5118
JUL 19 1982
RU 88
GE-AK82

Recent Shore Ice Ride-up and Pile-up Observations

Part I

Beaufort Sea Coast, Alaska

by

Austin Kovacs

June 82

For inclusion in book
"The Alaska Beaufort Sea"

Introduction

Sea ice acting on arctic coasts modifies the shore, producing unique beach morphology. A number of the morphological features produced are depicted in Figure 1. In addition, sea ice thrusting up onto the shore can produce gouges, furrows and striations, and when it melts it can leave potholes or pitted beach topography. Sea ice as an erosive agent is not well documented, but it is known that both fine-grained material and boulders have been removed from the shore zone by drifting sea ice (Fig. 2 and 3). However, sea ice thrusting against the land can move offshore sediment and boulder landward, and in this way it helps to restore beach material displaced by wave erosion. In addition, ice-push ridges and barricades help protect the shore from wave attack and run-up onto the land. The topographic landforms created when sea ice advances onto the shore are signatures which "provide information on the frequency of occurrence and magnitude of the forces at play, and maximum transgression beyond the water's edge.

Sea ice pile-up (Fig. 4) and ride-up (Fig. 5) on arctic and subarctic shores are frequent and predictable events. These phenomena have pulverized boats, destroyed piers and wharfs and on occasion crushed houses along with their unlucky inhabitants. Stefansson (1969) stated: "'houses which stand one or two hundred yards from the beach are in danger'* of ice ride-up. These events cause concern today about the safety of facilities located along these shores and on manmade islands out at sea. Questions arise as to the frequency and severity of these events.

A survey of shore ice pile-up and ride-up along the coast of Norton Sound and the Alaska coasts of the , Bering, Chukchi and Beaufort Seas in the winters of 1979-80, 1980-81 and 1981-82 revealed many locations where significant (greater than 5 m) onshore ice movement had occurred, both recent and old. This paper, Part I, discusses observations and current findings related to onshore sea ice incursions along the Alaskan Beaufort Sea coast. It is an extension of previous reports by Kovacs and Sodhi (1980); Kovacs, Sodhi and Cox (1982); and Kovacs and Kovacs (1982) on sea ice encroachment on arctic and subarctic shores which includes field observations and theoretical analyses. Parts II and III of this series will present information on shore ice pile-up and ride-up on the Chukchi Sea coast and on the Bering Sea - Norton Sound coasts of Alaska, respectively.

Winter 1979-80 Observations

The 1979-80 winter observations along the Beaufort Sea coast were made from Pt. Barrow to Barter Island. Records were made of ice ride-ups which extended 5 or more meters in from the sea. Lesser ice thrusts were considered too frequent and of limited significance.

In November 1979 an ice pile-up was observed west of Cape Halkett (position 1 in Figure 6), which extended nearly 300 m along the coast. The ice blocks were 25 cm thick, and were piled up to 3 1/2 m high on top of the 2-m-high coastal bluff (Fig. 7). In places, the ice blocks were up to 30 m inland from the edge of the bluff. In summer, the sea extends to the base of this bluff. Shallow water exists offshore. Rapid erosion of the shoreline (6 to 10 m/yr) gives rise to very turbid offshore water.

In April 1980 sea ice ride-up was measured 8 m inland on Igalik Island and 13 m inland on Kulgurak Island (positions 2 and 3, respectively, in Figure 6).

West of Cape Simpson (position 4 in Figure 6) 40-cm-thick sea ice had thrust inland 16 m, and east of Pt. McLeod at position 5 it was found on top of the 3-m-high bluffs and up to 20 m inland. At positions 6 and 7, ice extended 5 to 10 m inland.

Spy Island (position 8 in Figure 6) was overridden by fall ice of unknown thickness. The ice override distance could not be determined because of drift snow but was in excess of 80 m. During the summer, Jim Helmericks (personal discussion) noted that island material had been pushed up into piles and the island cut down in places so that storm wave run-over occurred. This action was reported to have cut the island into four sections.

At position 1 in Figure 8, l/2-m ice overrode the 1 l/2-m-high Collinson Pt. spit for a distance of 50 m. At positions 2 and 3 ice 1.1 m thick had ridden up the 2-m-high beach and moved 5 to 20 m inland. Long sections of the coast at positions 4, 5 and 6 had ice pile-up on the beach. At position 4, ice 1/2 m thick had thrust inland up to 60 m on the island (see Fig. 9). At positions 7 and 8 ice 1/2 m thick piled up to 5 m high and moved over 10 m inland on the barrier island.

Winter 1980-81 and Summer 1981 Observations

The Beaufort Sea coast from Pt. Barrow to the U.S.-Canadian border was overflown in April 1981. As in April 1980, sea ice was again observed on Kulgurak Island (position 3 in Figure 2). This year the ice had piled up or thrust inland 7-8 m.

At Point Drew (see Figure 6) 30-cm-thick sea ice had invaded nearly the entire spit which is over 1 km long. Ice pile-ups up to 3 m high existed along most of the spit, and complete ice override of 75 m of the spit at the west end had occurred. In August, even though most of the beach on the seaward side of the spit had been modified by storm wave run-up, much ice-thrust beach topography still existed. The spit was found to consist for the most part of peat and fine-grained silt. The ice pushed this material into piles up to 1.5 m high. Sea ice and driftwood were found incorporated into the debris of the larger piles (Fig. 10). In some locations, large slabs of peat material about 25 cm thick had been displaced and stacked layer upon layer (Fig. 11). This section of the coastline is receding at a rate of 6 to 10 m per year (Lewellen, 1977; Hartz, 1978). Therefore, summer storm waves and coastal currents rapidly modify the coastline and in so doing remove ice ride-up scars from the land.

On 26 June, at about 1030, sea ice up to 1/2 m thick moved in upon the beach along a broad section of the coast near the Lonely DEW Line Station (Fig. 6). People who observed the event stated that the ice piling lasted less than 10 minutes and reached a height of 4 m (Fig. 12). In late August we found that the ice ride-up had dozed up beach gravel consistently for a distance of 30 m from the water's edge along more than 500 m of the shore. The longest inland ice advance as determined by ice gouge length was 59 m. No ice remained exposed on the beach but ice was found under several of the ice-push gravel piles (Fig. 13).

Along the beach at Lonely DEW Line Station, several old ice scars not detected on previous reconnaissance flights were discovered (Fig. 14). The ice-push tundra berm furthest from the sea was 85 m inland. The berms were impregnated with driftwood, which was incorporated into the soil during ice dozing (Fig. 15).

Aerial photos of this coastline taken in 1945, before development had occurred, show that these features were in existence then. A better quality 1949 aerial photo of these features is shown in Figure 16. Our aerial photo assessment of shoreline retreat in the immediate area of the ice scars is about 1/2 m per year. Therefore, in 1945 the furthest-inland. ice scar we measured in 1981 must have been around 100 m from the ocean. How far inland the ice-push features were right after the ice ride-up event occurred is, of course, unknown.

In May at Ksook, the site of a turn-of-the-century trading post shown in Figure 6, the shore ice pile-up and ride-up formations shown in Figure 17 were observed. The higher ice pile-ups, extending westward away from the house in Figure 17 , were situated on a low-lying coast. These ice piles were up to 5 m high and 20 m inland from the *sea.* Fingers of sea ice extended inland up to 35 m. The ice pile-up directly north of the hut "in Figure 17 was 1 m higher than the 2-m-high bluff (Fig. 18) on which the ice came to rest.

Aerial views taken in August 1981 of the ice-pushed tundra relief and coastline are shown in Figure 19. These views show that the previous winter's shore ice ride-up displaced and scarred a significant area of the shoreline. Ground views of the ice-pushed relief are shown in Figure 20. We found the coastline west of the hut where the ice moved inland to be composed of peat. Large slabs of this material up to 0.25 m thick were found to have been peeled loose and displaced inland by the ice (Fig. 20).

A profile of one of the ice-pushed peat piles and the shoreline relief is presented in Figure 21. This pile reached an elevation of 2.4 m, or about 1.6 m above the undisturbed terrain. Other ice-push features were either higher or further inland (up to 29 m). The seabed off shore was shallow and composed of stiff peat and silt. The shallow slope of the seabed, 3.8°, is probably the result of the high rate of coastline erosion in this area. Indeed, this coast is retreating faster than any other area on the entire Alaskan Arctic Ocean. Typical annual retreat is reported to be 10 to 25 m per year, depending on summer storms and specific shoreline -site (Lewellen, 1977; Hartz, 1978). This retreat can be illustrated in the 1949 photo shown in Figure 22. The arrows point to five structures. Those north of the dashed line, which represents the shoreline location obtained from the September 1981 aerial photo inlaid at the bottom of Figure 22, are now gone. Since 1949, some 410 m of coastline has eroded north of the remaining house. This represents an average of 12.8 m of erosion per year. The last remaining Ksook structure *was* 19 m from the bluff in late 1981 and will probably be destroyed within two summer open water seasons if annual shoreline retreat continues to average over 10 m per year.

East of Ksook, at position 9 in Figure 2, fall ice was observed piled 1 *to* 3 m high along some 150 m of the 2-m-high coastal bluff. The ice extended 5 to 15 m inland.

On the north side of Thetis Island and Spy Island (positions 8 and 10 respectively in Figure 2) fall ice less than 1/2 m thick was piled up to 3 m high and 12 m inland.

Along the north side of Pingok Island (position 11 in Figure 6) fall ice *was* observed piled 3 to 4 m high and 30 m inland on the coastal bluff, which *is* 3 1/2 to 4 m above sea level. This ice extended some 1 km along the coastline.

Two- to four-meter-high pile-ups were also noted along most of the western end of Long Island (position 9 in Figure 8).

It is worth noting that in mid-March off the eastern end of Long Island a broad area of ice moved from the northeast to within 100 m of the shore. The ice was 1.55 m thick. Significant rafting and riding occurred, as shown in Figure 23. Ice movement stations on either side of this area recorded little *or* no ice movement at the time, but a station some distance "'upstream'^s experienced movement in excess of its recording capacity. We measured one finger raft between ridges A and B which was 155 m long and three grounded ridges over 8 m high (Fig. 24). In short, 1.55-m ice came close to riding up onto Long Island.

In late October, 15- to 20-cm-thick ice moved from the west 30 m onto No Name Island (position 11 in Figure 6). It completely overrode a steep-sloped 1 l/2-m-high gravel berm placed there by construction crews and moved inland 20 *to* 30 m.

Ice of similar thickness was driven 10-15 m up onto the north side of several islands at position 12 in Figure 8. On one of these islands the ice was estimated to have moved at a relatively slow rate of 0.6 to 1.5 m per hour (Vaudrey and Potter, 1981).

Along the beach east' of Collinson Pt. (from positions 1 to 13 in Figure 8) *most* of the shore was covered with 30-cm-thick ice debris piled up to 4 m high. In late August, we measured one area where 510 m of beach was continuously scarred by ice ride-up. These scars extended inland up to 30 m from the water's edge (Fig. 25). Ice-pushed gravel piles up to 1 m high, but typically less than 1/2 m high, were observed (Fig. 26).

Bathymetric and evaluation survey measurements made along the line shown in Figure 25 were used" to construct the profile shown in Figure 27. Above the 2-m depth, the seabed was found to slope at an angle of 11°. From the water's edge to a distance of 10 m inland, the beach profile has been modified by storm wave run-up. As a result, the forebeach Profile . shown in Figure 27 is concave in shape and devoid of all ice-scar relief, as shown in Figure 25.

Some of the *most* important ice ride-up features to be studied were first observed in May 1980 on the southeast side of Camden Bay (position 14 in Figure 8). Only aerial photos of the features could be obtained at the time (Fig. 28). The features were not recent ice ride-ups but were scars plowed into the tundra by a major onshore ice movement some years before. " In May 1981, the length of the longest ice scar was measured and was found to exceed 120 m, a major inland advance.

In August 1981 more detailed observations along this section of the coast were made. These included additional aerial photography, elevation surveys and offshore bathymetric measurements. Summer views of the tundra scars, shown in wincer in Figure 28, are shown in Figure 29. The scars are surrounded by ice-pushed soil berms. Some of the scars also contain a sizable area of water, suggesting that the terrain is depressed. Another aerial view of the surrounding shore area is given in Figure 30, and a view of the coast about 1 km to the southwest is shown in Figure 31. These photographs show other ice-push soil berms which we did not observe during the winter due to excessive snow cover. We also observed a significant number of additional ice-scarred tundra features along this section of the coast which were not apparent during the winter due to snow cover. These scars indicate that a major onshore ice movement occurred at some time in the past, and that this event left intermittent ice scars in the tundra along a large section of the coast. In addition, we observed numerous recent ice-push gravel piles which extended up to 20 m inland from the water's edge (Fig. 31). These features indicate that onshore ice movement is a frequent event along this coastline.

Panoramic views of the tundra scar shown in Figures 29a and b are shown in Figures 32a and b respectively. These views show a beach composed of surprisingly coarse gravel, much driftwood debris, and ice-push tundra berms over 1.5 m high. Most of the driftwood was carried on shore by high water storm events. However, we also found wood deeply embedded in the ice-push tundra berms, indicating that it was incorporated into the berm during ice plowing. The back of the berm behind the person in Figure 32b is shown in Figure 33. Note the apparent difference in elevation of the berm from the two sides.

An elevation survey was made along the lines shown in Figure 29. An elevation survey was also made of the undisturbed tundra just north of the berm beyond the B profile line drawn in Figure 29a. The seabed relief was determined by taking soundings from an inflatable raft. The survey results are shown in Figure 34. The seabed near the beach is shown to slope at an angle of 8° to a depth of 2 m. Beyond this depth, the seabed has a very shallow slope. The steeper slope near shore above the 2-m depth may be controlled in part by ice-push, which transfers gravel up onto the beach. The natural or non-ice-scarred tundra surface (profile A) is shown to have an elevation which is more than twice that of the ice-scarred terrain along profile B. It should be noted that profile B does not represent the deepest area of this ice-scarred feature. The deeper area was up to 1/2 m below the pond water level, an area we did not attempt to profile.

Ice plowing clearly resulted in the displacement of surface material. This in turn exposed the underlying material, which allowed solar radiation to thaw the ground ice. Differential subsidence in the scarred area then occurred. A striking feature of the ice-scarred terrain was that all surfaces were covered by vegetation, indicating that these scars are quite old. The longest ice scar was found to extend 130 m in from the water's edge.

The ages of these ice-scarred features are unknown. A July 1950 view of the coastline (Fig. 35) shows the features existed at that time, and ice ride-up had intermittently scarred the tundra along a 2.9-km section of the coast. A 1943 *image* of this coastline revealed the same scars. The features are therefore over 35 years old. We estimate from 1950 and 1981 aerial photos that the shoreline is receding at 0.35 m per year, or ≈ 14 m since 1943. The ice-push berms we measured were therefore farther from the water in 1943 than they are today.

