Natural Resources Canada | Ressources naturelles Canada

Coastal Erosion And Nearshore Profile Variability In The Southern Beaufort Sea, Ivvavik National Park, Yukon Territory

Donald L. Forbes

Geological Survey of Canada, Bedford Institute of Oceanography,
1 Challenger Drive (PO Box 1006), Dartmouth, Nova Scotia, B2Y 4A2
[tel: 902-426-7737; fax: 902-426-4104; e-mail: forbes@agc.bio.ns.ca]

Open File 3531

1997

This document was produced by scanning the original publication.

Ce document est le produit d'une numérisation par balayage de la publication originale.

COASTAL EROSION AND NEARSHORE PROFILE VARIABILITY IN THE SOUTHERN BEAUFORT SEA, IVVAVIK NATIONAL PARK, YUKON TERRITORY

Donald L. Forbes

Geological Survey of Canada, Bedford Institute of Oceanography,
1 Challenger Drive (PO Box 1006), Dartmouth, Nova Scotia, B2Y 4A2
[tel: 902-426-7737; fax: 902-426-4104; e-mail: forbes@agc.bio.ns.ca]

INTRODUCTION

Background and objectives

This report describes a 1996 field survey program and associated airphoto study along the Yukon coast of the Beaufort Sea in Ivvavik National Park (Figure 1). This study was undertaken to determine coastal erosion rates, processes, and hazards in relation to archeological and cultural heritage sites, many of which are concentrated along the coast in this region (Neufeld & Adams, 1993). The project, carried out on behalf of Parks Canada (Canadian Heritage, Western Arctic District, Inuvik), was a continuation of work initiated in 1995 (Solomon, 1996; see also Covill, 1996). The present report follows the general format of Solomon (1996) and some of the background material is closely based on that report.

The 1996 work was to be carried out at the same study sites as in 1995. These were:

- Niakolik Point (site 30Y48/ Borden no. NhVh-5),
- Stokes Point (site 30Y57/ Borden no. NiVi-5),
- Catton Point/ Ptarmigan Bay (site 30Y61/ Borden no. NiVj-2),
- Nunaluk Spit (site 30Y94/ Borden no. NjVk-1),
- Clarence Lagoon (site 30Y96/ Borden no. NjVo-5).

The first objective of the 1996 program was to complete data gaps identified by Solomon (1996) at the end of the first year's work, including:

⇒ new aerial photography at all sites,
⇒ nearshore bathymetry and thaw profiles at Niakolik Point, Nunaluk Spit, and Clarence Lagoon,
⇒ samples of nearshore seabed sediments at all sites except Catton Point,
⇒ samples of onshore beach and cliff deposits at Nunaluk Spit,
⇒ detailed survey of graves at Stokes Point,
⇒ survey of cabin structures at Niakolik Point and Nunaluk Spit,
⇒ absolute positioning of site control marks using DGPS and precise ephemeris data.

A substantial number of these objectives were achieved, including the aerial photography, nearshore bathymetry and sampling, onshore sampling, and detailed site surveys at four of the

sites. Thaw profiling and absolute positioning were dropped from the program for reasons of logistics, equipment limitations, and time constraints. As in 1995, weather and logistical problems again prevented us from reaching Clarence Lagoon by boat. As a result, we still lack data on nearshore conditions at this site.

Another objective of the 1996 survey was to assess the year-to-year variability in site conditions, erosion rates, and shore-zone morphology in relation to longer-term trends deduced from the historical airphoto record. This was achieved by:

⇒ repetitive cliff and beach surveys at four sites (15 survey lines),
⇒ repetitive nearshore surveys at three sites (6 survey lines),
⇒ analysis of previously published data from other sites along the Yukon coast,
⇒ digital analysis of new and existing aerial photographs.

As noted by Solomon (1996), historical observations of the coast may provide some guidance in predicting future behaviour under similar environmental conditions. However, environmental excursions (involving winds, waves, water levels, ice conditions) outside the range of historical data, or changes in system characteristics (sediment type, ice content, geotechnical properties, shore-zone morphology), may lead to changes in the rates of erosion, thaw progression, sediment transport, nearshore profile adjustment, shoreline change, and land loss. For this reason, realistic assessment of coastal hazards (such as flood risk, ice ride-up and pile-up, retrogressive-thaw slope failure, and shoreline retreat) requires a detailed knowledge of the physical environment and an understanding of the geological processes operating at the coast. Part of the work reported here is directed to furthering this understanding of the coastal system.

Physical setting and previous work

Ivvavik National Park encompasses approximately half of the Yukon coast bordering the southeast Beaufort Sea (Figure 1). It extends from the Babbage River, at Niakolik Point, to the international boundary, west of Clarence Lagoon (Figure 1), excluding Herschel Island (Qikiqtaruk Territorial Park).

This coast was first described in the European literature by Franklin (1828) and many of the English-language place names used today were introduced by him. Observations by Amundsen (1908), Stefansson (1922), O'Neill (1924), Bostock (1948), and Mackay (1960) provided the basis for more detailed studies over the past 30 years. Later contributions making specific reference to coastal geology and processes along the Yukon coast include Mackay (1963), McDonald & Lewis (1973), Lewis (1975), Lewis & Forbes (1974, 1975), Forbes (1975, 1976, 1981, 1989), Short (1979), Forbes & Frobel (1985), Harper et al. (1985), Pinchin et al. (1985), Hill et al. (1986), Dickins et al. (1987), Hill (1990), Hill et al. (1990), Solomon et al. (1994), Solomon & Covill (1995), and Forbes et al. (1994, 1995). Because of similarities between the western Yukon coast and the Alaskan coast to the west, relevant reports from the US side of the border include Wiseman et al. (1973), Harper et al. (1978), Kovacs & Sodhi (1980), Owens et al. (1980), Harper & Owens (1981), Reimnitz & Barnes (1987), and Reimnitz et al. (1988, 1990), among others. The present study builds on previous efforts to determine coastal erosion rates and processes in Ivvavik National Park, reported by Forbes et al. (1993), Solomon (1996), and Covill (1996).

The Yukon Coastal Plain is conterminous with the Alaskan North Slope and reaches its narrowest point (<10 km) near Clarence Lagoon, within Ivvavik National Park (Figure 1). The coastal plain expands eastward to almost 40 km near the eastern park boundary and is flanked on the south by pediment surfaces rising into the Richardson, Barn, and British Mountains, with elevations up to 1600 m. The regional topography exerts a profound influence on many aspects of the physical environment, ecology, and human occupation history. The coastal plain and adjacent continental shelf are underlain by a succession of Jurassic and younger sedimentary rocks and sediments (Norris et al., 1963; Blasco et al., 1990). Continuous permafrost extends to depths of 600 m or more (Mackay, 1972; Judge, 1986). Ground ice occurs in ice-bonded sediments, where excess ice forms segregated veins, ice wedges, and massive ice bodies (Mackay, 1971; Mackay et al., 1972).

Low tundra cliffs backing much of the coast in Ivvavik National Park are composed of ice-bonded but otherwise unlithified Quaternary sediments, including glacial units, fluvial and colluvial sediments, thermokarst lake deposits, and peat (Hughes, 1972; Rampton, 1982). Exposure and thaw of icy sediments and massive ice at the coast leads to loss of strength and volume, accelerating coastal erosion through a number of processes such as basal undercutting, ice-wedge thaw and gullying, block failure, active layer flows, and massive retrogressive-thaw flows [RTF] (Mackay, 1966, 1986; Forbes & Frobel, 1985; Harper, 1990). Long-term rates of coastal retreat commonly exceed 2 m/a (McDonald & Lewis, 1973; Forbes & Frobel, 1985; Harper et al., 1985; Solomon et al., 1994) and may be much higher for short intervals of time bracketing major storms (Solomon & Covill, 1995).

Sediments derived from cliff erosion, from river discharge, and from the inner shelf are deposited along the coast in beaches, spits, and barriers and in numerous shallow embayments behind the barriers (McDonald & Lewis, 1973; Lewis & Forbes, 1974; Forbes et al., 1994). The total length of barrier shoreline along the Yukon coast is about 67 km (27% of the coast), of which a large proportion occurs within the park. Prominent features include the Spring River spit, Stokes Point foreland, Catton Point spit, and Nunaluk Spit (Figure 1). Individual barriers range in length from approximately 100 m to more than 20 km [with gaps] (Table 1). Including the Babbage Estuary at the park boundary (Forbes, 1981; Forbes et al., 1994), 14 lagoons and estuaries have been catalogued within the park (Table 1). These range in surface area from 0.09 to 45 km^2. The largest rivers are the Babbage, with its tributary Deep Creek, draining 5000 km^2 to the coast near Kay Point, the Firth, draining 6200 km^2 and emptying through Nunaluk Spit, and the Malcolm, draining 1100 km^2 west of the Firth (Figure 1). Three years of hydrological studies on the lower Babbage River in the mid-1970s documented maximum flood discharges ranging from 380 to 580 m^3/s during snowmelt runoff in June (Forbes, 1979, 1981) and total annual sediment discharge of about $3x10^8$ kg, of which some 40% bypassed the estuary (Forbes et al., 1994). No comparable data exist for sediment discharge from other streams in the area, nor on long-term output from the lower Babbage River, although gauging stations were established on the Firth River in 1972 and the upper Babbage in 1976 (Water Survey of Canada, 1992).

The coastal wave climate is dominated by local winds and constrained by sea ice (which limits the fetch over open water). The most severe wave conditions are usually associated with winds from the west and northwest, which also result in positive storm surges (Henry, 1975; Henry & Heaps, 1976). Winds from the northeast are sometimes associated with greater fetch and can produce large waves. Although significant swell is rare in the Beaufort Sea, Wiseman et al. (1973) reported an easterly event at Pingok Island (Alaska) in 1972. A low 3.8 s swell from the east was observed during southerly winds at Catton Point on 26 July 1996. The largest waves in

the region have significant wave heights of 3.5 m or more in deep water, with peak periods up to 10 s (Pinchin et al., 1985; Eid & Cardone, 1992). Major geographical features (notably Herschel Island and Kay Point) exert significant sheltering effects, resulting in very different wave exposure at various sites along the coast (Figure 1).

The coastal waters adjacent to Ivvavik National Park are ice-covered for at least 8 to 9 months of the year. Freeze-up typically occurs in October but may be initiated in September (Amundsen, 1908; Stefansson, 1922). Break-up begins with river discharge over the ice in late May and early June (Lewis & Forbes, 1974; Forbes, 1975, 1981). The extent of open-water fetch during the summer months is highly variable from year to year, ranging from 20 to 50 km in heavy ice years to 200 km or more under favourable conditions. This has significant implications for wave energy and coastal erosion (Solomon et al., 1994).

West of Herschel Island, ice may remain against the coast throughout the summer in some years. Furthermore, during winter, the shear zone (marking the boundary between landfast ice and the mobile polar pack) approaches close to the coast from Herschel Island west (Marko, 1975; Reimnitz et al., 1978). Intense scour of the seabed, primarily in water depths >8 m, is associated with pressure ridges that develop in the shear zone (Lewis, 1978). Localised scour in shallower water is associated with ice pile-up along the coast, with grounding of pressure-ridge fragments and other thick ice that drifts into shallow water (Kovacs & Mellor, 1974), and with wave-induced wallowing of ice fragments during summer storms (Reimnitz & Kempema, 1982). Localised strudel scour also occurs where snowmelt discharge from rivers drains through the ice seaward of the limit of bottomfast ice, forming steep-sided pits (Reimnitz et al., 1974). This was first documented off the Colville, Kuparuk, and Sagavanirktok Rivers in Alaska (Reimnitz & Bruder, 1972). In the study area, it has been observed off the Babbage River (Forbes, 1981; Dickins et al., 1987; Pilkington et al., 1988).

The Canadian coast west of Herschel Island experiences ice conditions very similar to those along the Alaska coast, where ice plays a major role in sediment transport and coastal sedimentation (Reimnitz et al., 1990). In this area, ice push (through ride-up or pile-up) may play a significant role in sediment supply to beaches and barriers (Harper & Owens, 1981; Harper, 1990). Veneers of fine gravel deposited on top of coastal bluffs up to 6 m high in Ivvavik National Park (McDonald & Lewis, 1973; Forbes & Frobel, 1985) and up to 9 m or more in Alaska (Duguid, 1971; Kovacs & Sodhi. 1980) are attributed to ice push (Kovacs & Sodhi, 1988; Reimnitz et al., 1990; Forbes & Taylor, 1994). Nevertheless, observations of beach morphology and processes along this part of the coast provide clear evidence for significant modification by waves in some years (Short et al., 1974; Short, 1979; Forbes et al., 1993).

East of Herschel Island, somewhat different conditions prevail. In this area, the shear zone often lies farther offshore. The landfast ice may be more extensive, although it is unpredictable, being described by Cooper (1974) as "quasi-landfast" ice. Extensive open water has been observed on several occasions in early to mid winter southwest and southeast of Herschel Island and open water may be present along the west coast of Mackenzie Bay in February (Cooper, 1974; Forbes, 1975). Although ice pile-up is less common along this part of the coast, grounded ice-island fragments have been observed and a 10 m high shore-ice pile-up has been documented at Shingle Point (Lewis & Forbes, 1975).

Astronomical tides in the study area have a maximum range of 0.5 m or less (Figure 3). Meteorological effects (air pressure and wind shear) generate positive and negative storm surges well in excess of the tidal range (Henry, 1975), accounting for more than 80% of the variance in

water levels (Forbes, 1981). Driftwood deposits indicate that surges up to about 2 m above mean sea level have occurred in the study area within the past 50 years (Forbes & Frobel, 1985; Forbes, 1989). The maximum water level at Herschel Island during the severe storm of September 1970 was estimated at 1.3 m (Canada Department of Public Works, 1971). However, data from the Babbage River delta indicate that the highest surge in the region was not associated with either of the largest storms documented in the Mackenzie Delta area but rather with another storm sometime between 1952 and 1970, most probably the storm of October 1963 (Forbes, 1989). Positive storm surges are important because they can submerge beaches, enabling direct wave attack at the base of coastal cliffs and widespread overtopping of barrier beaches (Lewis & Forbes, 1975). Another severe storm in September 1993, associated with a storm surge of about 2 m at Tuktoyaktuk, caused extensive erosion at Tuktoyaktuk, North Head (Richards Island), and Kay Point (Solomon & Covill, 1995). No data are available on the height of this surge along the Yukon coast.

CONDITIONS DURING THE 1996 FIELD SEASON

Winds

Observations of wind speed and direction were recorded by Environment Canada at Tuktoyaktuk and Pelly Island (Figure 2) in 1996. Data for the 5-month interval June 1 to October 31 were acquired for this study from the Climatological Services Centre (Environment Canada, Prairie and Northern Region, Edmonton). Figure 4 presents the data from Pelly Island, as this station is closer to the study area and more representative of over-water winds off the Yukon coast. Taking a speed of 20 knots (~10 m/s or 37 km/h) as the wind-speed criterion for storm identification (after Solomon et al., 1994), hourly data at Pelly Island for the 1996 open-water season show 7.46% of observations above the storm threshold. Equivalent data for Tuktoyaktuk show an exceedence of only 1.99% at the automatic station and 1.56% at the airport, compared to <1% for the 1995 season (Solomon, 1996). These data highlight the much higher windspeeds at the exposed Pelly Island site.

In 1996, wind speeds >10 m/s at Pelly Island were rare in June and October, but quite frequent during July, August, and September (Figure 4). Wind speeds >15 m/s were recorded during storms in early June, late July, late August, and early October. During the field survey (Figure 5), winds >10 m/s were experienced early on July 22 from the northwest (estimated at 30 knots from the west at Catton Point), during the afternoon of July 26 from the southwest, in the early hours of July 27 veering from southwest to northwest through the night, and on July 28 and 29 from the east. On July 23, Pelly Island recorded windspeeds of 6 to 7 m/s (<14 knots) from the southeast. At Catton Point, the wind was estimated at 15 knots from the east, increasing to east 20 knots later in the day. This difference in wind speed and direction between Pelly Island and Catton Point is to be expected, given the distance of about 150 km between the sites across Mackenzie Bay (Figure 2). Long-term data from the former DEW Line stations at Komakuk Beach and Shingle Point, and three years of data from Kay Point (Forbes, 1981), show significant differences in the directional distribution of winds between sites (Burns, 1973). The data for 1996 (Figure 5) show significantly lower wind speeds at Tuktoyaktuk than at Pelly Island and a lag of up to 3 hours or more from west to east. The wind direction was also more variable at Tuktoyaktuk, presumably because of local topography and structures.

Water levels

Tide gauge records from Tuktoyaktuk (Figure 3) were obtained from the Canadian Hydrographic Service of the Department of Fisheries & Oceans (Institute of Ocean Sciences, Sidney, British Columbia) for the same dates as the wind data presented above. The increase in the prevalence of meteorological forcing through July and into August is quite clear. The first surge above 1.0 m Chart Datum [CD] (0.7 m above mean water level [MWL]) occurred on July 22 (associated with the northwesterly wind and snow experienced at Catton Point on that date). The second, above 1.3 m CD (1.0 m above MWL), occurred on July 27, when the sea rose against the foundations of the Northern Whaling & Trading Company warehouse at Pauline Cove on Herschel Island. Subsequent surges >1.0 m CD in 1996 occurred four times in August (the highest, >1.45 m CD, associated with strong northwest winds backing through west on August 26-27) and twice in mid-September (Figure 3). Low water levels (<0.1 m CD) occurred in association with easterly or southeasterly winds around July 10, July 29, August 1, and several times at the beginning and end of September (Figure 3).

Close inspection of the record during the field survey (Figure 5) shows high coherence between westerly or northwesterly winds at Pelly Island and storm surge elevations at Tuktoyaktuk. However, there is a phase lag between the two records and the timing of the surge in water level at Tuktoyaktuk is more closely correlated with the timing of local winds, though not to the absolute wind speed there. This is further evidence to suggest that the wind speed records at Pelly Island are more representative of over-water winds.

