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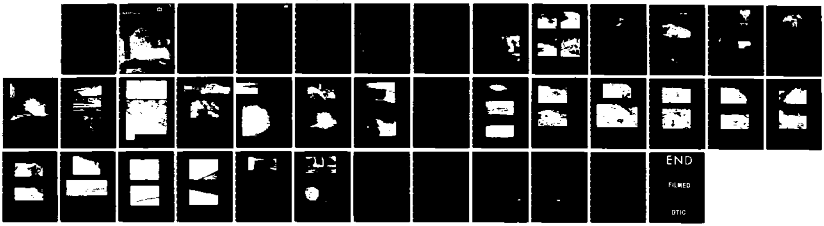

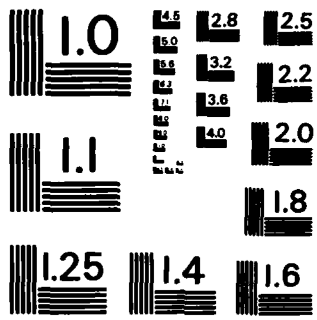

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CRREL REPORT 84-26

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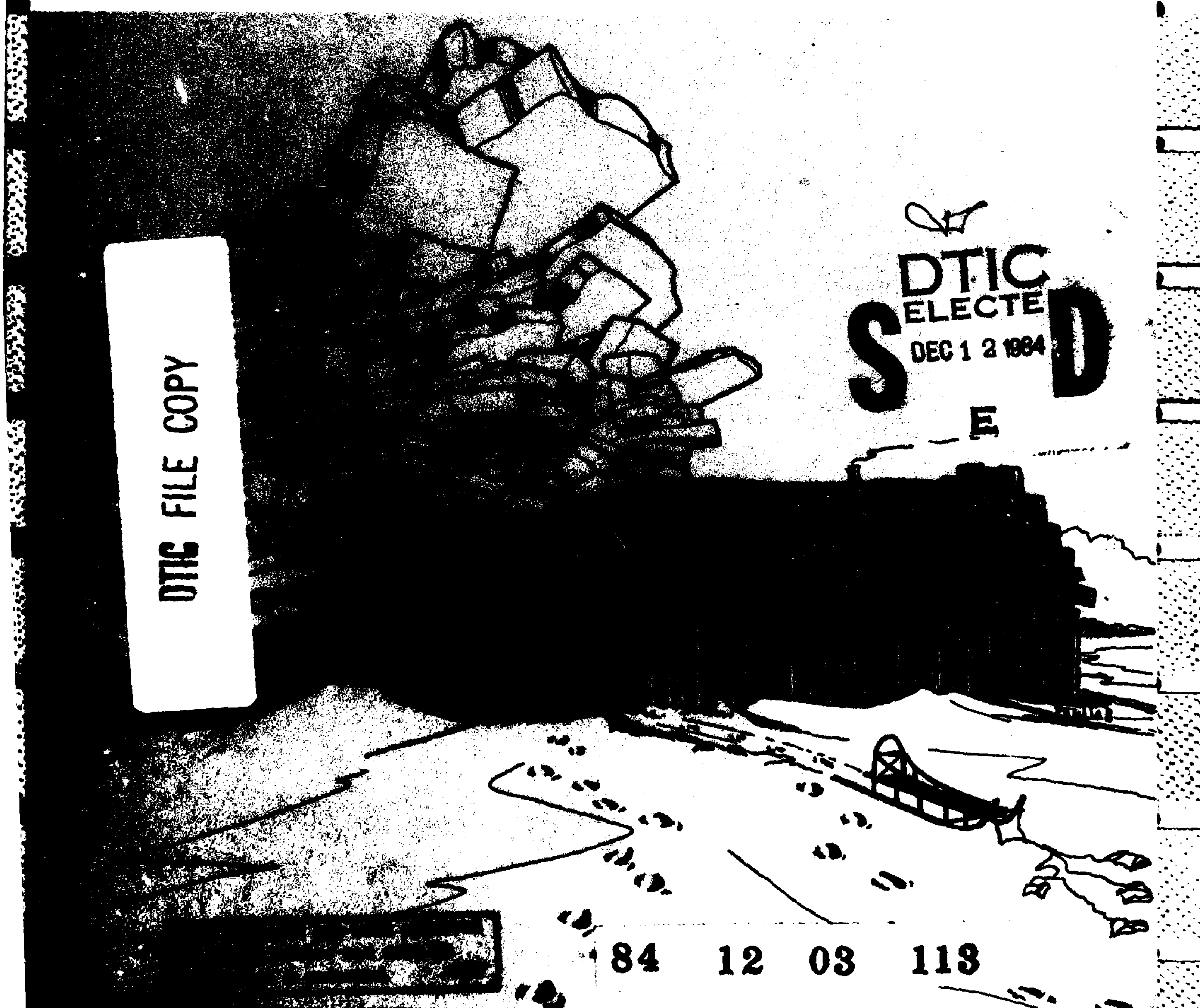
AD-A148 428

Shore ice ride-up and pile-up features

Part II: Alaska's Beaufort Sea coast—1983 and 1984



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CRREL Report 84-26

September 1984

Shore ice ride-up and pile-up features

Part II: Alaska's Beaufort Sea coast—1983 and 1984

Austin Kovacs

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Observations of shore ice pile-up and ride-up along the Alaska Beaufort Sea coast in 1983 and 1984 are presented. New information on historical accounts of onshore ice movement, uncovered since publication of Part I in this series, is reported. An account is given of ice overtopping a concrete caisson exploration island in the Canadian Beaufort Sea.

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PREFACE

This report was prepared by Austin Kovacs, Research Civil Engineer, Applied Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory. The study was funded by the U.S. Bureau of Land Management through the National Oceanic and Atmospheric Administration's Alaska Outer Continental Shelf Environmental Assessment Program.

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ILLUSTRATIONS

SHORE ICE RIDE-UP AND PILE-UP FEATURES
Part II: Alaska's Beaufort Sea Coast—1983 and 1984

Austin Kovacs

INTRODUCTION

This report extends the data base on major shore ice pile-up and ride-up events observed along the Beaufort Sea coast presented in Part I of this series (Kovacs 1983a). Part I covered the winters of 1979–80, 1980–81 and 1981–82. Part II presents observations made in early May and late July 1983 and mid-May 1984. Part I is also an extension of our other work on the subject (Kovacs and Sodhi 1980, Kovacs et al. 1982, Kovacs 1983a and b, Sodhi and Kovacs, in press), and includes the observations of Kovacs and Kovacs (1983) on sea ice movement onto arctic and subarctic shores. The accumulated data in these reports constitute evidence of the severity of these events and the forces active during them. Future reports in this series will present shore ice pile-up and ride-up observations made along the Kotzebue Sound and Chukchi Sea coasts of Alaska.

OBSERVATIONS

In early May 1983, a helicopter reconnaissance flight was made from Pt. Barrow to the U.S.–Canadian border (see Appendix, Fig. A1 and A2) for the purpose of observing shore ice pile-up and ride-up features extending 5 or more meters inland from the sea.

The first feature observed was a shore ice pile-up on Tapkaluk Island (position A, Fig. A1). The rubble, composed of ice blocks ½ m thick, was 3 to 4 m high and extended up to 10 m inland. Further east on Igalik Island (position B) we observed the remains of a large shore ice pile-up which formed here during the 1981–82 winter (Kovacs 1983a). April 1982 views of this pile-up are shown in Figure 1. In places the pile-up was over 11 m

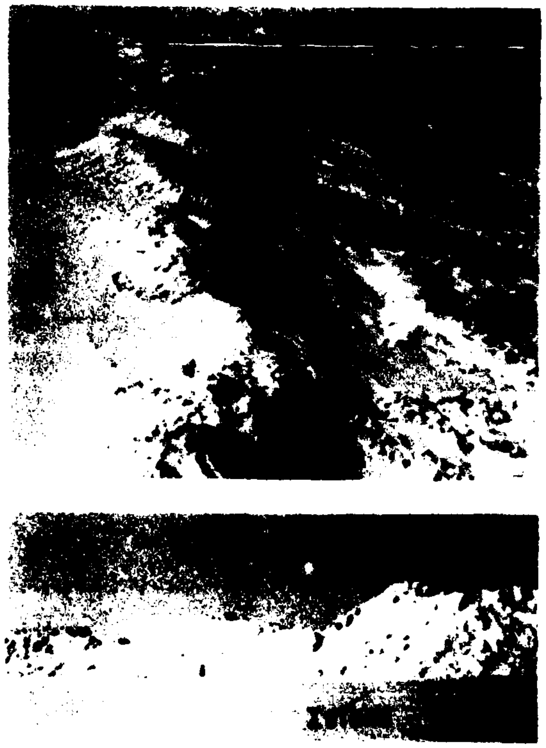
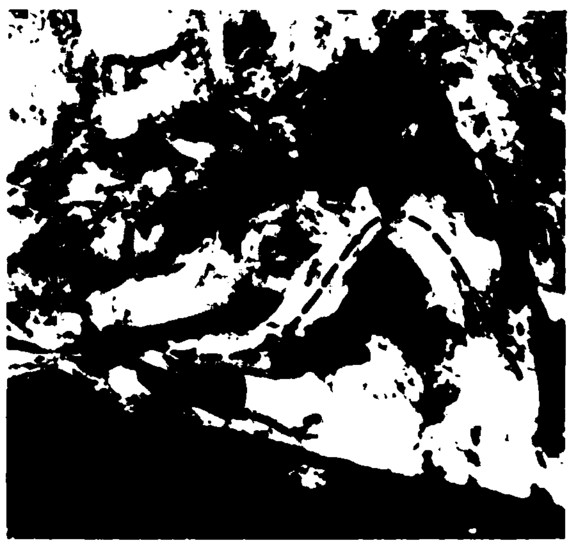


Figure 1. Aerial (a) and ground (b) views of ice pile-up on southeast Igalik Island, April 1982. Note size of person in relation to ice pile in photo b.

a. The island in the background is Kulgurak Island, which is seen to have an ice pile-up remaining at the northwest corner.

b. The back side of the ice pile-up (1) showing the wave-undermined ice extending out over the waters of Elson Lagoon. Note the general lack of ice block detail and absence of voids in the ice face.

c. The back (lagoon) side of the largest of the ice pile-up remains. Note that most of the ice is covered with sandy gravel.



d. A side view of the far end of the large ice pile-up. The internal block structure and sediment are visible, as is one portion of an ice sheet which had buckled into a convex shape, as outlined by the dotted line.