It is interesting to speculate whether these scars were formed at the time of the 2 July 1914 Camden Bay ice ride-up event described by F. Johansen in his daily log. "First some ice was screwed up close to the beach here and there; then came an immense and continuous pressing of the ice from far offshore onto the beach. Like the movement of a glacier the whole body of sea ice moved eastward; without regard for shallow water the coastal ice was pressed up on the beach and during this slow but continuous movement the ice ploughed down into the sand where this was the beach material. On the coast of tundra-bluffs the ice first shoved away the boulder gravel wall in front, tearing it up, going over it and raising often immense boulders and driftwood trunks on its 'back' after which it " ploughed into the tundra-bluffs and overlapped these. The movement of the ice lasted for almost an hour. Some parts of the higher tundra-bluffs had their seaward side covered by the coastal ice stretching to the upper margin of these and immense blocks of ice, boulders or tree trunks from the beach were raised and pushed still further in on the tundra.'" At the end of a report by O'Neill (1924), several photos appear which show an ice ride-up with ice-pushed tundra soil, boulders and driftwood before it. This event apparently occurred in Camden Bay in 1914 when Johansen reported his observations. If the tundra ice scars were formed at this time and the shoreline erosion averaged 0.35 m per year, then the ice-pushed tundra berms would have been about 23 m further inland or some 150 m from the sea in 1914.

The pond at arrow A in Figure 35 is in the ice scar shown in Figure 29a. It is interesting that this feature appears on maps as a pond (Anon., 1976). This may be the only pond ever shown on a map which was formed as a result of an ice ride-up. We have named this feature Ice Scar Pond in Figure 8.

Continuing along the coast in April 1981, we observed fall ice ride-ups to 20 m inland at numerous locations between positions 14 and 3 on the east side of Camden Bay and at positions 7 and 15 east of Barter Island

(Fig. 8). No significant onshore ice movements were noted from position 15 on to the U.S.-Canadian border. However, in early September we overflew the Icy Reef barrier islands northwest of Demarcation Bay and noted that the islands had many ice-push gravel ridges and were highly gouged and pitted over their entire surface (Fig. 36), indicating that sea ice frequently invades these islands.

Winter 1981-82 Observations ,

In early April 1982 the coastline from Pt. Barrow to the U.S.-Canadian border was again overflown. On an island just southeast of Martin Island and on Sanigaruak and Igalik Islands large shore ice pile-ups existed (see positions 12, 13 and 2 respectively in Figure 6). An aerial and ground view of the ice pile-ups at positions 12 and 2 are shown in Figures 37 and 38 respectively. We made numerous measurements of the angles of repose of the 0.55-m-thick ice blocks in the ridges. The angles varied from 30° to 45° and av^r^ged 37". This angle may represent the angle of internal friction of the sea ice rubble. Offshore water depth measurements were also made and these indicated a relatively shallow seabed slope of 3°. The highest ridges we measured at positions 12 and 2 *were* 11.4 m and 11.9 m, respectively. Portions of the shore ice pile-ups extended up·to 25 m inland.

West of Lonely at position 14 in Figure 6, a small quantity of 1/2-m-thick ice had ridden up onto the edge of the 2-m-high coastal bluff.

This year again we observed 1/2-m-thick fall ice piled Up on the 2-m-high bluff at Ksook. The ice piled up *to* 3 m high on the bluff and moved up to 6 m inland (Fig. 39).

At position 9 we observed many ice-pushed tundra beams 5 to 10 m in from the edge of the coastal bluff. These scars were apparently caused by the ice ride-up and pile-up noted at this location during the 1981 spring reconnaissance.

On Thetis Island (position 15 in Figure 6) 0.6-m-thick ice was pushed up to 6 m inland and 2 to 4 m high along several hundred meters of the shore. Offshore water depths revealed a slope of 3″.

Large ice pile-ups and long ride-ups were observed on many of the Jones Islands. The ice incorporated in these formations varied between 0.4 and 0.65 m thick. An aerial view of the ice pile-up on the west end of Spy Island (position 8 in Figure 6) is shown in Figure 40. As shown in Figure 41, the ice pile-up extended over 25 m inland on the beach, reached a height of 8.5 m, and had side slopes of 36°. Near the beach the seabed is shown to have a slope of 6.3°.

On Leavit Island (position 16 in Figure 6) 0.45-m-thick ice completely overrode approximately 75-m-wide section of the island (Fig. 42). The length of the ice thrust, from the sea side to where it stopped on the lagoon side, was 66 m. The island appeared to be 1 to 1 1/2 m high at the ice override site.

An elevation survey over one section of the ice pile-up on Pingok Island (position 11 in Figure 6) is shown in Figure 43. At this location ice piled up to, a height of 7.4 m and toppled onto the 3 l/2-m-high island "bluff." The ice extended over 30 m inland from the sea at this site.

On the barrier islands 5 to 10 km southeast of Brownlow Pt. (position 16 in Figure 8) several 5- to 10-m ice ride-ups were observed.

On Konganevik Pt. (position 17 in Figure 8) an old ice scar was observed on the tundra. This feature was estimated to end 6 m from the sea.

At position 18 in Figure 8, a 26-m-long old ice scar was measured. The scar ended several meters up the side of the steep coastal bluff.

On the barrier island at position 19 in Figure 8, dirt-laden ice was observed pushed in piles up to 6 m high and up to 7 m inland on the shore. The dirt was carried ashore by ice which had gouged up offshore sediment.

Ice scars extending 5 to 10 m inland were noted at position 4 in Figure 8. These features are probably related to the ice pile-ups observed on this island in the spring of 1980.

Again, we observed no significant onshore ice movement between Barter Island and Clarence Lagoon about 10 km inside the Canadian border. Nevertheless, a Stefansson photo shows that thick spring ice can be thrust ashore along this coastline (Fig. 44).

Information on ice pile-up and ride-up was also obtained from discussions with several natives in Kaktovik, Barter Island. Archie Brewer and Tommy O. Gorden mentioned that in the spring of 1953 or '54 ice piled against the steep (700-f-) bluff at Barter Island. Some ice blocks were pushed onto the edge of the bluff, which they estimated was 7 m above the sea.

Alfred Linn, Sr. mentioned that in October or September 1964 ice was pushed inland on the spit leading to the Barter Island airstrip. The ice rode up the beach and over the road, stopping within a few meters of the telephone poles located along the south side of the spit. In 1982 the distance from the sea to the poles was measured to be ≈ 75 *m.* The ice ride-up may therefore have thrust inland some 70 m during the 1964 event.

Gorden also mentioned that he had lived in the area of Demarcation Bay many years ago and on a number of occasions had seen ice pile-ups over 20 m high on Icy Reef, the barrier islands which extend northwest of Demarcation Bay. In our two spring reconnaissances along this coast we observed no . significant ice pile-ups or ride-ups. Two years of observation is clearly not sufficient to document' the recurrence interval or severity of such events.

It was also of interest to hear from several Kaktovik villagers that they believed sea ice conditions today are not as "severe" as existed say 20 years ago. We have heard similar views from natives living in the Norton Sound area.

At the abandoned Bullen Point DEW Line Station, on the mainland southwest of the Maguire Islands (position 20 in Figure 8), we inspected a garage which had been damaged by shore ice ride-up and pile-up. During the 1973-74 winter, Walter Audi of Kaktovik, Barter Island (pers. comm.), observed ice that had moved inland and piled up on top of the 4 to 5 m-high garage roof. The 30-m-thick ice, which moved from the west-northwest, caved in and entered portions of the steel-framed building shown in Figure 45. We found this building to be located 25 m from the water at an elevation of about 5-6 m. The interesting aspect of this event is that it occurred in a relatively sheltered location which is not only inside the barrier islands but also protected in part by the Bullen Point spit.

Niel (Sparky) Bogert provided information on an ice pile-up which reached 6 m high on the Prudhoe Bay west dock causeway. The event occurred in July 1979. The ice blocks in the pile-up were over 1 m thick. Some sections of the causeway were also overridden. The ice was reported to be easily removed from the surface by bulldozers.

Old Ice Ride-Up Features

Most of the old ice-push tundra scars on the east side of Camden Bay. were clearly visible during our winter reconnaissance flights. Other ice *scar* features were difficult to detect or were not observed because of drift snow obscuration. This led *to* an analysis of in-house summer aerial photography of the Cape Simpson to Cape Halkett coastline to determine if old shore ice ride-up scars could be observed. While this analysis was limited by the airphoto coverage available, numerous sites were observed where sea ice thrust features existed over 5 m from the sea.

In a 1949 photo of the coast northwest of Cape Simpson, near position 4 in Figure 6, a 200-m-wide ice ride-up scar existed (Fig. 46). The farthest inland portion of the ice thrust scar was 60 m.

Other 1949 aerial imagery revealed the following for the coastline between Point Drew and Cape Halkett shown in Figure 6. West of Lonely at position 14 a l-km-long section of the beach and back shore contained ice ride-up scars. Most extended over 50 m from the sea, but some were nearly 100 m inland (Fig. 47).

Along the coast at Pitt Pt. several old ice scars existed that extended from the beach up onto the tundra bluff (see insert in Fig. 48). The longest scar extended some 70 m inland from the *sea.* Along the low-lying beach to the east of these scars many ice thrust beach striations existed which terminated up to 100 m inland at an ice-pushed gravel ridge (Fig. 48).

Several kilometers further east was another scar which ended 60 m from the sea' up on a tundra bluff.

Four kilometers west of Ksook was a l-km-long section of coast where continuous ice ride-up striation scars existed. This ice thrust feature extended up to 65 m inland from the sea but was more typically 30 to 40 m inland (Fig. 49) .

Coastal erosion since 1949 has removed most of these ice thrust features but newer ones can be observed on recent aerial imagery. For example, in a 1978 aerial photo of Pitt point, ice-pushed gravel ridges can be observed which extended along much of the coast. These features, shown in Figure 50, are typically 45 to 50 m in from the *sea,* but on occasion extend 10 to 20 m further inland.

Discussion

The data assembled in this report and by Kovacs and Sodhi (1980) and Harper and Owens (1981) show that sea ice along the shores of the Beaufort Sea has thrust inland significant distances, both over gentle, sloping terrain and up onto steep coastal bluffs. We have shown that shore ice ride-up is a destructive phenomenon in that it can push aside and doze up beach and tundra material as well as damage coastal facilities. Shore ice ride-ups and pile-ups to 20 m inland from the sea appear to be relatively frequent events along the Beaufort Sea coast. Inland ice thrusts of 50 m *are* not very frequent, and 100-m penetrations are relatively infrequent but do occur. However, the data base on shore ice ride-up and pile-up remains inadequate for drawing conclusions on the frequency or severity of these events for specific coastal sites. In short, these phenomena occur under poorly defined and unpredictable conditions along most of the Beaufort Sea coast. The data suggest that shore ice ride-up and pile-up is more frequent west of Narwhal Island. However, this may be due to the fact that fewer aerial photos and reconnaissance missions have been flown to the *east* of Narwhal Island.

The findings of this brief study are that ice ride-up *leaves* scars and soil berms on the coast which can remain visible for many decades. Old ice scars and ice-push soil berms revealed inland ice movements over 130 m long. Some of these features were found to be over 30 years old, as revealed by aerial photography. Many other ice features were found to have been removed or modified by coastal erosion and *storm* wave processes.

In the few years of this study, we have observed ice override of Point Drew spit and Spy and Leavit Islands and Collinson Point and reported on an override of the Prudhoe Bay west dock causway. Previously ice override of several small islands southeast of Narwhal Island and of Janette and Tapkaluk Islands was reported (Kovacs and Sodhi, 1980). These events are significant, but more important is the fact that they and many of the ice ride-ups reported in this study extended over 50 m inland, both on lowlying and steep sloping terrain. The 50-m and longer ice ride-ups take on special importance when one considers that many of the exploratory manmade islands being built off the Arctic coast today are on the order of 100 m in diameter. It is clear that in the design of these islands, ice ride-up defense must be considered. This has not been overlooked by industry which is actively evaluating the problem in terms of island elevation, beach slope configuration, onshore and offshore defensive structures, and ice weakening concepts. How effective these efforts will be, however, remains to be determined under long-term field evaluation.

To better understand the potential hazard of shore ice ride-up and pile-up to coastal development, we need to know the frequency, magnitude and inland limits reached by these events. Further reconnaissance flights coupled with on-site observations and surveys are vital to achieving this understanding.

Acknowledgments

This study was funded in part by the U.S. Bureau of Land Management through the National Oceanographic and Atmospheric Administrationfs Alaska Outer Continental Shelf Environmental Assessment Program and by Gulf Canada Resources.

The author wishes to acknowledge the field assistance of Roy Dehart, Richard J. Roberts, Cynthia A. Royal, Betty A. Kovacs and Garry Van Denberg, the help of Robert Frost who provided information on and copies of old aerial photography, the sustained interest in the report topic and support of Dr. Brian D. Wright and the helpful review comments of Walter B. Tucker.

References

Alestalo, J. and J. Häikiö (1979) Forms created by thermal movement of lake ice in Finland in winter 1972-73, Fennia, 157: 2, p. 51-92.

Anon (1976) Camden Bay and approaches, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Map no. 16044.

Harper, J.R. and E.H. Owens (1981) Analysis of ice override potential along the Beaufort Sea" coast of Alaska, 6th Int. Conf. on Port and Ocean " Engineering under Arctic Conditions, Laval University, Quebec, Canada, Vol. II and 111. ,

Hartz, R.W. (1978) Erosional hazards map of the arctic coast of the National Petroleum Reserve - Alaska, U.S. Geological Survey Open-File Report 78-406.

Kovacs, A. and B.A. Kovacs (1982) Some recent shore ice pile-up and ride-up observations along the Alaska arctic coast, USACRREL Technical Note (unpublished).

Kovacs, A. and D.S. Sodhi (1980) Shore ice pile-up and ride-up: Field observations, theoretical analyses, Cold Regions Science and Technology, Vol. 2.

Kovacs, A., D.S. Sodhi and G.F.N. Cox (1982) Sea ice environment around Fairway Rock, Bering Strait, Alaska, U.S. Army Cold Regions Research and Engineering Laboratory, CRREL Report.

Lewellen, R. (1977) A study of Beaufort Sea coastal erosion, northern Alaska, NOAA/BLM Environmental Assessment of the Alaska Continental Shelf, Annual Reports of Principal Investigators for the year ending March 1977, Vol. XV, Transport.

O'Neill, J.J. (1924) Report of the Canadian Arctic Expedition 1913-1918, Vol. XI Geology and Geography, 'Part A. The Geology of the Arctic Coast of Canada West of Kirt Peninsula, Southern Party 1913-16, (Ed.) F.A. Acland, Ottawa, Canada.

Stefansson, V. (1969) The friendly Arctic, The Story of Five Years in Polar Regions, Greenwood Press, N.Y.

Vaudrey, K.D. and R.E. Potter (1981) Ice defense for natural barrier islands during freeze-ups 6th Int. Conf. on Port and Ocean Engineering under Arctic Conditions, Laval University, Quebec, Canada, Vol. I.

Illustrations

Figure 18. View of 2-meter high coastal bluff showing 0.25-m-thick tundra mat and underlying massive ice and ice-rich silt. The latter is easily undercut and eroded by the seawater.

Figure 19. Ice-pushed peat piles on the coast near Ksook. Note the general size and stacking configuration of the displaced peat slabs. Arrow in upper photo "indicates pile shown in lower photo.

Figure 20. Ice-pushed peat on coast west of Ksook. Note the Ksook house behind helicopter and the coastal bluff in the upper left of photo a. "

Figure 21. Offshore and beach profile across one of the ice-pushed piles near Ksook.