Sea ice

Summary maps of ice conditions in the western Arctic were supplied by Environment Canada (Canadian Ice Service, Ottawa), for the open-water season of 1996. Breakup along the Yukon coast was initiated with development of a sinuous broad lead in the general area of the shear zone during the week leading up to June 11. This had concentrations of 1/10th thick first-year ice in vast floes (2 to 10 km across) occupying a band up to 25 km wide off Kay Point and extending west to Herschel Island. By June 18, this area of low ice concentration had expanded north of 70°N (>100 km north of Kay Point) and west beyond the Alaska border, but a narrow band of fast ice remained along the coast of Ivvavik National Park. By July 2, open water was present along the coast west to Komakuk Beach and the area of 1/10th thick first-year ice had expanded west along the Alaska coast. Open fetch was restricted to 60 km northeast of Catton Point and about 35 km north of Nunaluk Spit by 8/10ths thick first-year ice in medium floes (100 to 500 m typical diameter). The situation then deteriorated, with 4/10ths thick first-year ice in medium floes closing against the north shore of Herschel Island the following week.

By July 16, four days prior to the start of the survey program described in this report, a wide area of open water had again opened north of Herschel Island and 75 km of open-water fetch was available northeast of Catton Point, while 2/10ths thick first-year ice in big floes (500 to 2000 m typical diameter) was present along the coast to the west. This situation persisted through July 23, but 5/10ths thick first-year ice returned to surround Herschel Island by the end of the survey program one week later.

The most extensive open water of the season developed by August 6, when open-water fetch was >150 km to the north of Herschel Island and >200 km to the northeast of Catton Point However varying concentrations from 5/10ths to 8/10ths thick first-year ice in medium floes lay along the coast from Herschel Island west almost to Barter Island (Alaska). This had increased to >9/10ths

mixed thick first-year and old ice by August 13. The fetch to the northeast of Catton Point was still about 130 km on September 10 (in 1/10th old ice) and 90 km two weeks later (in 2/10ths old ice). The most open conditions of the season west of Herschel Island occurred on September 10, when nearly open water (1/10th old ice in medium floes) covered an area extending 50 km north of the coast as far west as the international boundary and a narrow fetch window was open offshore to the northwest.

Freeze-up was initiated by the end of September, with 8/10ths to >9/10ths mixed old, grey, and new ice present along the entire Yukon coast by October 1. Complete fast-ice cover was established west of Herschel Island by October 8. Ice remained mobile in Mackenzie Bay until late in the month, but fast ice was established along the entire Yukon coast by October 29, except along the north side of Herschel Island, where the mobile shear zone brushed the coast.

In summary, initial breakup along the coast as far west as Komakuk Beach occurred earlier than the median. However, the maximum extent of open water was below average and ice remained along the coast west of Herschel Island during most of the summer. Freeze-up occurred earlier than the median.

Waves

No quantitative wave data are available for the 1996 season in this area. Fetch limitation by ice and land resulted in very limited wave development during the westerly storms of July 22 and 27. However, the northwesterly events of late August and mid-September occurred at times of more extensive open water, with significant potential for wave development. It is important to note, however, that most of the coast of Ivvavik National Park east of Herschel Island is relatively protected from the northwest. Niakolik Point, at the southeast corner of Herschel Basin, has a very narrow refraction window to waves propagating from northwest of Herschel Island (Forbes, 1981), although significant potential exists for wave development between Herschel Island and Niakolik Point.

Several pertinent observations were made at Catton Point during the 1996 field survey. The brief northwesterly storm of July 22 set up a small surge within the lagoon at Ptarmigan Bay, with significant reworking of driftwood and gravel along the inner (landward) side of the barrier. Again, on July 26, strong southerly winds generated 0.3 m waves inside the lagoon, causing some toe erosion along the shore below the fishing cabin on the southeast side of the hill. This appears to be the cause of significant shore erosion noted along this inner shore (see Catton Point section below; also Covill, 1997 [in Appendix I]). The easterly swell with 0.2 m breaker height along the outer shore during this southerly wind event was noted earlier. Wave conditions on the outer shore under easterly winds were noted on July 23 and 25. On the 23rd, the wind increased from an estimated 15 knots early in the day to approximately 20 knots in the early evening. At this time, 3.2 s waves were breaking at an angle of about 20° near line 2 on the Catton Point barrier, generating a longshore current and swash-zone pebble transport toward the northwest. The waves were plunging on the step at the base of the beach (characteristic breaker height, H_b, was about 0.5 m). Earlier in the day, shortly after the wind came up, 0.5 m waves were encountered in Workboat Passage on our return from Nunaluk Spit between 0130 and 0300 h MDT (UT-6 h). On July 25, under relatively light winds from the east, 3.2 s waves with H_b= 0.4 m were present along the outer shore at Catton Point. These were followed by low 3.8 s swell the following day.

Water temperature

Water temperatures were logged in about 3 m water depth on the shoreface at Catton Point for five days in late July 1996 (Figure 5). The temperature dropped from almost 11°C at the start of the deployment to 4°C on July 22. The temperature then remained at about 7±1°C for two days before increasing to 10°C early on July 25. A slow cooling trend followed through the 25th and accelerated on the morning of the 26th, dropping almost to 5°C before recovery of the instrument. Solomon (1996) reported water temperatures at this site for about seven days in early August 1995. Similar temperatures were observed, ranging from a minimum of 1.6°C to a maximum of 9.8°C.

METHODS

Surveys in 1996 were obtained using a Geotracer 2000 real-time kinematic (RTK) differential global positioning system (GPS) satellite receiver survey instrument, with horizontal and vertical resolution of about 0.1 m. This system uses two receivers, one mounted on a tripod over a fixed reference station and the other (the rover) at a measured height on a survey rod or other mobile platform, communicating with the reference station receiver in real time via a radio modem. The positional error depends on the accuracy of the coordinates and elevation available for the reference station control point. Surveys in 1996 utilised the same survey control as Solomon (1996) but 1996 positions were recorded in WGS84 (NAD83) horizontal datum, rather than NAD27 as used in 1995. Geological Survey of Canada (GSC) benchmarks established specifically for the shore surveys consist of 3-inch aluminum caps with 3-digit numbers (referenced as GSC-nnn) on steel reinforcing bar (rebar) driven into the ground. These do not extend below the seasonal thaw layer and are therefore subject to potential frost heave. Installation of antiheave benchmarks (hollow pipe with collars and holes, extending below the seasonal thaw layer) would be preferable.

Nearshore profiles were surveyed using a 4.7 m inflatable boat (Figure 6) with a 25 hp outboard motor. The GPS antenna was placed at a height of about 1.1 m on a short mast forward and the echosounder transducer was mounted approximately 0.25 m below the water line on a bracket attached to the transom. The layback from the GPS antenna to the transducer was 2.5 m. Echosounding profiles were generally run toward shore, in which case the layback distance was added to the distance along-profile seaward of the baseline. Soundings were obtained using a Knudsen™ 320M hydrographic echosounder operating at 200 kHz. The Geotracer 2000 RTK GPS system was used in differential mode for positioning the boat. In this case, the navigational precision was better than ±1 m. Depths were displayed on a chart recorder and digitised in relation to navigation fixes recorded on a 386 handheld computer operating in DOS. Depths were recorded at a resolution of 0.01 m and are considered accurate to ±0.05 m. Distance along profile was taken as the line-of-site distance from the onshore reference control point or baseline to the echosounder transducer.

Sediment samples (Appendix II) were collected from the cliffs at Nunaluk Spit and from the beach at Nunaluk and Catton Point. Bottom samples were obtained from the nearshore at Stokes Point west, Catton Point, and Nunaluk Spit using a Ponar grab sampler and the same positioning system as for the bathymetric surveys. Samples were described and analysed for grain size at the Bedford Institute of Oceanography in Dartmouth, using standard techniques including microscopic analysis, dry sieving, settling tube (Syvitski et al., 1991), and SediGraph™ (Coakley

& Syvitski, 1991). Moment statistics were computed and results presented in SI and ϕ units, where $D_\phi = -\log_2 D_{mm}$ and D is grain size in units indicated by the subscript (Krumbein, 1934).

Water temperatures were logged at a site off Catton Point beach in 3.1 m water depth, 0.3 m off the bottom. A submersible Vemco Minilog™ temperature logger was programmed to record temperatures at 1 hour intervals. The sensor was attached to a polypropeline line anchored to a 50 lb lead core weight and marked by a surface float. The mooring was put in at 0100 h MDT on July 22 and recovered at 1503 h MDT on July 26.

Survey data were reduced using Microsoft QBasic and Excel 5.0 software operating under MS-DOS 6.2 and Windows 3.1 on a Pentium notebook computer. Interannual changes in shoreline position were determined by photogrammetric analysis, under contract to Tekmap Consulting (Covill, 1996, 1997 [Appendix I]). Air photographs taken in different years were digitally scanned and rectified to an arbitrary grid, using the public-domain Geographic Resource Analysis System (GRASS) developed by the US Army Corps of Engineers, running on UNIX workstations. The rectification procedure removed tilt, rotation, and lens distortion by a non-linear (rubber-sheet) least-squares algorithm. Topographic relief in the study area is sufficiently small that 3-dimensional orthorectification was considered unnecessary. Vector representations of distinctive features (such as the top and base of coastal cliffs) were digitised from the rectified air photographs in a common coordinate system. Although no independent analysis of errors has been carried out for this study, another recent investigation using the same methods estimated the uncertainties at approximately $\pm 2.3/\Delta t$ m/a, where Δt is the time (in years) between two photographs (Forbes & Hosoi, 1995). The error increases with decreasing scale of the photographs.

New vertical photography was obtained in July 1996 under contract through Jack M. Byrne Consultants (Fort Macleod, Alberta) and Foto Flight (Calgary), using a Beech King Air aircraft (C-FBCN). There were 33 exposures within Ivvavik National Park (flight line A28278) and the film has been deposited with the National Air Photo Library in Ottawa. The photography covered all sites in the survey program (Figure 1) at a scale of 1:6000. Surveyed targets (driftwood log crosses) were placed on benchmarks at Catton Point but the photography was completed before targets could be put in place at the other sites. Surveyed log structures, graves, and other prominent features provide other control for rectification of the photography at the four sites where ground surveys were completed in 1996. Previous photography at several sites along the Yukon coast (Figure 1) was obtained by the Geological Survey of Canada [GSC] in 1992 (Forbes et al., 1993, 1995). In addition to the vertical photography, oblique photography of the park shoreline from Clarence Lagoon to Niakolik Point was obtained on July 28, using a Cessna 185 on floats (C-FZNL) chartered from Arctic Wings and Rotors out of Pauline Cove (Herschel Island).

GSC coastal monitoring sites are designated by unique 4 digit reference numbers on a national basis. Site numbers for the Yukon coast are shown in Figure 7. The sites examined in this report are also keyed to the archeological identification codes and Parks Canada site numbers (Neufeld & Adams, 1993).

Mobilisation for the 1996 survey was from Inuvik to Herschel Island, using a DHC-6 Twin Otter on large tyres (C-GDHC) chartered from Aklak Air. The field party was evacuated in the same way at the end of the survey. Travel from Herschel Island to the base camp at Catton Point and to the other field sites was by boat.

RESULTS

Niakolik Point (site **30Y48** Borden no. **NhVh-5** [GSC site **5278**])
Survey date: 24 July 1996 (JD 206)

Site description

Niakolik Point lies opposite the distal end of Kay Point Spit at the entrance to the Babbage River estuary in Phillips Bay (Figure 8). A detailed description of the site was provided by Solomon (1996). Relevant studies in the Babbage River estuary and vicinity in the 1970s, with follow-up activities in the 80s and early 90s, have been reported by McDonald & Lewis (1973), Lewis & Forbes (1974, 1975), Lewis (1975), Carson et al. (1975), Forbes (1981, 1989), Forbes & Frobel (1985), and Forbes et al. (1994, 1995), among others. Although Niakolik Point was used as a campsite for some of these studies, relatively little work has been done on the point itself.

The adjacent Babbage River estuary is shallow (Figure 8) and freezes to the bottom in winter. The deepest pools in the delta distributary channels (as deep as about 8 m) remain unfrozen with hypersaline water below the ice (Steigenberger et al., 1975). The 2000 m wide baymouth entrance section between Niakolik Point and the distal end of Kay Point Spit (Figure 8) is characterised by a broad central shoal with minimum depth of about 0.9 m (below MWL). The surface of this shoal (Figure 9) is extensively reworked into low-amplitude sand waves (with wavelengths of the order of 10s of metres and trough-crest heights of 0.5 m or less), representing complex interactions between incoming waves, river outflow, tidal and storm-surge currents (Forbes, 1981). It is flanked by two channels at least 2.4 and 2.3 m deep. These channels deepen seaward. The western channel adjacent to Niakolik Point deepens from 2.3 m near the point to at least 2.6 m at line 2 (Figures 9 & 10). These channels remain unfrozen at their base in mid-winter, when the ice is bottomfast on the central shoal and throughout most of the estuary.

Niakolik Point forms a low peninsula of marshy ground extending eastward into the bay (Figure 10). It is backed by vegetated slopes rising to a relatively flat tundra surface about 15 m above sea level. The top of this hill is marked by large ice-wedge polygons. The side slopes are smooth to hummocky colluvial surfaces, representing former retrogressive-thaw flows along a marine or lake margin. These slopes are now relatively stabilised, though still subject to limited solifluction movement. To the north and west, beyond the limit of the fringing supratidal flats (near the left-hand margin of Figure 8), the base of the slope is exposed to wave action along the outer shore of Phillips Bay. This contributes to maintenance of active retrogressive-thaw flow slides from headwalls cutting back into the upper tundra surface and mudflows delivering sediment to the nearshore across a discontinuous beach. The stratigraphy in this area consists of up to 3 m of peat capping 1 to 3 m of ice-rich silt and sand over 1 to 5 m of glacial till or outwash sand and gravel (McDonald & Lewis, 1973).

Solomon (1996) subdivided the low ground at Niakolik Point into three zones (Figure 10). These are: (1) the relatively well-drained surface in the middle, on which the lower cabin is situated; (2) the poorly drained area of degrading rectilinear ice-wedge polygons along the estuary shore to the south and west of zone 1 (vicinity of lines 4 to 6 in Figure 10); and (3) a low-lying area on the outer side of zone 1, including a complex of sandy beach, spit, and washover deposits, driftwood accumulations, peaty pond deposits and supratidal silts. The outer shore in zone 3 is characterised by a narrow sand and sandy gravel beach, backed by a low peaty scarp ranging

from 0.9 to 1.0 m high (crest elevation above MWL) at lines 1 and 3 to 1.5 m at line 2 (Figure 10). The top of the scarp is strewn with driftwood at line 1 and covered with a thin washover veneer of silt and sand at line 3. This washover deposit becomes progressively more extensive alongshore toward the point (pale unvegetated surface in Figure 10). The estuary shore in zone 2 has no beach and consists of a very low peat scarp up to 0.6 m high, relatively stable but characterised by collapse of small undercut blocks.

Cultural resources at Niakolik Point include a log house and other remains of Inuvialuit habitation at the base of the hill (primarily in zone 1), another log house at the top of the hill, and two sets of graves (Figure 10). The lower house was approximately 145 m from the erosional scarp on line 2 at the time of our survey in July 1996. The distance to the low peat scarp along the estuary shore was about 107 m.

Surveys and shore retreat measurements

Three profile lines, marked by wooden stakes and posts, were established in 1995 along the outer shore of Niakolik Point in zone 3 (Solomon, 1996). Proceeding southeastward into the bay toward the point, these are lines 1 to 3 (Figure 10). Two lines, marked by wooden stakes, were established by Solomon (1996) along the estuarine shore in zone 2 (lines 4 and 5), while a previously established profile (line 6), marked by iron pipe, was rediscovered during the 1996 survey (Figure 10). A benchmark (GSC-140) was established beside the lower house in 1995 (Solomon, 1996). The distances between markers on each of the six lines are given in Table 2.

No bathymetric surveys were obtained at this site in 1995 but a nearshore profile was surveyed in 1996 along line 2 (Figure 11) and at the breach in the spit (Figure 9). These show a narrow terrace or bar at line 2, in a depth of about 0.7 m. The seaward face has a slope of about 1.4°, diminishing in about 1.9 m water depth to an outer slope of 0.3°, which extends into the marginal channel (Figure 9). The profile near the spit breach (Figure 9) shows an irregular spit platform in depths of 1.0 to 1.5 m. In part, this may be a product of fluvial deposition on the downstream (outer) side of the spit, which deflects the main channel outflow of the Babbage River during the spring freshet.

Figure 11 shows 1996 surveys along all six shore profile lines. Changes between the 1995 and 1996 surveys are shown in Figures 12 and 13. Along the outer shore, scarp retreat ranged from 6.3 m at line 1 to 6.0 m at lines 2 and 3 (Table 2) and a breach developed through the neck of the spit at the point (Figure 10; Appendix I). Along the estuary shore, 0.3 m of retreat was measured at line 5, but no significant change could be detected at line 4.

These field observations are consistent with the photogrammetric results (Appendix I), which indicate mean retreat rates of 6.8 m/a at line 1, 5.0 m/a at line 2, and 4.9 m/a at line 3, over the 4-year interval 1992-1996. The 1995-1996 survey results demonstrate that these high rates of retreat are not solely attributable to the major 1993 storm, but result from the more typical weather conditions of late summer and autumn 1995 and early summer 1996. The photogrammetric data indicate a significant acceleration in erosion rates along this outer shore from longer-term means of 0.54±0.04 m/a [mean ± standard error] between 1952 and 1970 (Covill, 1997 [in Appendix I]) and 1.43±0.61 m/a from 1970 to 1992. During the latter interval, erosion was much higher at line 3 (averaging 2.63 m/a over the 22 years) than at lines 1 and 2 (0.98 and 0.67 m/a respectively).

Nearshore sediments

Preliminary descriptions of sediment samples collected onshore in 1995 were reported by Solomon (1996). It was intended to collect complementary nearshore samples in 1996 but we were unable to do so. However, some data are available from a comprehensive bottom sampling program in the Babbage River delta and estuary in July-August 1975 (Figure 130 and Appendix A.12 of Forbes, 1981).