Figure 2. Aerial (a) and ground (b, c and d) views of ice pile-up remains on Igalik Island, August 1982.

Figure 3. Remains of shore ice pile-up (1, 2 and 3) on Igalik Island in May 1983.

high and it consisted of ice blocks 0.55 m thick. The pile-up as it appeared in August 1982 is shown in Figure 2. At this time the remaining ice was up to 5½ m high, and in places it was covered with a layer of sediment brought ashore by ice which had gouged into the sea floor. An aerial view of the ice formations remaining on 25 May 1983 is shown in Figure 3. Arrow 1 points to ice pile no. 1 shown in Figure 2. This pile was still about 4 m high. The ice blocks at the base of this formation (Fig. 3) are from the breakup of the cantilevered portion of the ice shown in Figure 2. Much of the remaining ice was found covered with seabed sediment up to 0.20 m thick, and the underlying ice structure was discolored by similar debris (Fig. 4). Sea ice movement onto the land thus helps to restore the beach with material eroded by waves and current processes.

In early August 1983 when we flew over Igalik Island in a fixed-wing aircraft the ice formations were still visible. Protected as they were from solar radiation by the mantle of dirt, portions of these ice formations survived the last few weeks of the 1983 summer and were found to be up to 2 m high in early May 1984.

On the northwest end of Kulgurak Island (position C, Fig. A1), ½-m-thick sea ice had piled to a height of 5 m and extended up to 10 m inland. Farther along the island we saw where ice had gouged into the beach for a distance of about 30 m from the sea. This ice ride-up scar was formed during the spring of 1982 and will remain until removed by storm overwash processes.

Sea ice was found pushed up to 25 m inland on Tulimanik Island (position D). This ice was also ½ m thick. The ice invaded several hundred meters of the shoreline.

Southeast of Tulimanik Island (position E) ½-m-thick sea ice had piled up to 10½ m high on a 2-m-high island (Fig. 5 and 6). At site 1 (Fig. 5) the ice had been pushed 80 m from the seaward side of the island, across the island and onto the lagoon ice. At site 2, the sea ice had been pushed about 40 m across the island and about 80 m onto the lagoon ice. A view of this 120-m-long by 30-m-wide override,* as seen from the seaward side, is shown in Figure 7. Note the seabed debris incorporated in the ice rubble.

The mainland can be seen a short distance beyond site 1 in Figure 5. Along ½ km of this coast, ½-m-thick sea ice was found piled up to 5 m high and 30 m inland on the 2- to 3-m-high coastal bluff.

Near the Lonely Dew Line Station (position F, Fig. A1) a shore ice pile-up was observed which reached 5 m high and extended over 8 m inland.

*The term *ice override*, as used in this report, signifies an event in which the ice has moved completely over an island, causeway, etc.

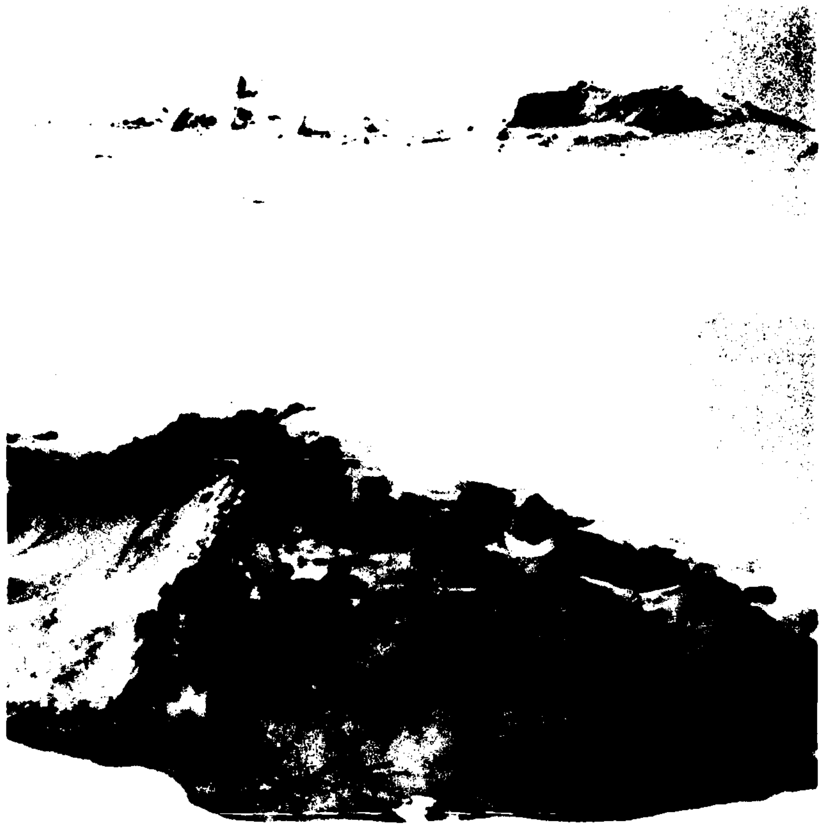


Figure 4. Debris-covered ice, Igalik Island.

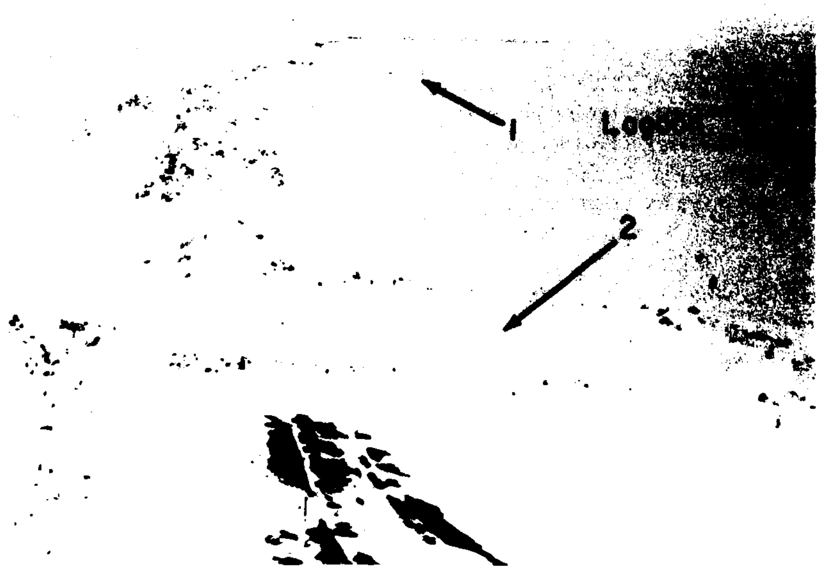


Figure 5. Shore ice pile-up and two ice overrides on barrier island at position E in Figure A1.

Figure 6. Shore ice pile-up at position E in Figure A1. Arrow indicates point where the sea ice thrust 120 m over the island and onto the lagoon ice on the south side. Note that the ice sheet at the top of the shore ice pile-up rose vertically out of the rubble. An explanation of ridge building related to this phenomenon can be found in Kovacs and Sodhi (1979, 1980) and Sodhi and Kovacs (in press).

Figure 7. Ice override at site of arrow in Figure 6.

Figure 8. Sea ice blocks in pile-up on Spy Island.

East of Lonely (position G1) an ice-pushed debris pile discussed by Kovacs (1983a) was still visible. In August 1982 this debris pile was up to 3 m high. Additional internal ice melting during the remainder of the 1982 summer had reduced the pile to about half this height by May 1983.

On the barrier island at position G2 many ice-pushed gravel berms extended up to 15 m inland. In early August 1983 we flew past this island in a fixed-wing aircraft and saw places where sea ice had completely overridden the island. No ice remained, but the island's surface was visibly scarred by ice gouge striations. We could also see where the ice had gouged up the shallow sediments for a distance of about 20 m on the south side of the island. We believe this ice override event occurred during the 1983 spring breakup.

A few hundred meters west of Esook (Fig. A1) portions of the 5-m-high ice-pushed peat piles first observed in May 1981 by Kovacs (1983a) were still visible. Subsequent internal ice melting had reduced their height to about 1½ m. The building at Esook (spelled *Ksook* in Kovacs 1983a) was measured to be about 14 m from the edge of the 2-m-high coastal bluff. In the spring of 1982 the structure was about 19 m from the bluff. The bluff had retreated 5 m in one year—not unusual for this section of coast, where average shoreline erosion has been found to be over 10 m per year (Kovacs 1983a).*

*In May 1984 we found the building to be 12 m from the bluff.

About 1 km east of Esook, sea ice was found piled up to 2 m high along the edge of a 3-m-high bluff. And on the east side of Cape Halkett sea ice was piled up to 1 m high on top of the 3-m-high bluff.

Large shore ice pile-ups were found on Spy, Pingok and Long Islands (positions H, I and J, Fig. A1 and A2). Smaller pile-ups were noted on Cottle Island (position K) and on a small island east of Pingok Island (position L). The ice incorporated in these pile-ups varied in thickness from 0.5 to 0.8 m (Fig. 8). On Spy Island the ice rubble extended over 800 m along the north shore (Fig. 9) and reached a height of 8 m (Fig. 10). For a distance of about 150 m on the eastern end of the pile-up the ice rubble extended across the island onto the lagoon ice (Fig. 9 and 11). The island was about 18 m wide at this location. Here again a large quantity of offshore sediment was found incorporated in the ice rubble (Fig. 10). This seabed material became even more noticeable during our late July visit to Spy Island in a small Alaska Fish and Wildlife outboard motor boat. An aerial view of Spy Island taken on 23 July 1983 shows the sediment-darkened shore ice pile-up (Fig. 12). The east end of the ice feature still extended across portions of the island. For scale the large pond at the center of the upper photo in Figure 12 is 130 m long.