Figure 22. Aerial view of the coast at Ksook in 1949 with insert at bottom showing the coast outline in 1981. Near vertical arrows point to same house.

Figure 23. Rafted sea ice off Long Island.

Figure 24. Surface view of ridges shown in Figure 23.

Figure 25. Ice-push beach morphology along coast east of Collinson Point.

Figure 26. Ice-push beach striations and gravel piles along the shore east of Collinson Point.

Figure 27. Seabed-beach profile along line drawn in Figure 25.

Figure 28. Typical winter view of ice-scarred tundra relief.

Figure 29. Summer view of ice-scarred tundra features shown in Figure 28.

Figure 30. Aerial view of ice-scarred coast.

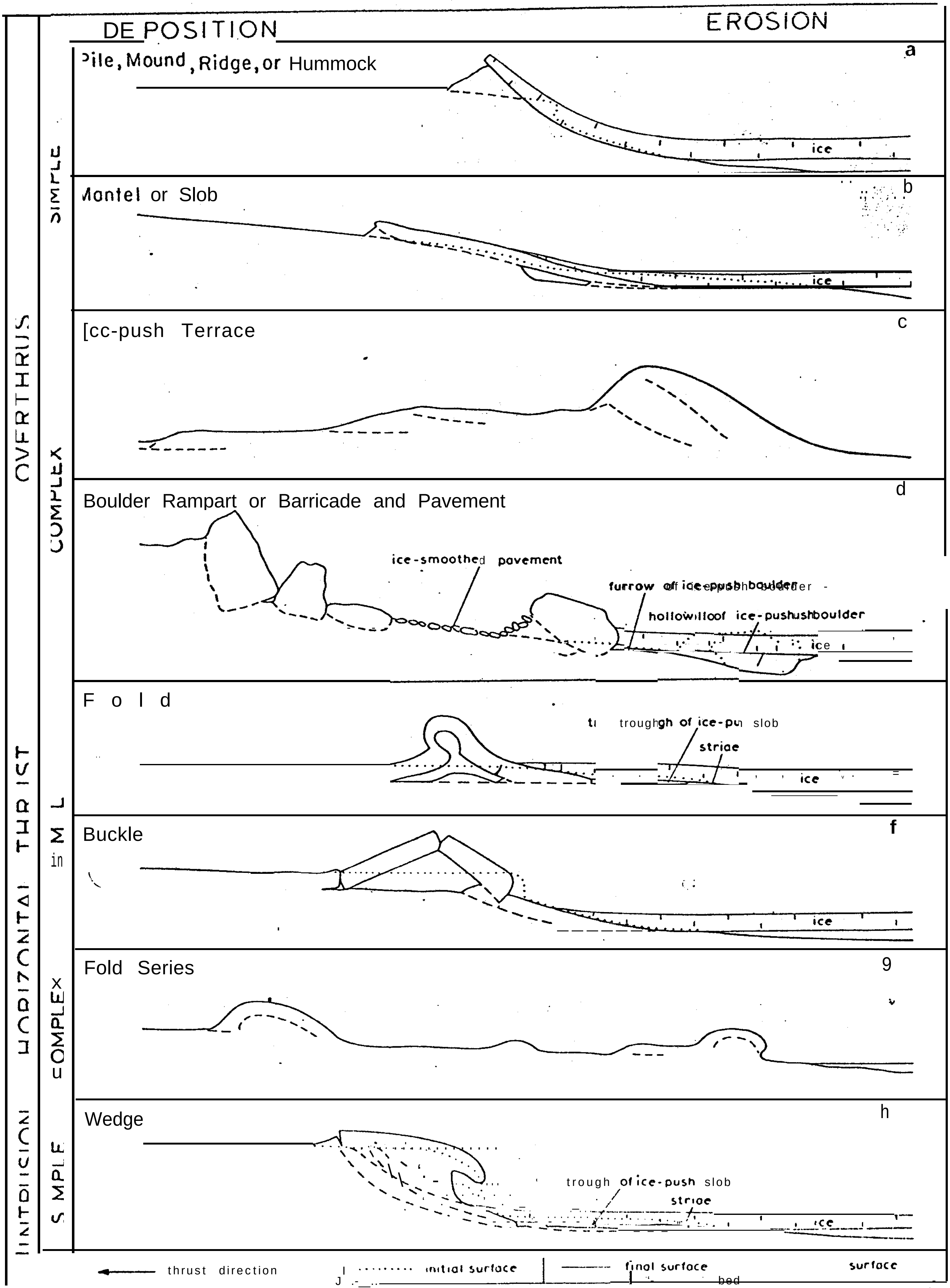
Figure 31. Old ice-pushed tundra berms and ice-pushed gravel piles on the beach which were the result of the previous winter ice ride-up.

Figure 32. Beach views of ice-scarred tundra. Views a and b show interior of features B and C respectively in Figure 29.

Figure 33. Ice-pushed tundra berm behind person in Figure 32b as seen from landward side.

Figure 34. Seabed-beach-tundra profiles.

Figure 35. Ice-scarred tundra features along southeast side of Camden Bay. Insert is 1947 imagery showing the northern continuation of the coast beyond the arrow-in the upper right-hand corner of the larger photo. Arrows point to many of the major ice scars. The arrow at-the-bottom left points to the terrain shown in Figure 31.


DEPOSITION
EROSION
OVERTHRUST
SIMPLE
COMPLEX
HORIZONTAL THRUST
INTRUSION
SIMPLE
COMPLEX
Pile, Mound, Ridge, or Hummock
a
ice
Mantel or Slab
b
ice
c
d
Boulder Rampart or Barricade and Pavement
ice-smoothed pavement
furrow of ice-push boulder
hollow of ice-push boulder
ice
Fold
trough of ice-push slob
striae
ice
Buckle
f
ice
Fold Series
Wedge
h
trough of ice-push slob
striae
ice
thrust direction
initial surface
final surface
surface
bed

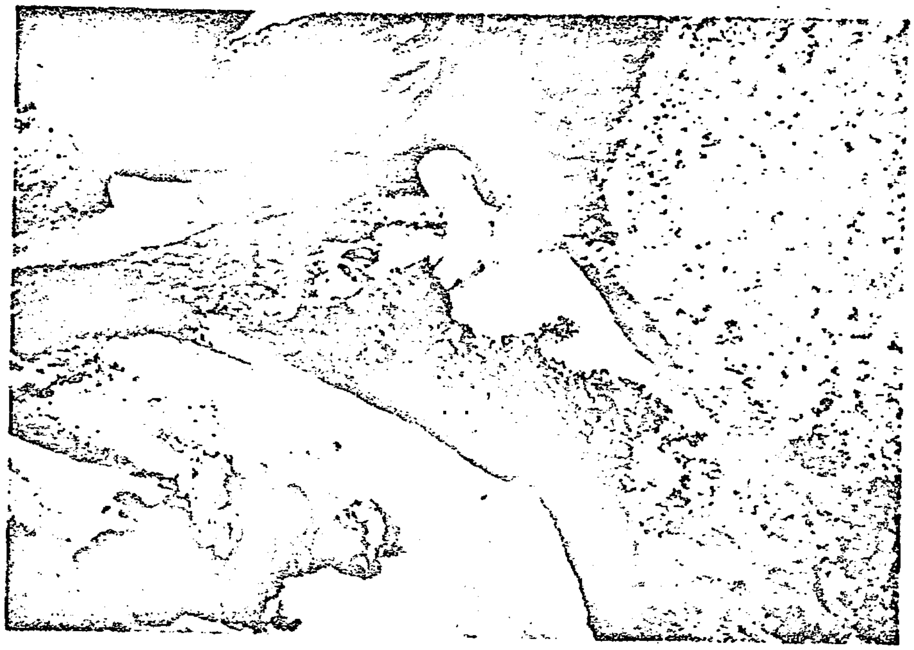
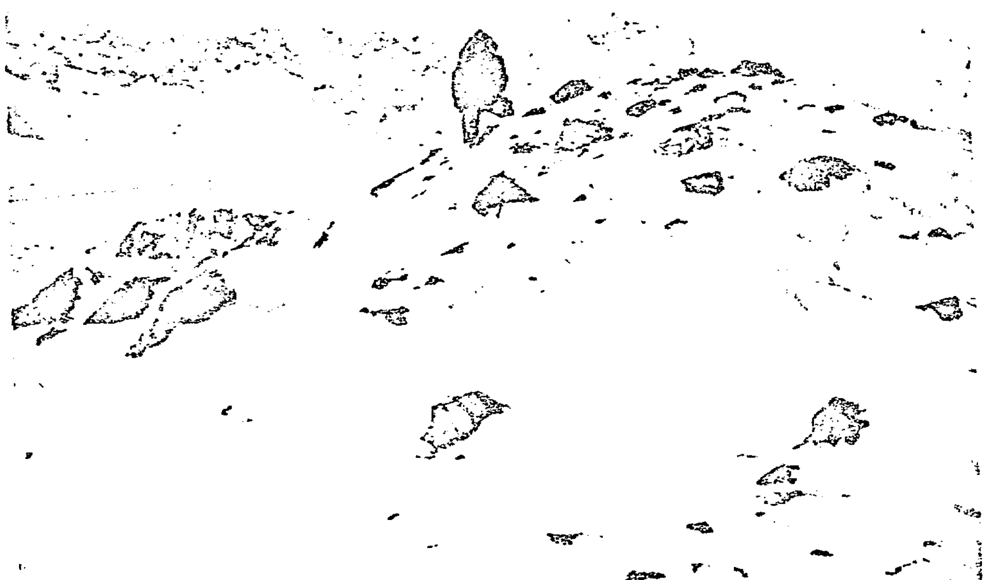


FIG 2



3

4

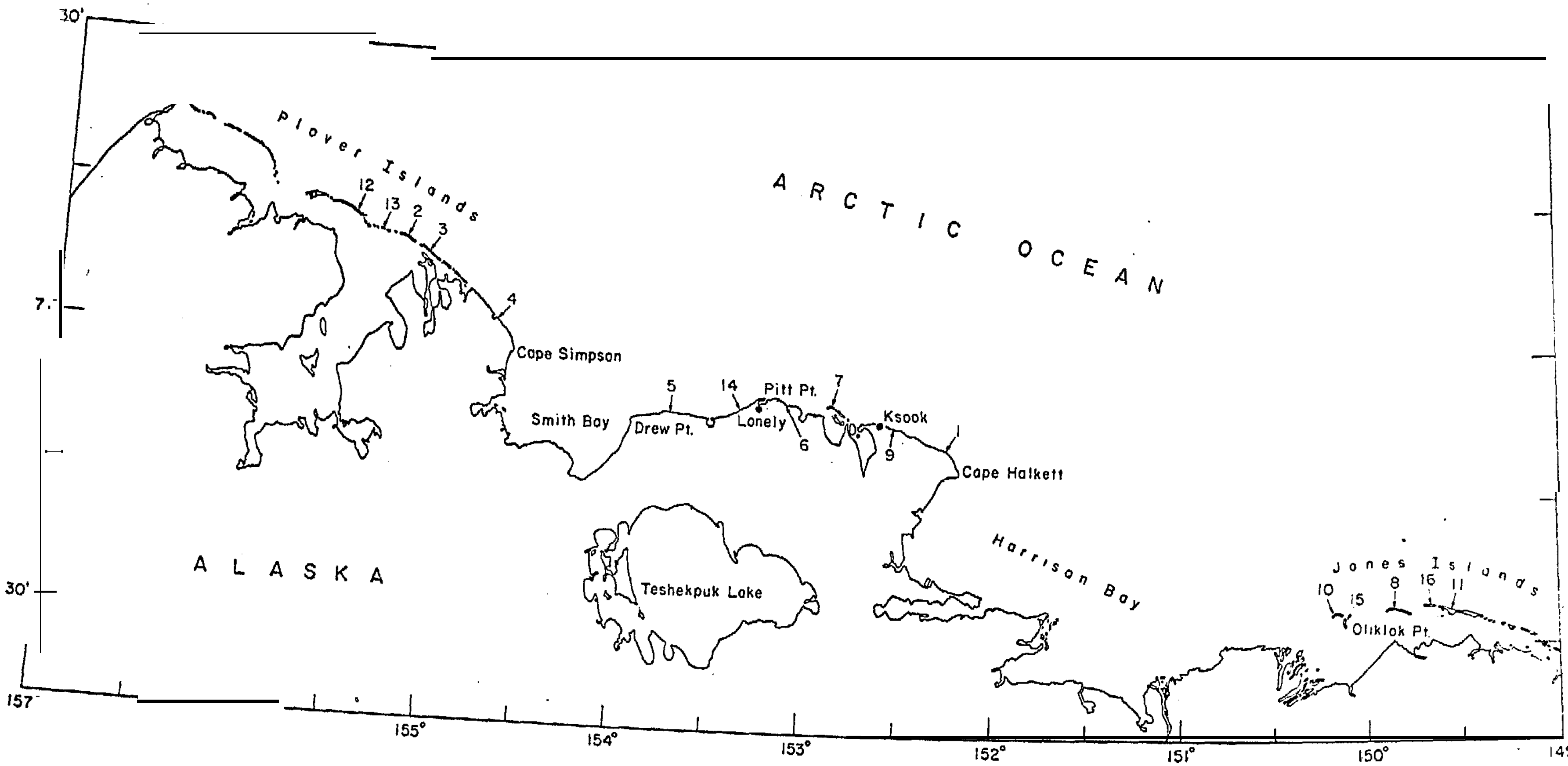

ARCTIC OCEAN
ALASKA
Plover Islands
12
13
2
3
4
Cape Simpson
Smith Bay
5
Drew Pt.
14
Pitt Pt.
Lonely
6
7
Ksook
9
1
Cape Halkett
Teshekpuk Lake
Harrison Bay
Jones Islands
10
15
8
16
11
Oliktok Pt.
157°
155°
154°
153°
152°
151°
150°
149°
30'
7