Four samples taken along the estuary floor off zone 2 on the south side of Niakolik Point were sandy to slightly sandy clayey silts, with median grain size ranging from 20 to 29 μm (5.11 to 5.64ϕ), silt/clay ratios of 5.8 to 7.0, and sand fractions ranging from 4 to 12%, except 29% in the sample nearest the point. Samples taken in the main channel near the point were silty sands with 11 to 31% mud and median grain size between 94 and 132 μm (2.92 to 3.41ϕ). On the outer side of the point, samples taken on the central baymouth shoal were fine sands and silty sands, with median grain size between 79 and 128 μm (2.97 to 3.66ϕ) and silt concentrations ranging from 4 to 23% (one sample contained 14% clay). On the inner flank of the shoal, bottom sediments range from sandy silts to silty and muddy sands (median grain size between 49 and 113 μm (3.15 to 4.35ϕ), sand fractions between 27 and 86% and clays from 0 to 9%). Samples taken in the marginal channels on either side of the baymouth shoal (Figure 10) were generally finer (muddy sands to sandy muddy silts) with median grain size between 24 and 79 μm (3.66 to 5.38ϕ), silt/clay ratios from 2.7 to 5.7, clay fractions from 6 to 21%, and sand from 21 to 60%. The high organic fraction in these sediments (Solomon, 1996) may be related to erosion of peat along the shore, but is also a function of high particulate organics (plant fibre) discharged from the Babbage River during spring floods (Forbes, 1981).

Stokes Point west (site **30Y57** Borden no. **NiVi-5** [GSC site **5260**])
Survey date: 24 July 1996 (JD 206)

Site description

Stokes Point is a prominent coastal foreland which has gradually migrated toward the southeast, depositing a wide beach-ridge plain at the down-drift end of the system (Forbes, 1980). The northwestern part of the foreland consists of a low, narrow, sand and gravel barrier enclosing a shallow lagoon. Inlets have opened intermittently through this barrier at various times in recent decades (McDonald & Lewis, 1973; Kendel et al., 1975; Forbes, 1981) and lately a very wide double breach has developed with a small barrier island in the middle (Figure 15). A bowhead whale carcass was stranded on the northwest side of this island in the inlet at the time of our survey.

The study site lies at the extreme northwest end of the Stokes Point lagoon and barrier (Figure 14). It occupies a low terrace of polygonal tundra, at an elevation of about 4 to 6 m. This terrace is the floor of a former lake whose shoreline was probably breached by coastal erosion, causing the lake to drain. Higher, ice-rich, upland tundra surrounds the former lake basin, extending to the coast a little more than 150 m northwest of the study site (Figure 4 of Solomon, 1996). From this point and extending several kilometres alongshore to the northwest, it forms prominent cliffs up to 22 m or more in height. These are retreating by a variety of processes, including wave notching, gullying, active-layer slumping, small debris flows, and retrogressive-thaw flow (RTF) slumping. An active RTF hollow, initiated sometime between 1970 and 1985, had expanded by

1992 to affect the entire upland tundra cliff between the lower terrace and the first gully, some 350 m northwest of the study site (Solomon, 1996; Covill, 1996, 1997 [in Appendix I]). McDonald & Lewis (1973) reported photogrammetric measurements of coastal erosion along the 4 km of shore to Roland Bay ranging from 0.7 to 1.7 m/a over the 18 years 1952-1970. The beach along this section of upland tundra coast is narrow to discontinuous.

The shore at the study site (Figure 15) consists of a narrow gravel beach at the base of low cliffs. The beach expands southeastward past the end of the cliffs to form the barrier in front of Stokes Point lagoon (Figure 14). Beach sediments show a range of grain size from coarse sand, granules, and fine pebbles at the water line to pebble-cobble gravel on the berm and well-sorted medium sand at the top of the beach (Solomon, 1996). Longshore sinuosity at the base of the beach, with a characteristic wavelength of about 80 m (Figures 15 & 16), appears to represent a longshore transport bedform (cf. Stewart & Davidson-Arnott, 1988). As such, it indicates that short-term variations in beach width, beach erosion or accretion, and the nearshore bar morphology can be expected as these features move alongshore.

The barrier close the study site is strewn with driftwood logs, with a large buildup on the upper beachface. The crest and backshore are marked by coalescing washover fans and channels, indicating widespread overwash and landward transport of sediments during storms. The crest elevation is less than 2 m. This process will tend to narrow the beach in front of the cliffs updrift, encouraging further cliff erosion. Taken together, these observations suggest a potential for highly episodic erosion at this site, making estimates of long-term retreat somewhat tenuous, especially if based on short-term data. A small bayhead beach has formed within the lagoon in the lee of the outer barrier, enclosing a small triangle of supratidal marsh, which is flooded during storm surges (Figure 15).

The cliffs at the study site are eroding by a combination of ice-wedge melt-out, gullying, undercutting, minor slumping, and block collapse. Sediments forming the cliffs consist of dark grey organic-rich mud with abundant wood fragments (Solomon, 1996).

Cultural features include several graves marked by flat-lying driftwood logs (including remains of a kayak at one), and another feature that is either a grave or the footings of a log structure. Most of the graves lie 12 to 15 m or more from the top of the cliff in the vicinity of profile line 2 (middle [benchmark] line), but one grave on profile line 1 (west line) is 2.05 m from the cliff edge at its nearest corner (Figure 16).

Surveys and shore retreat measurements

Three profile lines were established and surveyed in 1995 (Solomon, 1996), denoted Stokes west, Stokes BM, and Stokes east, respectively. In this report, these lines are numbered 1 to 3 from northwest to southeast (Figures 15 and 16). Lines 1 and 2 originate on the drained-lake tundra terrace and intersect the cliff and beach. Line 3 crosses the proximal end of the barrier. The two outer lines are marked by two wooden stakes each, while the central line is marked by a wooden stake and benchmark GSC-145 (cap on rebar). Distances between markers on each line are shown in Table 3.

Bathymetric surveys, initially run along these lines in 1995, were repeated in 1996 (Figure 17). These show a prominent nearshore bar within about 50 m of the beach on both occasions. The 1996 surveys show bar crests at 1.0 m depth and 44 m offshore on line 1, 1.3 m depth and 49 m offshore on line 2, and 1.1 m depth and 53 m offshore on line 3 (Figure 17). Therefore, in

contrast to observations in 1995 suggesting a crescentic or sinuous bar morphology (Solomon, 1996), the present data indicate a linear bar at the time of the 1996 surveys. The shoreface profiles seaward of the bar are similar on all three lines, with two linear segments: an upper, slightly convex-up, subtle secondary bar segment extending to about 5 m water depth with a mean slope of about 0.7° and a lower, less steep, concave-up segment at <0.6°. The bar morphology is varied, with relatively abrupt crests and symmetric profiles on lines 2 and 3, but a broader rounded crest and steep seaward face on line 1. Irregular depressions on the shoreface seaward of the bar are interpreted as troughs or pits resulting from ice scour or wallow (Figure 17).

Comparisons between the 1995 and 1996 nearshore profiles (Figures 18, 19, 20) indicate no detectible change seaward of the bar (the slightly higher profile on line 1 is probably within the positioning and survey error, while the profiles on the other two lines match very closely). Line 1 (Figure 18) shows no change in the bar centroid, but a seaward shift and slight deepening of the crest, with removal of sediment from both the seaward and landward slopes. A widening of the trough was accompanied by substantial beachface retreat (Table 3). On line 2 (Figure 19), there is little change in crest position but a significant landward shift of the bar centroid and trough, through infilling of the 1995 trough. The beachface built seaward 0.6 m on this line (Table 3). In contrast, the changes on line 3 (Figure 20) involve near-complete removal of the 1995 bar volume, a seaward shift of more than 20 m in the bar crest position and a significant reduction in bar volume. The beachface on this line retreated by almost 2 m (Table 3).

The beach is bounded seaward by an abrupt coarse sand and gravel step, up to 1.2 m high. The beach is convex-up with a small lower swash bar and a minor upper berm. It is backed by collapsed blocks and minor slump deposits on lines 1 and 2 and by a shallow trough and a driftwood pile on line 3. Beach slopes range from 10° to 13° on the lower foreshore (face of the swash bar) to about 3.5° on the upper beach. As noted above, there was significant retreat of the lower beachface on lines 1 and 3 (though little change in barrier crest position) and minor accretion on line 2. These changes may simply reflect migration of the shoreline sinuosity noted earlier.

Cliff retreat at this site amounted to 1.0 to 1.1 m over the year between the 1995 and 1996 surveys (Table 3). This compares with photogrammetric estimates of rates between 0.2 to 0.7 m/a averaged over the 4-year interval 1992-1996 (Covill, 1997 [in Appendix I]). In the longer term, rates of recession have been lower at this site, except for the interval 1985-1992, when retreat rates ranged from 0.5 to 0.7 m/a at the top of the cliff (but only 0.1 to 0.3 m/a at the base). These data show no clear signature of the September 1993 storm. It is unclear whether the higher rate of retreat measured over the past year can be extrapolated into the future (see Discussion).

Photogrammetric measurements of RTF headwall retreat at the slump updrift of the study site (Covill, 1997 [Appendix I]) indicate continuing rapid expansion (2.9 m/a from 1985 to 1992 and 2.4 m/a from 1992 to 1996). Recession at the base has been slower, but averaged 0.8 m/a over the interval 1992-1996.

Nearshore sediments

Three nearshore grab samples were obtained on line 2 at this site (Figure 17). Sample 33 was taken on the inner slope of the bar in about 1.7 m of water and samples 35 and 34 were taken on the seaward shoreface in depths of about 2.7 and 3.7 m, respectively. All three samples consist of moderately well sorted, subangular to subrounded, medium to fine, brown lithic sand with <30%

quartz and some foraminifera in sample 34. The mean grain size decreases progressively seaward from 0.255 mm (1.97ϕ) for sample 33 inside the bar and 0.207 mm (2.27ϕ) for sample 35 on the outside flank, both medium sands, to 0.140 mm (2.84ϕ) for sample 34 on the outer shoreface, a fine sand. Sorting ranges from 0.9 to 1.4ϕ and skewness from positive at the inner and outer samples to slightly negative at sample 35.

Catton Point/ Ptarmigan Bay (site **30Y61** Borden no. **NiVj-2** [GSC site **5054**])
Survey dates: 21-26 July 1996 (JD 203-208)

Site description

Catton Point consists of a gravel barrier, beach, and recurved spit extending alongshore to the northwest into the mouth of Workboat Passage (Figures 1 & 21). The spit continues to extend by recurve progradation at the point (indicating net longshore sediment transport toward the northwest), while retreating landward along much of its length by storm-wave washover and associated deposition along the landward shore (Figure 22). The lagoon behind the barrier is open to the northwest into Workboat Passage and small spits have formed by sediment transport to the southeast along the inner shore of the spit and barrier.

The study site lies near the middle of this system, where a dome-shaped tundra island up to 14 m high anchors the beach near its midpoint (Figures 21 & 23). Southeastward longshore sediment transport within the lagoon is evident from the formation of a small barrier at the northwest end of the island inside the spit and development of a bulbous foreland (incipient spit) along its southwestern shore. The southern lagoon shore of the tundra remnant consists of a low bluff undergoing rapid erosion. The seaward side of the island is flanked by a wide beach comprising at least three storm berms capped by large quantities of driftwood. This section of the beach has been building seaward for many years (Figure 22). A low bluff at the base of the slope behind the beach, and evidence of stabilised retrogressive-thaw flow (RTF) basins along the southern half of the seaward hillslope (Figure 24), as well as the linear form of the seaward margin, indicate that it was formerly an erosional shore.

Cultural and archeological features surveyed at this site include Inuvialuit graves with upright paddles, in a cluster on the northwest slope (Figure 23). Two sets of log house footings have also been located, one partially displaced down the upper slope of the former RTF basin on the seaward side and the other at a relatively stable site on top of the hill, near an extensive field of wooden stakes. More recent structures at the southeast corner of the tundra remnant and on the beach include the cabin belonging to Danny and Annie Gordon of Aklavik, two conical smokehouses constructed of driftwood logs, and two log camping shelters. One of these formed the nucleus of our camp in the present study.

Surveys and shore retreat measurements

Two survey lines were established in 1995, one (line 1) running out across the seaward slope and beach from the middle of the hill and the other (line 2) extending across the barrier near the camp (Solomon, 1996). These were marked by a benchmark (GSC-147) and wooden stake on line 1 and by a benchmark (GSC-148) and measured line orientation on line 2. A second benchmark (GSC-314) was established on line 2 in 1996 (Figure 23).

The beach on line 1, at the base of the hill, is 53 m wide and consists of two major storm ridges with several smaller berms, especially on the seaward ridge (Figure 25). The inner storm ridge is the highest, with a crest elevation of 2.0 m and two prominent berms on the outer ridge reach elevations of 1.9 and 1.7 m. The upper beachface on the seaward side of the outer ridge has a slope of about 8°, below which several small berms or swash bars are present, with a seaward slope at 18° at the water line. The beach then drops away steeply (about 7°) into the bar trough, which is deeper than 2.2 m (Figure 25). There is one bar with a depth of 1.7 m over the crest, 32 m from the shoreline. The seaward face of the bar is a gently diminishing slope to about 130 m offshore in about 2.9 m water depth, beyond which the shoreface is almost linear with a very gently slope of 0.1°.

Line 2 crosses the barrier just south of the hill and campsite (Figure 23). In this location the barrier is 77 m wide and up to 1.5 m high. As at line 1, there are two prominent ridges, with several smaller berms and driftwood accumulations. The back ridge (older) has cusps with a wavelength of 22 m. The next ridge seaward is more sandy with a higher proportion of discs in the pebble-cobble fraction. Cusps on this ridge have a wavelength of 15 m. Cusps at a wavelength of 10.5 m on the lower berm were truncated by the small wave events observed during the survey (see above). A storm ridge up to 1.25 m high on the inner side of the barrier is related to wave activity in the lagoon and runup on the inner shore. The lower berm along the outer shore is slightly wider than on line 1, but otherwise the beach morphology is similar. The steep, high, seaward face of the beach below water level is slightly steeper than at line 1 and the trough is not quite as deep. The bar at this site is very subtle and almost non-existant (Figure 25).

Overlay of the 1996 beach and nearshore surveys on equivalent data from 1995 shows little change at the shoreline (Table 4), but some berm accretion on the beachface (Figures 26 & 27). The most dramatic difference is the formation of a prominent bar at line 1, primarily by scour of the trough (the bar crest elevation is no higher than the smoothly sloping bottom in 1995). A suggested slight deepening farther seaward is probably not significant, though an apparent low rise in the 1995 profile is absent in 1996. Similar trends are evident at line 2 (Figure 27), where the smoothly concave inner nearshore slope of 1995 is replaced in 1996 by a deeper profile with a distinct trough and a subtle bar. The apparent deepening on this profile (up to 0.5 m) is substantial and may be real, although more detailed comparison of sounding locations would be needed to substantiate this conclusion.

The relative stability of the beach at Catton Point is evident in Table 4, which shows beachface retreat of <0.4 m over one year at line 1 and advance of <0.2 m at line 2. These changes are not significant, being comparable to changes in beach morphology caused by the small storms observed in 1995 and 1996 (see Solomon, 1996, and section above on wave climate). The photogrammetric data (Covill, 1997 [Appendix I]) corroborate these results, showing slow to negligible accretion over the past 20 years (1976-1996). However, the low cliff along the southern shore of the tundra remnant (on the lagoon side) has been eroding at a rate of 0.2 m/a over the past 20 years and more rapidly before that. The low tundra shore along the southern margin of the lagoon has retreated as much as 75 m over the past 26 years (a long-term mean rate of almost 2.9 m/a; Covill, 1997 [Appendix I]).

Nearshore sediments

Samples 23 and 24 were taken on line 2, the first in a depth of about 3.5 m on the outer shoreface and the second in the trough at the base of the beach (Figure 25). Samples 25 and 26 were collected on line 2 at the seaward limit of the outer bar slope and on the inner bar crest. The two

outer samples are slightly silty, angular, brown, lithic fine sands with up to 30% quartz. The mean grain size is 0.103 mm (3.27ϕ) in sample 23 and 0.119 mm (3.07ϕ) in sample 25. They are moderately well sorted (1.3ϕ and 1.1ϕ, respectively) with high positive skewness and kurtosis. Samples 24 and 26 are slightly coarser, fine-medium, subangular to subrounded, brown sand with up to 50% quartz and a few fine crystalline pebbles in sample 26. These have mean size of 0.151 mm (2.73ϕ) for sample 24 in the trough on line 2 and 0.200 mm (2.32ϕ) in sample 26 on the bar crest on line 1. These samples are well sorted (both 0.9ϕ). Sample 24 has high positive skewness (+7.1ϕ) and very high kurtosis (64ϕ), while sample 26 has very low skewness (+0.7ϕ).

Nunaluk Spit (site **30Y94** Borden no. **NjVk-1** [GSC site **5053**])
Survey dates: 22-23 July 1996 (JD 204-205)

Site description

This site consists of a low tundra remnant anchoring Nunaluk Spit just west of the main Firth River outlet (McDonald & Lewis, 1973; Solomon, 1996). The spit itself is a long, narrow, sand and gravel barrier (Lewis & Forbes, 1974) with several associated barrier islands at the east end, separated by inlets to the Firth River estuary (Figure 1).

The tundra remnant is about 4 to 5 m high, sloping down to the east and south, and extends roughly 100 m alongshore and 80 m from front to back (Figure 28). It consists of ice-bonded sandy mud with minor gravel and may represent an erosional remnant from dissection by the Firth River when it extended farther seaward to a lower sea level (Forbes, 1980; Hill et al., 1993), or from migration of the outlet channels through Nunaluk Spit at close to present sea level. Some lateral erosion may also occur by overwash flows during storm surges. The seaward face is subject to ongoing coastal erosion, which has produced a roughly linear cliff face. At the time of our 1996 survey, the west end of the cliff showed evidence of more recent toe erosion than other parts. This section had a relatively clean exposure on the top half of the cliff, including organic-rich sandy mud near the top and ice-bonded mud lower on the cliff. The lower part of the cliff was obscured by active-layer thaw slumping. The central and eastern part of the cliff were covered by partially vegetated slump blocks and hardened mud lobes.

