Attachment D

Dynamic ice-wallow relief of northern Alaska's nearshore

By: Erk Reimnitz and Edward Kempema

ABSTRACT

Contour maps with O.S-m depth interval were prepared for a small area seaward of Reindeer Island, a barrier island in the Beaufort Sea, Alaska, by repeated surveys with very accurate navigation and very close trackline spacing. The maps reveal numerous closed depressions and mounds about 50-100 m in diameter and 2-3 m in relief, presumably related to grounded ice floes common in the area year round. Some of the features were obliterated over the course of three seasons while new ones formed. Although the depressions resemble kettles, they are formed by very different mechanisms. We believe that these bedforms represent erosion and deposition caused by: (a) intensified flow around stationary ice floes serving as obstacles and (b) pulsating currents generated by vertical oscillations or rocking motions of grounded floes in a seaway. Because sediment transport occurs around the ice, not where it directly touches the sea floor, the depressions are much larger than the base of the acting floes.

Ice-wallow bedforms, although not found everywhere, are characteristic of arctic nearshore regions with non-cohesive sediments, and most likely occur in other ice-stressed coastal environments in differing degrees. The bedforms studied here are highly active and must be considered in planning nearshore construction activities.

INTRODUCTION

Reindeer Island is a small barrier island 13 km north of Prudhoe Bay in the Alaskan Beaufort Sea (Fig. 1). Accurately navigated surveys were run in the nearshore area on the seaward side of the island in 1976 and 1979 to monitor changes in bathymetry. Calm waters, in the presence of ice, allow surveys into depths of less than 2 m. Such surveys reveal numerous irregular pits and mounds with 2 - 3 m of relief. This topography is quite similar in appearance, but at a much larger scale, to that of pitted beaches and of subaerial sea-ice kettles discussed by Nichols (1961) and Greene (1970), which are strictly depositional features. We believe that the major bedforms off Reindeer Island represent combined erosion and deposition in response to intensified action of currents and waves around grounded ice and are characteristic of the high-latitude littoral zone.

Studies of beaches influenced and modified in various ways by ice are numerous (e.g. Nichols, 1961; Rex, 1964; Hume and Schalk, 1964, 1967; Greene, 1970; Owens and McCann, 1970; McCann and Carlisle, 1972; Short, 1973, 1976; Hume and Schalk, 1976; Taylor and McCann, 1976; Dionne, 1976). Few, however, deal with the morphology and processes of the nearshore zone. Short (1973, 1974) documents a series of longshore bars and troughs off Pingok Island in the Beaufort Sea that are quite similar to those found at low latitudes. He reports no irregularities in the rhythmic morphology, howevever, even though the region is fully exposed to sea ice. Repeated depth profiles recorded by Schalk and Hume (1961) and Hume and Schalk (1976) off Barrow, Alaska, recorded

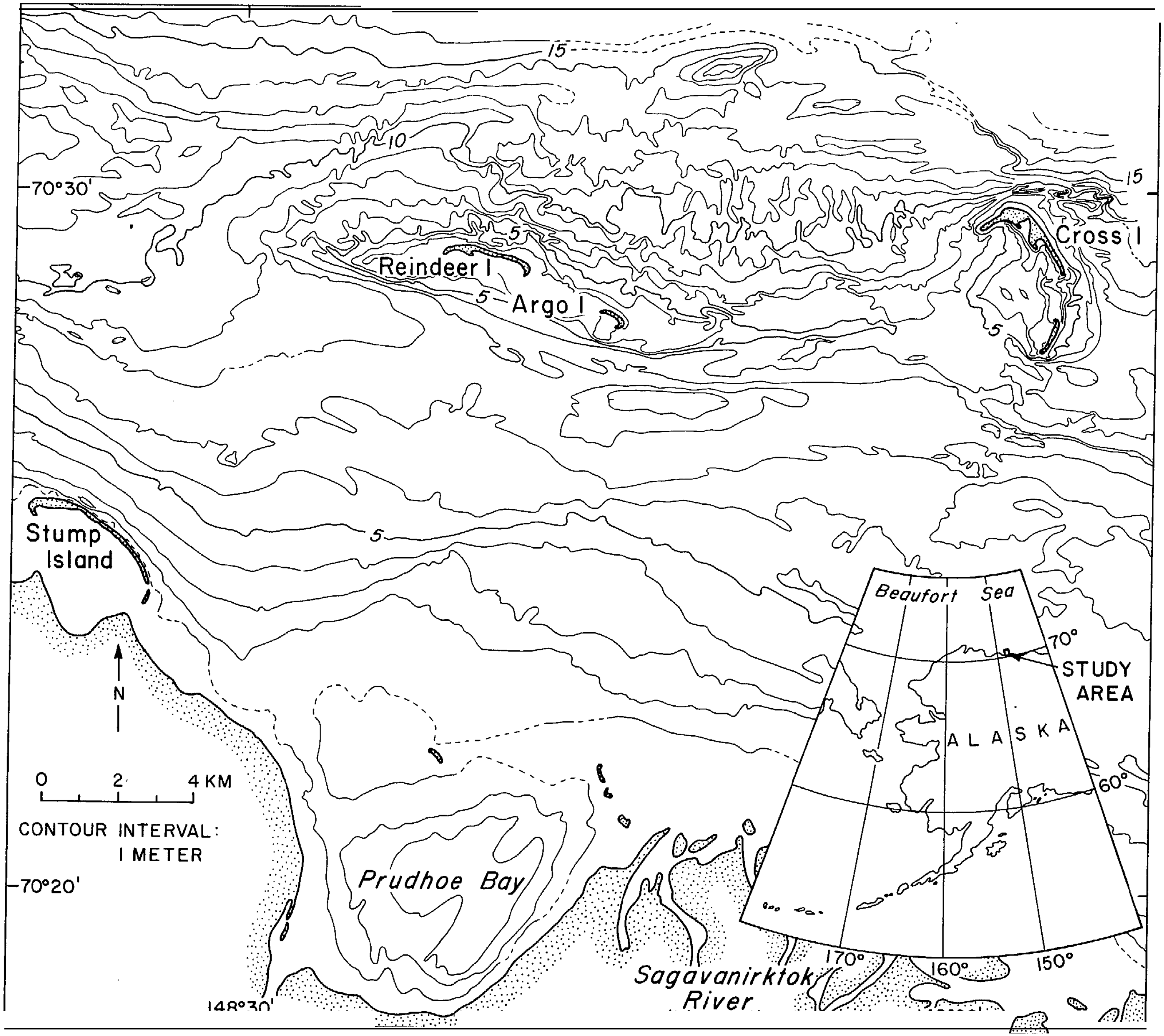


Figure 1. Location map showing irregularly crenulated nature of isobaths seaward of the line of islands, and showing locations of navigation stations.