Fig 6

5

7a

7b

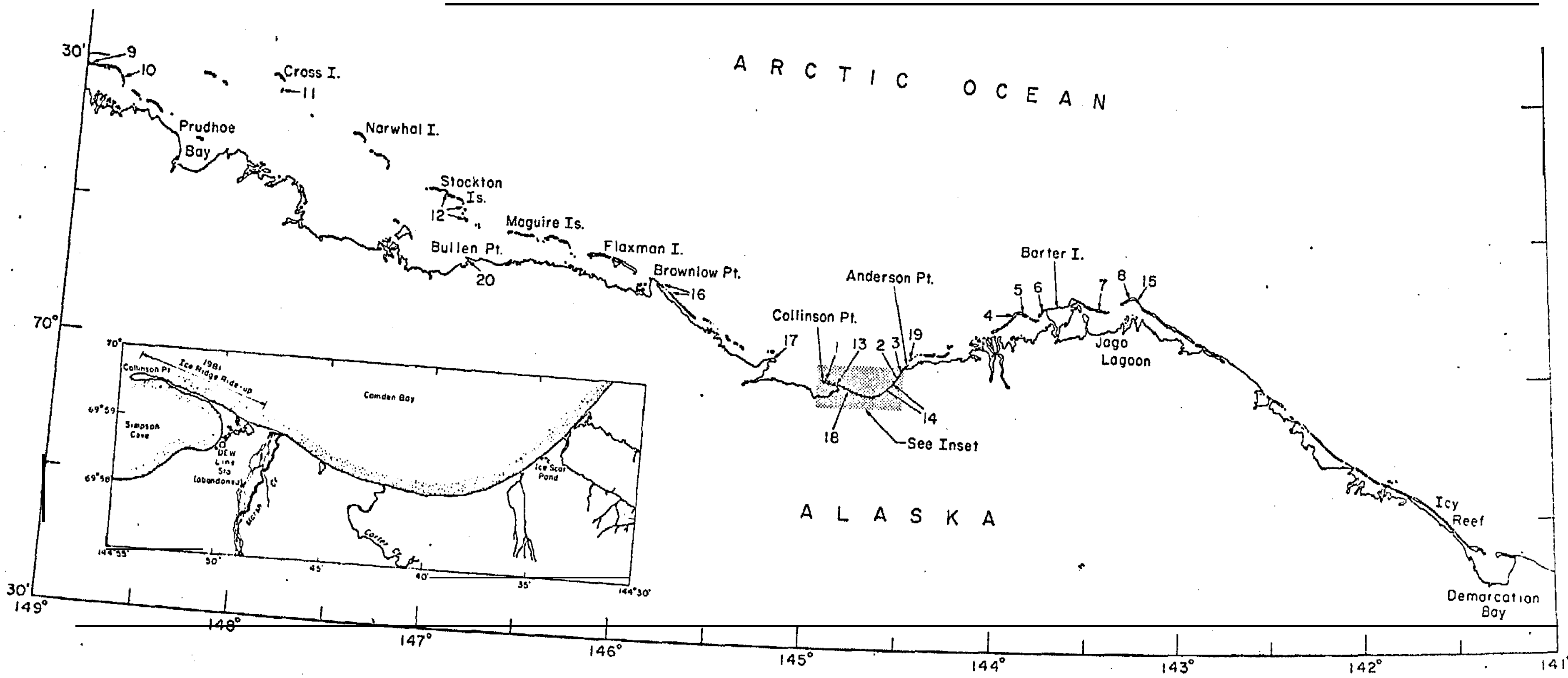
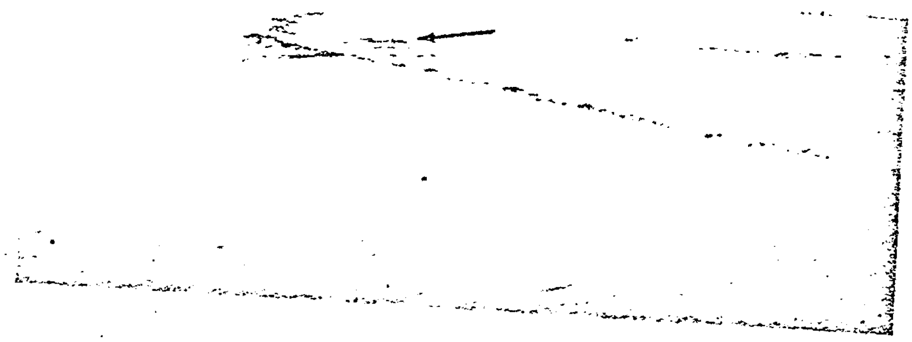
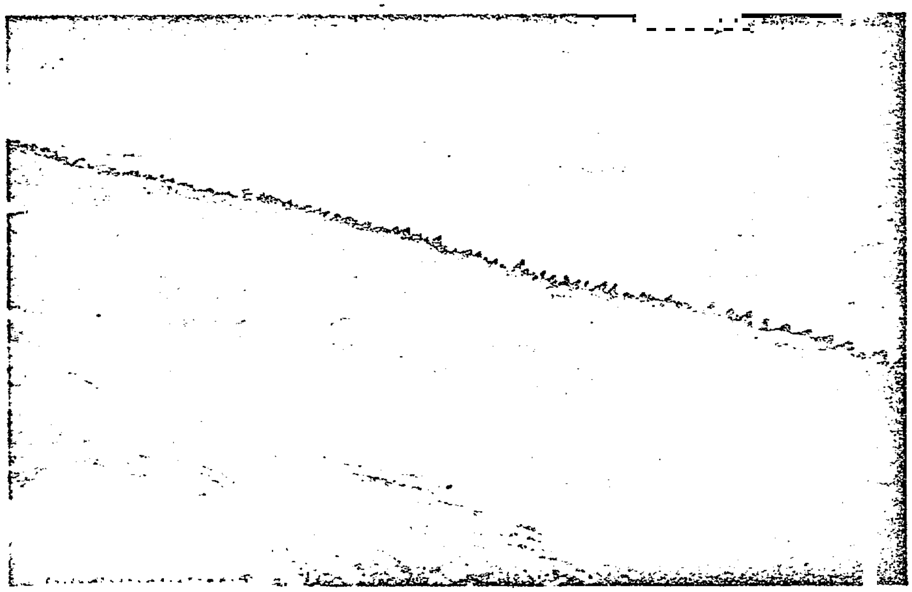

ARCTIC OCEAN
ALASKA
Prudhoe Bay
Cross I.
Narwhal I.
Stockton Is.
Maguire Is.
Flaxman I.
Bullen Pt.
Brownlow Pt.
Collinson Pt.
Anderson Pt.
Barter I.
Jago Lagoon
Icy Reef
Demarcation Bay
See Inset
Camden Bay
Simpson Cove
Collinson Pt
1981 Ice Ridge Ride-up
DEW Line Sta (abandoned)
Ice Scar Pond
149°
148°
147°
146°
145°
144°
143°
142°
141°
70°
30'