In addition to tent sites, the most prominent cultural feature at this site is a log house (Figure 29). According to Willy Stefansson, who assisted with this survey, the house was built in 1934 by his 20-year old father, son of Vilhjalmur Stefansson. At the time of our 1996 visit, this house was partially unroofed but still relatively sound. At its nearest corner, it was 18.4 m from the cliff top.

Surveys and shore retreat measurements

A geodetic benchmark (21/ A56), marked Topographical Survey of Canada, is present just landward of the cliff edge near the middle of the site. In October 1993, this was 5 m back from the cliff edge (last description by the Geodetic Survey of Canada), by August 1995 it was about 1 m from the edge (Solomon, 1996), and in July 1996 the distance to the edge was 1.12 m. This indicates that almost 4 m of erosion occurred between late 1993 and mid-summer 1995, *after* the major storm of September 1993 (Solomon & Covill, 1995). A Geological Survey of Canada benchmark (GSC-143) was established 21.7 m landward of the geodetic benchmark in 1995. This marked the central of three survey lines established on the tundra remnant (Solomon, 1996). A fourth line was established on the barrier beach 80 m west of the benchmark line. These lines

(Figures 28 & 30), here numbered 1 to 4 from west to east, were previously designated 80W, 30W, BM, and 30E by Solomon (1996). Lines 1, 2, and 4 are marked by wooden stakes.

All four lines were resurveyed in 1996 and a nearshore bathymetric profile was completed on line 2 (Figure 30). A large ice floe grounded on the beach prevented us from doing bathymetry on line 3 (BM line).

The survey on line 1 shows a prominent barrier crest at 2.44 m above mean sea level (taking the geodetic benchmark elevation as 5.14 m) and a lower berm at about 1 m (Figure 31). The sediment on this line was predominantly sand with minor gravel and scattered driftwood, except near the outer shore, where fine pebble gravel predominated. The backshore slope was dissected by shallow braided washover channels with typical relief of about 0.2 m. The foreshore beachface slope on this and the other three lines was remarkably constant (7°-8°) and linear (Figure 31). The beachface morphology on lines 2 to 4 at the base of the cliff was similar to that at line 1. The beach width in this area ranged from 18 to 24 m. Fine-pebble gravel predominated on the lower swash bar and sandy gravel or pebbly sand elsewhere.

The nearshore profile (Figure 32) shows the linear beachface slope continuing to a depth of almost 2 m, where it terminates at a 22 m wide terrace. This defines what appears to be a subtle nearshore bar, beyond which the shoreface slope diminishes exponentially, becoming almost linear below about 5 m water depth, about 250 m offshore. Alternatively the bar may be an ice-pushed berm, a plausible interpretation given the high concentration of drifting and grounding ice floes in the area at the time of the survey. As noted by Solomon (1996), an uncontrolled bathymetric profile off line 3 in 1995 revealed a prominent bar and trough in 1 to 2 m water depth at the base of the beach, whereas a 1972 profile in the same vicinity (McDonald & Lewis, 1973) was uniformly concave-up at the base of the steep beachface slope (Figure 33), with a broad zone of positive relief between 4.5 and 5.5 m depth about 250-350 m off the beach. This profile was run by dead-reckoning from a horizontal sextant position offshore and cannot therefore be used for quantitative analysis of changes.

Whereas the cliff on line 3 receded almost 4 m from October 1993 to August 1995, it suffered no significant erosion in the year preceding this survey (Table 5). Similarly there was little or no change on the cliff at line 4 (Figure 34). At the west end of the site, however, in the vicinity of line 2, the cliff suffered toe erosion and was cut back about 1 m at the top (slightly more at the base), while the beach receded 1.8 m in the same time interval. The beach at line 3 retreated 1 m , whereas at line 4 it advanced by a small amount. This pattern is consistent with the substantial 5.4 m of beachface retreat at line 1, suggesting that landward migration of the barrier may tend to drive episodic retreat at the tundra site, as the beach and cliff there are intermittently left protruding seaward beyond the mean shoreline position.

Over a longer time span, photogrammetric measurements (Covill, 1997 [Appendix I]) show cliff-top recession averaging 0.03 to 0.33 m/a over the past 20 years, but up to 2.6 m/a in the early 1970s and 1 to 2 m/a over the 18 years before 1970. Barrier retreat at line 1 varied from 1.4 m/a (1952-1970) to 2.4 m/a (1970-1976) to 0.3 m/a over the past 20 years.

Cliff and beach sediments

Two samples were taken from the fresh cliff face at line 2 (Figure 31). Sample 29 from near the top of the cliff is an organic-rich, very poorly sorted, sandy mud with 29% sand, 35% silt, and 36% clay. The mean grain size is 8 μm (7.01ϕ), with sorting of 3.8ϕ, negligible skewness (-0.1ϕ) and low kurtosis (1.7ϕ). Sample 30, from an ice-bonded layer lower in the cliff (Figure 31), is almost equal parts sand (48%) and silt (52%) with no clay. It is also poorly sorted (4.4ϕ), with mean size of 36 μm (4.81ϕ), slight positive skewness (+0.2ϕ) and low kurtosis (2.1ϕ).

Beach sediments (Figure 31) range from well sorted sand with pebbles at the top of the beach (sample 31) to moderately well sorted fine pebble gravel at the swash bar (sample 32). The upper beach sand has 0.8% fine gravel (2< D ≤ 8 mm) and 0.4% silt (D≤ 62 μm). This is a coarse lithic sand with about 30% quartz, angular to well-rounded, with mean grain size of 0.432 mm (1.21ϕ), sorting 0.7ϕ, high positive skewness (+3.3ϕ) resulting from the gravel tail, and very high kurtosis (69ϕ). The swash bar gravel (sample 32) has a mean size of 4.44 mm (-2.15ϕ), sorting of 0.8ϕ, slight negative skewness and low kurtosis. The grain size in this sample ranges from granules (3.6% finer than 2 mm) to 22 mm pebbles, with a mode in the very fine pebble fraction (2.8< D <4.0 mm).

Nearshore sediments

Two grab samples were obtained in the nearshore (Figure 32), one on the terrace at the foot of the beachface in a depth of 1.9 m (sample 27) and the other lower on the shoreface in 3.7 m of water (sample 28). The shallower sample is a pebbly, medium, quartz and lithic sand, subangular to well rounded, with 1.8% silt and 2.0% fine pebbles (2< D ≤11 mm). The mean grain size is 0.204 mm (2.29ϕ). It is moderately sorted (1.2ϕ) and positively skewed (+1.7ϕ). The deeper sample is a gritty, silty, fine sand with 12% silt and 0.3% granules and very fine pebbles (1.0< D ≤4.0 mm). The sand is angular with a high proportion of rock fragments and about 30% quartz. The mean size is 0.100 mm (3.32ϕ). It is moderately sorted (1.8ϕ) with high positive skewness (+3.1ϕ) and moderate kurtosis (13ϕ).

Clarence Lagoon (site **30Y96** Borden no. **NjVo-5** [GSC site **5051**])
Survey dates: no surveys in 1996

Solomon (1996) provided a site description and survey data for this site. Survey results and earlier observations going back to 1912 at the nearby international boundary (GSC site 5010) were summarised in Forbes et al. (1993, 1995).

Although attempts to reach this site by water were unsuccessful in 1996, we did obtain new airphoto coverage to supplement the 1992 photography. This has made it possible to measure coastal recession rates between 1992 and 1996 (Covill, 1997 [Appendix I]). Photogrammetric measurements were made at the three profile lines established by Solomon (1996), just west of the inlet, and at two additional transects across RTF slopes farther west alongshore (Appendix I). The results are highly variable for the cliff top and more consistent at the base. Cliff-top recession ranged from 0.0 to 1.6 m/a during the 4-year interval 1992-1996 while cliff-base retreat varied between 0.15 and 0.66 m/a.

DISCUSSION & RECOMMENDATIONS

Coastal circulation and water properties

Water temperature and salinity are of interest in this context because of their importance for the thaw of ice-bonded sediments at the coast and beneath the nearshore seabed (e.g. Dyke, 1991; Vidrine, 1996). Some insight has been gained from measurements of near-bottom temperatures on the shoreface at Catton Point during this project in 1995 (Solomon, 1996) and 1996 (Figure 5). In 1996, an abrupt temperature decrease was associated with the westerly storm of July 22 — this may have resulted from warm surface water being pushed away from the coast at Catton Point, initiating upwelling within Herschel Basin. Decreasing water temperature was also associated with easterly winds on July 25 and with strong southerlies on July 26. East winds are commonly associated with upwelling in the Beaufort Sea, through Coriolis deflection to the north, driving surface water offshore and generating a negative surge (Herlinveaux & de Lange Boom, 1975; Forbes, 1981). Solomon (1996) observed a sharp drop in water temperature at Catton Point on 5-6 August 1995, correlated with strong easterly wind at Tuktoyaktuk (northeasterly at Catton Point) and he inferred upwelling associated with a negative storm surge. However no obvious cooling was observed under similar wind and surge conditions 4 days later. In Phillips Bay, off Niakolik Point, Forbes (1981) observed two abrupt intrusions of cold ($\leq$0.5°C) saline ($\geq$24‰) water in late July and early August 1977, both associated with easterly winds and unusually low water levels. Between these two events, warm (>12°C) brackish (7‰) water was present. During four seasons of water mass observations in Phillips Bay (Forbes, 1981, unpublished data), bottom temperatures in the baymouth area off Niakolik Point ranged from 0°C to 17°C and salinities from as high as 67‰ or more in late winter (Steigenberger et al., 1975) to 0‰ during the snowmelt runoff to as high as 25‰ after mid-July. Brackish water was encountered at 22 m in a borehole at the front of the Babbage Delta in March 1974 (Lewis & Forbes, 1974), perhaps related to brine concentration beneath ice in an 8 m deep distributary channel nearby.

Taken together, these observations indicate extreme seasonal variability, the importance of winter freezing and circulation processes, and a complex response to wind events during the open-water season. In the vicinity of Catton Point, temperatures may be affected by movement of water through Workboat Passage as well as exchanges with deeper water in Herschel Basin, warmer water behind the barrier, or incursions from Mackenzie Bay and north of Herschel Island. In other areas, such as Phillips Bay and Nunaluk Spit, freshwater discharge from rivers may play an important part. In years of very heavy ice concentration, such as 1974, when vertical mixing is inhibited, freshwater discharge from the Mackenzie River may form an extensive surface plume extending well west along the Yukon coast. In that summer, the highest salinity observed off Niakolik Point was 2.5‰ (Forbes, 1981) and salinities in surface waters (forming the bottom water in nearshore areas) may not have exceeded 10‰, although concentrations >30‰ were found below the picnocline in depths of 20 m or more (Herlinveaux et al., 1976).

Coastal retreat

Overall, the rates of coastal retreat observed from early August 1995 to late July 1996 at the Niakolik, Stokes, Catton, and Nunaluk study sites are broadly consistent with the site ranking presented by Solomon (1996), as are the 4-year rates determined from 1992 and 1996 aerial photography at Clarence Lagoon, Stokes Point, and Niakolik Point. Catton Point and Nunaluk Spit were not included in the 1992 airphotos, but other evidence is available to support the interpretation. It should also be noted that retreat rates measured over short intervals are typically

higher and more variable than longer-term averages (Dolan et al., 1991; Fenster et al., 1993). Prediction of future rates is therefore somewhat speculative. However, an understanding of coastal sediment transport and erosion processes, nearshore dynamics, and longer-term morphological development can provide a useful context for interpretation of the coastal recession data.

Catton Point is the most stable site, if the ocean side of the tundra remnant is considered as the core of the site. A 20-year comparison of airphotos (1976-1996) indicates an average *accretion* of 0.35 m/a in this area. However, the barrier to the east and the spit to the west are both migrating landward, erosion is occurring along the southern lagoon shore of the tundra remnant and along much of the mainland shore of the lagoon, where at one point it has amounted to 75 m over 26 years (2.87 m/a from 1970 to 1996 — Covill, 1997 [Appendix I]). This erosion may ultimately threaten a number of log houses and other remains of settlement, although the measured rates of erosion are less in the extreme east end of the lagoon where these are concentrated. The grave site on the northwest slope of the tundra remnant is relatively safe from coastal erosion in the near term, but occupies a slope with well-developed cryogenic banding. Some human remains are exposed on the surface and further heave and down-slope creep or solifluction can be anticipated.

The 4-year rates of cliff-top recession west of Clarence Lagoon average 0.69±0.37 m/a, while the cliff-base mean for the same time interval is 0.36±0.09 m/a. Although these results include two lines in the area of RTF failure, the highest cliff-top retreat was observed at line 3 outside that area. Mean long-term rates of coastal recession at the international boundary, not far to the west, have averaged 0.72 m/a (1912-1972; McDonald & Lewis, 1973) and 0.83 m/a (1972-1984; Forbes & Frobel, 1985). No change was observed between 1991 and 1992 (Forbes et al., 1993). This section of the coast requires more comprehensive study, including analysis of the lagoon and barrier system, coastal retreat on the east side of the lagoon, and the varying extent and activity of RTF failures in the area. Another issue of concern on this part of the coast, extending east to Komakuk Beach and Nunaluk Spit, is the role of shore-ice pile-up, over-ride, and ice-push in cliff-top sedimentation (Forbes & Taylor, 1994) and beach nourishment (Reimnitz et al., 1990).

Rates of cliff recession at Stokes Point average 0.47±0.25 m/a for the cliff top and 0.31±0.04 m/a at the cliff base for the 4 years 1992-1996. At the RTF failure to the west, the 4-year rates of headwall and basal retreat were 2.43 and 0.84 m/a, respectively (Covill, 1997 [Appendix I]). There has been a slight increase in erosion rates at this site over the past 26 to 44 years and a significantly higher rate over the past 12 months (1.08±0.05 m/a at the cliff top on lines 1 and 2). This is consistent with the trend one would expect at this site. The narrow beach at the site and absence of a beach updrift suggest that sediment moving southeast along the coast bypasses most sites updrift of Stokes Point lagoon, where it may accumulate by washover or inlet trapping, or Stokes Point proper, where it may be deposited in the downdrift beach ridges. Seaward transport is another possibility, particularly under downwelling conditions that may be associated with positive storm surges under north or northwest winds (Héquette et al., 1996). Furthermore, a drift divergence occurs somewhere between Stokes Point and Ptarmigan Bay, where longshore transport is toward the northwest at Catton Point. The large-scale sinuosity of the beach at the Stokes Point site implies some sediment storage, but this is simply part of the longshore transport system. Assuming no significant increase in sediment supply rates alongshore, progessive landward movement of the beach and cliff in front of the archeological site can be expected as the updrift end of the Stokes Point barrier continues to migrate landward by washover during storms. This, coupled with any increase in wave energy resulting from climate change (Solomon

et al., 1994), may lead to higher rates of coastal retreat at this site. In any case, the grave site on line 1 (west line), part of which is less than 2.1 m from the cliff top, is now at imminent risk of loss. Other parts of this site may be affected within 10 to 15 years if recent rates of retreat persist and sooner if the rates continue to increase.

High temporal and spatial variance in erosion rates at Nunaluk Spit may reflect the variable summer ice conditions west of Herschel Island, where extensive open water is present in some years but not in others. This episodic pattern of coatal recession makes medium- to long-term prediction of the erosion risk extremely difficult. The long-term (20-year) rates of cliff-top and cliff-base erosion at this site are 0.17±0.09 and 0.29±0.02 m/a, respectively (Covill, 1997 [Appendix I]). At line 1 on the adjacent barrier, the crest has migrated onshore at an average rate of 0.26 m/a over the same time interval. However, 4 m of retreat was observed at the cliff top on line 3 between late 1993 and mid-1995. Survey data presented in this report show no change in the cliff on line 3 or line 4 between 1995 and 1996, but 1 m of beach retreat on line 3, 1.8 m on line 2, and 5.4 m on line 1. The cliff top at line 2 retreated 1.1 m during the year. The evidence indicates that erosion occurs episodically and possibly out of phase on different parts of the cliff face, even at such a small site. In this setting, migration of the adjacent barrier may play a role in initiating retreat at the flanks of the tundra remnant.

Niakolik Point has the highest rates of 1992-1996 shore recession, not only on the outer shore where they averaged 5.57±0.63 m/a, but also along the lagoon shore where the 4-year rate was 1.25±0.15 m/a. Though no significant change was observed at the inner shore lines (4 to 6) in 1995-1996, ongoing erosion can be anticipated at this site. On the outer shore, the 1-year rate of retreat was consistent with the 4-year data, averaging 6.10±0.10 m between early August 1995 and late July 1996. Although most cultural and archeological remains at this site are set well back from the shore or on top of the hill, the erosion hazard at Niakolik Point requires careful monitoring.

Recommendations

SCIENTIFIC ISSUES

- Annual monitoring (which may be as simple as tape measurement from line markers to the cliff edge) is recommended to maintain a watch on erosion rates and a better estimate of year-to-year variability.
- Efforts should be made to maintain the reference markers on a regular basis (checking and replacing or setting them back from the shore as needed when the annual survey is done). Installation of antiheave benchmarks is recommended.
- Comprehensive physical shore-zone description and mapping in a GIS framework would provide a solid basis for comparing short-term erosion data and ranking erosion, flood, ice ride-up, and slope failure hazards along the coast.
- Changes in coastal stability onshore may be driven by changes in the nearshore, as well as changes in sediment supply alongshore. There is a need for better understanding of wave climate, nearshore dynamics, and thermal-mechanical interaction in the development of nearshore profiles.
- Erosion on the shoreface may also occur by frazil- and anchor-ice entrainment during freeze-up storms or under occasional open-water conditions in winter (Reimnitz et al., 1987; Kempema et al., 1989). There is a need for better understanding of freeze-up processes and their role in coastal and shoreface erosion along the Yukon coast.

- Multibeam bathymetric mapping in the nearshore provides data comparable to aerial photography on land. This technique is revolutionising marine and coastal geology in other areas and is being applied to improved understanding of coastal stability and processes in other National Park settings (e.g 1997 surveys in Gros Morne National Park and PEI National Park). Serious consideration should be given to implementing a similar survey along the western Yukon coast, particularly in connection with waste cleanup requirements related to DEW Line decommissioning at Komakuk Beach.
- Comprehensive analysis of long-term morphological evolution and trends on a coastal cell or system basis rather than site by site would provide a more solid foundation for assessing coastal erosion hazards and setting coastal management goals within the park.
- Consideration should be given to monitoring slope creep at grave sites on the northwest side of the Catton Point hill, as well as establishing shore erosion monitoring lines and reference markers along the mainland lagoon shore in that area.