the formation of isolated depressions where ice temporarily grounded during late summer storms. The depressions probably represent a pitted topography similar to that off Reindeer Island, but the wide spacing between survey lines prevented three-dimensional documentation of the holes, and the report shows only cross sections. Similar observations on drastic changes in relief in an arctic nearshore region were reported by Dr. B. J. Wiseman (written communication, 1978). In 1972 numerous sounding lines run off Pt. Lay in the Chukchi Sea showed no significant irregularities, with a rapid increase in depth from shore to 10 m, from where the depth increased only gradually seaward. Three years later a large shoal had developed 450 to 900 m from shore, on which l-m waves were breaking and landing barges grounded. Wiseman estimated the shoal was 7 to 8 m above the surrounding bottom, but had no boat to verify this. We believe this shoal was not a long, shore-parallel bar, but an isolated mound similar to those found in our study area. Reimnitz, et al. (1972), in a study of ice gouging off Reindeer Island, used fathograms to show features with broad, undulating relief, quite different from jagged relief caused by the plowing action of ice (Reimnitz et al. , 1973; Reimnitz and Barnes, 1974). The origin of the features remained unexplained until the present analysis of repeated, accurately controlled, dense survey networks, which provides a satisfactory explanation for the origin of the broad undulating relief typical of arctic nearshore regions.

Regional Setting

Reindeer Island lies on the west end of a long, broad shoal carrying a number of other small islands (Fig. 1). The present island is about 2,000 m long, as much as 300 m wide, and as much as 1 m high. The presence of scattered ice throughout most of the short summer season and complete ice cover for 9 months each year make the area a low-wave-energy environment. However, in rare years of little ice and increased fetch, waves with a height of of 2 to 3 m can develop. Under such conditions, Reindeer Island and the other small barrier islands, migrate rapidly. The average migration rate (over the past 30 yrs.) for Reindeer, Argo, and Cross Islands is 11 m/yr (Reimnitz, et al., 1980). Barnes and Ross (1980) observed a migration of 18 m in 10 days on Cross Island (Fig. 1) during a 1979 storm. Recently, Arctic barrier islands have tended to divide into two or more fragments and newly formed inlets tend to deepen (Reimnitz et al., 1980). Figure 2 compares Reindeer Island in 1950 and in 1980.

A detailed bathymetric study and diving observations were made near Reindeer Island in 1972 (Reimnitz and Barnes, 1974). These investigations show three sinuous bars parallel to the shoreline. The bottom sediment is predominantly sand, especially on the bars. In the outer portion of the survey area, in water 8 to 10 m deep, the sand cover thins, exposing underlying overconsolidated mud. Grounded ice typically marks the nearshore topographic highs, which act as filters catching ice of equal draft. An example is shown in figure 2, where ice is seen grounded on nearshore bars. Because very different survey techniques were used in the 1972 studies, a comparison of that bathymetry with the modern data would not be fruitful.