FIG 8

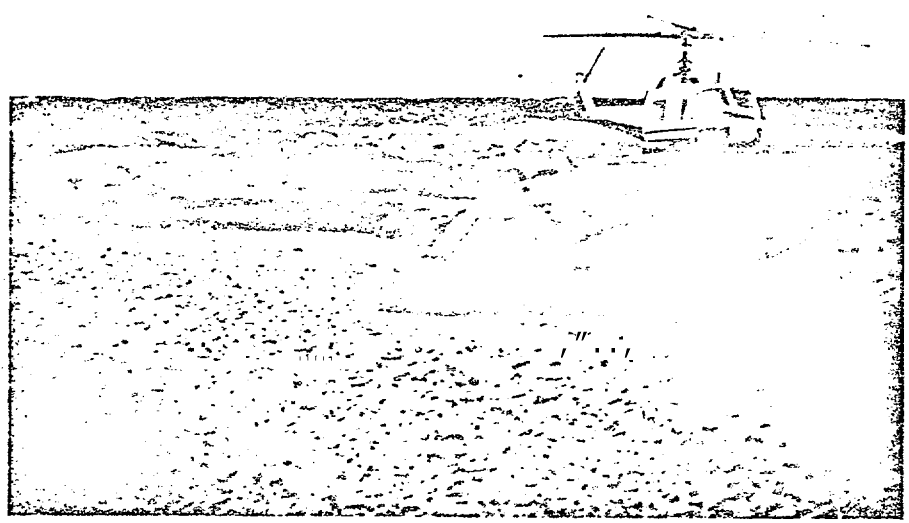


9

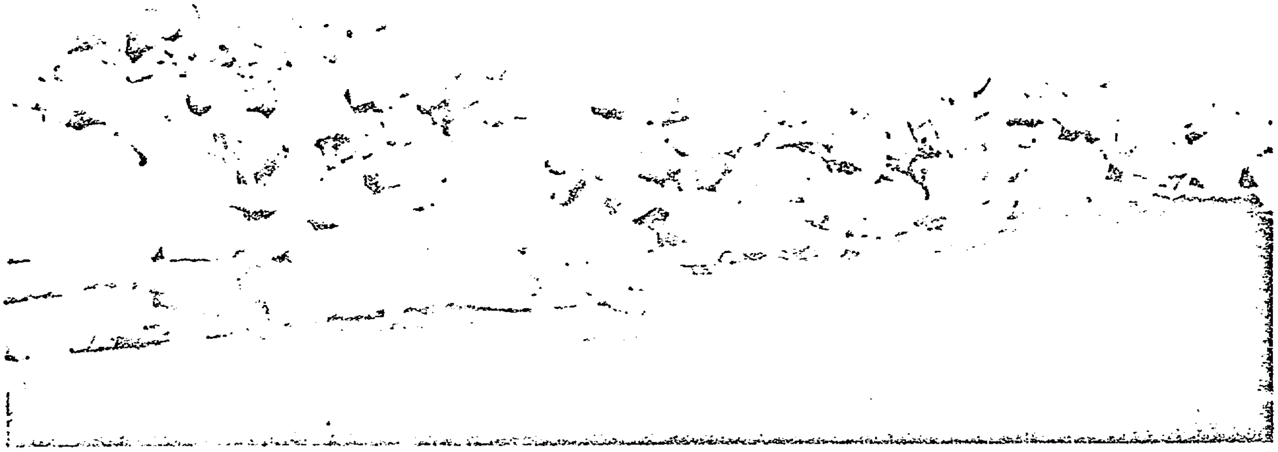
10



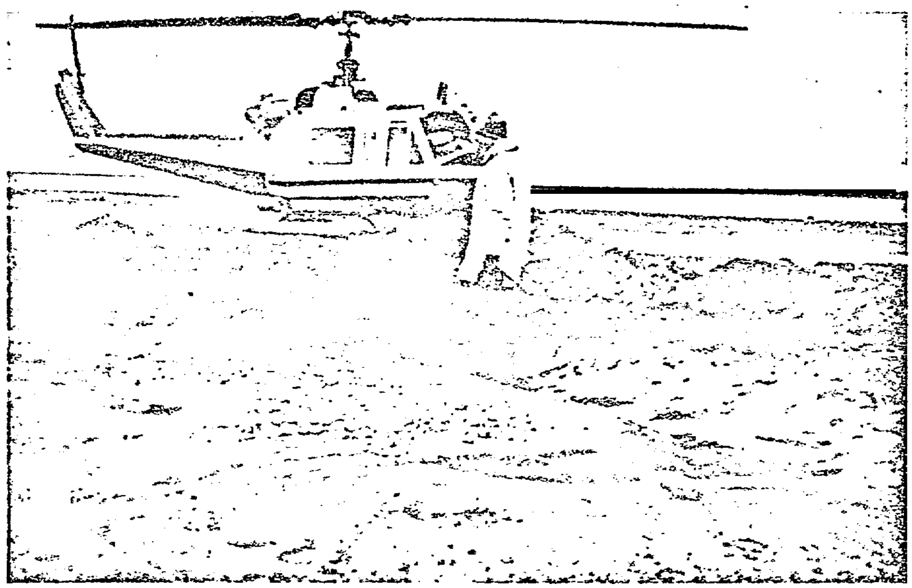
11a



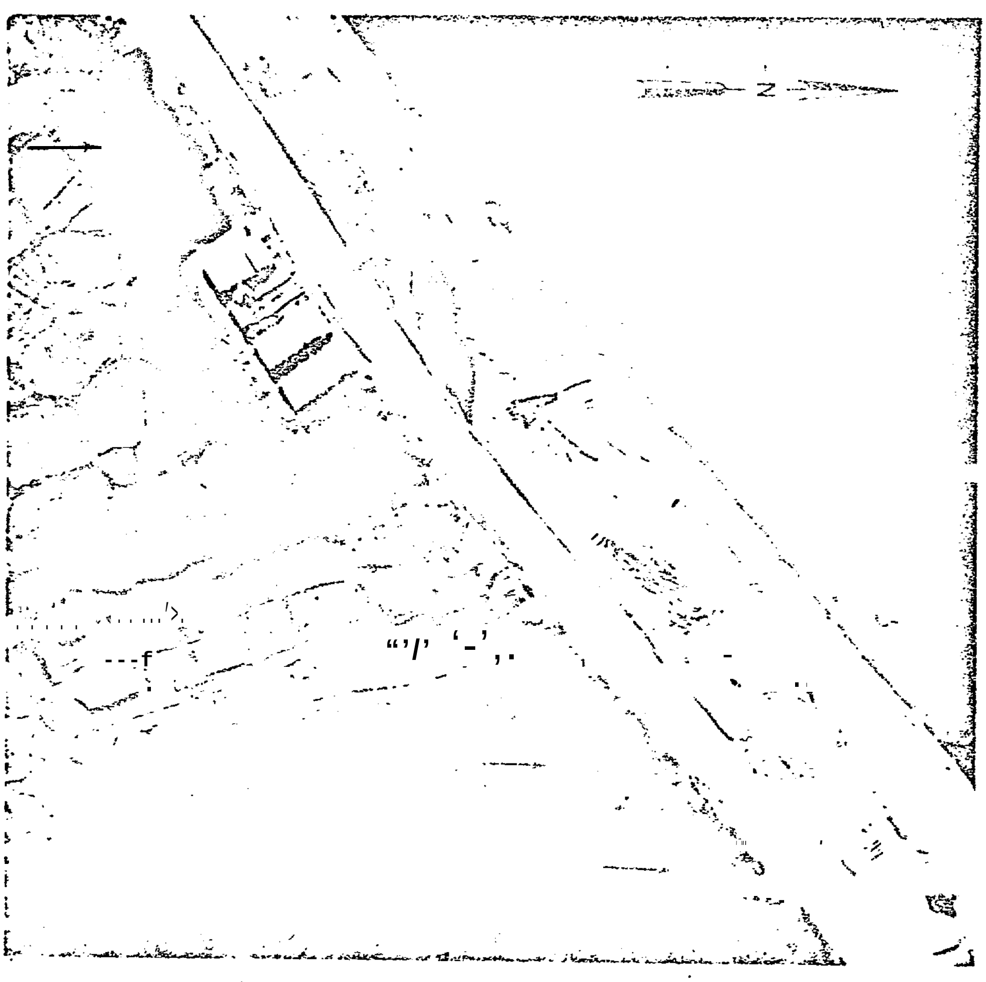
11b



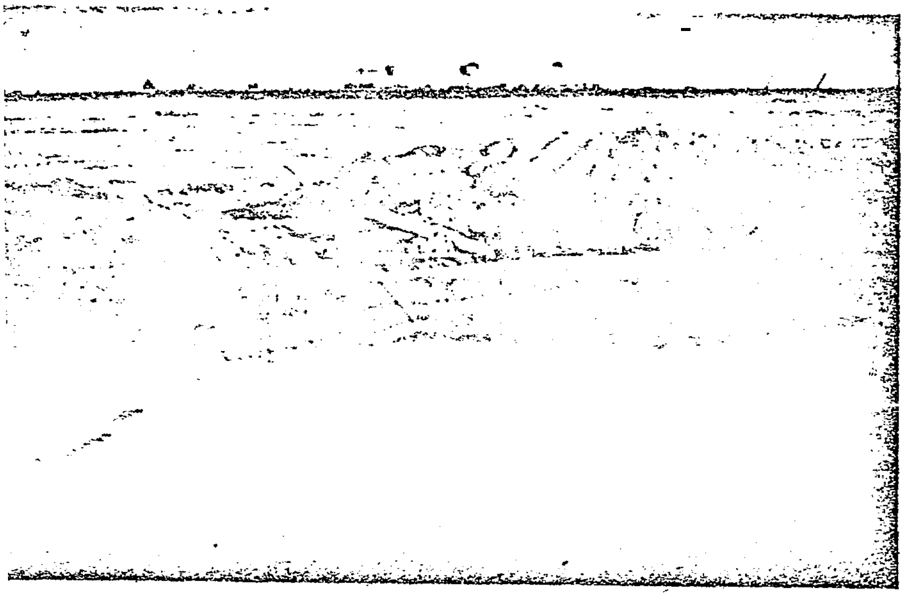
12



13

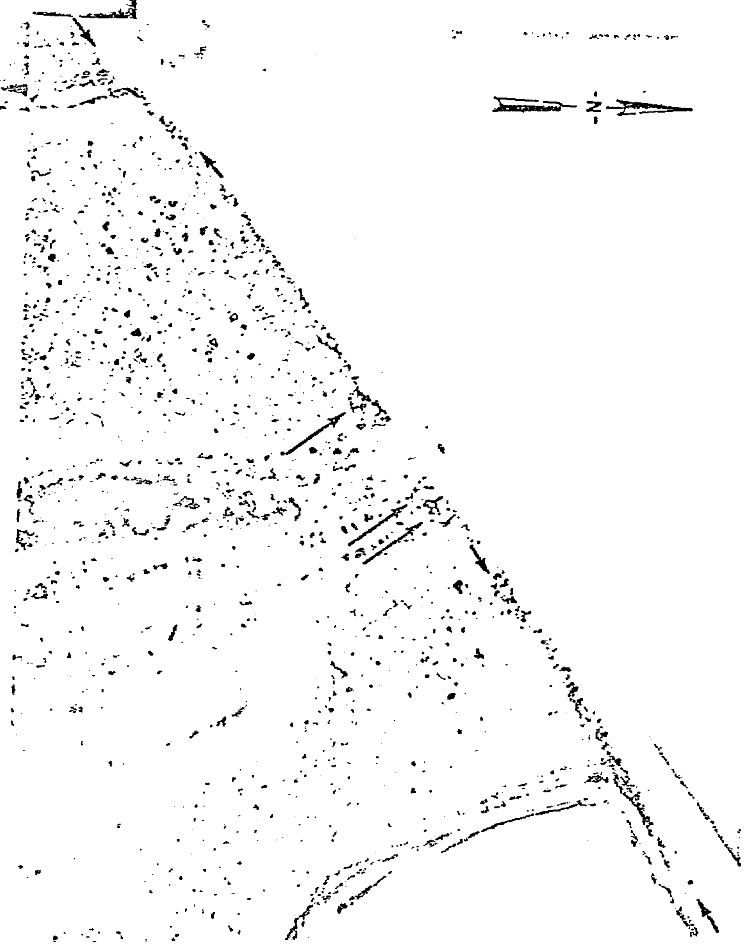


14



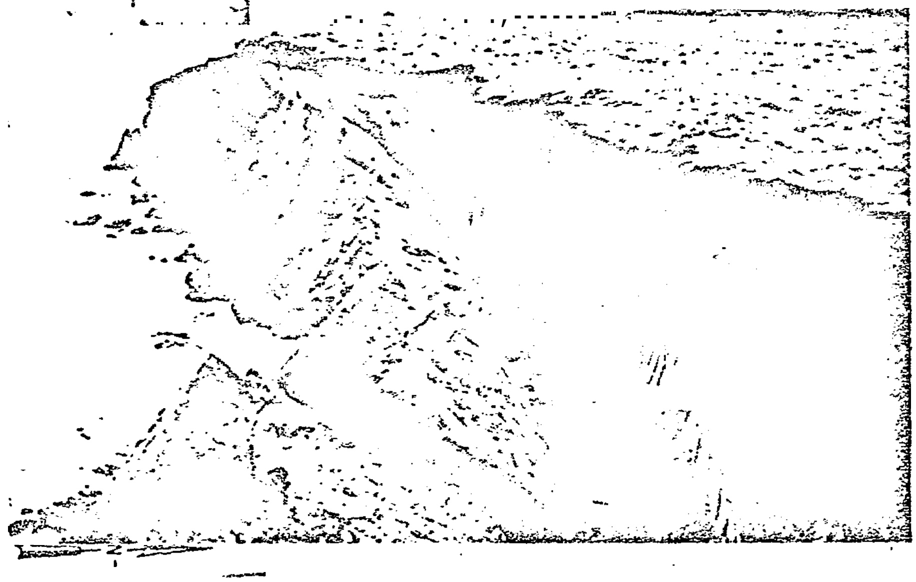
15a

/J---

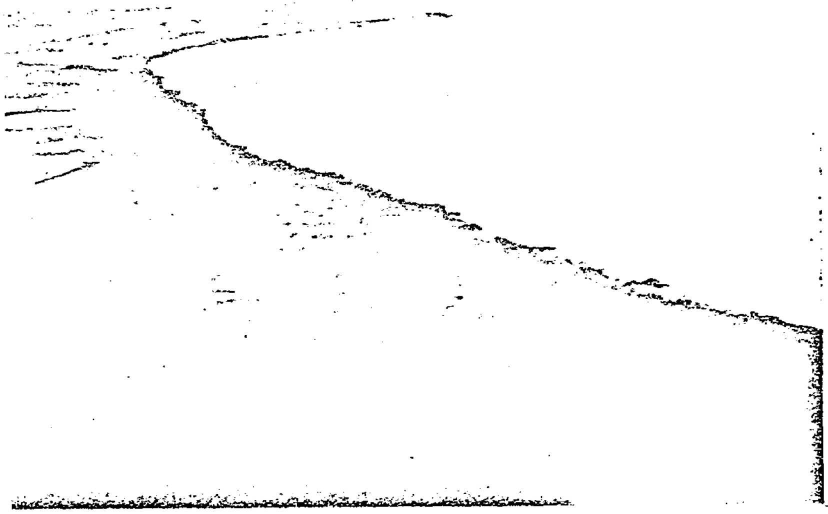


16

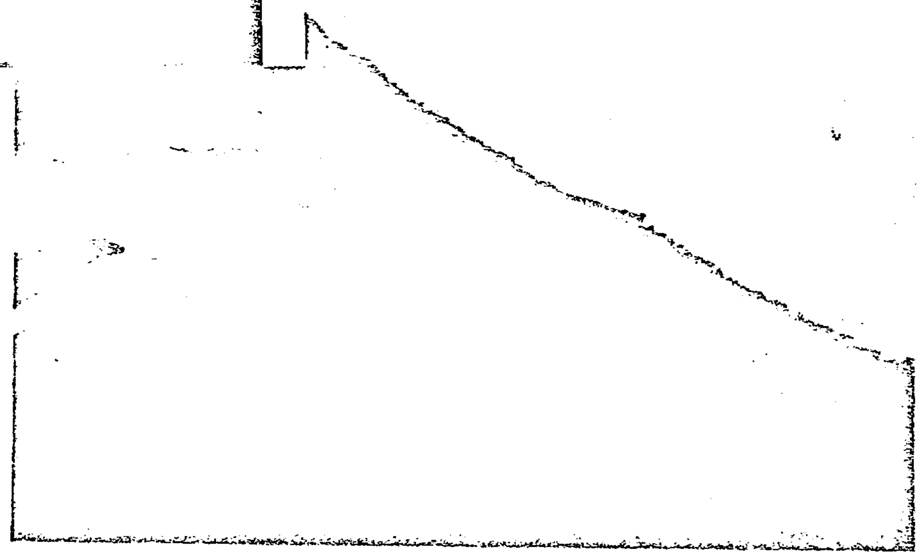
17



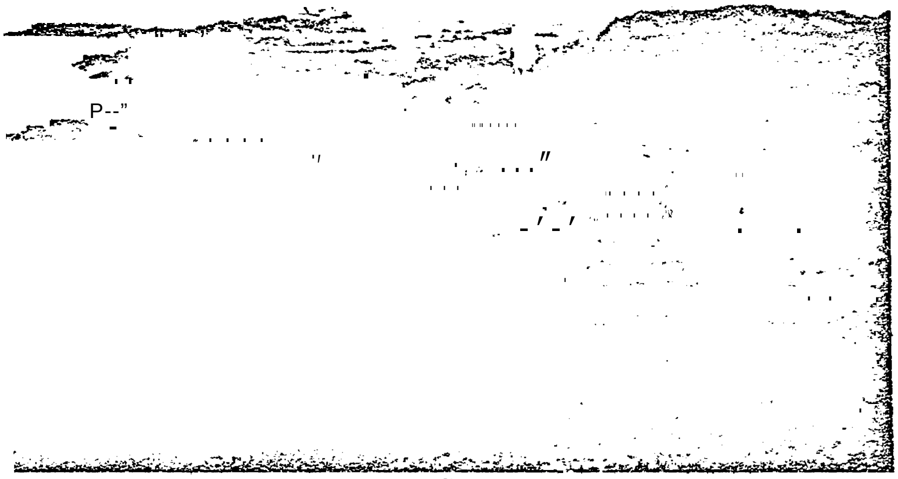
18



19a

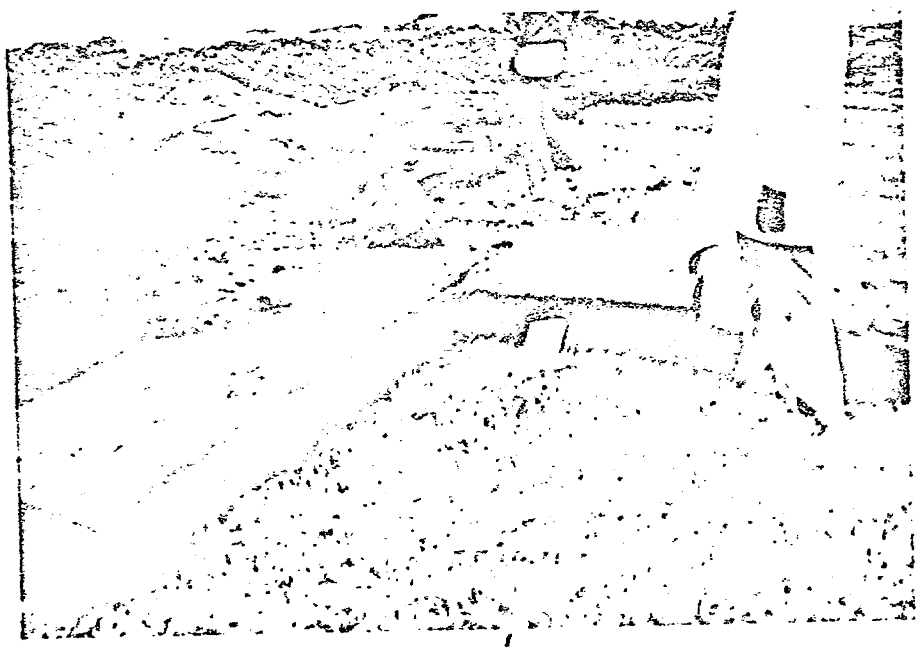


19b

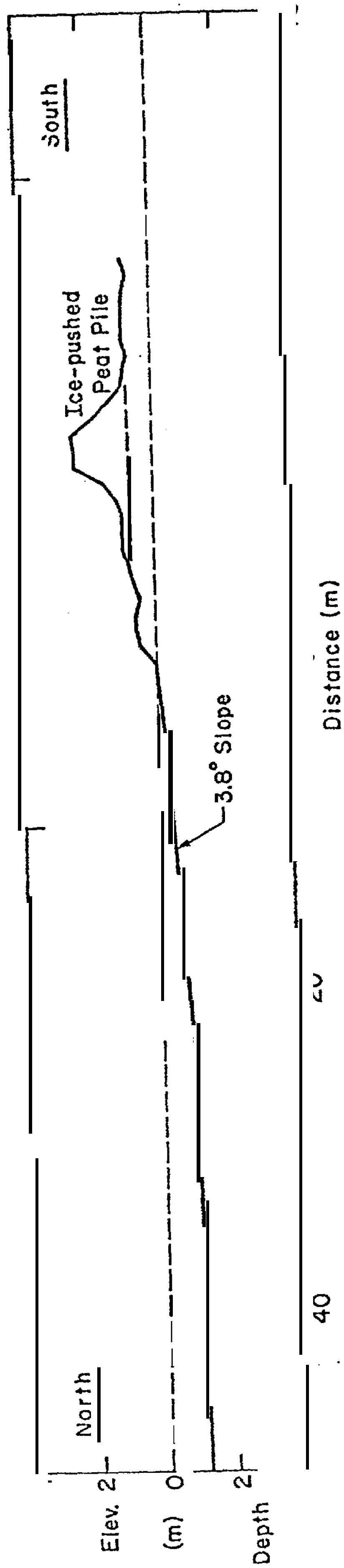


a.

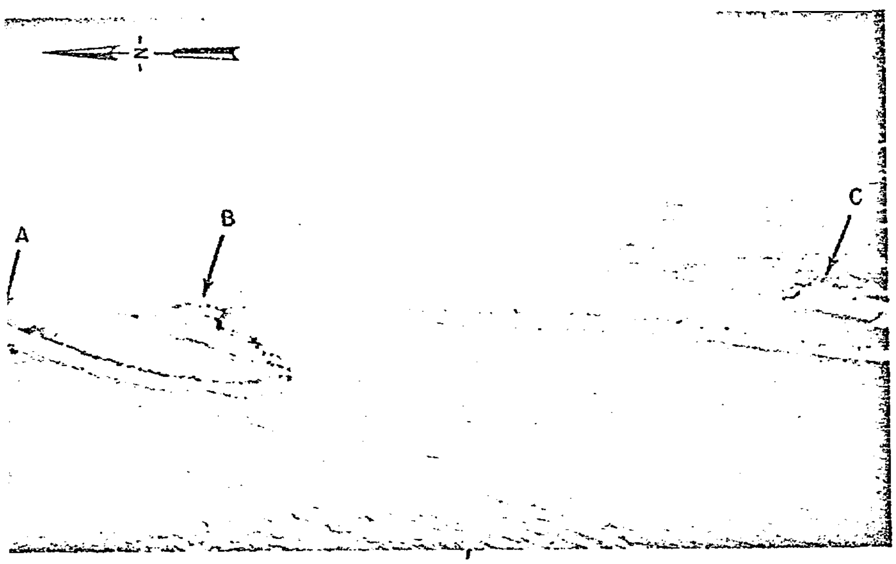
20a



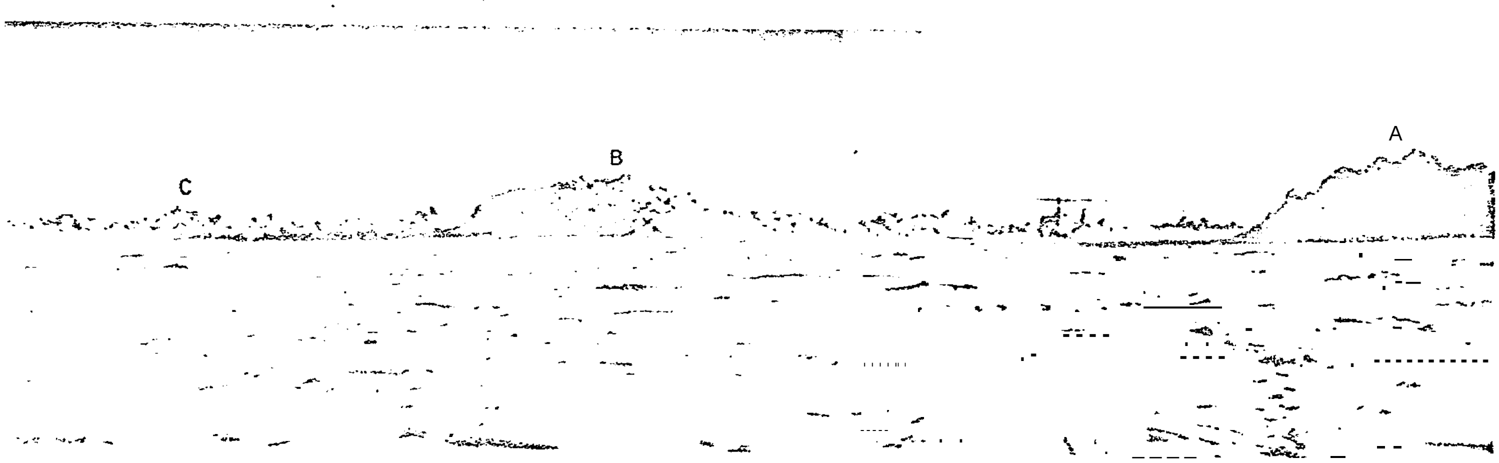
20b


South
Ice-pushed Peat Pile
3.8° Slope
Distance (m)
20
40
North
Elev. 2
(m) 0
Depth 2