MANAGEMENT ISSUES

- There is no immediate threat to cultural resources at Niakolik Point, but the situation should be monitored on a regular basis.
- Loss of one grave at Stokes Point is imminent and other resources at this site may be threatened within 10 years if recent rates of erosion are maintained or accelerated.
- Cultural resources at Catton Point are not significantly threatened by coastal erosion (although erosion along the lagoon shore of the hill may threaten the fishing camp in due course). However, slope movement is a potential medium-term threat to the grave sites on the northwest slope, as well as to the cabin footings on the seaward face of the hill.
- Shore erosion is a potential threat to several former habitations on the mainland lagoon shore at Ptarmigan Bay and this may require watching over the next few years.
- Erosion appears to be focused now at the west end of the cliff at Nunaluk Spit, where it poses the greatest long-term threat to the log structure. The Geodetic Survey benchmark at this site is under imminent threat as soon as erosion resumes on that section of the cliff.

ACKNOWLEDGEMENTS

Park wardens Mervin Joe and Willy Stefansson provided willing, conscientious, and able assistance in the field. Their positive attitude and enthusiasm were much appreciated. Thanks are due to Vicki Sahanatien for her support and assistance in the development and realisation of this project, for diplomatic contributions, and patience in awaiting results. I also thank Bill Fox for supportive management. The hospitality and logistical support provided by Qikiqtaruk Territorial Park rangers on Herschel Island is gratefully acknowledged. Les Kutny of the Inuvik Research Centre (Aurora Institute) and Jerry McEachern of Polar Continental Shelf Project (Tuktoyaktuk) provided outstanding logistical support and assistance. Ernie Sargent of Canadian Hydrographic Service (Sidney) was helpful as ever in the provision of essential Tuktoyaktuk tidal observations and Maria MacLeod of the Canadian Ice Service (Ottawa) helped with prompt delivery of ice data. Jack Byrne (Jack M. Byrne Consultants Ltd) organised the aerial photography and Bob Covill (Tekmap Consulting) did the photogrammetric analysis. Fred Jodrey (GSC-Atlantic) provided the usual enthusiastic, competent, and reliable technical assistance in preparations for the field season and on the first phase of the 1996 surveys outside Ivvavik National Park. Meticulous grain-size analysis was completed by Donald Clattenburg. This work has benefitted greatly from the assistance and contributions of Steve Solomon, through provision of 1995 data, scientific discussion, and review of the draft report.

REFERENCES

Amundsen, R. 1908. The north west passage. Constable, London, 2 volumes.

Blasco, S.M., Fortin, G., Hill, P.R., O'Connor, M.J. & Brigham-Grette, J. 1990. The late Neogene and Quaternary stratigraphy of the Canadian Beaufort continental shelf. In: The Arctic Ocean region (Grantz, A., Johnson, L. and Sweeney, J.F., editors). Geological Society of America, The Geology of North America, L, 491-502.

Bostock, H.S. 1948. Physiography of the Canadian Cordillera, with special reference to the area north of the fifty-fifth parallel. Geological Survey of Canada, Memoir 247, 106 p.

Burns, B.M. 1973. The climatology of the Mackenzie Valley- Beaufort Sea. Environment Canada, Atmospheric Environment Service, Downsview. Climatological Studies 24, 2 volumes.

Canada Department of Public Works. 1971. Beaufort Sea storm, September 13-16, 1970: investigation of effects in the Mackenzie Delta region. Unpublished report, Engineering Programs Branch, Ottawa, 22 p.

Carson, J.M., Hunter, J.A. & Lewis, C.P. 1975. Marine seismic profiling, Kay Point, Yukon Territory. Report of Activities, Geological Survey of Canada, Paper 75-1B, 9-12,

Coakley, J.P. & Syvitski, J.P.M. 1991. SediGraph technique. In: Principles, methods, and application of particle size analysis (Syvitski, J.P.M., editor). Cambridge University Press, Cambridge &c., 129-142.

Cooper, P.F., Jr. 1974. Landfast ice in the southeastern part of the Beaufort Sea. In: The coast and shelf of the Beaufort Sea (Reed, J.C. & Sater, J.E., editors). Arctic Institute of North America, Arlington, 235-242.

Covill, R. 1996. Report on historical coastal erosion at five sites in Ivvavik National Park. Contract report to Geological Survey of Canada (Dartmouth) and Parks Canada (Inuvik). Tekmap Consulting, Windsor Junction, Nova Scotia, 15 p. (Appendix A in Solomon, 1996).

Covill, R. 1997. Photogrammetric analysis of coastal erosion at five sites in Ivvavik National Park. Contract report to Geological Survey of Canada (Dartmouth) and Parks Canada (Inuvik). Tekmap Consulting, Windsor Junction, Nova Scotia, 11 p. (Appendix I of this report).

Dickins, D.F. & Associates Ltd. 1987. Aerial reconnaissance survey of ice break-up processes in the Canadian Beaufort Sea coastal zone. Geological Survey of Canada, Open File 1687, 16 p. & 5 appendices.

Dolan, R., Fenster, M.S. & Holme, S.J. 1991. Temporal analysis of shoreline recession and accretion. Journal of Coastal Research, 7, 723-744.

Duguid, J.O. 1971. Thin gravel deposits on wave-eroded cliffs near Barrow, Alaska. Arctic, 24, 304-306.

Dyke, L.D. 1991. Temperature changes and thaw of permafrost adjacent to Richards Island, Mackenzie Delta, NWT. Canadian Journal of Earth Sciences, 28, 1834-1842.

Eid, B.M. & Cardone, V.J. 1992. Beaufort Sea extreme waves study. Environmental Studies Research Funds, Report 114.

Fenster, M.S., Dolan, R. & Elder, J.F. 1993. A new method for predicting shoreline positions from historical data. Journal of Coastal Research, 9, 147-171.

Forbes, D.L. 1975. Sedimentary processes and sediments, Babbage River delta, Yukon Coast. Report of Activities, Geological Survey of Canada, Paper 75-1B, 157-160.

Forbes, D.L. 1976. Sedimentary processes and sediments, Babbage River delta, Yukon coast: a progress report. Report of Activities, Geological Survey of Canada, Paper 76-1C, 165-168.

Forbes, D.L. 1979. Bottomfast ice in northern rivers: hydraulic effects and hydrometric implications. Proceedings, Canadian Hydrology Symposium (Vancouver, 1979). National Research Council Canada, Associate Committee on Hydrology, Ottawa, 179-184.

Forbes, D.L. 1980. Late Quaternary sea levels in the southern Beaufort Sea. Current Research, Geological Survey of Canada, Paper 80-1B, 75-87.

Forbes, D.L. 1981. Babbage River delta and lagoon: hydrology and sedimentology of an Arctic estuarine system. Ph.D. dissertation, University of British Columbia, Vancouver, 554 p.

Forbes, D.L. 1989. Discussion - Maximum storm surge elevations in the Tuktoyaktuk region of the Canadian Beaufort Sea. Letter to the Editor, Arctic, 42, 182.

Forbes, D.L. & Frobel, D. 1985. Coastal erosion and sedimentation in the Canadian Beaufort Sea. Current Research, Geological Survey of Canada, Paper 85-1B, 69-80.

Forbes, D.L. & Hosoi, Y. 1995. Coastal erosion in South Tarawa, Kiribati. South Pacific Applied Geoscience Commission, Suva. Technical Report 225, 77 p. & 5 appendices.

Forbes, D.L. & Taylor, R.B. 1994. Ice in the shore zone and the geomorphology of cold coasts. Progress in Physical Geography, 18, 59-89.

Forbes, D.L., Solomon, S.M. & Frobel, D. 1993. Coastal erosion studies in Northern Yukon National Park. Unpublished report to Canadian Parks Service, Inuvik. Geological Survey of Canada, Atlantic Geoscience Centre, Dartmouth, 23 p.

Forbes, D.L., Solomon, S.M. & Frobel, D. 1995. Report of coastal surveys in the Beaufort Sea. Geological Survey of Canada, Open File 3053, 39 p. & 4 appendices.

Forbes, D.L., Solomon, S.M. & Hamilton, T.S. 1994. Morphology and sedimentary processes of microtidal embayments, Beaufort Sea coast, western Arctic Canada. Proceedings, Hornafjörður International Coastal Symposium (Höfn). Icelandic Harbour Authority, Kópavogur, 363-372.

Franklin, J. 1928. Narrative of a second expedition to the shores of the Polar Sea in the years 1825, 1826, and 1827. John Murray, London (reprinted 1969, Greenwood, New York), 320 p. with appendices.

Harper, J.R. 1990. Morphology of the Canadian Beaufort Sea coast. Marine Geology, 91, 75-91.

Harper, J.R. & Owens, E.H. 1981. Analysis of ice override potential along the Beaufort Sea coast of Alaska. In: Proceedings, Conference on Port and Ocean Engineering under Arctic Conditions (POAC 1981, Québec), 974-984.

Harper, J.R., Owens, E.H. & Wiseman, W.J., Jr. 1978. Arctic beach processes and the thaw of ice-bonded sediments in the littoral zone. In: Proceedings, 3rd International Permafrost Conference, 195-199.

Harper, J.R., Reimer, P.D. & Collins, A.D. 1985. Beaufort Sea physical shore-zone analysis. Geological Survey of Canada, Open File 1689, 105 p.

Henry, R.F. 1975. Storm surges. Environment Canada, Victoria. Beaufort Sea Project, Technical Report 19, 41 p.

Henry, R.F. & Heaps, N.S. 1976. Storm surges in the southern Beaufort Sea. Journal of the Fisheries Research Board of Canada, 33, 2362-2376.

Héquette, A., Desrosiers, M. & Forbes, D.L. 1996. The role of shoreline configuration and coastal morphology on nearshore sediment transport under storm combined flows, Canadian Beaufort Sea. Proceedings, International Conference on Coastal Change (Bordomer-IOC, Bordeaux, 1995). Intergovernmental Oceanographic Commission, Workshop Report 105 Supplement, 563-570.

Herlinveaux, R.H. & de Lange Boom, B.R. 1975. Physical oceanography of the southeastern Beaufort Sea. Environment Canada, Victoria. Beaufort Sea Project, Technical Report 18, 97 p.

Herlinveaux, R.H., de Lange Boom, B.R. & Wilton, G.R. 1976. Salinity, temperature, turbidity and meteorological observations in the Beaufort Sea: summer 1974, spring and summer

1975. Environment Canada, Institute of Ocean Sciences, Patricia Bay. Pacific Marine Science Report 76-26, 224 p.
Hill, P.R. 1990. Coastal geology of the King Point area, Yukon Territory, Canada. Marine Geology, 91, 93-111.
Hill, P.R., Blasco, S.M., Harper, J.R. & Fissel, D.B. 1991. Sedimentation on the Canadian Beaufort Shelf. Continental Shelf Research, 11, 821-842.
Hill, P.R., Forbes, D.L., Dallimore, S.R. & Morgan, P. 1986. Shoreface development in the Canadian Beaufort Sea. In: Proceedings, Symposium on Cohesive Shores (Burlington). National Research Council Canada, Associate Committee for Research on Shoreline Erosion and Sedimentation, Ottawa, 428-448.
Hill, P.R., Héquette, A. & Ruz, M.-H. 1993. Holocene sea-level history of the Canadian Beaufort Sea. Canadian Journal of Earth Sciences, 30, 103-108.
Hill, P.R., Héquette, A., Ruz, M.-H. & Jenner, K.A. 1991. Geological investigations of the Canadian Beaufort Sea coast. Geological Survey of Canada, Open File 2387, 328 p. & appendix.
Hughes, O.L. 1972. Surficial geology of northern Yukon Territory and northwestern District of Mackenzie, Northwest Territories. Geological Survey of Canada, Paper 69-36, 11 p.
Judge, A. 1986. Permafrost distribution and Quaternary history of the Mackenzie region: a geothermal perspective. In: Correlation of Quaternary deposits and events around the margin of the Beaufort Sea (Heginbottom, J.A. & Vincent, J.S., editors). Geological Survey of Canada, Open File 1237, 41-50.
Kempema, E.W., Reimnitz, E. & Barnes, P.W. 1989. Sea ice entrainment and rafting in the Arctic. Journal of Sedimentary Petrology, 59, 308-317.
Kendel, R.E., Johnston, R.A.C., Lobsiger, U. & Kozak, M.D. 1975. Fishes of the Yukon coast. Environment Canada, Victoria. Beaufort Sea Project, Technical Report 6, 114 p.
Kovacs, A. & Mellor, M. 1974. Sea ice morphology and ice a a geologic agent in the southern Beaufort Sea. In: The coast and shelf of the Beaufort Sea (Reed, J.C. & Sater, J.E., editors). Arctic Institute of North America, Arlington, 113-161.
Kovacs, A. & Sodhi, D.S. 1980. Shore ice pile-up and ride-up: field observations, models, theoretical analyses. Cold Regions Science and Technology, 2, 209-288.
Kovacs, A. & Sodhi, D.S. 1988. Onshore ice pile-up and ride-up. In: Observations and theoretical assessment: Arctic coastal processes and slope protection designs (Chen, A.T. & Leidersdorf, C.P., editors). American Society of Civil Engineers, New York, 108-142.
Krumbein, W.C. 1934. Size frequency distribution of sediments. Journal of Sedimentary Petrology, 4, 65-77.
Lewis, C.F.M. 1978. The frequency and magnitude of drift-ice groundings from ice-scour tracks in the Canadian Beaufort Sea. Proceedings, 4th International Conference on Port and Ocean Engineering under Arctic Conditions, St John's, 568-579.
Lewis, C.P. 1975. Sediments and sedimentary processes, Yukon Beaufort Sea coast. Geological Survey of Canada, Paper 75-1B, 165-170.
Lewis, C.P. & Forbes, D.L. 1974. Sediments and sedimentary processes, Yukon Beaufort Sea coast. Canada, Environmental-Social Committee, Northern Pipelines, Task Force on Northern Oil Development, Report 74-29, 40 p.
Lewis, C.P. & Forbes, D.L. 1975. Coastal sedimentary processes and sediments, southern Canadian Beaufort Sea. Environment Canada, Victoria. Beaufort Sea Project, Technical Report 24, 68 p.
Mackay, J.R. 1960. Small boat harbours of the Yukon coast. Geographical Bulletin no. 15, 19-30.
Mackay, J.R. 1963. Notes on the shoreline recession along the coast of the Yukon Territory. Arctic, 16, 195-197.

Mackay, J.R. 1966. Segregated epigenic ice and slumps in permafrost, Mackenzie Delta area, Northwest Territories. Geographical Bulletin, 8, 59-80.
Mackay, J.R. 1971. The origin of massive icy beds in permafrost, western Arctic coast, Canada. Canadian Journal of Earth Sciences, 8, 397-422.
Mackay, J.R. 1972. Offshore permafrost and ground ice, southern Beaufort Sea, Canada. Canadian Journal of Earth Sciences, 9, 1550-1561.
Mackay, J.R. 1986. Fifty years (1935-1985) of coastal retreat west of Tuktoyaktuk, District of Mackenzie. Geological Survey of Canada, Paper 86-1A, 727-735.
Mackay, J.R., Rampton, V.N. & Fyles, J.G. 1972. Relic Pleistocene permafrost, western Arctic, Canada. Science, 176, 1321-1323.
Marko, J. 1975. Satellite observations of the Beaufort Sea ice cover. Environment Canada, Victoria. Beaufort Sea Project, Technical Report 34, 137 p.
McDonald, B.C. & Lewis, C.P. 1973. Geomorphic and sedimentologic processes of rivers and coast, Yukon Coastal Plain. Environmental-Social Committee, Northern Pipelines, Ottawa. Task Force on Northern Oil Development, Report 73-39, 245 p.
Neave, K.G., Judge, A.S., Hunter, J.A. & MacAulay, H.A. 1978. Offshore permafrost distribution in the Beaufort Sea as determined from temperature and seismic observations. Current Research, Geological Survey of Canada, Paper 78-1C, 13-18.
Neufeld, D. & Adams, G. 1993. Cultural resources of Northern Yukon National Park. In: Northern Yukon National Park resource description and analysis. Canadian Parks Service, Natural Resource Conservation Section, Prairie & Northern Region, Winnipeg, RM Report 93-01/INP, ..-..
Norris, D.K., Price, R.A. & Mountjoy, E.W. 1963. Geology, northern Yukon Territory and northwestern District of Mackenzie. Geological Survey of Canada, Map 10-1963.
O'Neill, J.J. 1924. Geology of the Arctic coast of Canada, west of the Kent Peninsula. In: Report of Canadian Arctic Expedition 1913-1918; volume 2, Geology and geography, 10A-18A.
Owens, E.H., Harper, J.R. & Nummedal, D. 1980. Sediment transport processes and coastal variability on the Alaskan North Slope. In: Proceedings, 17th International Coastal Engineering Conference (Sydney). American Society of Civil Engineers, New York, 1344-1363.
Pilkington. R. & Associates & PFL Arctic & Offshore Technology Ltd. 1988. A study of the occurrence of strudel scours in the Canadian Beaufort Sea. Geological Survey of Canada, Open File 2272.
Pinchin, B.M., Nairn, R.B. & Philpott, K.L. 1985. Beaufort Sea coastal sediment study: numerical estimation of sediment transport and nearshore profile adjustments at coastal sites in the Canadian Beaufort Sea. Geological Survey of Canada, Open File 1259, 712 p.
Rampton, V.N. 1982. Quaternary geology of the Yukon Coastal Plain. Geological Survey of Canada, Bulletin 317, 49 p.
Reimnitz, E. & Barnes, P.W. 1987. Sea-ice influence on Arctic coastal retreat. Proceedings, Coastal Sediments 87 (New Orleans). American Society of Civil Engineers, New York, 1578-1591.
Reimnitz, E. & Bruder, K.F. 1972. River discharge into an ice-covered ocean. Geological Society of America Bulletin, 83, 861-866.
Reimnitz, E. & Kempema, E.W. 1982. Dynamic ice wallow relief of northern Alaska's nearshore. Journal of Sedimentary Petrology, 52, 451-462.
Reimnitz, E., Barnes, P.W. & Harper, J.R. 1990. A review of beach nourishment from ice transport of shoreface materials, Beaufort Sea, Alaska. Journal of Coastal Research, 6, 439-470.
Reimnitz, E., Graves, S.M. & Barnes, P.W. 1988. Beaufort Sea coastal erosion, shoreline evolution and sediment flux. United States Geological Survey, I-Map 1182G.