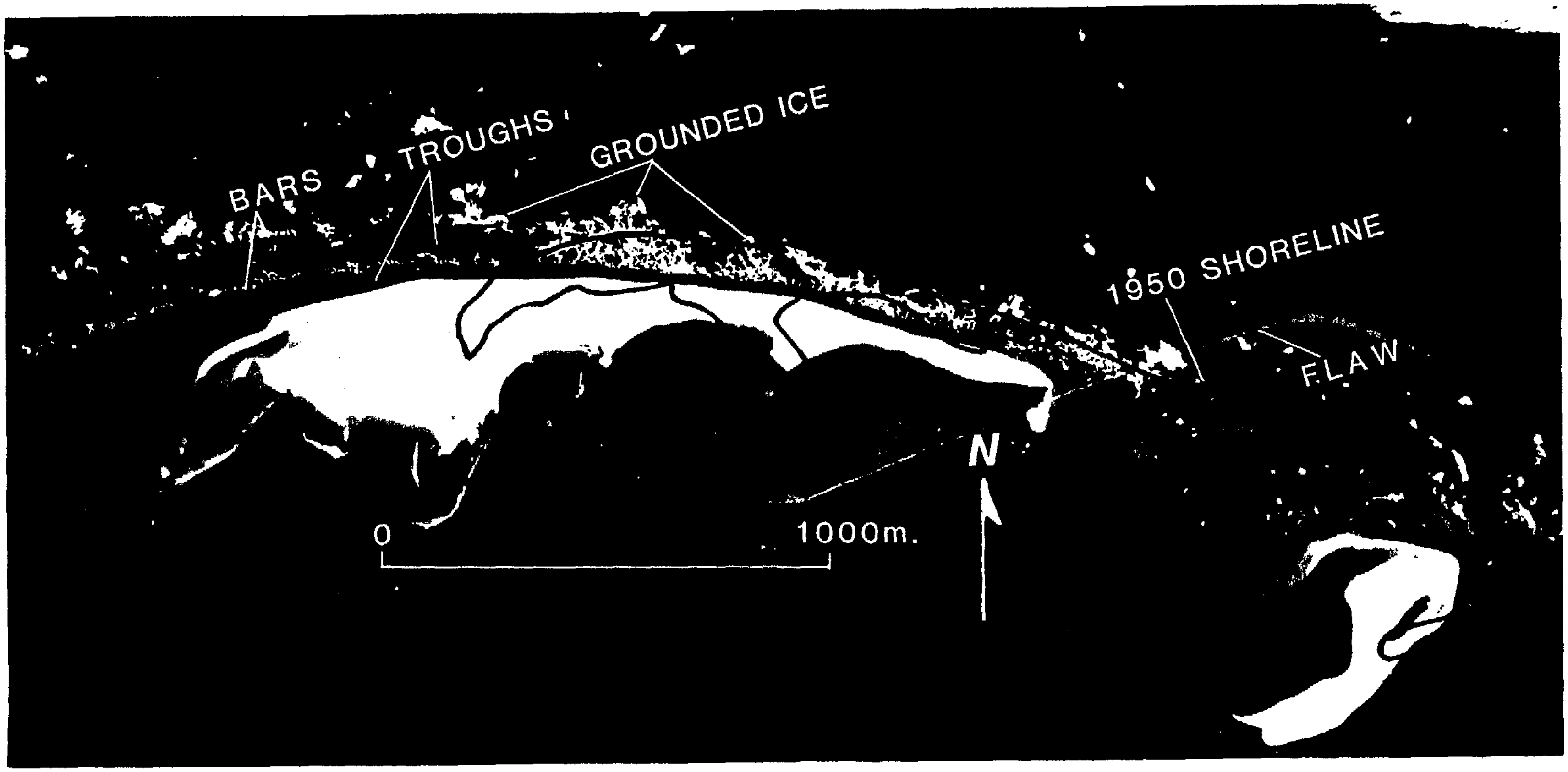


Figure 2. Aerial photograph of Reindeer Island taken July 17, 1980, with the 1950 shoreline superimposed. The trough between the beach and the first offshore bar is 2.5 m deep, but was not covered by our survey lines. A comparison of Reindeer Island in 1950 and 1980 shows how the island has broken in two and migrated to the southwest. The northeast-trending linear flaw is a photo-processing artifact.

METHODS

The first survey was run in 1976 with a Del Norte Trisponder[1] navigation system. The navigation system measures ranges with an accuracy of ± 3 m, and records them on magnetic tape. The shore stations are located at the Humble borehole on Reindeer Island and on the Cross Island RACON tower (Fig. 1). Given the angles between the two ranges used in the study area, the position error can be as much as 5 m. Depths were recorded by a precision survey fathometer with resolution of 10 cm. The ranges and depths were digitized and plotted by computer; contouring was done manually. The line spacing for the 1976 survey was approximately 150 m in an east-west direction and 500 m in a north-south direction (Reimnitz and Kempema, 1980).

The second survey was made in 1979. Essentially the same methods and equipment were used as in the 1976 survey. Part of the navigation data was recorded at 10-sec intervals on magnetic tape and plotted by computer. Water depths were taken from the fathograms and entered manually on this plot. Several additional survey lines, run later in the season through the same area, were also plotted manually (on a UTM-grid) from a paper printout of ranges. Water depths were entered manually on these lines. The depths at line crossings from the two surveys, run about four weeks apart, match precisely, and we are confident of the accuracy of these data. The lines on the 1979 survey were run in a grid pattern with approximately 100-m spacing. This closer spacing provides much better resolution of bottom features than did the 1976 survey. The survey grids for both years are presented by Reimnitz and Kempema (1980).

RESULTS

The water depths measured in the 1976 and 1979 bathymetric surveys were contoured at O.S-m intervals (Figs. 3 and 4). Since the same shore stations were used for both surveys, these two charts can be accurately matched, and changes in water depth and morphology during the 3-yr period can be determined. The greater complexity of the 1979 bathymetry is due to a denser survey net, which explains some of the apparent bathymetry changes. However, real morphological changes are pronounced.

In 1976 the morphology consisted of numerous irregular depressions and mounds (Fig. 3). We attempted to contour the data to show long, continuous, shore-parallel bars, suggested by grounded ice lineations seen here in some years (see Reimnitz and Kempema, 1980) and reported by other investigators elsewhere (Short, 1973; Harper, 1978). Such bars did not exist within the survey area, but may have existed landward of the 3-m isobath, where grounded ice prevented surveying, and where a bar was found in the 1979 survey. In 1972, however, the sea floor landward of the 3-m isobath was a gently sloping sand-plain, rippled and reworked by small waves (Reimnitz and Barnes, 1974).

In 1979 the morphology still consisted of numerous irregularly scattered, isolated mounds and closed depressions with as much as 2 m of relief with respect to the surrounding sea floor (Fig. 4). A single, well-developed, continuous bar lies about 100 m from shore, parallel to the shore. This bar

[1]Any use of trade names is for descriptive purposes only, and does not constitute endorsement by the USGS.