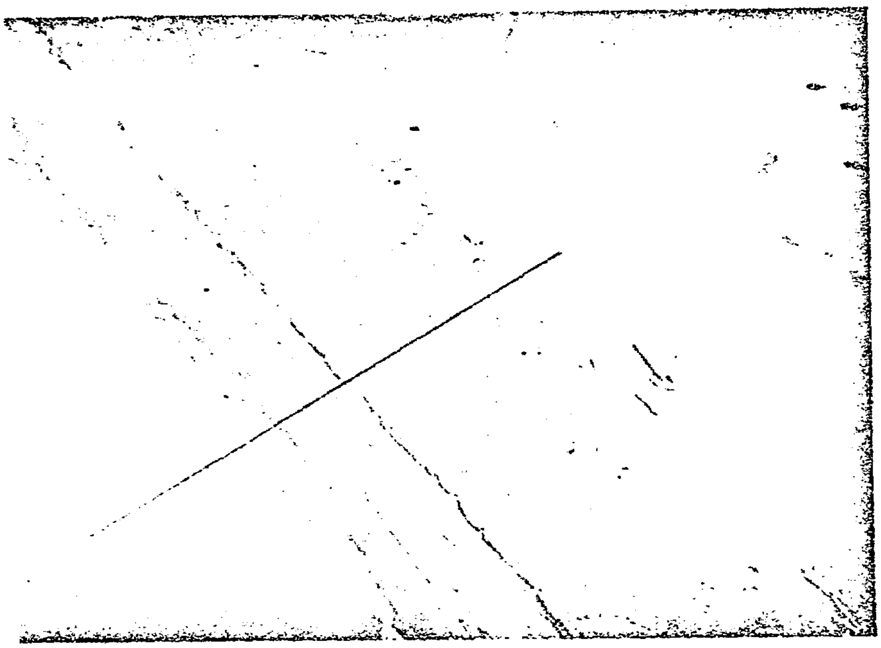
22



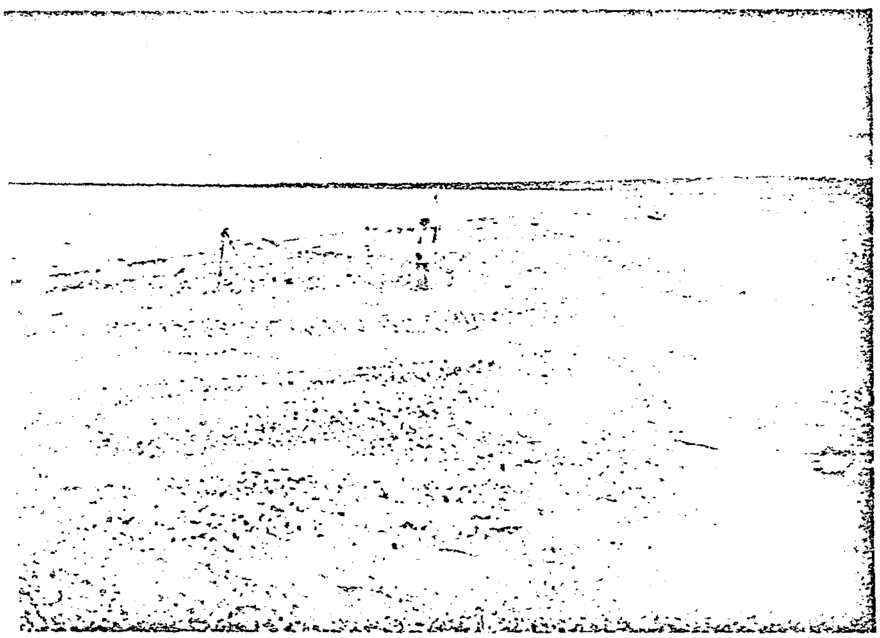
23



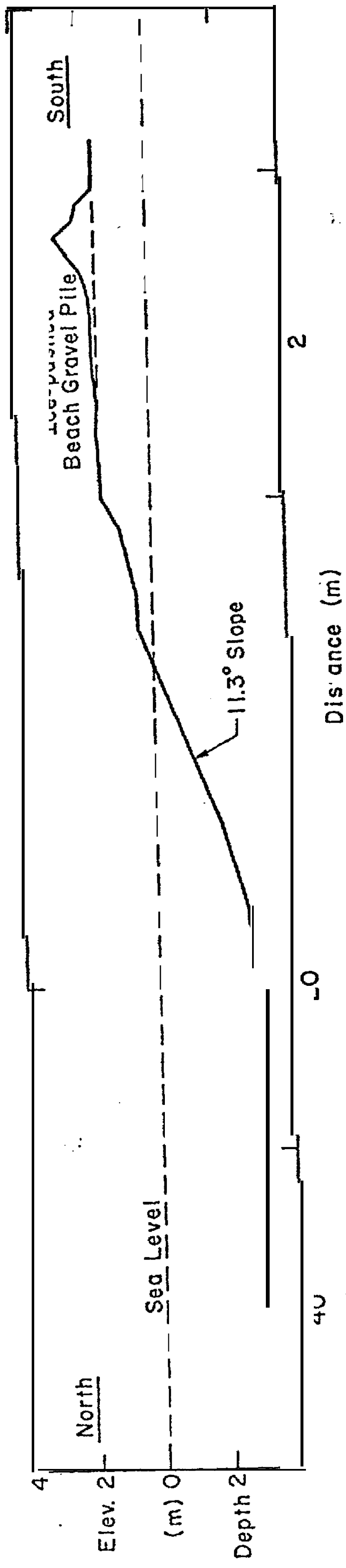
24



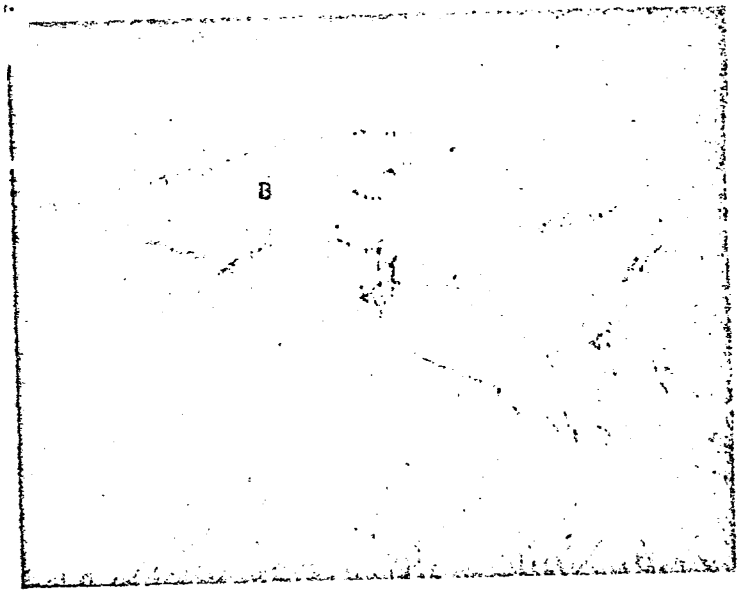
25



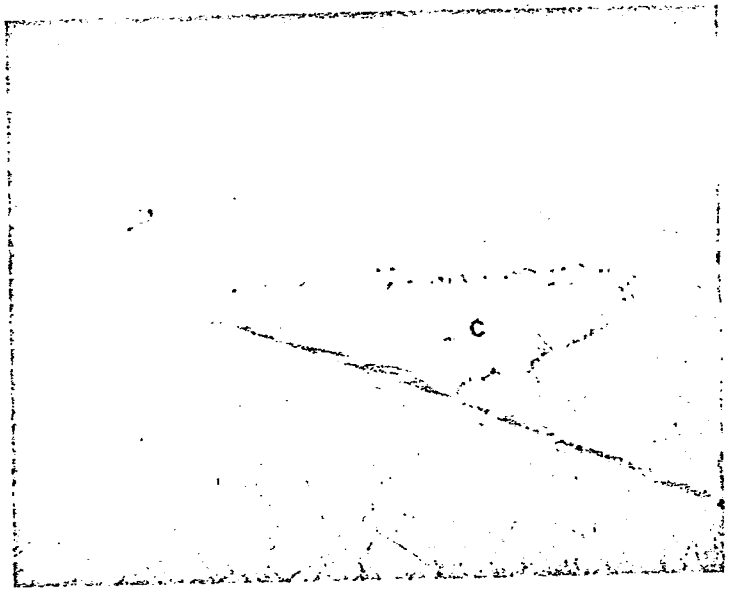
.26


South
Beach Gravel Pile
11.3° Slope
Distance (m)
Sea Level
North
4
Elev. 2
(m) 0
Depth 2

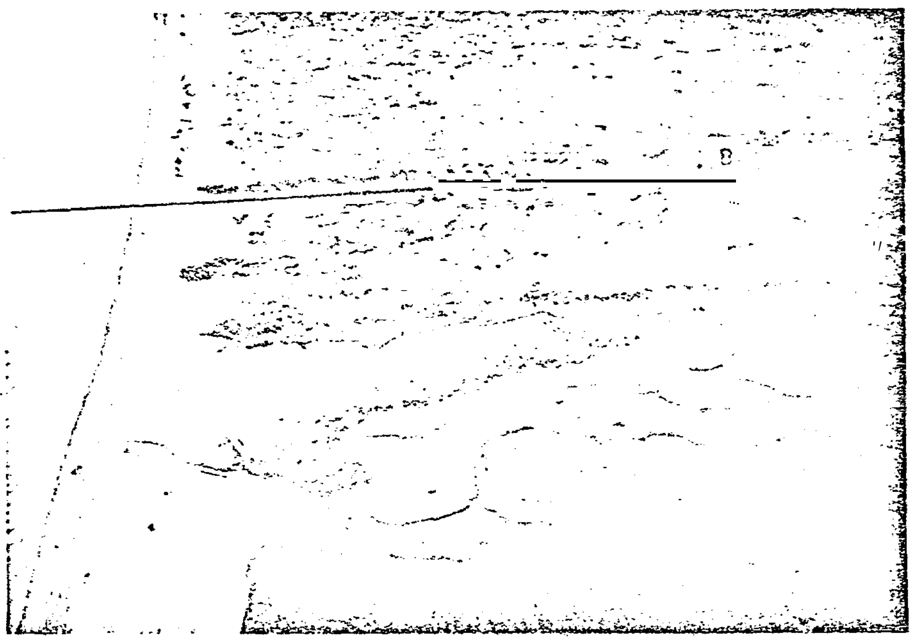
27



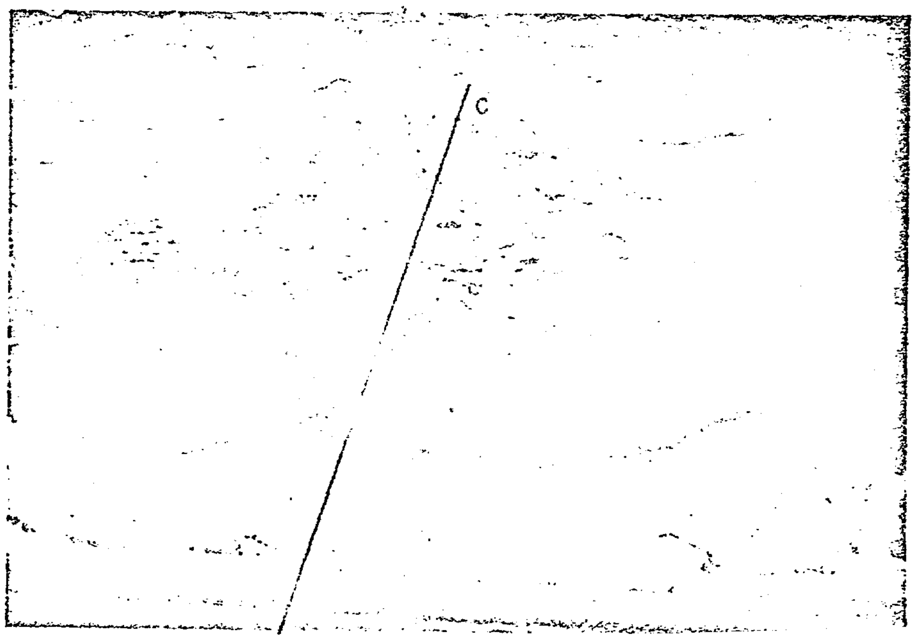
28a



28b

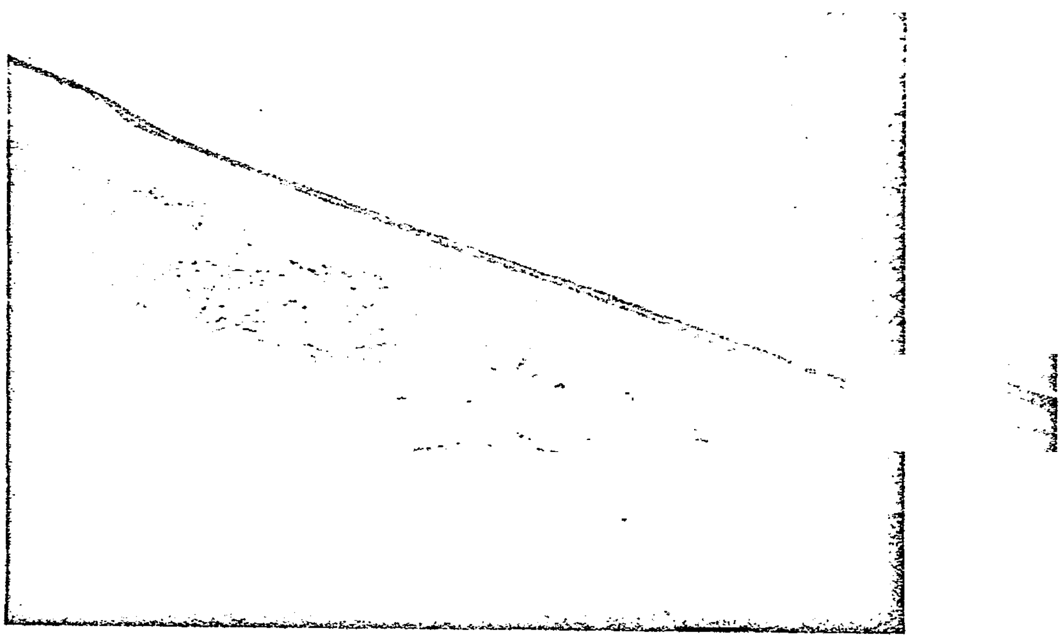


29a



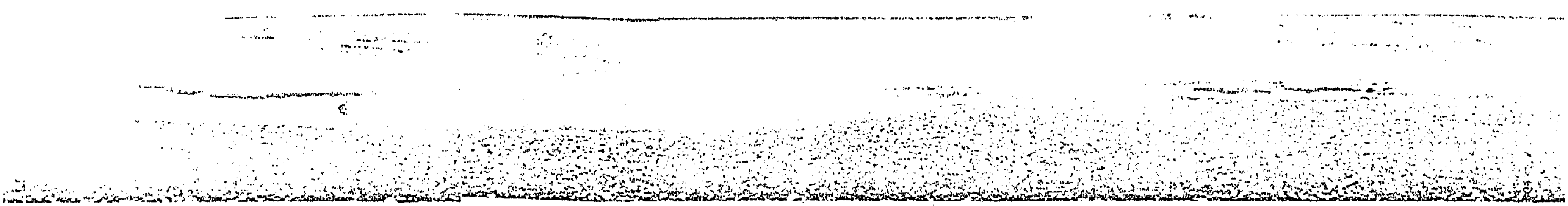
29b

30'