Reimnitz, E., Kempema, E.W. & Barnes, P.W. 1987. Anchor ice, seabed freezing, and sediment dynamics in shallow Arctic seas. Journal of Geophysical Research, 92C, 14671-14678.
Reimnitz, E., Rodeick, C.A. & Wolf, S.C. 1974. Strudel scour: a unique Arctic marine geologic phenomenon. Journal of Sedimentary Petrology, 44, 409-420.
Reimnitz, E., Toimil, L. & Barnes, P.[W.] 1978. Arctic continental shelf morphology related to sea-ice zonation, Beaufort Sea, Alaska. Marine Geology, 28, 179-210.
Shearer, J.M. 1972. Geologic structure of the Mackenzie Canyon area of the Beaufort Sea. Geological Survey of Canada, Paper 72-1A, 179-180.
Short, A.D. 1979. Barrier island development along the Alaska-Yukon coastal plains. Geological Society of America Bulletin, part II, 90, 77-103.
Short, A.D., Coleman, J.M. & Wright, L.D. 1974. Beach dynamics and nearshore morphology of the Beaufort Sea coast, Alaska. In: The coast and shelf of the Beaufort Sea (Reed, J.C. & Sater, J.E., editors). Arctic Institute of North America, Arlington, 477-488.
Solomon, S.M. 1996. Ivvavik National Park coastal erosion study. Geological Survey of Canada, Open File 3323, 24 p., 20 figs, and appendix.
Solomon, S.M. & Covill, R. 1995. Impacts of the September 1993 storm on the coastline at four sites along the Canadian Beaufort Sea. Proceedings, Canadian Coastal Conference (Dartmouth). Canadian Coastal Science & Engineering Association, 779-796.
Solomon, S.M., Forbes, D.L. & Kierstead, B. 1994. Coastal impacts of climate change: Beaufort Sea erosion study. Atmospheric Environment Service, Canadian Climate Centre, Report 94-2; Geological Survey of Canada, Open File 2890, 35 p., 31 figs, & 2 appendices.
Stefansson, V. 1922. Hunters of the great north. Harcourt, Brace & Company, New York, 301 p. and 2 maps.
Steigenberger, L.W., Robertson, R.A., Johansen, K. & Elson, M.S. 1975. Biological/engineering evaluation of the proposed pipeline crossing sites in northern Yukon Territory. Environment Canada, Fisheries and Marine Service, Pacific Region, Report PAC/T-75-11, 456 p.
Stewart, C.J. & Davidson-Arnott, R.G.D. 1988. Morphology, formation and migration of longshore sand waves: Long Point, Lake Erie, Canada. Marine Geology, 81, 63-77.
Syvitski, J.P.M., Asprey, K.W. & Clattenburg, D.A. 1991. Principles, design, and calibration of settling tubes. In: Principles, methods, and application of particle size analysis (Syvitski, J.P.M., editor). Cambridge University Press, Cambridge &c., 129-142.
Vidrine, J.C. 1996. Thermal-mechanical erosion of frozen cliffs and beaches. M.Civ.Eng. dissertation, University of Delaware, 108 p.
Water Survey of Canada. 1992. Surface water data reference index, Canada 1991. Environment Canada, Inland Waters Directorate, Ottawa, 412 p.
Wiseman, W.J., Jr, Coleman, J.M., Gregory, A., Hsu, S.A., Short, A.D., Suhayda, J.N., Walters, C.D., Jr & Wright, L.D. 1973. Alaskan Arctic coastal processes and morphology. Louisiana State University, Baton Rouge; Coastal Studies Institute, Technical Report no. 149, 171 p.

TABLES

Table 1 Morphometric data for lagoons, estuaries, and barriers along the Yukon coast in Ivvavik National Park, after Forbes (1981) and other sources.

Table 2 One-year (1995-1996) rates of shore retreat at Niakolik Point (site 5278), with distances between markers and from forward marker to erosional shore scarp on erosion monitoring profiles.

Table 3 One-year (1995-1996) rates of cliff and beach retreat at Stokes Point west (site 5260), with distances between markers and from forward marker to cliff edge and beach step on erosion monitoring profiles.

Table 4 One-year (1995-1996) rates of beach erosion/accretion at Catton Point (site 5054), with distances between markers and from forward marker to top of beach step on erosion monitoring profiles.

Table 5 One-year (1995-1996) rates of cliff and beach retreat at Nunaluk Spit (site 5053), with distances between markers and from forward marker to cliff edge and seaward water line on erosion monitoring profiles.

FIGURES

Fig. 1 Yukon coastal region, showing limits of Ivvavik National Park, place names, topography, bathymetry, and approximate locations of 1992 and 1996 aerial photography.

Fig. 2 Canadian Beaufort Sea coast, showing locations of wind recorders, tide gauge, sites of coastal monitoring by the Geological Survey of Canada, and place names mentioned in the text.

Fig. 3 Water levels at Tuktoyaktuk (station 06485) from 1 June to 8 October 1996 (data courtesy Canadian Hydrographic Service). Tide gauge failed on latter date (E. Sargent, pers. comm., 1997). Stippled band shows the dates of the field surveys described in this report (see Figure 5). Time scale in julian days (JD) with day number at 2400 h MST (UT-7 hours).

Fig. 4 Hourly wind speeds and directions at Pelly Island (station 2203095) from 1 June to 31 October 1996 (data courtesy Environment Canada). Stippled band shows the dates of the field surveys described in this report (see Figure 5). Time scale in julian days (JD) with day number at 2400 h MST (UT-7 hours).

Fig. 5 Hourly wind speeds and directions at Pelly Island (heavy line) and Tuktoyaktuk (lighter line with lower windspeeds lagging Pelly Island record), 15-minute water levels at Tuktoyaktuk, and hourly near-bottom water temperatures at Catton Point (0.3 m off seabed in 3.1 m water depth), 19-30 July 1996 (JD 201-212). Time scale in julian days (JD) with day number at 2400 h MST (UT-7 hours).

Fig. 6 Schematic diagram showing layout of echosounding and navigation equipment in survey boat (scale approximate).

Fig. 7 Yukon coast, showing study sites and other coastal monitoring sites both inside and outside Ivvavik National Park, with corresponding GSC site numbers.

Fig. 8 Babbage River delta and estuary, showing location of Niakolik Point, survey line across baymouth section to Kay Point Spit, and sediment sample locations (after Forbes, 1981).

Fig. 9 Bathymetric profile across Babbage Estuary baymouth section from Niakolik Point (at left) to the distal end of Kay Point Spit (at right). Also shows beach and nearshore profile on line 2.

Fig. 10 Vertical airphoto of Niakolik Point (5278/ 30Y48/ NhVh-5) with overlay of 1996 survey data (WGS84), including major cultural remains at the site (lower and upper houses and graves). Date of photo: 1996/07/25.

Fig. 11 Surveyed shore profiles along outer shore (lines 1 to 3) and inner estuarine shore (lines 4 to 6) at Niakolik Point, including nearshore bathymetry on line 2.

Fig. 12 Shoreline retreat along outer shore at Niakolik Point indicated by differences between 1995 and 1996 surveys at lines 1 to 3.

Fig. 13 Minor changes along estuary shore at Niakolik Point indicated by close fit between 1995 and 1996 surveys at lines 4 and 5 (approximately 0.3 m erosion at line 4).

Fig. 14 Looking southeast from Stokes Point west (GPS antenna positioned over GSC-145 benchmark), showing graves in foreground with Stokes Point barrier and lagoon beyond. Date of photo: 1996/07/24.

Fig. 15 Vertical airphoto of Stokes Point West study site (5260/ 30Y57/ NiVi-5) with overlay of 1996 survey data (WGS84), including cultural features (primarily graves). Large numbers 1 to 3 identify profile lines. Date of photo: 1996/07/25.

Fig. 16 Survey points onshore (showing water line, base and top of cliff, graves, kayak remains, and possible footings of a structure) and offshore (showing echosounding profile lines [numbers 1 to 3] and sampling locations [33 to 35]), Stokes Point west (site 5260), 1996. [a96_5260.grf]

Fig. 17 Cliff, beach, and nearshore surveys at Stokes Point west (site 5260), 24 July 1996, and locations of three grab samples.

Fig. 18 Overlay of 1995 and 1996 profiles on line 1 at Stokes Point west (site 5260).

Fig. 19 Overlay of 1995 and 1996 profiles on line 2 at Stokes Point west (site 5260).

Fig. 20 Overlay of 1995 and 1996 profiles on line 3 at Stokes Point west (site 5260).

Fig. 21 Oblique airphoto looking southeast from Workboat Passage, with the recurved spit at Catton Point in the foreground and the study site on the dome-shaped island in the distance. Date of photo: 1996/07/28.

Fig. 22 General setting of Catton Point study site, showing the barrier and spit, the tundra island at the study site, and transects used for ground surveys (1 and 2) and photogrammetric measurements (1 to 12). The 1953, 1976, and 1996 shorelines illustrate a number of processes, including extension of the spit recurve system, landward retreat of the barrier at both ends, with beach progradation in the central section, breaching of the spit halfway along the spit northwest of the study site (before 1976), growth of small spits on the inside of the barrier, and rapid retreat of the tundra shoreline on the inner side of the lagoon.

Fig. 23 Vertical airphoto of Catton Point study site (5054/ 30Y61/ NiVj-2), showing onshore and nearshore survey points, benchmarks, and sediments samples, location of the temperature sensor mooring, and the distribution of cultural and archeological features. Date of photo: 1996/07/25.

Fig. 24 Looking east from Catton Point hill (near GSC-147 at top of line 1), showing stabilised RTF scars on seaward slope, wide gravel beach at base, and fishing camp with driftwood structures on the beach in the distance (near line 2). Date of photo: 1997/07/25.

Fig. 25 Beach and nearshore profiles surveyed on lines 1 and 2 at Catton Point in 1996. Also shows locations of sediment samples (23 to 26) and temperature sensor mooring (T).

Fig. 26 Overlay of 1995 and 1996 profiles on line 1 at Catton Point (site 5054).

Fig. 27 Overlay of 1995 and 1996 profiles on line 2 at Catton Point (site 5054).

Fig. 28 Vertical airphoto of Nunaluk Spit site (5053/ 30Y94/ NjVk-1), showing survey control and onshore survey points and location of log house. Date of photo: 1996/07/25.

Fig. 29 Looking east toward tundra remnant from line 1 on Nunaluk Spit (site 5053). Note log structure on hill and driftwood on sandy gravel barrier crest in foreground. Tripod near cliff marks location of GPS base station (on geodetic benchmark). Date of photo: 1997/07/23.

Fig. 30 Composite plot showing 1996 onshore surveys (as in Figure 29) and seaward extension of line 2 across the nearshore and shoreface at Nunaluk Spit (site 5053).

Fig. 31 Beach and cliff profiles at Nunaluk Spit (site 5053) in 1996, including line across spit (line 1 [80W]) and three lines across tundra remnant cliff and beach (lines 2 (30W], 3 [BM], and 4 [30E]). Also shows locations of cliff and beach samples.

Fig. 32 Cliff, beach, and nearshore profile on line 2 (30W) at Nunaluk Spit (site 5053), also showing locations of nearshore samples.

Fig. 33 Overlay of 1972 and 1996 bathymetric profiles at Nunaluk Spit study site (5053). Earlier data from McDonald & Lewis (1973), shifted seaward to account for shore recession measured from airphotos (Covill, 1997 [Appendix B]).

Fig. 34 Overlay of 1995 and 1996 profiles on lines 2 and 4 at Nunaluk Spit (site 5053), showing cliff retreat on line 2 and no significant change on line 4.

APPENDICES

I Photogrammetric analysis of coastal erosion at five sites in Ivvavik National Park. Contract report to Geological Survey of Canada (Dartmouth) and Parks Canada (Inuvik), by R. Covill, Tekmap Consulting, Windsor Junction, Nova Scotia.

II Sample summary and grain-size distributions for sediment samples obtained at coastal sites in Ivvavik National Park in 1996.

TABLE 1

Morphometry of barriers and coastal embayments in Ivvavik National Park
(modified after Forbes [1981] with data from other sources cited below).

	name	*lagoon area* (km^2)	*inlet width*[1] (m)	*perimeter length*[2] (m)	*barrier width*[3] (m)	*barrier height*[4] (m)	*beach slope*[5] (tan β_f)	*nearshore slope*[5] (tan β_n)
1	Clarence[6]	3.20	30	2780			0.11	--
2	Backhouse	0.19	20	220				
3	Malcolm A	0.28	0	1500				
4	Malcolm B	1.40	0	5250				
5	Firth/ Nunaluk[7]	15.00	1370	20120	163	1.5	0.04	0.017
6	Workboat/ Herschel	45.00	2125	8175				
7	Ptarmigan/ Catton[7]	4.10	[0]	5000	75	1.4	0.11	0.002
8	[ ]	0.09	0	675				
9	Whale	2.30	<40	1590				
10	[ ]	0.13	0	100				
11	Roland	1.80	<70	570				
12	Stokes Point[8]	1.90	300	<3000	700	1.9	0.14	
	Stokes Point west[9]	0.61	[0]	2000			0.11	0.011
13	Spring/ Phillips[8]	1.60	<400	5250	255	1.0	0.12	--
14	Babbage/ Niakolik[9]	28.00	2020	6400	~50	1.5	0.09	0.030
	Kay Point spit[10]				61	0.9	0.07	0.010

[1] Width (alongshore length) of tidal inlet or outlet channel (Forbes, 1981).
[2] Length of outer shoreline delimiting the barrier-lagoon system, including inlet (Forbes, 1981).
[3] Mean width of subaerial barrier.
[4] Mean crest elevation of barrier.
[5] Beach slope refers to foreshore(intertidal); nearshore slope is variously defined.
[6] Barrier data from Solomon (1996); no nearshore data.
[7] Barrier data from Lewis & Forbes (1974), Solomon (1996), this study.
[8] Barrier data from Forbes & Frobel (1985).
[9] Barrier data from Solomon (1996) and this study.
[10] Barrier data from Lewis & Forbes (1974).

TABLE 2

One-year rates of shore-scarp retreat at Niakolik Point as determined from survey profiles in 1995 (Solomon, 1996) and 1996 (this report), with distances between markers and from forward marker to erosional scarp on each line.

line	rear mark	fwd mark	distance between (m)	forward marker to shore scarp 1995 (m)	forward marker to shore scarp 1996 (m)	erosion 95-96 (m/a)
1	stake	post	49.9	41.3	35.0	6.3
2	stake	stake	32.1	13.0	7.0	6.0
3	stake	post[1]	12.5	22.1	16.1	6.0
4	stake	stake	8.5	7.5	5.8	—[2]
5	stake	stake	17.6	4.5	4.2	0.3
6	pipe	pipe	41.9	—	4.6	—

[1] Original forward stake lost to erosion between 1995 and 1996.
[2] Scarp poorly defined. No significant erosion.

TABLE 3

One-year rates of cliff and beachface retreat at Stokes Point west (site 5260) as determined from survey profiles in 1995 (Solomon, 1996) and 1996 (this report), showing measured distances between markers, from forward markers to erosional scarp on lines 1 and 2, and from forward markers to top of beach step on all three lines.

line	rear marker	forward marker	distance between (m)	forward marker to top of cliff 1995 (m)	1996 (m)	erosion 95-96 (m/a)
1	stake	stake	11.6	9.7	8.6	1.1
2	GSC-145	stake	16.7	10.5	9.5	1.0

line	rear marker	forward marker	distance between (m)	forward marker to step[1] 1995 (m)	1996 (m)	erosion 95-96 (m/a)
1	stake	stake	11.6	30.5	26.4	4.1
2	GSC-145	stake	16.7	29.1	29.7	-0.6[2]
3	stake	stake	25.2	32.4	30.4	2.0

[1] Top of beach step at base of beach (step face up to 1.2 m high at this site) — this is considered the best measure of beach width at this site.

[2] Negative value represents seaward accretion; positive values represent retreat.

TABLE 4

One-year rates of beachface retreat at Catton Point (site 5054) as determined from survey profiles in 1995 (Solomon, 1996) and 1996 (this report), showing measured distances between markers and from forward markers to beach step on lines 1 and 2. The measured rates of change are not significantly different from zero.

line	rear marker	forward marker	distance between (m)	forward marker to step[1] 1995 (m)	1996 (m)	erosion 95-96 (m/a)
1	GSC-147	stake	35.3	78.4	78.0	0.4
2	GSC-314	GSC-148	17.6	40.9	41.1	-0.2[2]

[1] Top of beach step at base of beach.
[2] Negative values denote accretion.

TABLE 5

One-year rates of cliff and beachface retreat at Nunaluk Spit (site 5053) as determined from survey profiles in 1995 (Solomon, 1996) and 1996 (this report), showing measured distances between markers, from forward markers to top of cliff on lines 2 to 4, and from forward markers to water line on all three lines (WL based on common datum with benchmark 21/A56 at 5.10 m).

line	rear marker	forward marker	distance between (m)	forward marker to top of cliff 1995 (m)	1996 (m)	erosion 95-96 (m/a)
2	stake	stake	9.5	13.1	12.0	1.1
3	GSC-143	21/A56	21.7	1.1	1.1	0.0
4	stake	stake	9.8	11.7	12.1	~0.0[1]

line	rear marker	forward marker	distance between (m)	forward marker to MWL 1995 (m)	1996 (m)	erosion 95-96 (m/a)
1	stake	stake	9.9	33.8	28.4	5.4
2	stake	stake	9.8	36.7	34.9	1.8
3	GSC-143	21/A56	21.7	26.8	25.8	1.0
4	stake	post	9.8	39.9	40.7	-0.8[2]

[1] Difference is within survey error — cliff top difficult to define on this line (cf. Figure 34).
[2] Negative values denote accretion.