The large grounded shear ridge, which extended northward from the west end of the shore ice pile-up as seen in Figure 9, was still in place in July as

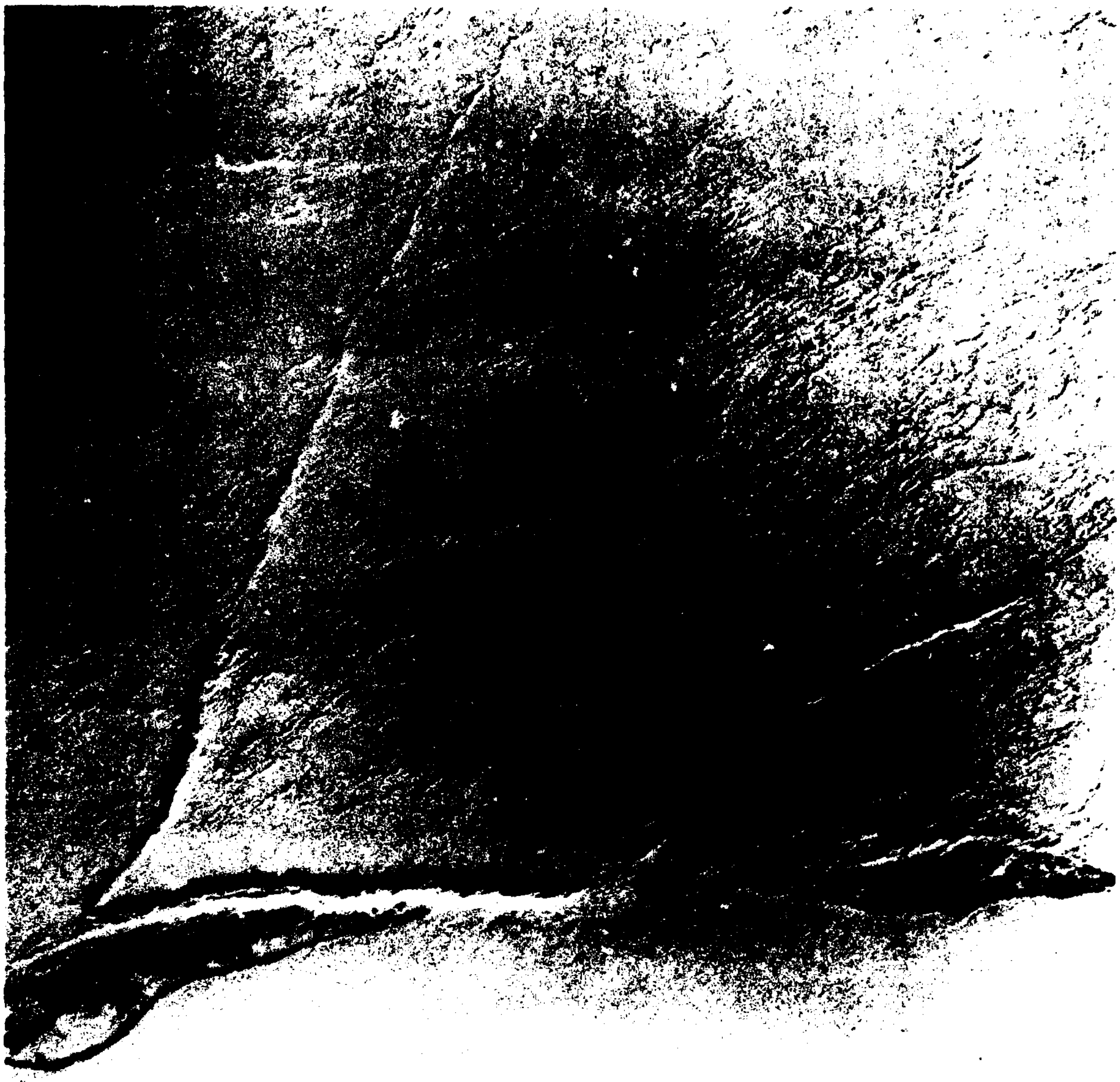


Figure 9. Aerial photo of shore ice pile-up on Spy Island, 22 March 1983 (photography by Air Photo Tech).

seen in Figure 12. A view of the grounded shear ridge from the island and the shore ice pile-up is shown in Figure 13.

The sediment debris covering the shore ice pile-up is quite apparent in Figure 13, and a smaller amount of debris can be seen on the ice surface of the offshore shear ridge. The sediment on the shore ice pile-up was found to consist of two types, a sandy silt and a gravelly sand. The former material can be found about 50 m offshore in water 4 or more meters deep, while the latter is generally found near shore in waters less than 4 m deep. This segregation of material indicates that during the ice piling event on Spy Island, the sea ice was driven down 4 or more meters to the seabed, where it then gouged up the sediments and transported this material shoreward. On the south side of the shore ice pile-up, melt and rainwater runoff had washed a large quantity of sediment debris onto the island. This material was up to 0.3 m

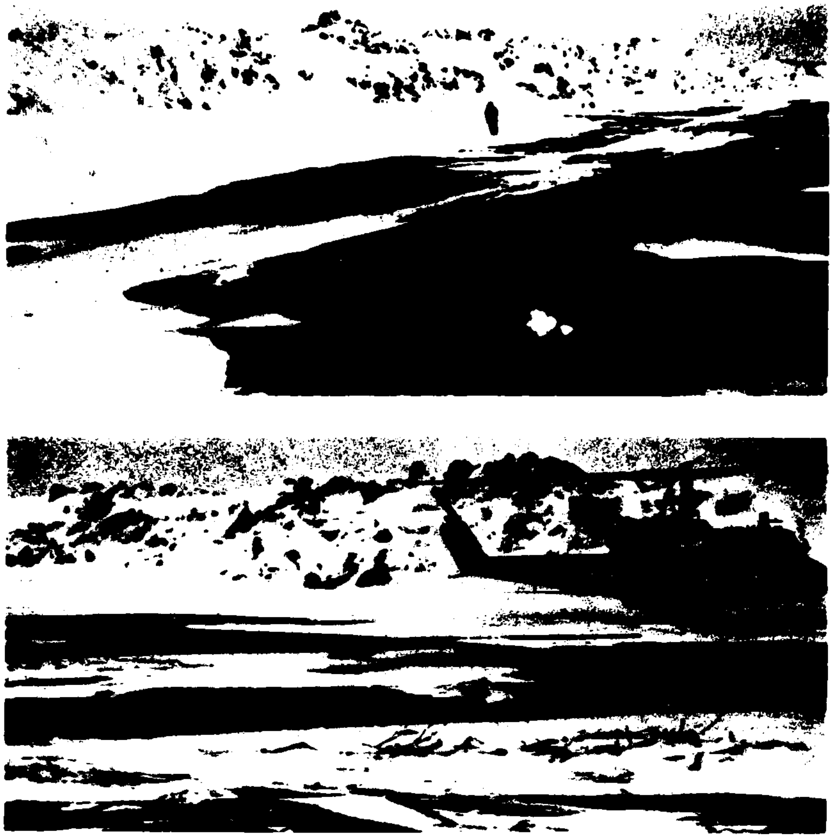


Figure 10. Ground views of shore ice pile-up on Spy Island. Note sediment incorporated in the ice rubble.

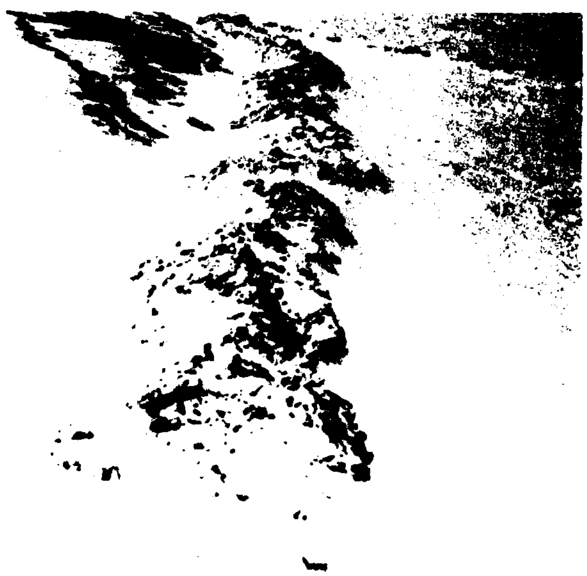


Figure 11. Portion of shore ice pile-up, in foreground, completely covering Spy Island.