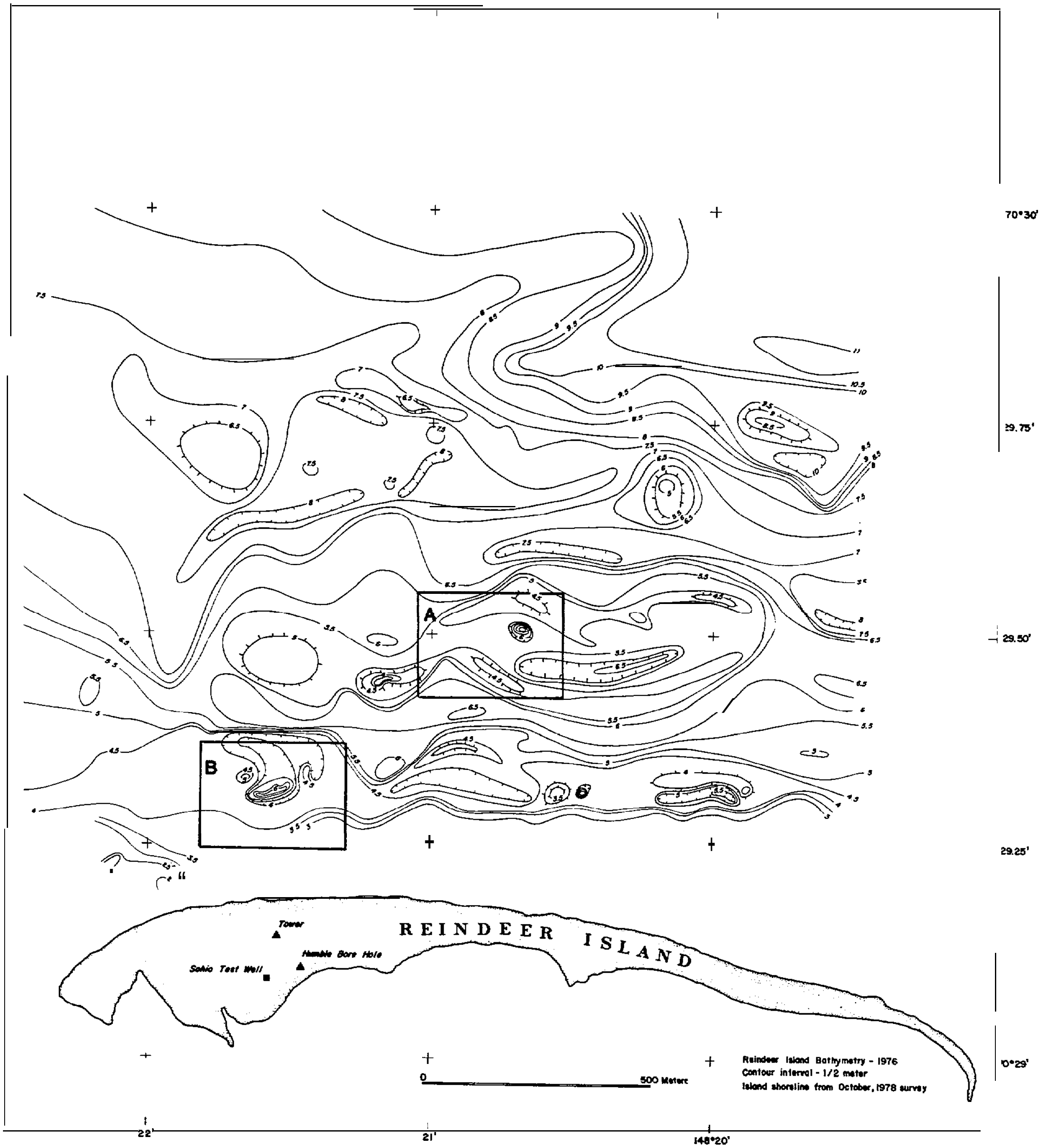


Figure 3. **Bathymetry** of ‘study area contoured at O. 5-m depth interval from 1976 surveys.

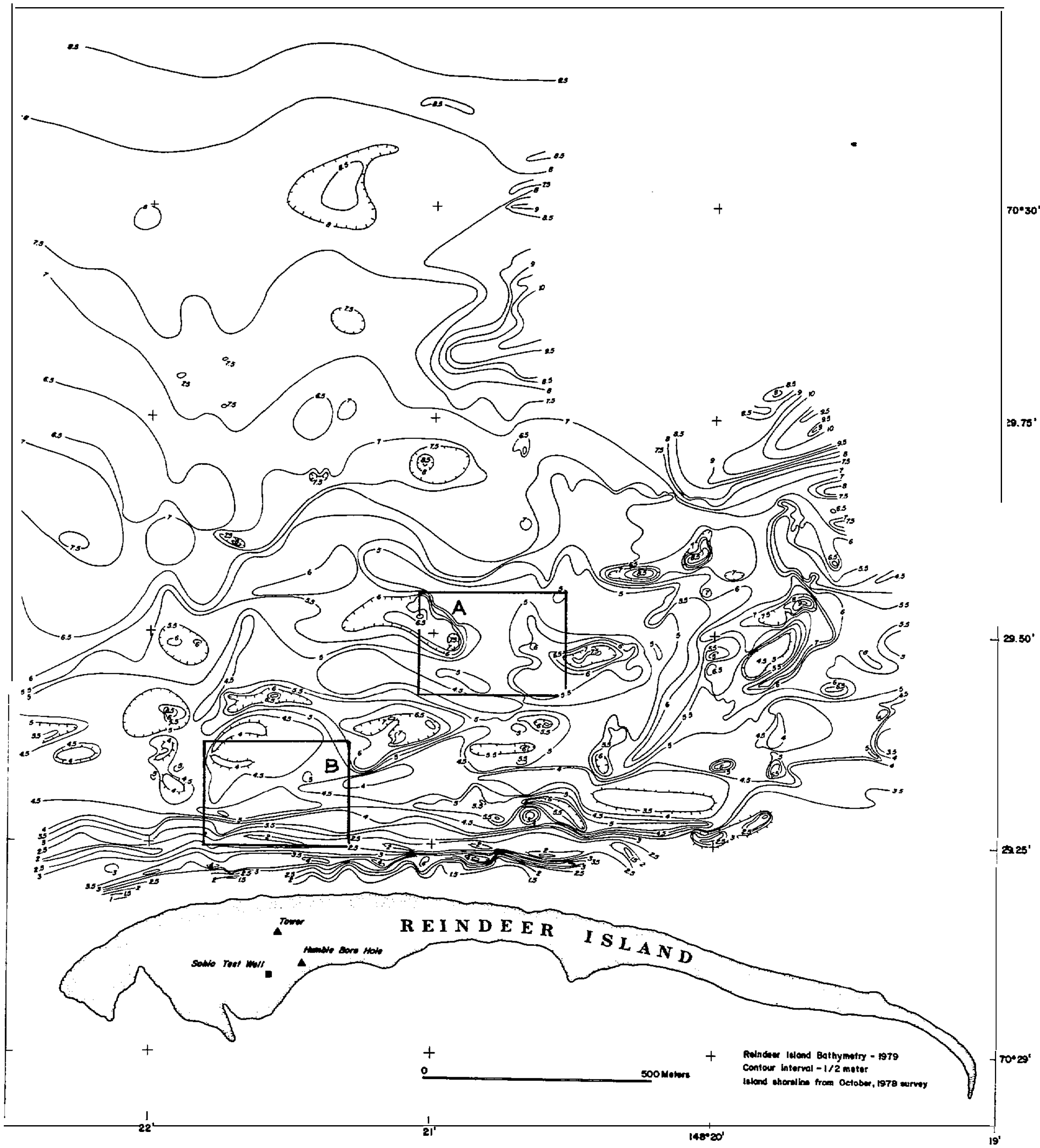


Figure 4. **Bathymetry** of study area contoured at 0.5-m depth interval from 1979 surveys.

stands more than 2 m above troughs on either side. The eastern extent of the bar remains obscure because dense fields of grounded ice were present during the survey period. This bar is clearly visible in Figure 2 which also shows another continuous bar adjacent to the beach. The crest of this bar along the beach is less than one meter below water, too shallow to cross with the survey vessel. In 1980, however, the vessel was taken into the trough between the bar-and the beach from the west end, and the bar was tracked to the middle of the island, where it ended against the beach. The trough in some places was only about 5 m wide, but 2 to 2.5 m deep. This bar and trough did not exist near the beach in 1972, when numerous scuba dives were made from the beach.