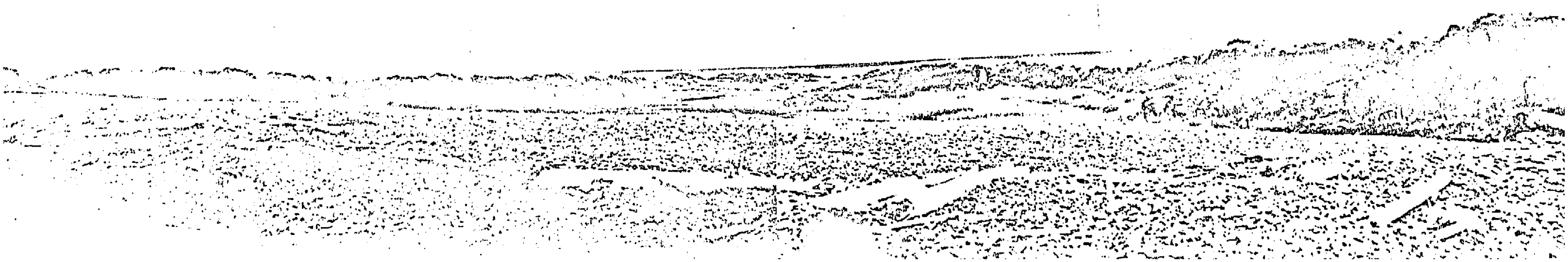


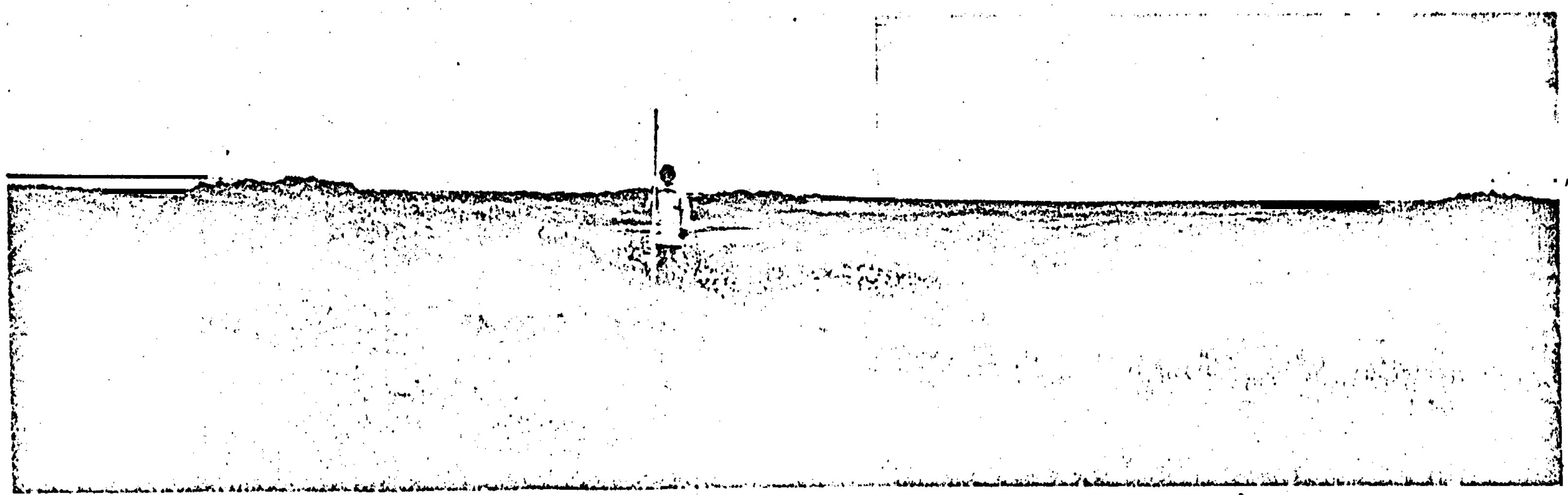
3/'

32b

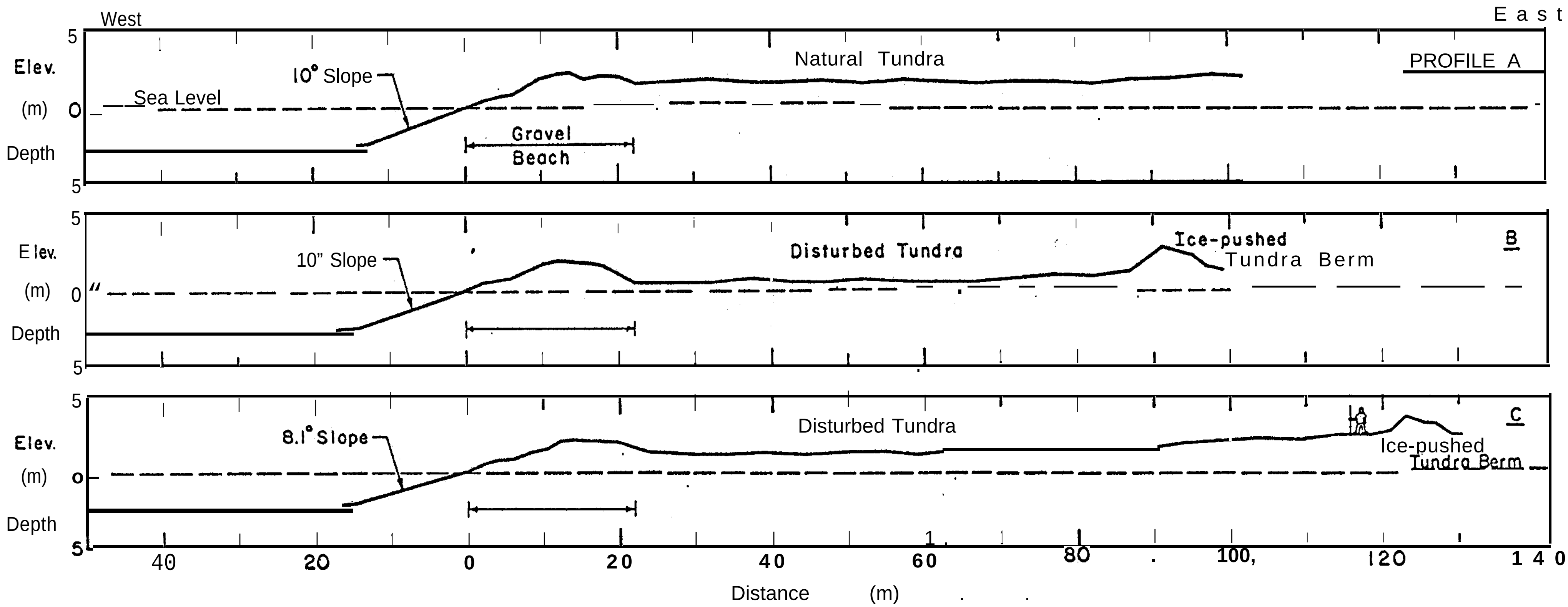


32a



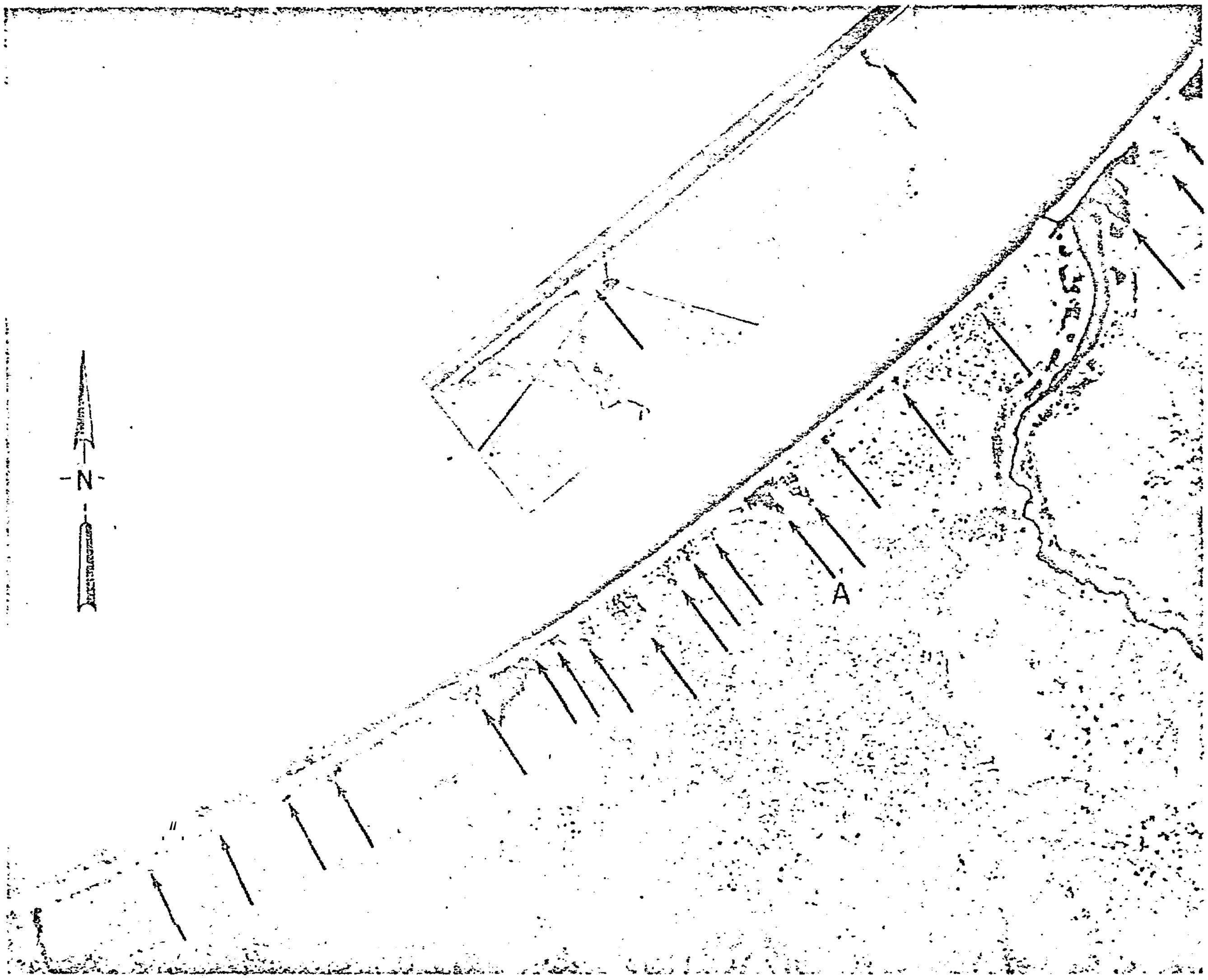


33

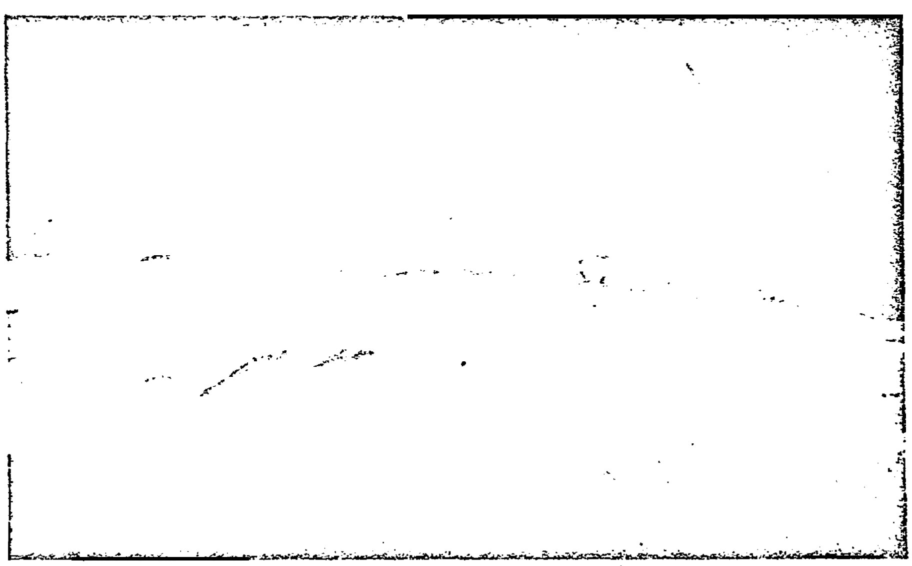


West
East
PROFILE A
Natural Tundra
10° Slope
Sea Level
Elev.
(m)
Depth
Gravel
Beach
B
Disturbed Tundra
Ice-pushed
Tundra Berm
10" Slope
C
Disturbed Tundra
8.1° Slope
Ice-pushed
Tundra Berm
40
20
0
20
40
60
80
100
120
140
Distance (m)