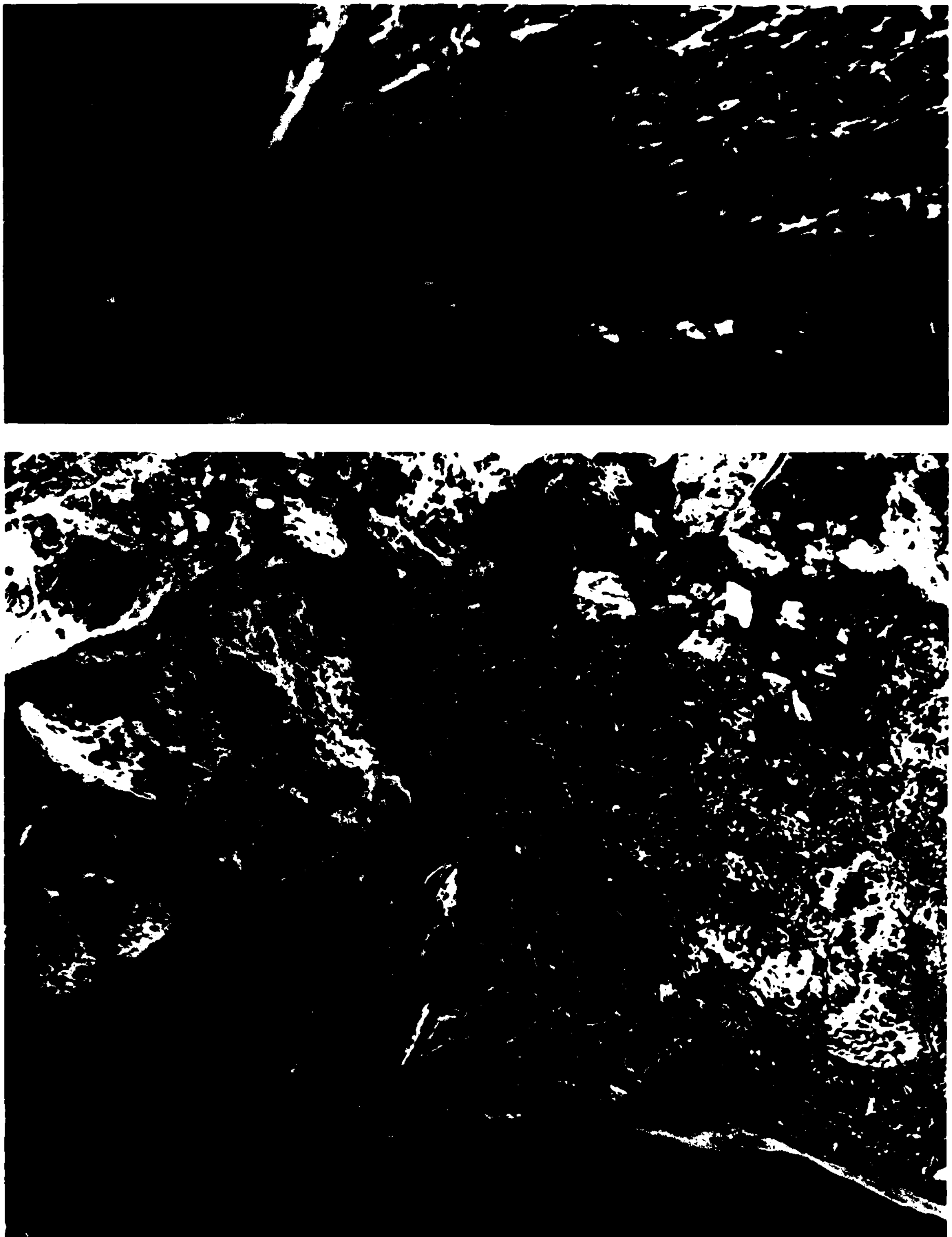


Figure 12. Spy Island shore ice pile-up, July 1983. The ice floes in the lower photo are dark from dirt which was blown out onto the ice during the winter. This transport was so heavy during the winter of 1982-83 that it is a striking feature in many of the spring Landsat images of both the Beaufort and Chukchi Sea coasts. The arrow in the upper photo indicates relative position and direction from which photo in Figure 13 was taken (photograph by Air Photo Tech).

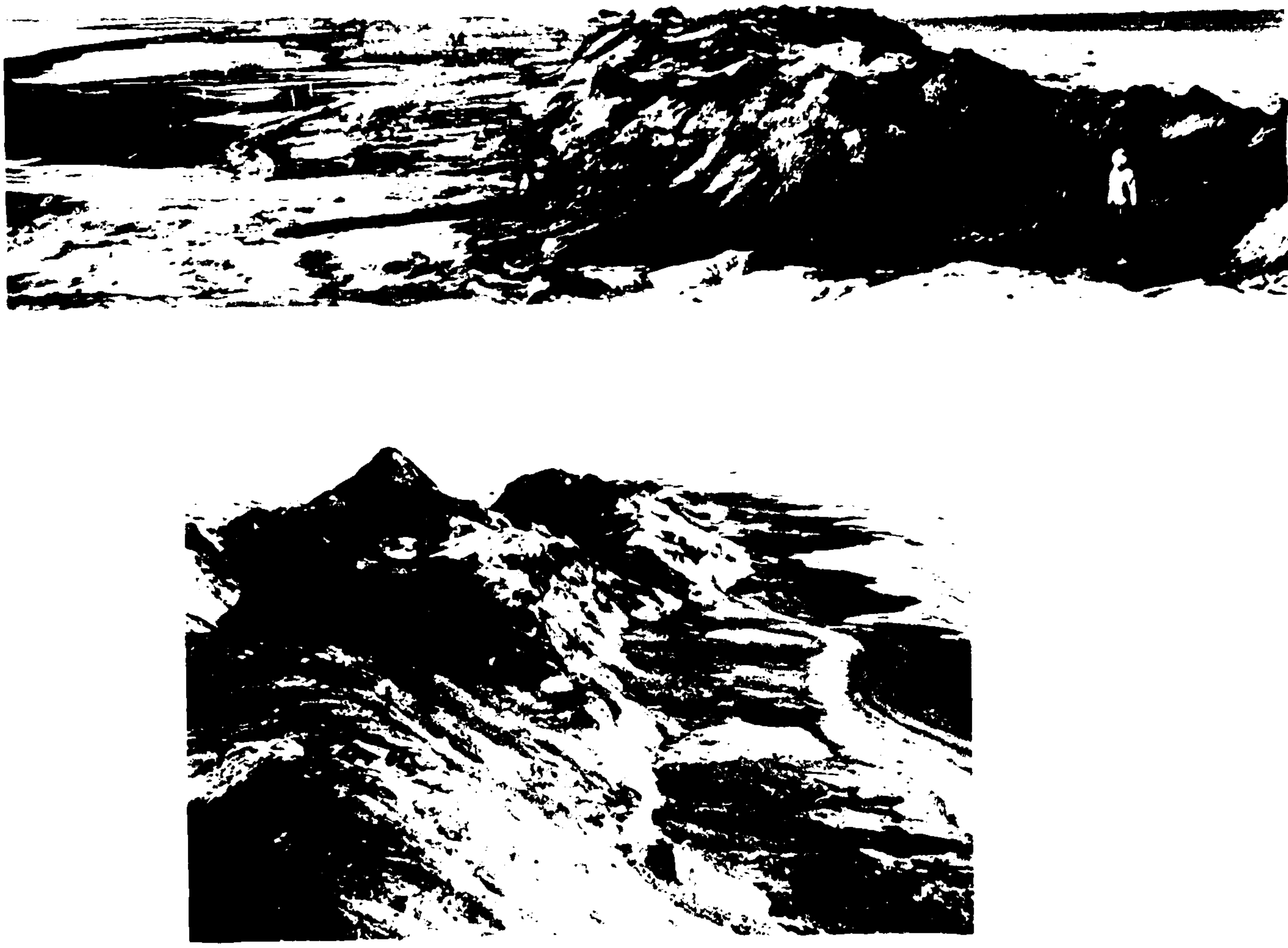


Figure 14. Shore ice pile-up on east end of Spy Island.

thick near the toe of the ice formation. At the end of July 1983, portions of the shore ice pile-up were still over 6 m high (Fig. 14).*

The shore ice pile-up on Pingok Island extended over 1 km along the eastern end of the island (Fig. 15). The ice rubble not only covered the 10- to 20-m-wide beach area, but also overtopped the 3-m-high inland bluff behind the beach. The ice pile-up was up to 10 m high. The ice rubble on the island, as seen from the top of the east end of the shore ice pile-up looking west, is shown in Figure 16.

A 1-km-long shore ice pile-up on Long Island is shown in Figure 17. For scale, the width of the ice runway is about 38 m. Offshore we saw where the [illegible]-m thick sea ice had been buckled upward (Fig. 18). The uplifted ice sheet surface was found to be laced with 0.15- to 0.2-m deep secondary fractures which extended away from the primary hinge fracture. At this depth there was another fracture plane which paralleled the ice surface (Fig. 19). This fracture occurred at the transition between the isotropic granular ice and the lower columnar ice layers. Under stress the two ice layers, having different "elastic" properties, were not strain compatible and separated. Apparently, the far field forces which formed the shore ice pile up were concentrated at this site and buckled the ice sheet. The localized stress needed to buckle the ice sheet can be estimated from the [illegible]

*In May 1984, several dirt covered ice mounds up to 3 m [illegible] still existed on the island.

Figure 13. Spy Island shore ice pile-up as viewed from the east. Note sediment on surface and accumulation at the base of the ice formation. Grounded shear ridge is seen beyond open water at top right.

Figure 15. Airphoto of Pingok Island shore ice pile-up (photograph by Air Photo Tech).

Figure 16. Pingok Island shore ice pile-up. Note offshore sediment incorporated into the ice rubble.