A comparison of Figures 3 and 4 reveals considerable changes in seabed morphology. To show these changes more clearly, Figure 5 focuses on two small sectors, A and B, which have been enlarged. Both sectors show semi-circular "potholes" in 1976 that were filled and replaced by different ones - as much as 2.5 m deep - by the year 1979.

DISCUSSION

Previous studies at low and high latitudes show that sandy nearshore environments are generally characterized by gently seaward-sloping bottoms with or without longshore bars (Greenwood and Davidson-Arnott, 1975; Short et al., 1974). The absence at lower latitudes of the type of relief studied here, where the major difference is the addition of ice as a geologic agent, lead us to attempt to explain the highly irregular relief of the arctic nearshore in terms of ice processes.

With the exception of several potholes that formed during fall storms in the offshore area near Barrow, Alaska (Schalk and Hume, 1961; Hume and Schalk, 1976), we have seen no description of nearshore bedform patterns similar to those off Reindeer Island. The large-scale potholes and mounds found here are, however, quite common in the Alaskan Beaufort Sea. In the past, survey lines generally were too widely spaced to reveal these bedforms. For example, the H.O. smooth sheets of the original survey show only 6 tracklines in the study area covered by our 27 tracklines. As a result of such sparse coverage, the seafloor relief could only be represented by very crenelated depth contours seaward of the offshore islands in figure 1, and elsewhere along the arctic shores. On the basis of the detailed, repeated studies presented here, we can eliminate three possible relief-forming processes, and suggest a likely origin for the bedforms.

The potholes and mounds underwent drastic changes over a period of three years, so these bedforms are as dynamic as ice gouges (Barnes, et al., 1978). But the morphology is quite different from that of ice gouges, which generally are straight to sinuous furrows with flanking ridges (Reimnitz et al. , 1972 and Reimnitz and Barnes, 1974), and are only as much as 0.5 m deep and 10 m wide in the nearshore environment (Rearic et al. , in press). One possible method of formation of the potholes is that sediment, frozen to the bottom of a grounded ice floe over a long period of time, is removed when the floe is finally dislodged. However, no cases have been reported of bottom sediment adfreezing to grounded floes in the volumes required to support such a theory. Also such a mechanism could only account for depressions, and not for large mounds which are also present. The direct physical action of sea ice alone, therefore, cannot account for all of the bedforms under study.

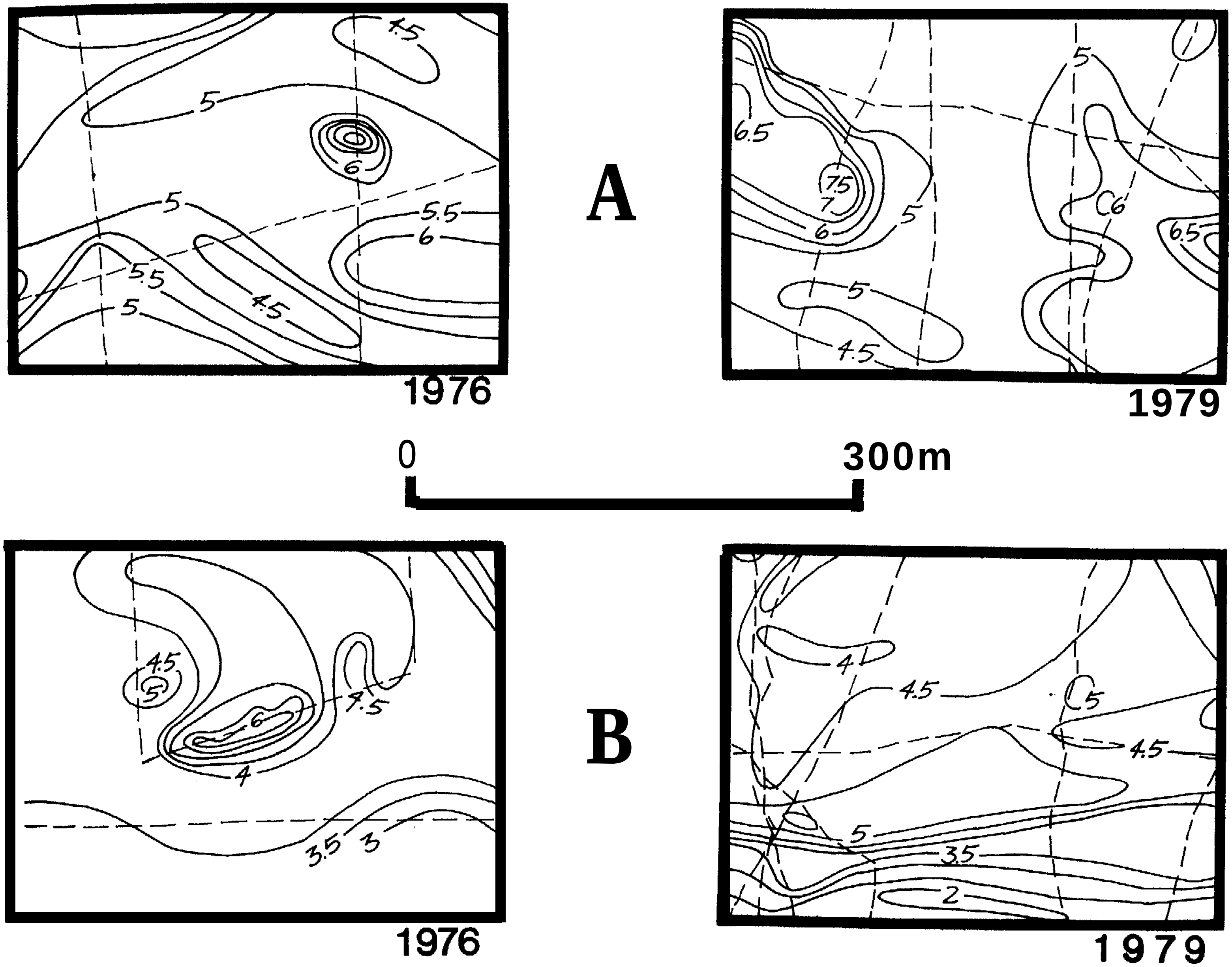
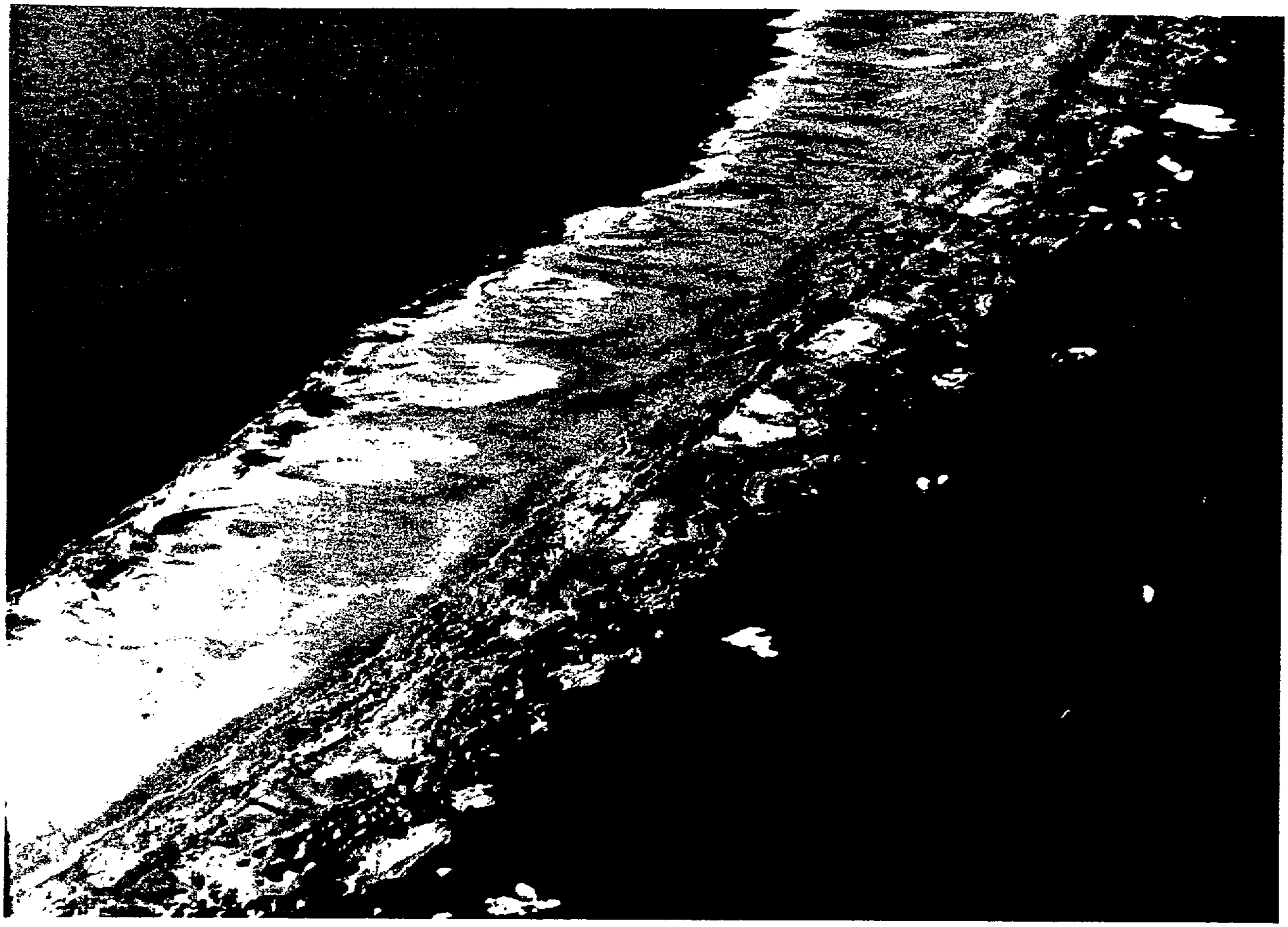


