fast pressure ridge ice, as indicated by aerial photographs (Fig. 8), is restricted almost completely to the zone of microrelief. The pressure ridge ice, as previously noted, sometimes contains large quantities of silt and occasionally shells. This supports the hypothesis of contact with the bottom. The sharpness of the microrelief and the scale are what one would expect if an average ice floe (4–6 feet thick and 20–100 feet in diameter) were up-ended by the pressure of other floes and driven into the bottom. The abrupt end of microrelief at 100 feet can be explained as the maximum depth at which pack ice grounds. Perhaps the relatively uniform value of this deeper limit represents a depth where a balance occurs between the buoyant force of the water on the pressure ridge ice and the load of ice floe telescoped upon ice floe by the maximum force of the polar ice pack in the Barrow area.

In 1952 the writer observed that the pressure ridge ice seaward of the 20-foot bench remained grounded for a period of more than twelve hours after the break-up of the ice over the 20-foot bench. In view of the constant coastal current in excess of one knot this observation is taken as proof that at least some pack ice grounds seaward of the 20-foot bench. The indirect and direct evidence are therefore considered to support the hypothesis of sea ice grounding to a depth of 100 feet to the exclusion of other hypotheses.

The probability of sea ice grounding as a function of time was not determined. It is suggested that, on the basis of the sharpness of the microrelief, grounding is most frequent between 20 and 80 feet. Grounding below this depth is probably less frequent and occurs with less bottom gouging than grounding within this depth range.

Ice grounding serves to mix the surface sediments, perhaps to a depth of 4 to 5 feet thereby destroying stratification, oxygenating the sediment, and considerably modifying the environment of benthonic organisms.

Aerial photographs of a coastal area taken in spring and early summer indicate the belt of pressure ridge ice and therefore the zone of ice grounding (Fig. 8). For increased accuracy photographs covering a period of several years should be used.

Subsequent to the completion of this paper MacGinitie (1955) has made a number of comments on sea ice grounding. His observations agree with those of this writer, but are of a more general nature. MacGinitie's winter observations are of special interest; he notes that the pack "ice grounds offshore where the water is 60 to more than 100 feet deep and forms what is spoken of as the 'big pressure ridge'" (p. 12). This major pressure ridge forms nine years out of ten and "from shore to a depth of over 100 feet offshore the bottom is rubbed and gouged by ice" (p. 14). Later he again mentions that "ice grounds out to a depth of 90 to 100 feet" inhibiting faunal development (p. 53) and that grounding ice may have rubbed organisms off large stones and boulders found in a rubble zone (p. 62).

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