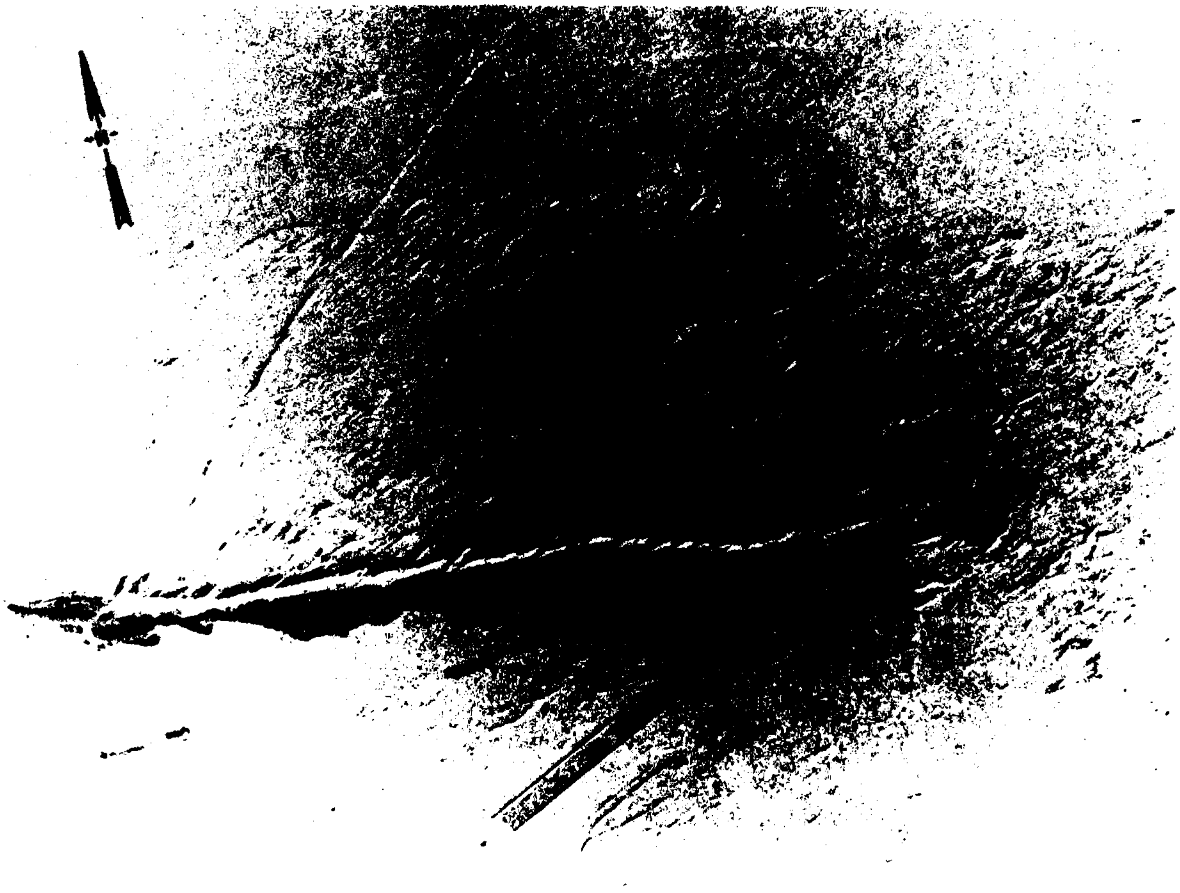


Figure 17. Shore ice pile-up on Long Island (photograph by Air Photo Tech).

Figure 18. Buckled ice sheet.

Figure 19. Internal fracture surface (dashed line).

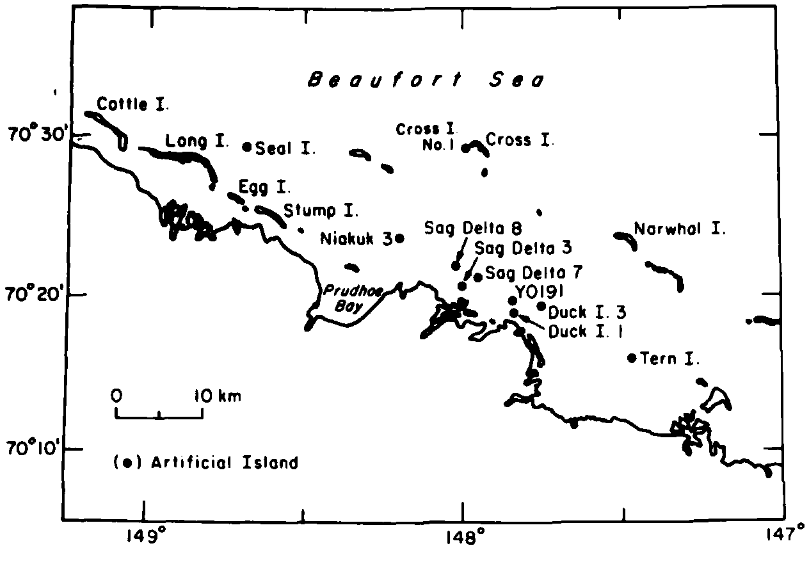


Figure 20. Stefansson Sound area.

$$B_s = K L^2/t$$

where B_s = buckling stress (N/m²)
K = foundation modulus (9810 N/m³)
L = characteristic length = $(E_{eff}t^3/12K)^{1/4}$
E_{eff} = effective Young's modulus of elasticity = $E/(1-\nu^2)$
t = ice thickness (0.5 m)
E = Young's modulus of elasticity of sea ice ($\approx$2 GPa)
ν = Poisson's ratio (0.3).

Using the values shown, the buckling stress was estimated to have been on the order of 1 MPa. The stress in the ice sheet needed to create the shore ice pile-ups on Spy, Pingok and Long Islands was probably on the order of ¼ MPa, as may be estimated from the work of Kovacs and Sodhi (1980).

Along the eastern end of Cross Island and on the east side of No Name Island (position M, Fig. A2) shore ice pile-ups up to 7 m high were observed.

On the northwest side of Narwhal Island (Fig. A2) the sandy gravel surface was scarred by a 20- to 25-m-long ice ride-up. This event is believed to have occurred during the 1982 spring breakup, as no ice was observed on the island at this location during our April 1982 reconnaissance. At the southwest end of Narwhal Island, ⅓-m-thick ice was thrust from the west approximately 30 m across the island. A 50-m-long override and a 35-m-long override were measured on two of the smaller islands (position N, Fig. A2) southeast of Narwhal Island. In addition, in several places ice was driven from the west onto these islands up to 30 m inland, and shore ice pile-ups to 3½ m high existed. This ice movement probably occurred about 19 October 1982 during a severe offshore storm. Winds gusting to 90 knots were reported by several offshore operators. The air temperature was about -3 °C. Barges were broken loose from their moorings and driven with the ice from Stefansson Sound over 180 km eastward to Barter Island (Fig. A2).

The October storm also pushed ⅓-m-thick ice up on the man-made exploration islands located in Stefansson Sound (Fig. 20). The artificial islands between Sag Delta 8 and Tern Island had the most ice rubble piled on their sloped, sandbag-covered sides. These islands are typically 4 m high. On three islands, sea ice had overtopped the sandbag perimeter wall around the top edge of the island. At one island, the ice extended up to 5 m inland and had piled 2 to 2½ m high. On another island the sea ice had piled up to 3 m high on one edge of the sandbag perimeter wall and in places had cascaded 3 m inland. An aerial view of one of the islands is shown in Figure 21. The ice rubble piled on the side of this island and on its surface is shown in Figures 22 and 23.

Farther east we observed a 5- to 8-m-long ice ride-up on the south side of Pole Island (position O, Fig. A2) and a 25-m-long ice override of the east end of the small island west of Tigvariak Island (position P). Ice thickness was ⅓ m.

Shore ice ride-ups were seen on several of the barrier islands located northeast of Anderson Pt.

Figure 21. Ice ride-up rubble on man-made gravel exploration island.

Figure 22. Ice ride-up on side of exploration island.

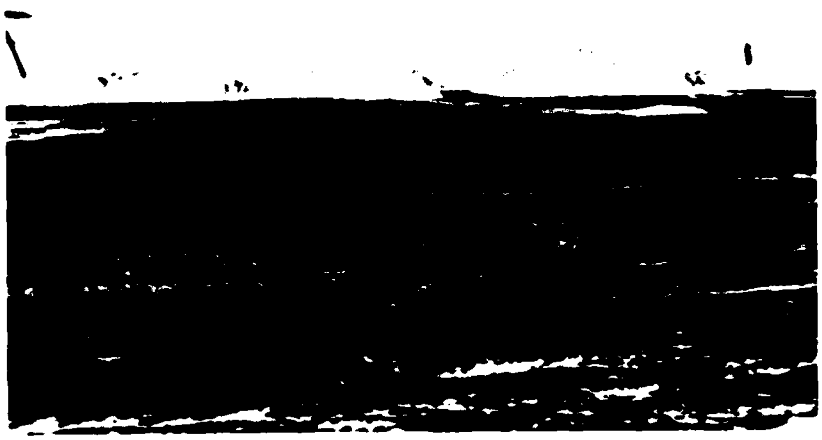


Figure 23. Ice piles on surface of exploration island.

a. Western end of bluff. Note the offshore boulders and the limited number of boulders resting along the edge of the bluff.

b. View of the boulder rampart on top of the eastern end of the bluff. Arrow points to driftwood log.

Figure 24. Boulder coast, 1982.

The island at position Q was extensively covered with ice that had thrust up to 40 m inland. This ice was also ⅓ m thick.

The last island where we observed shore ice ride-up was at position R. There were several places where ice ¼ m thick had overridden the island. The longest ice thrust was about 35 m long.

On 29 July, the coast from Prudhoe Bay to Barter Island was overflown. West of Konganevik Pt. (position S, Fig. A2) we visited the unique rock-littered shore described by Kovacs (1983a). This coast varies in elevation from a low-lying beach area on the east end of the rocky shore to a 1½-m-high bluff on the west end. The shoreline is gradually receding, and in the process rocks from the Flaxman Formation varying in size from gravel to boulders up to 1½ m long are being exposed. Along a 300-m-long section of shore, the

a. 1983.

b. 1979 (photograph courtesy of P. Barnes).

Figure 25. Western end of boulder coast rampart.

boulders are being reworked and concentrated by ice shove and ride-up processes.

When this shore was visited in May 1983 no sea ice movement onto the land had occurred and the lagoon ice was undeformed. However, by late July the boulder rampart along the shore and the tundra surface near the bluff had been extensively changed. Sea ice had been thrust inland at least 20 m, gouging up the tundra surface and pushing boulders and other debris inland. The western end of the shoreline was most extensively transformed. In the summers of 1979, 1981 and 1982 this coast-

Figure 26. Boulder rampart on east end of coastal bluff. Arrow points to same driftwood log as in Figure 24b.