Figure 5. Comparison of identical sectors of the sea floor with relief as mapped in 1976 and 1979. For locations refer to Figures 4 and 5. Tracklines are represented by dashed lines.

The submerged pothole and mound topography off Reindeer Island is, except for the much larger scale of bedforms, similar in morphology to the "pitted beach" topography described by Nichols (1961) and to the "sea-ice kettle" topography on beaches described by Greene (1970). There is however, an important genetic difference between the two types. The beach features previously described are collapse depressions which occur where pieces of ice stranded on accreting or prograding beaches are buried and subsequently melt. On the other hand, the seaward beach and the nearshore region of Reindeer Island, which are rapidly migrating southwestward and away from the survey area (Fig. 2), are erosional surfaces. Here grounded or stranded ice generally is not buried by sediments, and closed depressions therefore must be formed by entirely different processes.

A look at small-scale relief forms on nearby beaches and in the littoral zone, and at processes responsible for these, will be informative. Figure 6, a photograph of Cross Island taken in July, 1979, shows potholes and mounds formed around "multiyear" ice masses during storms occurring after September 20 in the previous fall. The water line in this photograph delineates a complex, intricate topography, which is a result of cut and fill under the action of water around grounded and wallowing ice. The freeze-up period in the fall of 1978, when the pothole topography formed, was one of the stormiest in memory (J. Helmericks, personal communication), marked by 12 days of strong northeasterly winds. While the multiyear ice driven by these winds into the littoral zone may have partially protected the beach, these storms probably caused erosion of the seaward-facing beaches, where the potholes formed. During a similar but ice-free storm during the fall of 1979, the pothole topography shown in figure 6 was destroyed, while the beach retreated 18 m in 10 days, due to erosion (Barnes and Ross, 1980).

Figure 7 shows a piece of ice that was stranded on a beach during a storm surge. The presence of ripple marks completely surrounding the stranded ice, the erosional notch in the ice far below what would have been the flotation line, and the fact that the picture was taken immediately after the storm surge, before much ice could have melted, are evidence that current scour is responsible for the excavation occupied by the ice. The process illustrated here did not result in levees and mounds as products of excavation around the ice, probably in response to the subsequent smoothing action by waves in shallow water, as the storm surge receded. But the lack of a gouge leading to the depression holding the ice is characteristic for ice-wallow terrain, where currents are the principal cause of bedforms. This relationship is similar to that of a deeply buried shipwreck in a scour depression nearshore, with no deep water marking the path along which wave action has worked the vessel shoreward. An example is given in figure 8, showing the Admiral Benson on Peacock Spit at the Columbia River entrance. The vessel is cradled in a 3-m deep scour depression it created on a sand flat while wallowing in breakers at high tide. According to Captain D. Flint (written communication, 1981), third mate on the vessel during the grounding, she worked her way landward to this position during the first week, but continued deepening the hole as the stern rose and fell in a seaway, and as the bow pivoted around the stern with changing wave directions.



gu Po an mo Cr
W an

Figure 7. Stranded ice mass resting in a current-scour depression on a barrier island. The ice rises at least 3 m above the surrounding surface. Note absence of ice gouges on this surface. It was submerged about 2 m during a preceding storm and thus simulates conditions observed around grounded ice on the inner shelf.