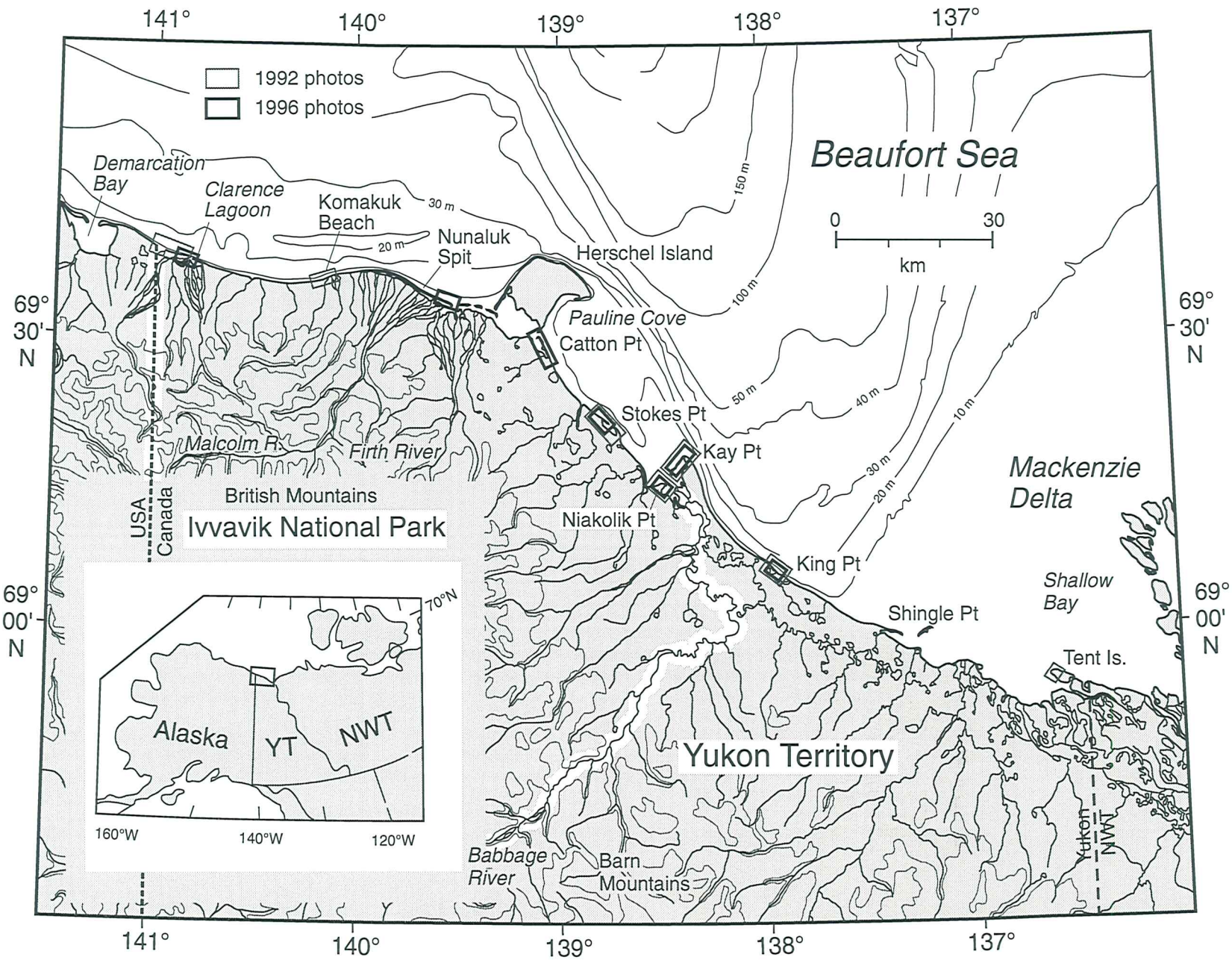

141°
140°
139°
138°
137°
1992 photos
1996 photos
Beaufort Sea
Demarcation Bay
Clarence Lagoon
Komakuk Beach
Nunaluk Spit
Herschel Island
30 m
20 m
150 m
100 m
50 m
40 m
30 m
20 m
10 m
0
30
km
69° 30' N
Pauline Cove
Catton Pt
Stokes Pt
Kay Pt
Malcolm R.
Firth River
British Mountains
Ivvavik National Park
USA
Canada
Niakolik Pt
Mackenzie Delta
King Pt
Shallow Bay
69° 00' N
Shingle Pt
Tent Is.
Yukon Territory
Alaska
YT
NWT
70°N
160°W
140°W
120°W
Babbage River
Barn Mountains
Yukon
NWT

Figure 1

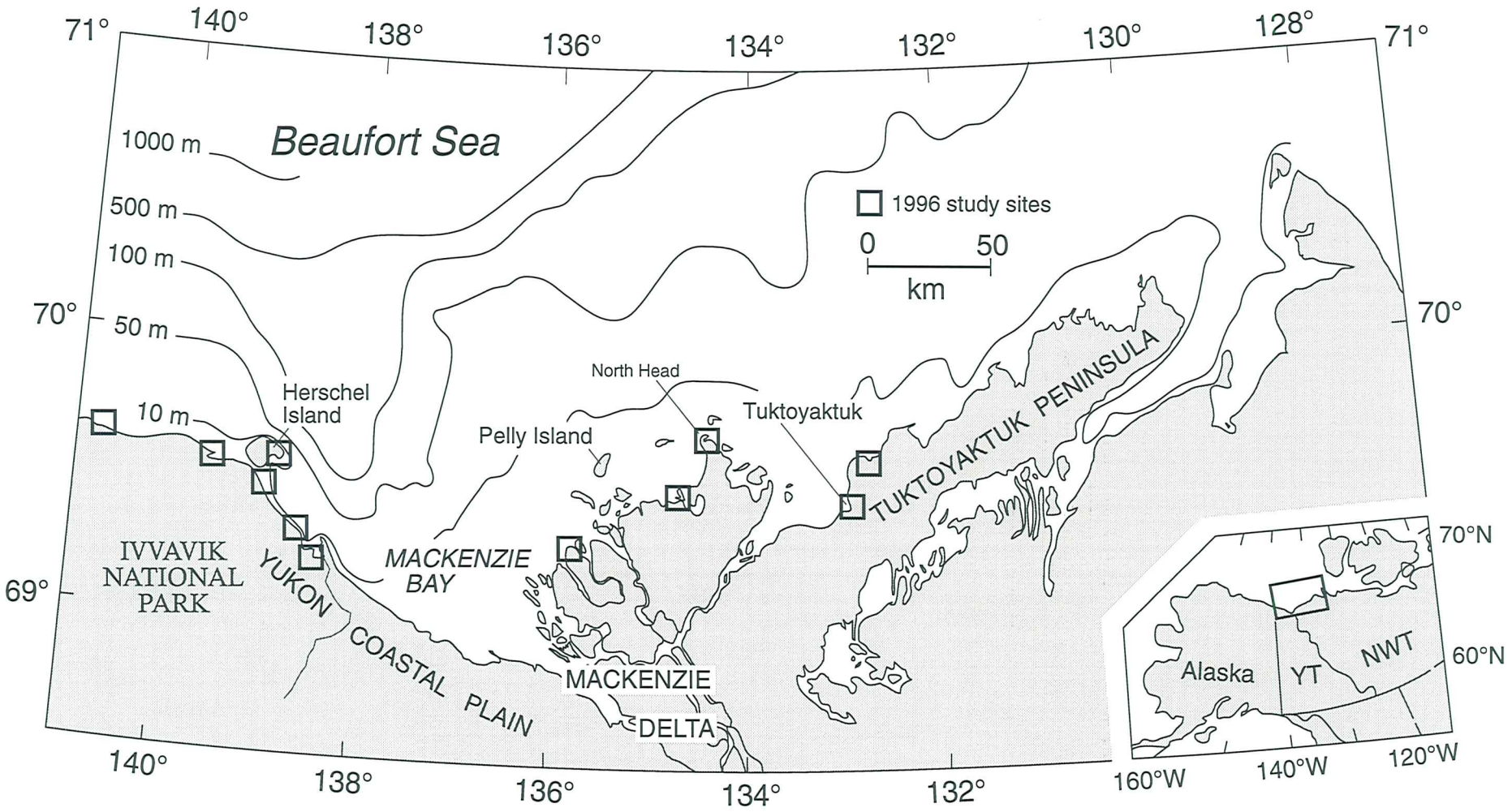

71°
140°
138°
136°
134°
132°
130°
128°
71°
Beaufort Sea
1000 m
500 m
100 m
50 m
10 m
1996 study sites
0
50
km
70°
70°
Herschel Island
North Head
Pelly Island
Tuktoyaktuk
TUKTOYAKTUK PENINSULA
IVVAVIK NATIONAL PARK
YUKON COASTAL PLAIN
MACKENZIE BAY
MACKENZIE DELTA
69°
70°N
60°N
Alaska
YT
NWT
160°W
140°W
120°W
140°
138°
136°
134°
132°

Figure 2

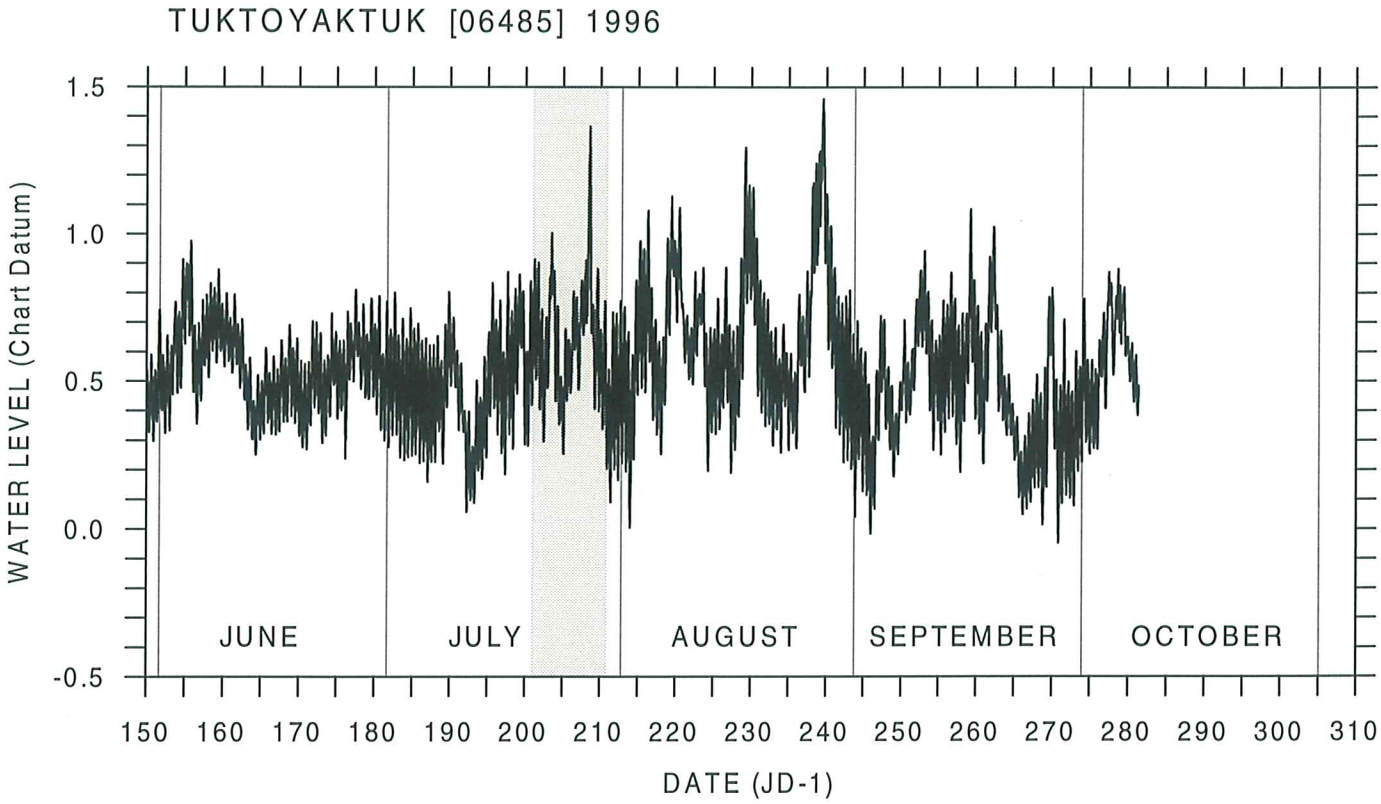

TUKTOYAKTUK [06485] 1996
WATER LEVEL (Chart Datum)
1.5
1.0
0.5
0.0
-0.5
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
150 160 170 180 190 200 210 220 230 240 250 260 270 280 290 300 310
DATE (JD-1)

Figure 3

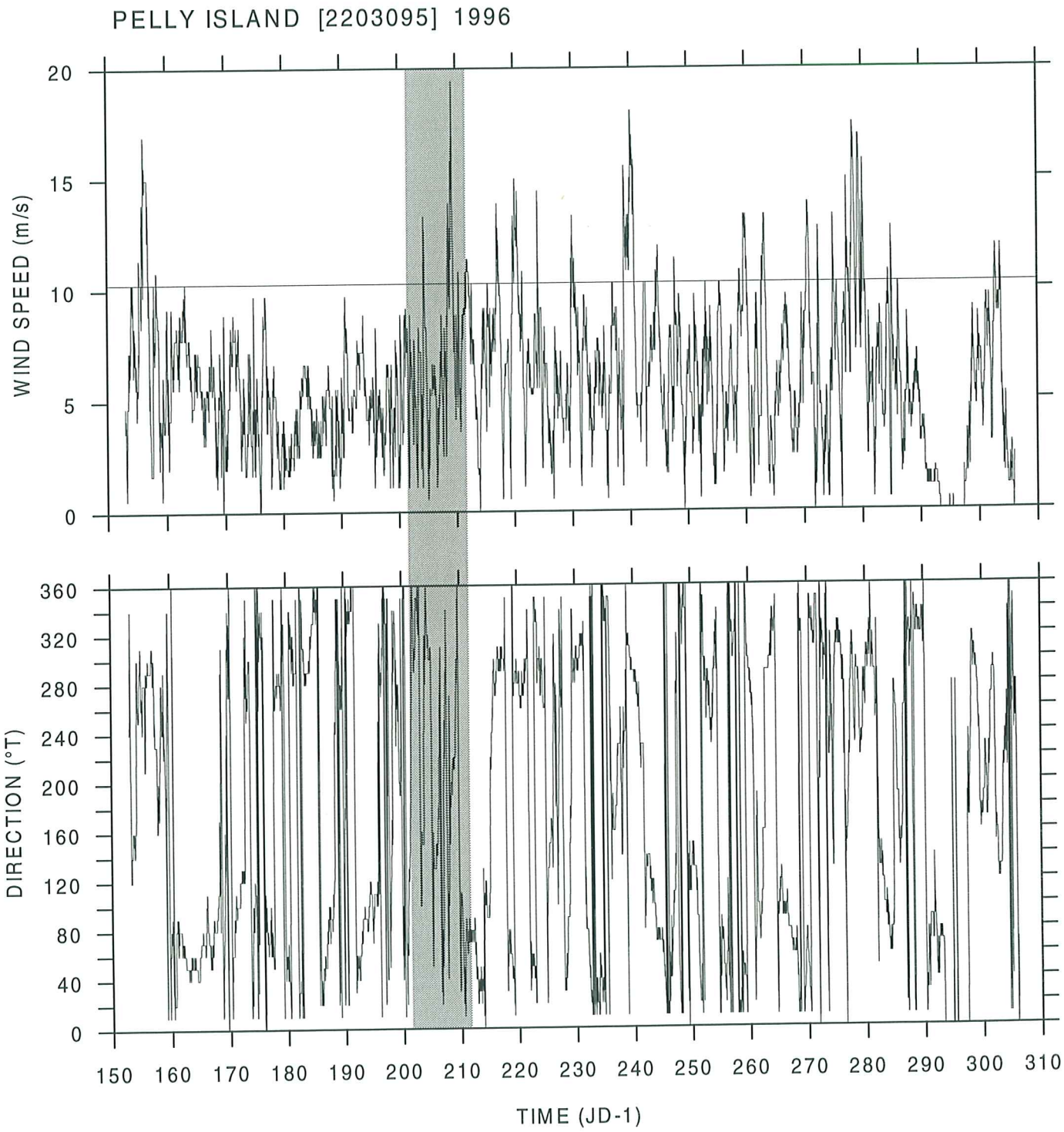

PELLY ISLAND [2203095] 1996
WIND SPEED (m/s)
20
15
10
5
0
DIRECTION (°T)
360
320
280
240
200
160
120
80
40
0
150 160 170 180 190 200 210 220 230 240 250 260 270 280 290 300 310
TIME (JD-1)