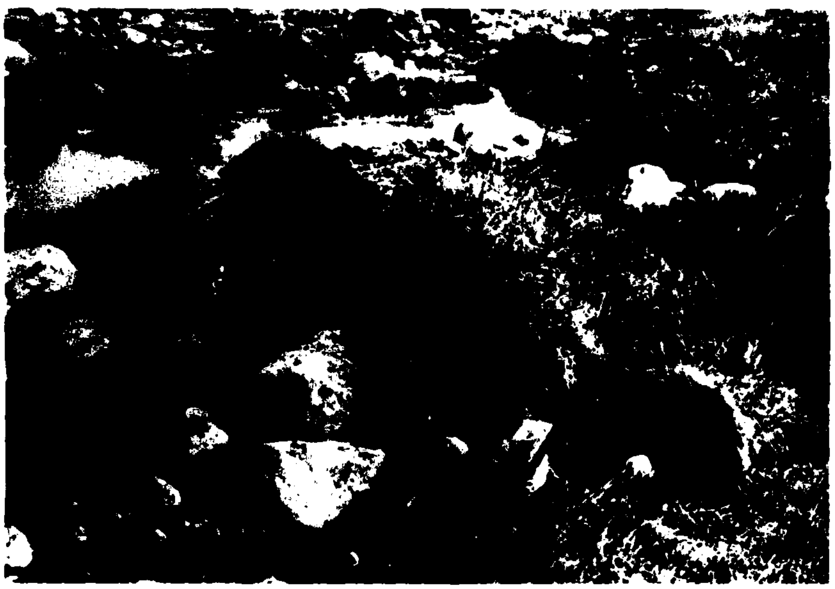


Figure 27. Ice-pushed tundra and boulder debris.

line consisted of boulders scattered randomly along the edge of the 1½-m-high bluff and a "beach" area as shown in Figure 24. A gradual rearranging of the boulders by ice-push and the receding of the bluff through erosion had occurred over these years. However, the transformation that occurred during the 1983 spring breakup was significant. On the western end of the bluff, a boulder ridge 1 to 2 m high now existed. As viewed from the east, this section of the bluff is shown in Figure 25a, and for comparison a 1979 view of the same bluff area is shown in Figure 25b. The boulder-littered shore as seen from the west end is shown in Figure 26. This view may be compared

Figure 28. Ice-scarred tundra, west end of boulder coast. Arrows point to two of the many boulders which were driven into the tundra mat.

Figure 29. West end of boulder coast. The vertical arrow points to the inland limit of ice-transported debris.

with a similar one taken in 1982 as shown in Figure 24b. The former shows that the boulder ridge along the edge of the bluff had increased in height and that the tundra surface was gouged, allowing water to pool in the depressions. In places, the tundra mat was folded back (Fig. 27) and large boulders were driven into this material (Fig. 28). An aerial view of the west end of the boulder coast is given in Figure 29. Arrows 1 and 2 indicate the two boulders marked in Figure 28. Figure 29 also shows that there is no longer a "beach" area as seen in Figure 24, and that the seaward face of the

Figure 30. Boulder coast morphology.

boulder rampart is either quite steep (arrow 3, see Fig. 30a) or has been rearranged to form a boulder pavement (arrow 4, see Fig. 30b). The changes that occurred between the summers of 1982 and 1983 at the east end of the boulder coast are shown in Figure 31.

In August 1982 the positions of four of the large boulders in the boulder ridge were determined in reference to inland benchmarks. Each boulder was marked with red paint for identification. In July 1983 we could only locate two of the marked boulders. The other two were either covered with ice-a

b

Figure 31. East end of boulder coast in (a) 1982 and (b) 1983.

push debris or were so tilted as to obscure the red identification markings. The two boulders which were relocated had been shoved inland 6½ m. The distance between the two boulders (34½ m) had remained unchanged.

From the boulder coast the reconnaissance flight continued eastward around Konganevik Pt. and along the Camden Bay shoreline (Fig. A2). During the May reconnaissance no onshore ice movement was observed along the coast. However, in July most of the southern shoreline of Camden Bay had been extensively modified by sea ice (see inset, Fig. A2). Ice-pushed gravel debris was found up to 30 m from the sea. The beach re-

Figure 32. Steeply sloped ice-pushed beach gravel on side of bluff.

Figure 33. Ice-pushed shore morphology.

lief consisted of ice-pushed gravel piles, pit marks, and gouges, as well as planed surfaces. In places the sea ice had moved onto the 4-m-high coastal bluffs (Fig. 32), transporting gravel and logs from the beach inland and pushing up the tundra surface. Examples of these ice-push coastline features are shown in Figures 33 and 34. Another example of extensive shore modification by ice ride-up is shown in Figure 35. Note the relative height and distance from shore of the ice-pushed soil berm on the face of the bluff (arrow).

In mid-May 1984 we made shore ice pile-up and ride-up observations along the Beaufort Sea coast from Pt. Barrow (Fig. A1) to Konganevik Pt. (Fig. A2). This year was unique in that very little onshore ice movement had occurred. At Pitt Pt. (Fig. A1) ice ½ m thick and about 75 m wide had thrust inland up to 10 m onto a low-lying beach. On the southeast end of Cross Island (Fig. A2) sea ice of similar thickness had been pushed some 20 to 30 m across a narrow portion of the island. The ice covered about 100 m of the island.

The event of greatest interest was observed at Flaxman Island (Fig. A2). Near the eastern end of the island sea ice ½ to ¾ m thick had piled up to 2½ m high and extended up to 7 m inland for a

Figure 34. Ice-gouged (a) and planed smooth (b) beach gravels. Arrow in photo b points to light-colored gravel transported by sea ice up on top of the bluff.

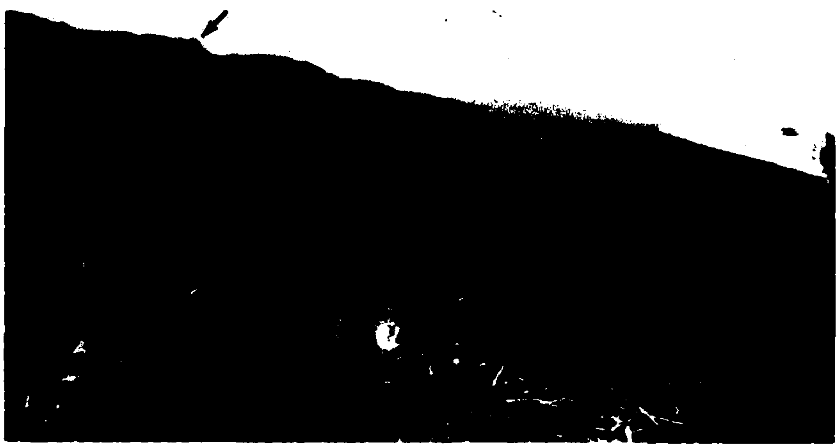


Figure 35. Sea-ice-modified beach. Beach gravels are scarred and pushed into piles (A, B, C, D) by sea ice movement onto the shore.

Figure 36. Sea ice ride-up debris piles along sea side of Flaxman Island. Dark area at upper left of photo is old drill pad site. Photo shows eastern end of island.

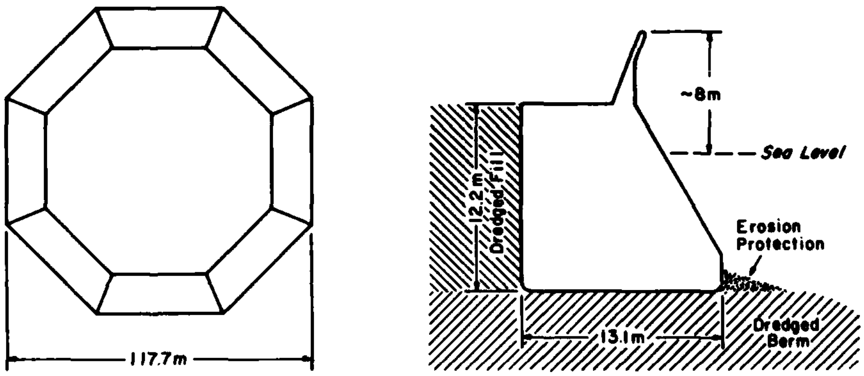


Figure 37. Kadluk concrete caisson-retained island structure.

distance of over 100 m along the 6-m-high coastal bluff (Fig. 36). Aerial photography taken in the summer indicates that the face of the bluff is nearly vertical and that there is virtually no beach along the base of the bluff. This onshore ice movement is one of the more significant events we have observed. It demonstrates that if near-vertical 6-m-high coastal bluffs can be overtopped by sea ice then so may the vertical walls of similar height around offshore man-made structures. In other words, vertical walls alone will not prevent ice movement onto a structure. This is verified by the event discussed below.

In addition to the ice ride-ups and overtopping on the man-made exploration islands mentioned earlier, there was another structure whose perimeter wall was overtopped by sea ice in 1984. This was the Esso Resources Canada caisson-retained concrete island Kadluk, which is located in Mackenzie Bay, Canada. The structure's wall cross section is shown in Figure 37 and a view of the island from the ice is shown in Figure 38. The top of the ice-wave deflector is about 8 m above the sea. During the first week of January 1984, 1-m-thick sea ice was driven against the structure, forming the grounded rubble formation shown in Figure 39. During the ice-piling event, several tons of sea ice overtopped the deflector and fell upon the concrete "floor" at location 1 in Figure 39. While no damage apparently resulted from this event, it does show that steep-sided structures like Kadluk can be overtopped by sea ice. Further refinement of the ice-wave deflector appears to be necessary to ensure that ice ride-up and overtopping of this type of structure will not occur. This will become even more important as exploratory structures are placed at locations more exposed to the dynamic movements of the arctic pack, sites

Figure 38. Kadluk Island. Arrow points to area where ice overtopped ice-wave deflector (photograph by W. Tucker).