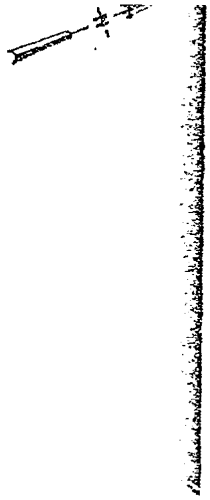
34



35

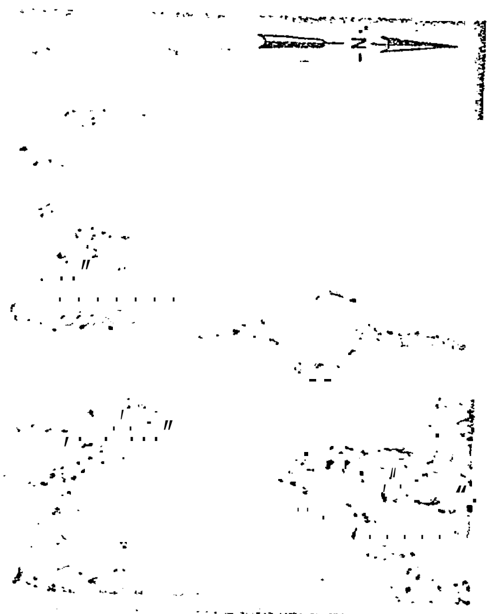


36

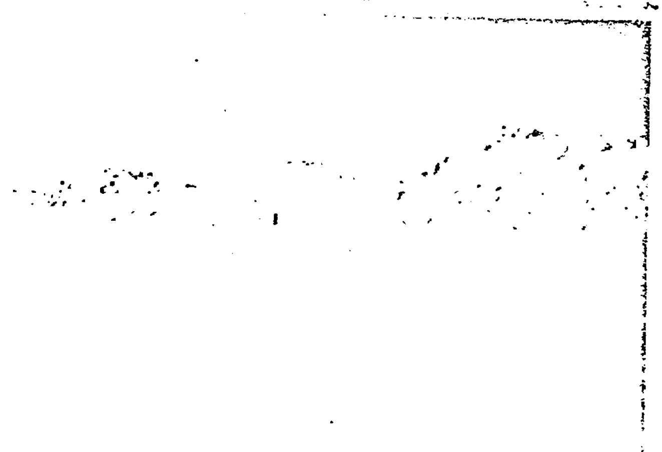


37a

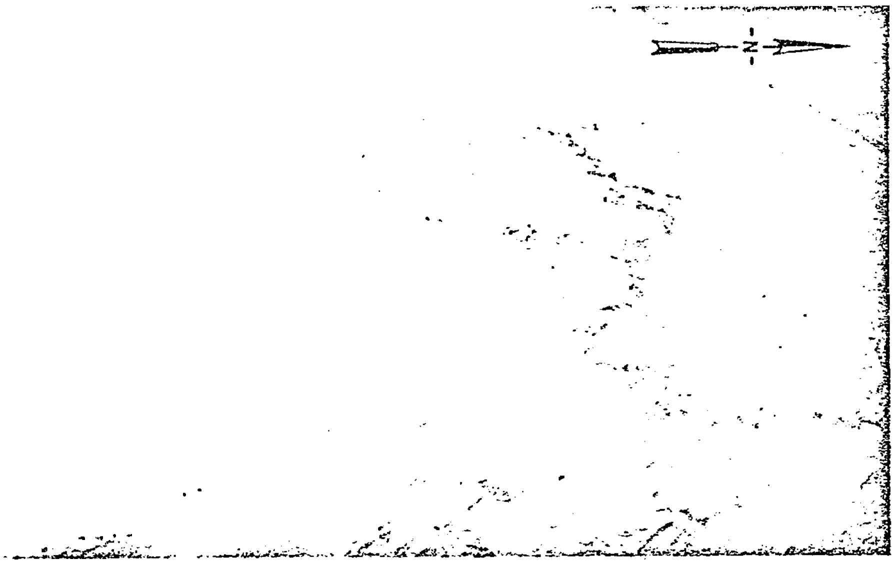
37b



38a



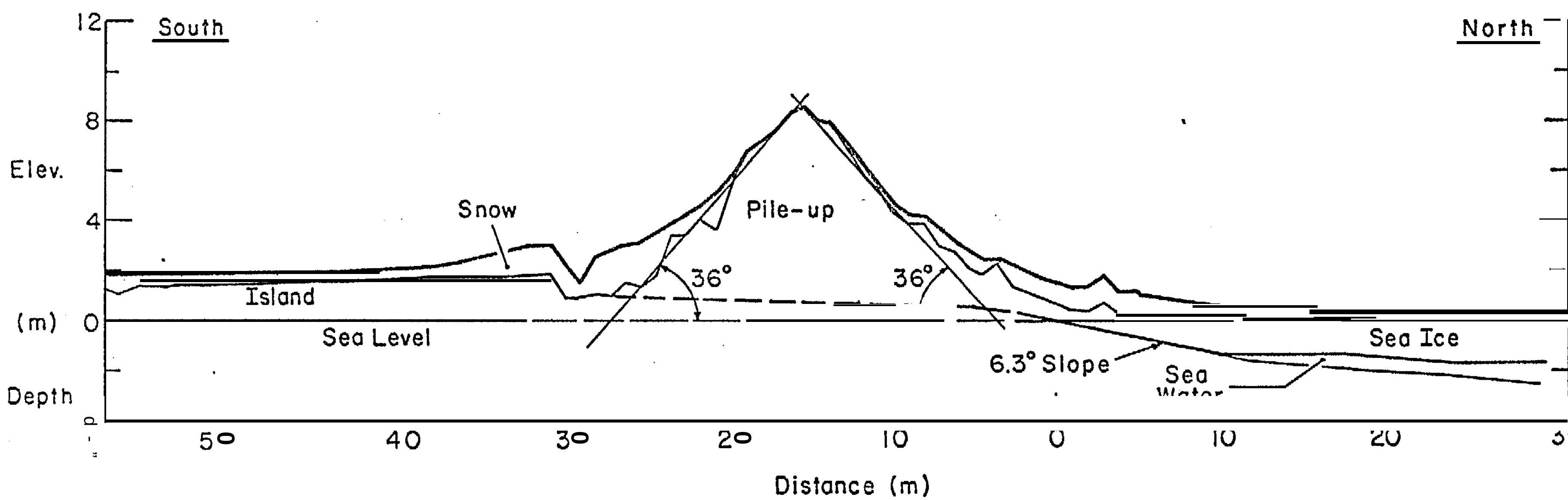
38b



39a

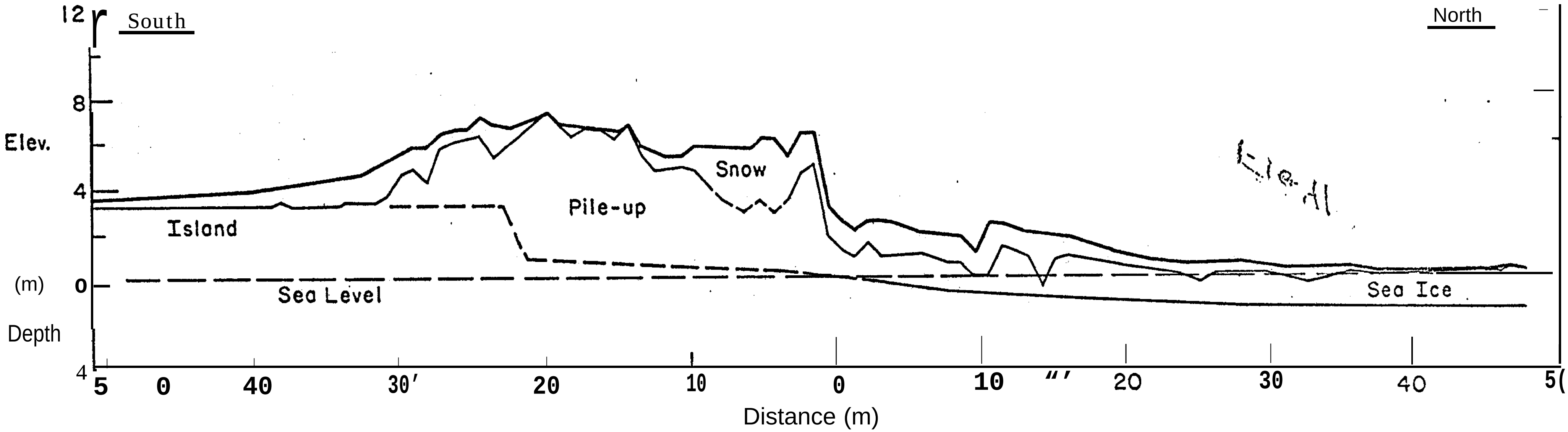
39b

40

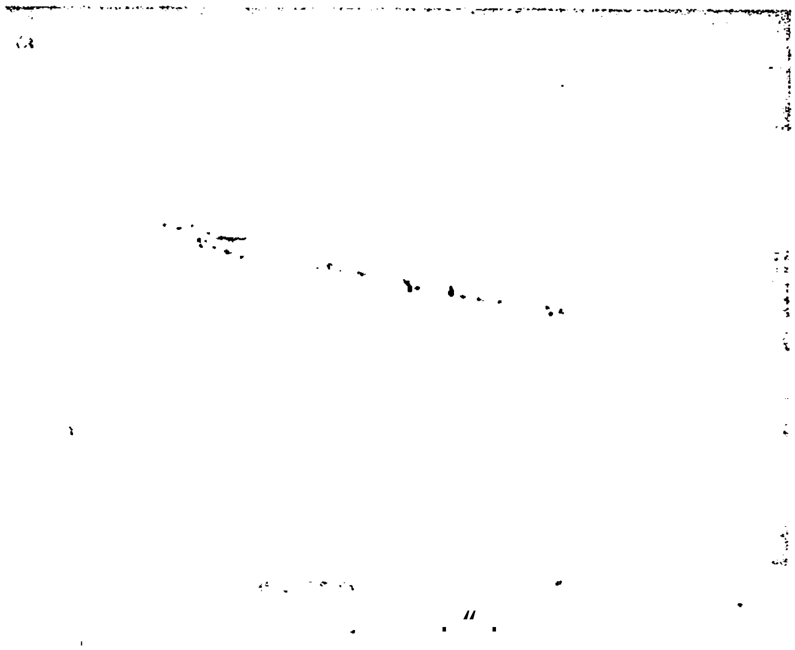


South
North
12
8
4
0
Elev.
(m)
Depth
Snow
Pile-up
Island
36°
36°
Sea Level
Sea Ice
6.3° Slope
Sea
50
40
30
20
10
0
10
20
30
Distance (m)

FIG 41



South
North
12
8
4
0
4
Elev.
(m)
Depth
Snow
Pile-up
Island
Sea Level
Sea Ice
5 0
40
30
20
10
0
10
20
30
40
Distance (m)

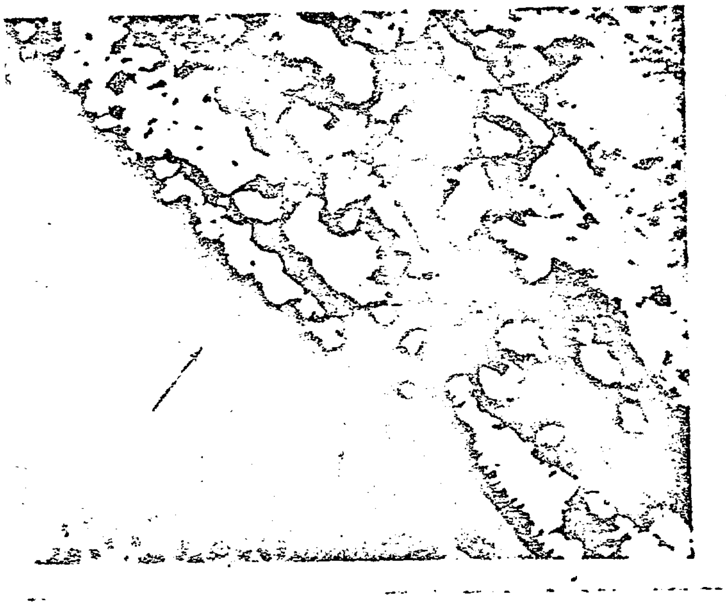


42

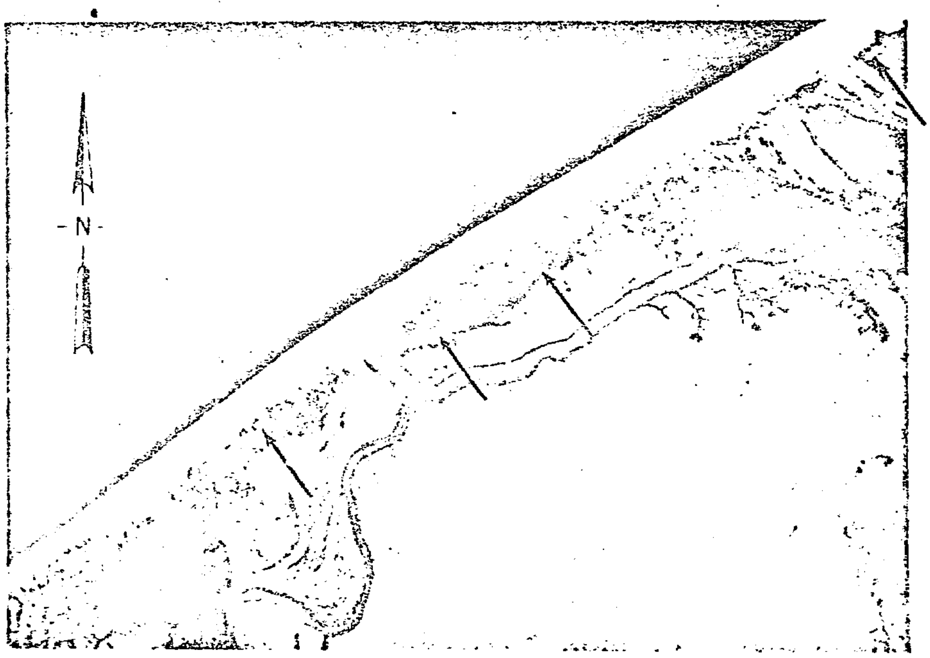
44

45a

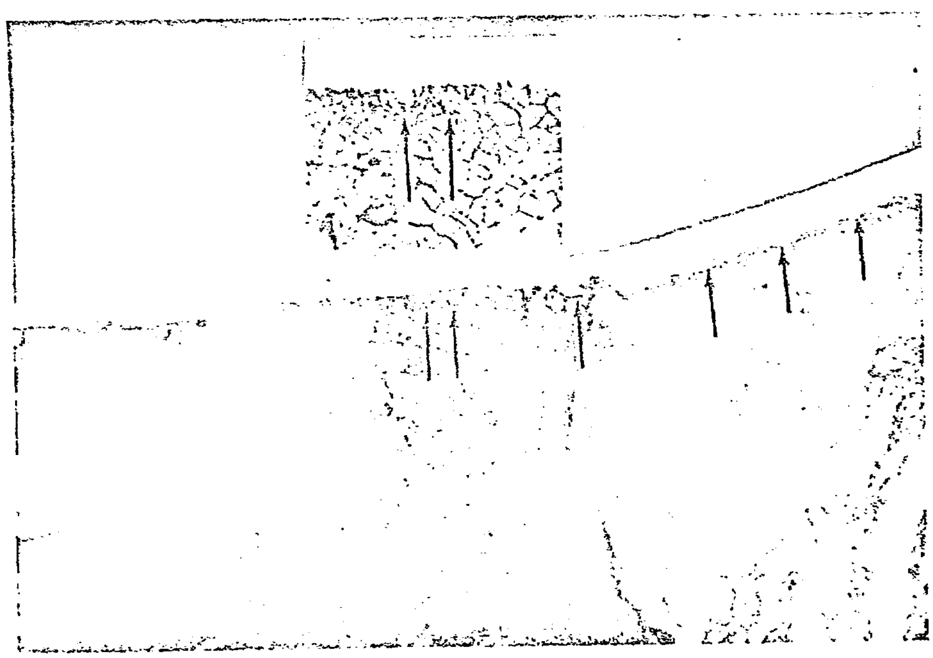
45b



46



47



48