Figure 8. The Admiral Benson on Peacock Spit at the Columbia River entrance in 1930. The vessel, caught in a large, 3-m deep cradle, serves as an analog to sea ice sitting in wallow depressions in the Arctic nearshore. Because of the ephemeral nature of ice, this relationship is difficult to demonstrate in the Arctic. (Photo courtesy of the Columbia River Maritime Museum.)

Reimnitz, et al. (1972) and Reimnitz and Barnes (1974) describe the above process for sea ice, and present various lines of evidence showing that grounded ice on the shallow shelf also commonly sits in closed depressions marked by current ripples, and that any ice gouges marking the route traversed by grounded ice have been eliminated by sediment reworking. Using the term ice gouge in this process is however, incorrect. While the ice, aided by the jetting action of water, moves through the sediment along a horizontal path, a linear furrow never forms. The scale of features previously ascribed to current action around grounded ice, however, is much smaller than the relief forms described in this paper.

The draft and other dimensions of multiyear ice floes are a function of water depth--the deeper the water, the larger the ice. In the Beaufort Sea this relationship applies for the inner shelf, from the beach out to about the 20-m-depth contour. Thus, floes with a draft of 15 m, for example, are not found in water much shallower than 15 m. Therefore, extrapolating from the small-scale cut-and-fill relief clearly related to wave and current action around grounded ice in the littoral zone, to the large features mapped in the survey area out to a depth of 8 m, where floes with large dimensions run aground, is not unreasonable.

We hypothesize that the pothole and mound topography is formed by hydraulic processes in two different ways that depend on the role played by ice. In one process the ice plays a passive role, representing a flow obstacle in a current or wave regime, and intensifying flow and creating turbulence around the ice surface, particularly along the ice-bottom contact. This process causes scour depressions, as previously described by Reimnitz and Barnes (1974), as well as mounds or partially surrounding rims of volumes about equal to that of the excavation. In the other hydraulic process the ice plays an active role, either by simple vertical oscillations or by wallowing in a seaway, displacing water forcefully away from the ice-bottom contact. An observer walking along an exposed beach during a storm with isolated ice floes near the coast would be awed by the spectacle of the wallowing and pounding ice and the waves crashing and cascading across the floes driven shoreward and aground by wind and waves. The resulting oscillating, sometimes radial pulses of currents, transport sediments away from the ice-bottom contact and deposit the sediment in irregular mounds in areas away from the ice floe. Diving observations made by Moign (1976) in Spitzbergen reveal glacial ice in crater-like depressions on the sea floor, and illustrate-the erosive aspect of this process.

With increasing tidal range, the amplitude of any ice wallow relief, forming under otherwise similar conditions, would increase accordingly, as ice could ride into shallows with the flood and be set down with the ebb. During the summer months separating our two Reindeer Island surveys, the N.O.S. tidal records for the area show that water levels did not rise more than .5 m above the contour datum. Therefore very little of the relief in figures 3 and 4 can be accounted for by long period deviations of ice flotation levels from mean lower low water.

In both of the hydraulic processes described above the ice is not in contact with the sediment interface at the point where sediment transport occurs. The resulting scour depressions, therefore, are larger than the ice keels responsible for these features, as shown in figure 7.

CONCLUSIONS

The new bathymetric studies in a small sector of nearshore terrain have permitted us to re-map an area of crenelated isobaths so accurately as to show semi-circular patterns and major bottom features that could not be resolved with any previously available coverage. On the basis of our own field observations, we believe that pothole and mound relief patterns are widespread along the shores of the Beaufort Sea. Therefore, caution is advised in using sparse sounding data to contour these regions. The semicircular bedforms are shortlived. They seem to develop better in granular sediment found near shore than in cohesive materials found over large regions farther from shore. Theoretically, such features could be formed at any water depth where ice contacts the sea floor.

In some ice-exposed arctic nearshore regions, continuous, shore-parallel bars prevail in strong contrast to the widespread irregular ice-wallow relief. One such area lies off Pingok Island, 40 km westward of the study area (Short, 1975; Reimnitz, et al., 1980). In recent years in the Reindeer Island study area, small shore-parallel troughs and bars have been found very near the beach. However, the trough adjacent to the beach certainly was not in existence in 1972 when the area was mapped using fathograms and diving observations (Reimnitz and Barnes, 1974).

Most of the nearshore regions along the open coast in the Beaufort Sea, however, are characterized by ice-wallow terrain, an irregularly undulating bottom covered by large potholes and mounds with 2-3 m of relief. The scouring action of water around grounded ice floes seems to be responsible for this morphology. If so, then ice responsible for ice-wallow relief must be stranded principally in the topographic depression it creates during storms, rathern than on topographic highs, where stranded ice is known to occur in calm weather. In water 3 to 6-m deep off Reindeer Island, where the depressions are best developed, maximum ice-gouge incision depths are 0.5 m and maximum ice-gouge incision widths are 10 m (Rearic and Barnes, in press). The scour depressions are therefore considerably larger than ice gouges. The processes leading to formation of these dynamic relief forms should be of concern to developers planning to cross the nearshore zone with buried pipes, as the safe burial depth may exceed 3 meters, rather than one meter as would be indicated by the maximum ice gouge incision depths for this zone.

ACKNOWLEDGMENT

This study is supported jointly by the U.S. Geological Survey and the Bureau of Land Management through interagency agreement with the National Oceanic and Atmospheric Administration under a multiyear program responding to needs of petroleum development of the Alaska continental shelf, and is managed by the Outer Continental Shelf Environmental Assessment Program (OCSEAP).