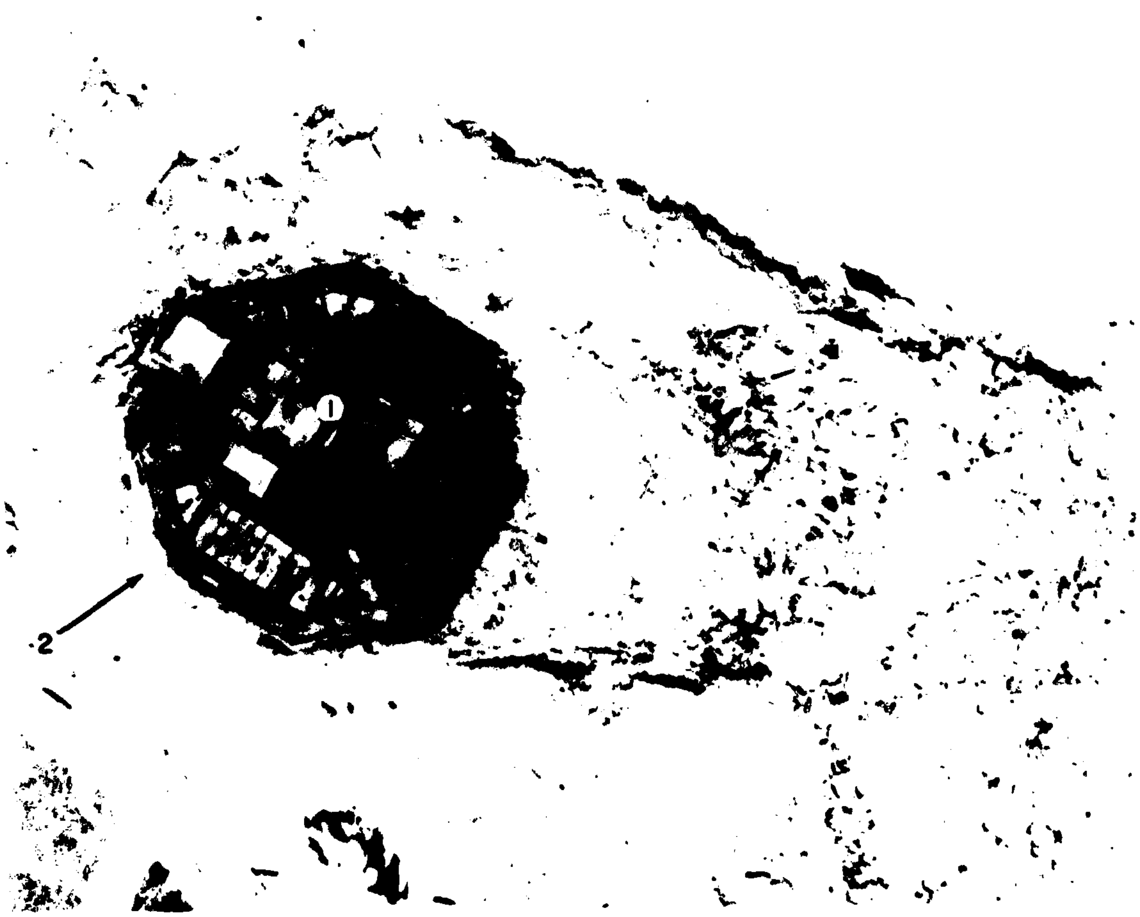


Figure 39. Ice rubble around Kadluk Island. Arrow 1 points to ice blocks on concrete surface. At arrow 2, thermal expansion of fast ice pushed both first- and multi-year sea ice vertically up the face of the caisson above the ice-wave deflector (photograph by Esso Resources Canada).

beyond the protective fast ice environment and the grounded ice zones as described by Kovacs (1976 and 1979).

DISCUSSION

It is clear from the observations presented in this report and the evidence given in the reports by, for example, Kovacs and Sodhi (1980) and Kovacs (1983a and b) that ice movement onto the shore can extensively modify the land. The typical landforms produced by onshore ice movement are gouges, striations and debris piles. Ice can also smooth the shoreline by producing boulder pavements and planed beaches. During onshore movement, ice can gouge up offshore material and transport it onto the land. In this way ice helps to restore the beach with material previously removed by wave and current erosion.

Shore ice ride-up and pile-up can also be a destructive process, in which shoreline structures are smashed and trees toppled by the ice. Kovacs and Sodhi (1980), Kovacs (1983a and b) and Sodhi and Kovacs (in press) have reported on this aspect. However, for the Beaufort Sea coast there is very little information on the destruction of man-made structures by sea ice movement onto the land. Kovacs (1983a) reported on a steel garage which was damaged by sea ice. This building was located about 25 m from the water on Bullen Point. The interesting aspect of this event is that the building was in a very sheltered location.

From an interview with Mr. Harold Itta, Shapiro and Metzner (1979) report that in July 1928 at Esook (Fig. A1) 1¼-m-thick sea ice was driven against the land. In some places the ice piled about 7 m high and in others it slid as a sheet up to 70 m inland. At one location the ice pushed a boat before it without destroying the craft. The large shore ice pile-ups which formed during this event lasted through the summer. This event was also described by Mr. Herbert Leavitt of Barrow to Mrs. Dorcas Ballot of the Inupiat History, Language and Culture Center at Barrow (1983, personal correspondence). Mr. Leavitt recalled that the July 1928 ice movement affected the entire coast from Pitt Point to the east beyond Esook. He states that the ice destroyed both tents and old cabins. Perhaps these cabins were located at some of the building sites shown by Kovacs (1983a) to have existed at Esook in the 1940's but that have since been removed by coastal erosion.

The only other location we have found in the literature where onshore ice movement along the Alaska Beaufort Sea coast may have destroyed a dwelling was on the east side of Barter Island. On page 278 of his diary, Jennes (1914) reported that during the excavation of an old ruin they found, under the decomposed fragments of the log roof and old turf, the skeletons of a man and woman lying side by side. Their possessions (stone lamp, bow, needle case, knives, harpoon heads, etc.) were also discovered resting in their logical places. The fate which befell these two people is unknown but they may have been killed by onshore ice movement overriding their dwelling. Such an event has recently been credited with the crushing of a sod dwelling and a family of five at Utkiavik, the old village at Barrow, Alaska, on the Chukchi Sea coast (Dekin 1982, Anonymous 1982, 1983a and b). This dwelling was located on a 6-m-high bluff. We estimate that the structure was some 80 m from the sea when it was destroyed. The specific location of the ruin on Barter Island is unknown, as Jennes provided no map or other siting information in his diary.

Other shore ice ride-up events undoubtedly have occurred along the Beaufort Sea coast in the past, which destroyed structures and perhaps took human life. Such events have not been recorded to date in the various Elders Conference proceedings published by the North Slope Borough, nor have we discovered any other references to such destruction. However, it is very clear that many natives living along the Beaufort Sea coast today are concerned with the damage that ice ride-up and pile-up on the land and artificial drilling islands could do to man-made structures.

Mr. Ernie Frankson expressed this concern at the 1978 Elders Conference in Barrow, Alaska, when he stated "if they are going to erect drills on these barrier islands we think maybe the ice may cause them to topple down" (Okakok and Kean 1981). Even so, the historical evidence supporting this concern is quite limited and indeed somewhat contradictory. Concerning the barrier islands between Cross Island and Flaxman Island, Mr. Henry Nashanik stated at the same conference that shore ice pile-ups do form from time to time on the beaches of these islands, but "the ice has never gone up over and past them" or "covered them out of sight" in all the years he subsisted along this coastline (Okakok and Kean 1981). The information we have presented shows that this does occur.

Mr. Otis Ahkivgak also mentioned at the conference that in the fall strong winds can quickly form ice pile-ups but that few pressure ridges form once the fast ice becomes thick and strong. This view supports that of Kovacs (1983a), who stated that shore ice pile-up and ride-up are primarily fall and spring events. The former occurs when the ice is thin and weak and thus more susceptible to deformation and the latter when the ice, having melted away from the shore, is mobile and easily driven against the land by onshore winds. Indeed it is during the spring when the ice is "plastic" that it retains enough stability to be pushed up steep slopes or over uneven obstacles.

Each year the phenomenon of shore ice pile-up or ride-up repeats itself somewhere, but on a site-specific basis it remains unpredictable. Kovacs (1983a) reported observing about three ice override events per year for the winters of 1980, 1981 and 1982. During 1983 we observed seven events and in 1984 only one at the time of the reconnaissances. The increase in ice override events observed in 1983 may or may not be significant, since our data base on shoreline ice processes covers only five winter seasons. As Kovacs (1983a) states, "To better understand the potential hazard of shore ice ride-up to coastal development, we need to know the frequency, magnitude and inland reach of the events. Further reconnaissance flights coupled with on-site observations and surveys are vital to achieving this understanding." The need for continued field observations will remain until a data base exists which is large enough to allow the formulation of reasonable severity predictions. This objective remains for others to achieve.

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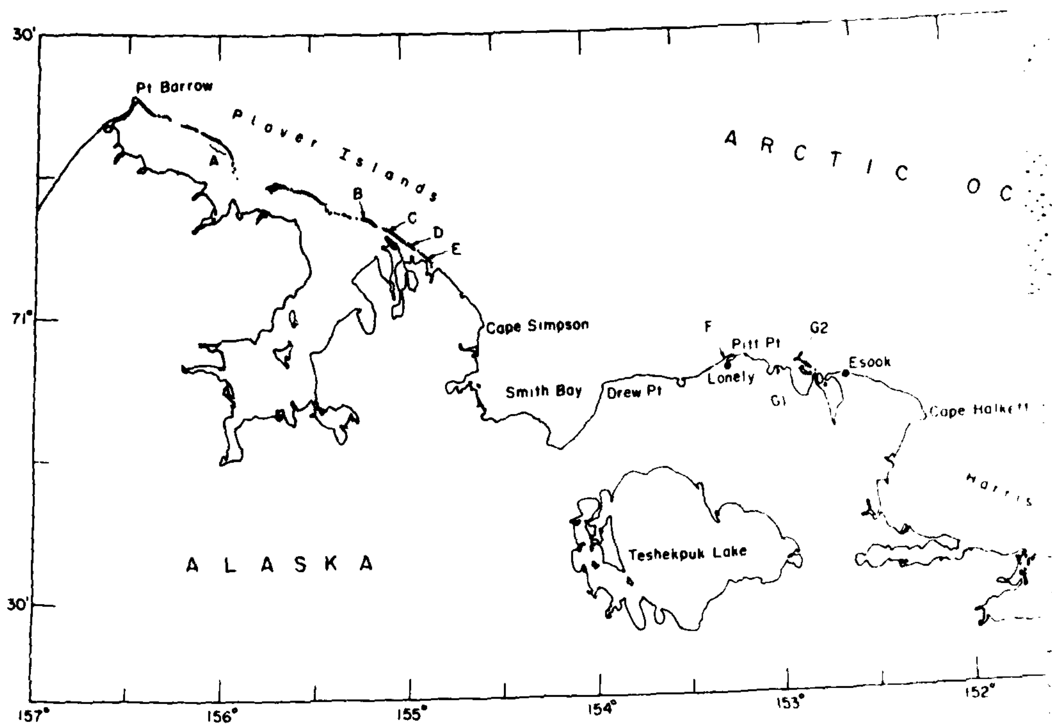

Figure A1. Western Alaska Beaufort Sea coast. Numbered arrows mark location of shore i

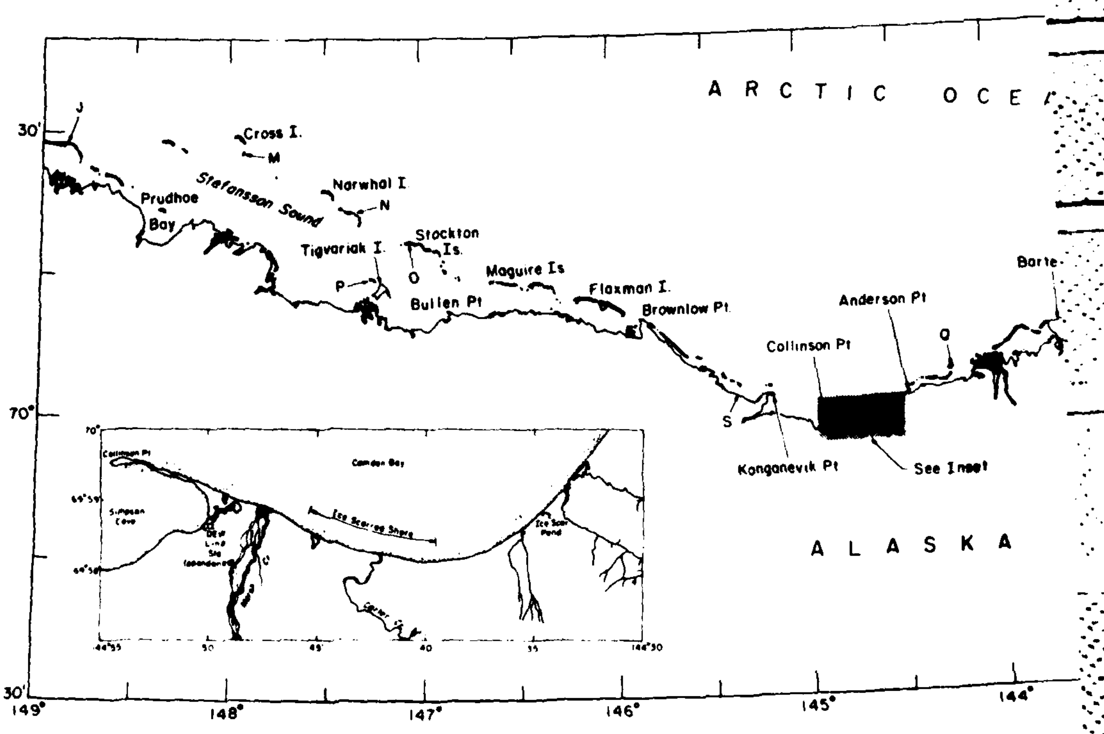

Figure A2. Eastern Alaska Beaufort Sea coast. Numbered arrows mark location of shore ice r

APPENDIX A. SITE LOCATION MAPS

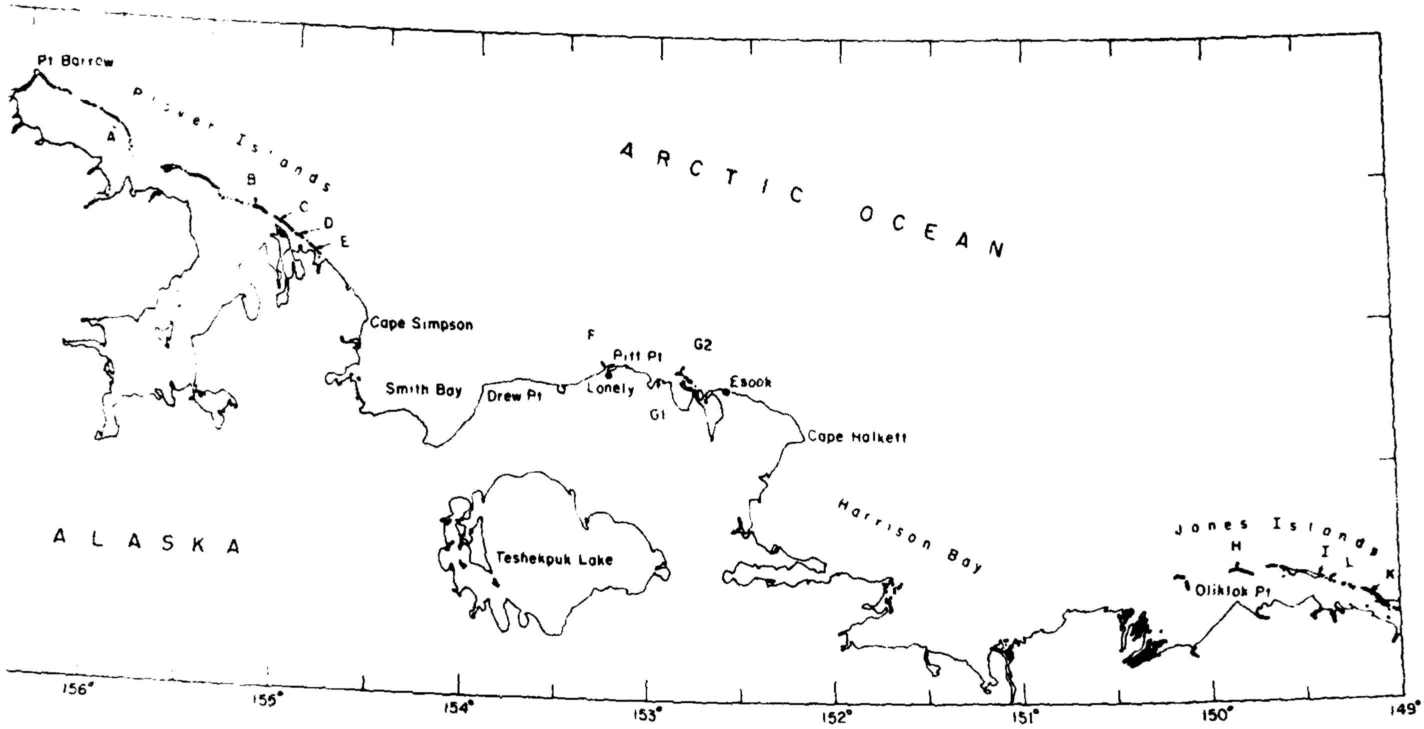

Figure A1. Western Alaska Beaufort Sea coast. Numbered arrows mark location of shore ice ride-up or pile-up sites discussed in text.

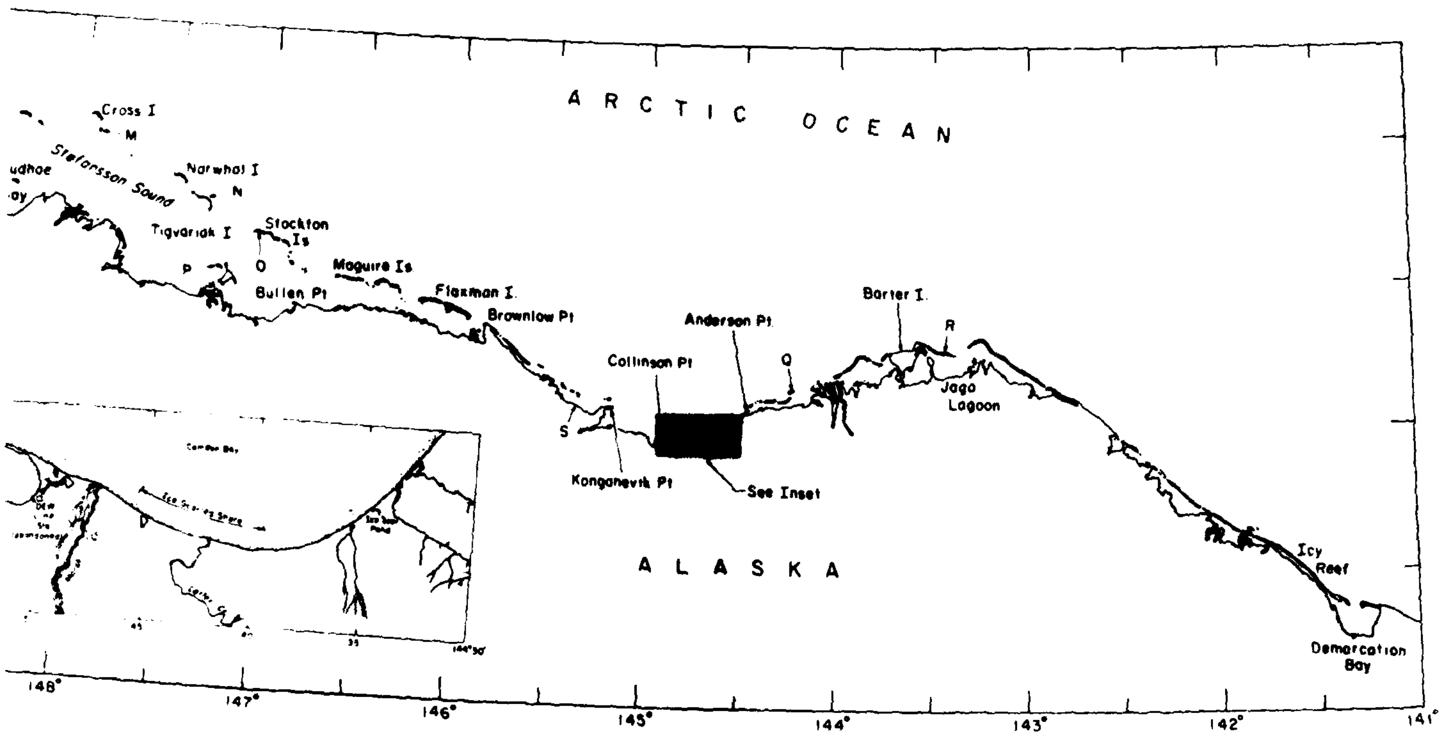

Figure A2. Eastern Alaska Beaufort Sea coast. Numbered arrows mark location of shore ice ride-up or pile-up sites discussed in text.

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