REFERENCES

BARNES, P. W., McDOWELL, D.M. , and REIMNITZ, ERK, 1978, Ice gouging characteristics: their changing patterns from 1975-1977, Beaufort Sea Alaska: U.S. Geological Survey Open-File Report 78-730, 42 p.

BARNES, P.W., and ROSS, ROBIN, 1980, Fall storm, 1979 - a major modifying coastal event in National Oceanic and Atmospheric Administration, Environmental Assessment of the Alaskan Continental Shelf, Principal Investigators Reports, Apr. 1979 - Dec. 1979 v. II, p. 238-249.

DIONNE, J.C., 1976, Le glaciel de la region de la Grande Riviere, Quebec subarctique, in Dionne, J.C., ed. , La Revue de la Geographic de Montreal, v. 30, Nos. 1-2, p. 133-153.

GREENE, H.G., 1970, Microrelief of an arctic beach: Journal of Sedimentary Petrology, v. 40 p. 419-427.

GREENWOOD, BRIAN, and DAVIDSON-ARNOTT, R.G.D. , 1975, Marine bars and nearshore sedimentary processes in Kouchibouguac Bay, New Brunswick in Hails, John, and Carr, Alan, eds., Nearshore Sediment Dynamics and Sedimentation, New York, John Wiley and Sons, p. 123-150.

HARPER, J.R., 1978, The physical processes affectng the stability of tundra cliff coasts, unpub. Ph.D. Thesis, Louisiana State University, 212 p.

HUME, J.D., and SCHALK, M., 1964, The effects of ice-push on Arctic beaches: American Journal of Science, v. 262, p. 267-273.

_______, 1967, Shoreline processes near Barrow, Alaska, a comparison of the normal and the catastrophic: Arctic, v. 20, n. 2, p. 86-103.

_______, 1976, The effects of ice on the beach and nearshore, Pt. Barrow, Arctic Alaska, in Dionne, J.C., cd., La Revue de la Geographic de Montreal, v. 30, Nos. 1-2, p. 105-114.

McCANN, S.B., and CARLISLE, J.R., 1972, The nature of the ice-foot on the beaches of Radstock Bay, southwest Devon Island, N.W.T., Canada, The Institute of British Geographers, Special Publication No. 4, p. 175-186.

MOIGN, ANNIK, 1976, l'Action des glaces flottantes sur le littoral et les fends marins du Spitsberg central et nerd-occidental, in Dionne, J.C., cd., La Revue de la Geographic de Montreal, v. 30, Nos. 1-2, p. 51-64.

NICHOLS, R.L., 1961, Characteristics of beaches formed in polar climates: American Journal of Science, v. 259, November 1961, p. 694-708.

OWENS, E.H., and McCANN, S.B., 1970, The role of ice in the arctic beach environment with special reference to Cape Ricketts, southwest Devon Island, Northwest Territories, Canada: American Journal of Science, v. 268, p. 397-414.

REARIC, D. M., BARNES, P. W., and REIMNITZ, ERK, Ice gouge data, Beaufort Sea, Alaska, 1972-1980, in National Oceanic and Atmospheric Administration, Environmental Assessment of the Alaskan Continental Shelf; Annual Reports of Principal Investigators for the year ending March, 1980, 14 pp. (in press) .

REIMNITZ, ERK, BARNES, P.W., FORGATSCH, T.C., and RODEICK, C.A., 1972, Influence of grounding ice on the Arctic shelf of Alaska: Marine Geology, v. 13, p. 323-334.

REIMNITZ, ERK, BARNES, P.W., and ALPHA, T.R., 1973, Bottom features and processes related to drifting ice on the arctic shelf, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-532.

REIMNITZ, ERK, and BARNES, P.W., 1974, Sea ice as a geologic agent on the Beaufort Sea shelf of Alaska, in Reed, J.C., and Sater, J.E., eds., The Coast and Shelf of the Beaufort Sea, Arctic Institute of North America, Arlington, Vs., p. 301-351,

REIMNITZ, ERK, KEMPEMA, EDWARD, ROSS, ROBIN, and OLSON, ROBERT, 1980, Additional observations on geomorphic changes in the Arctic coastal environment in National Oceanic and Atmospheric Administration, Environmental Assessment of the Alaskan Continental Shelf, Principal Investigators Reports, Apr. 1979 - Dec. 1980, v. II, p. 171-188.

REIMNITZ, ERK, and KEMPEMA, EDWARD, Super sea-ice kettles in the Arctic nearshore zone - Reindeer Island, in National Oceanic and Atmospheric Administration, Environmental Assessment of the Alaskan Continental Shelf, Principal Investigators Annual Reports for the year ending March, 1980, v. 4, p. 284-312.

REX, R. W., 1964, Arctic Beaches, Barrow, Alaska, in Miller, R.L., cd., Papers in Marine Geology, Shepard Commemorative Volume, New York, McMillan Co. , p. 384-400.

SCHALK, M., and HUME, J.D., 1961, Review of shoreline investigations 1954-1959, Point Barrow, Alaska, in The First National Coastal and Shallow Water Research Conference, Baltimore, Tallahassee, Los Angeles, October, 1961, Proceedings: The National Science Foundation and the Office of Naval Research, p. 91-94.

SHORT, A.D., 1973, Beach dynamics and nearshore morphology of the Alaskan Arctic Coast, unpublished Ph.D. Thesis, Louisiana State University, 140 pp.

SHORT, A.D., 1974, Offshore bars along the Alaskan Arctic coast: Journal of Geology, v. 83, p. 209-221.

SHORT, A.D., COLE, A.M., and WRIGHT, L.D. ,1974, Beach dynamics and nearshore morphology of the Beaufort Sea Coast, Alaska, in Reed, J.C., and Sater, J.E., eds., The Coast and Shelf of the Beaufort Sea, Arctic Institute of North America, Arlington, Vs., p. 477-488.

SHORT, A. D., 1976, Observations on ice deposited by waves on Alaskan arctic beaches, in Dionne, J.C., cd., La Revue de la Geographic de Montreal, v. 30, Nos. 1-2, p. 115-122.

TAYLOR, R.B., and McCANN, S. B., 1976, The effect of sea and nearshore ice on coastal processes in Canadian arctic archipelago, in Dionne, J.C., cd., "La Revue de la Geographic de Montreal, v. 30, Nos. 1-2, p. 123-132.