Figure 4

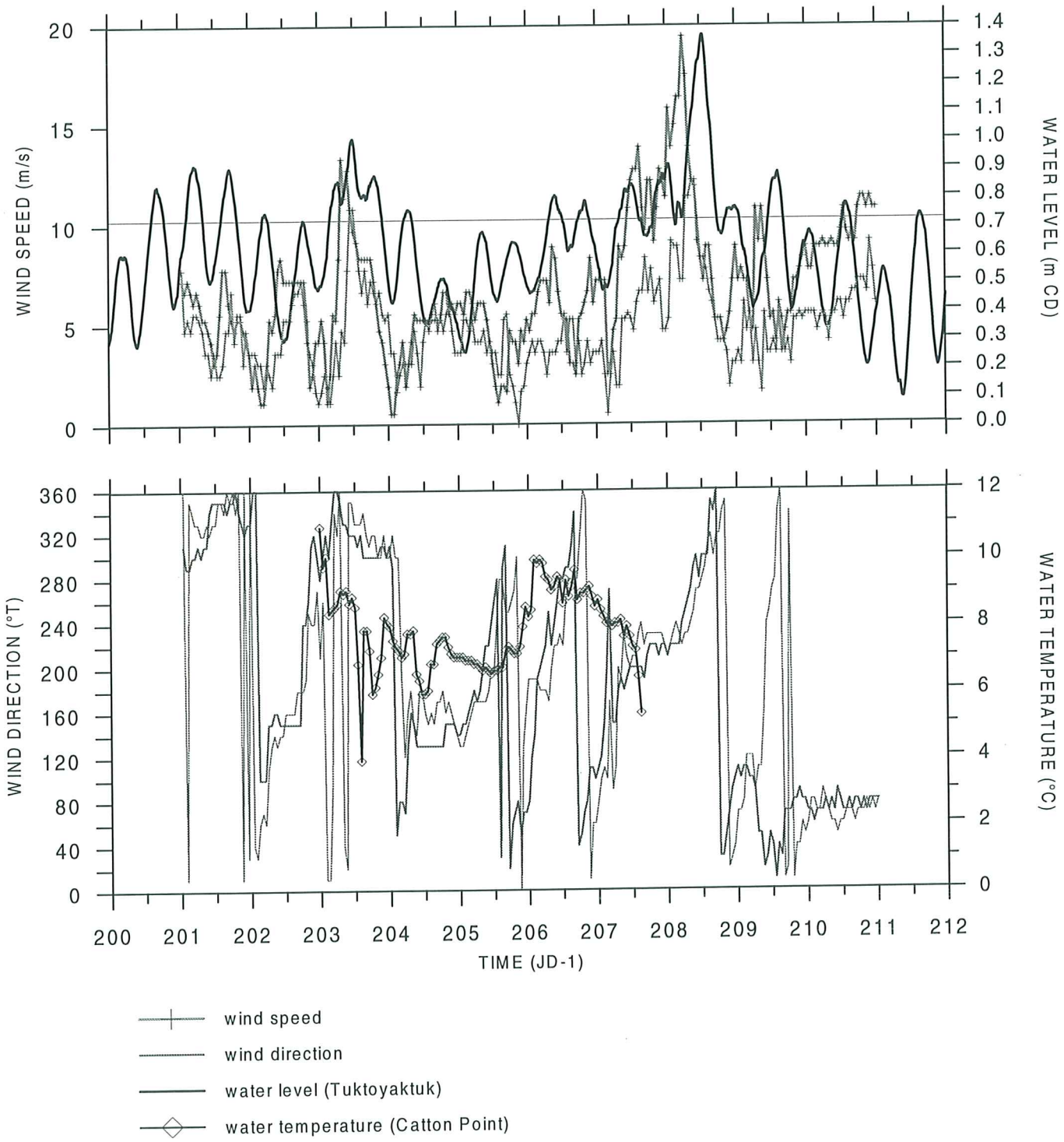

WIND SPEED (m/s)
WATER LEVEL (m CD)
WIND DIRECTION (°T)
WATER TEMPERATURE (°C)
TIME (JD-1)
wind speed
wind direction
water level (Tuktoyaktuk)
water temperature (Catton Point)

Figure 5

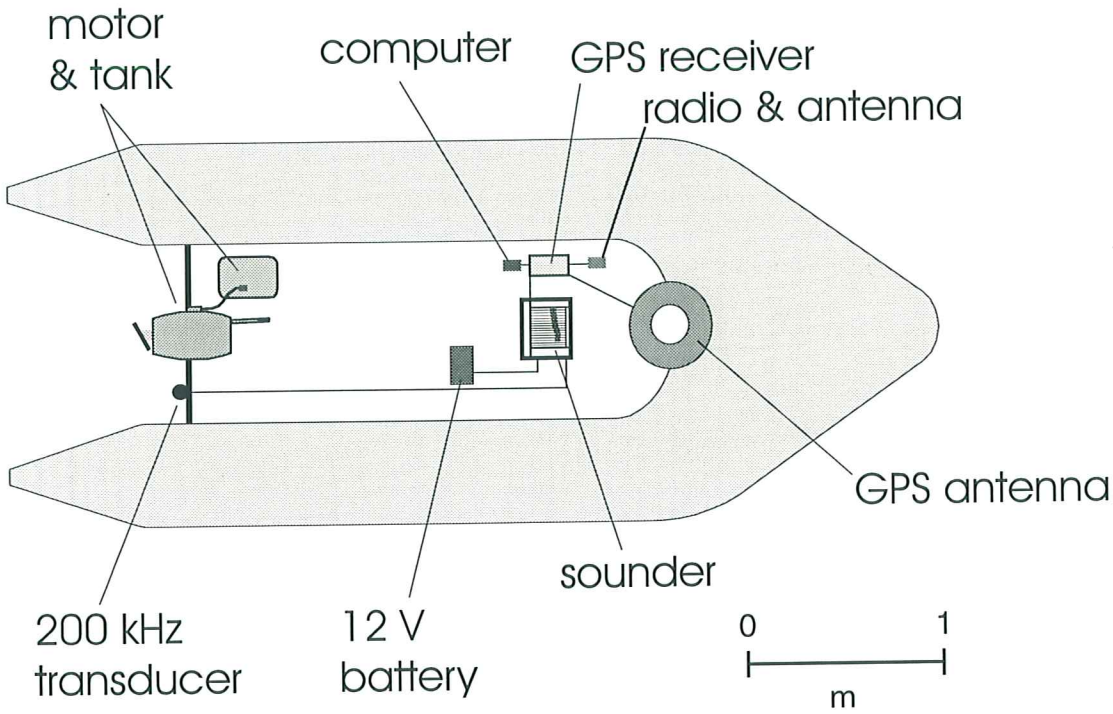

motor
& tank
computer
GPS receiver
radio & antenna
GPS antenna
sounder
200 kHz
transducer
12 V
battery
0
1
m

Figure 6

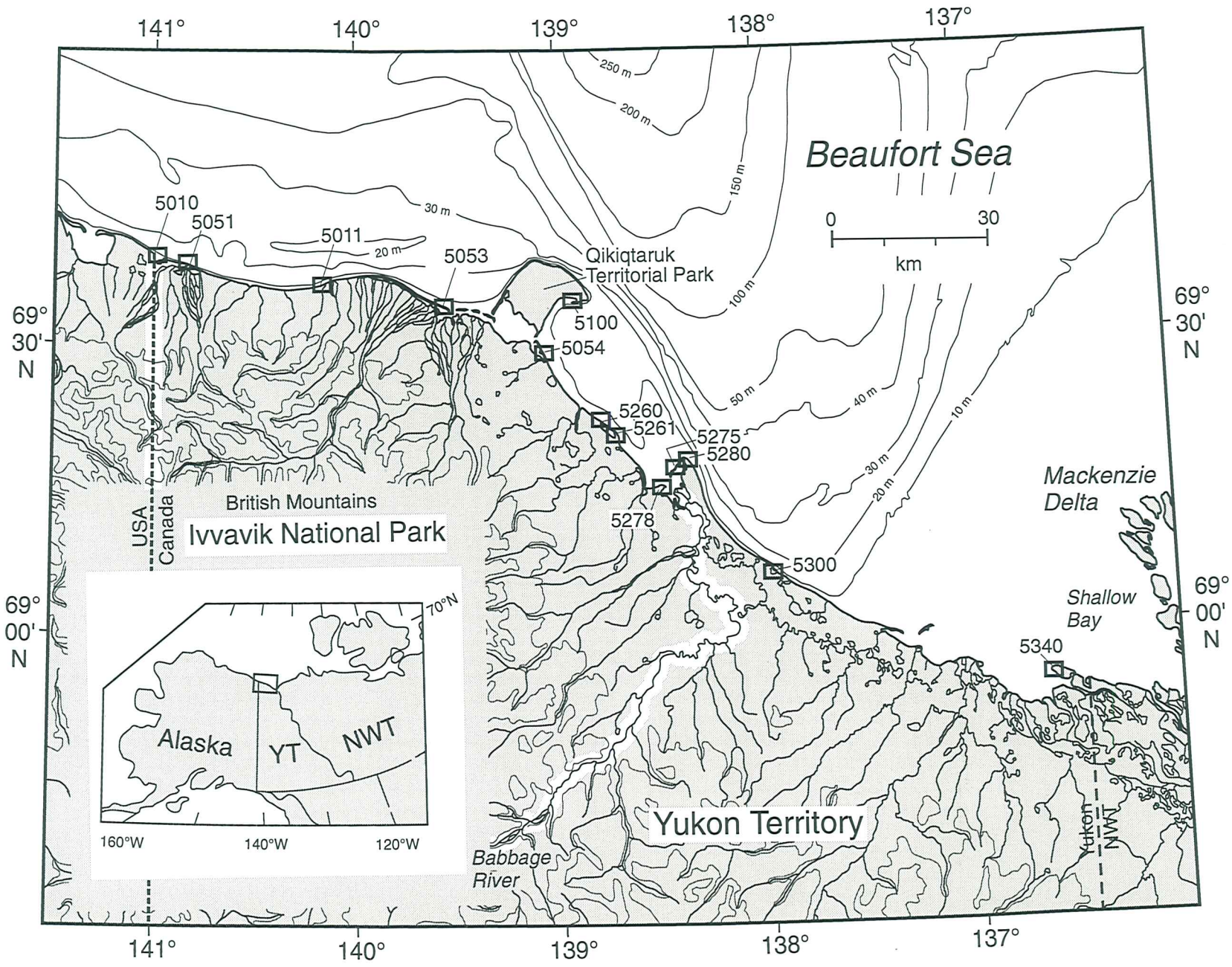

141°
140°
139°
138°
137°
69° 30' N
69° 00' N
250 m
200 m
150 m
100 m
50 m
40 m
30 m
20 m
10 m
Beaufort Sea
0
30
km
5010
5051
5011
5053
Qikiqtaruk
Territorial Park
5100
5054
5260
5261
5275
5280
5278
5300
5340
Mackenzie
Delta
Shallow
Bay
USA
Canada
British Mountains
Ivvavik National Park
Alaska
YT
NWT
70°N
160°W
140°W
120°W
Yukon Territory
Babbage
River
Yukon
NWT

Figure 7

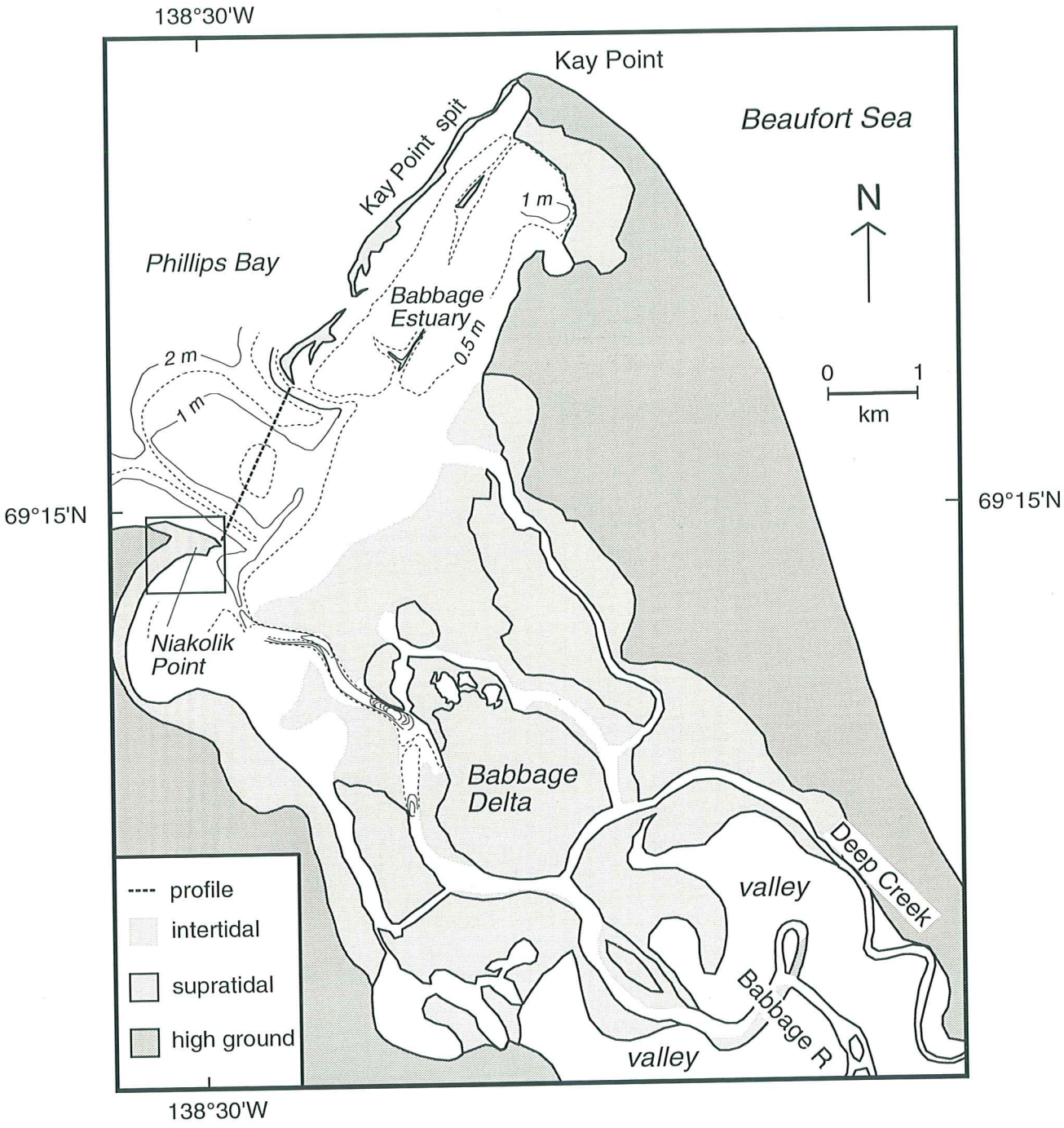

138°30'W
Kay Point
Beaufort Sea
Kay Point spit
1 m
N
Phillips Bay
Babbage
Estuary
0.5 m
2 m
1 m
0
1
km
69°15'N
69°15'N
Niakolik
Point
Babbage
Delta
Deep Creek
valley
Babbage R
valley
profile
intertidal
supratidal
high ground
138°30'W

Figure 8

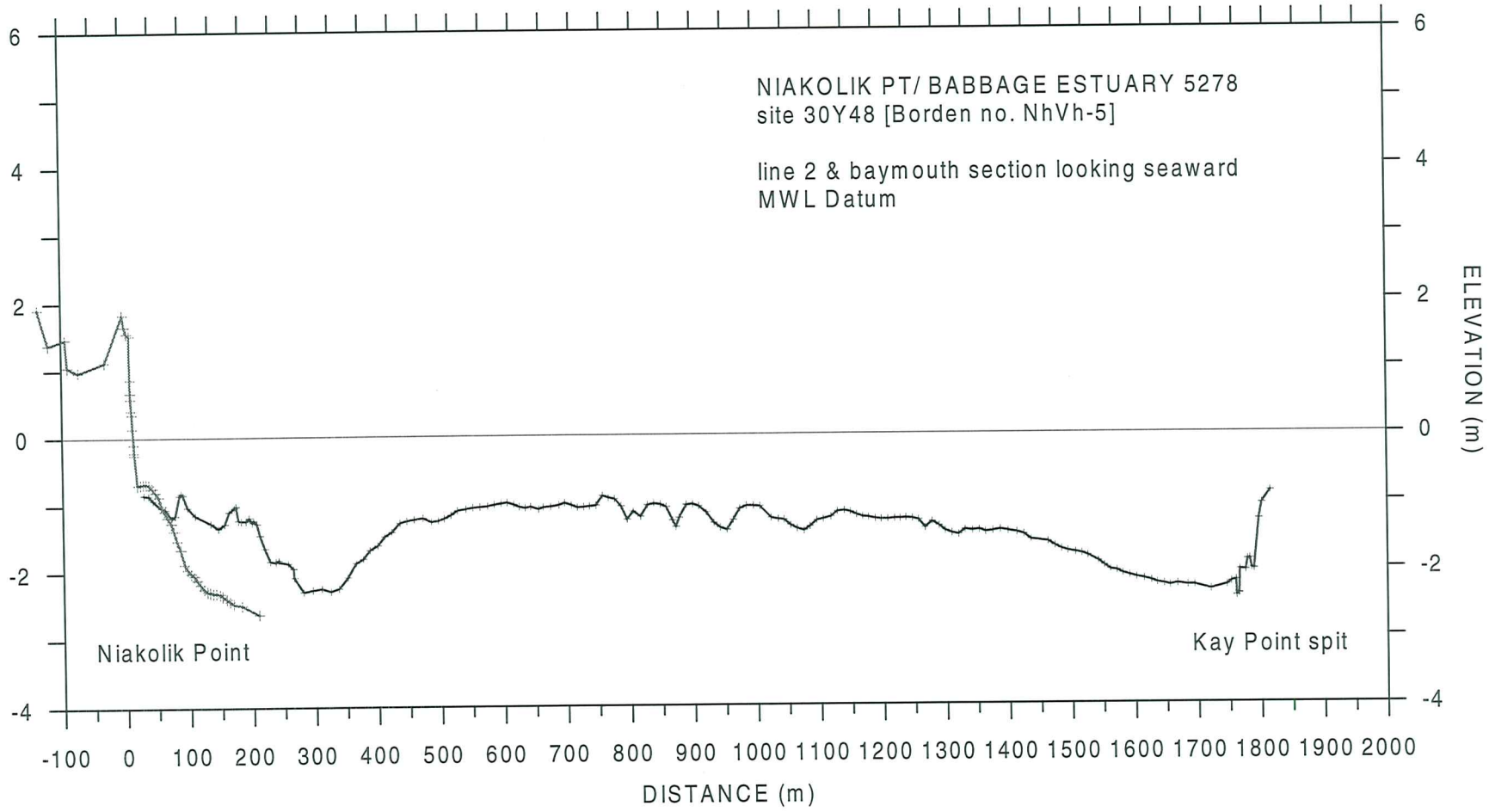

NIAKOLIK PT/ BABBAGE ESTUARY 5278
site 30Y48 [Borden no. NhVh-5]
line 2 & baymouth section looking seaward
MWL Datum
Niakolik Point
Kay Point spit
ELEVATION (m)
DISTANCE (m)
6
4
2
0
-2
-4
-100 0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000

Figure 9

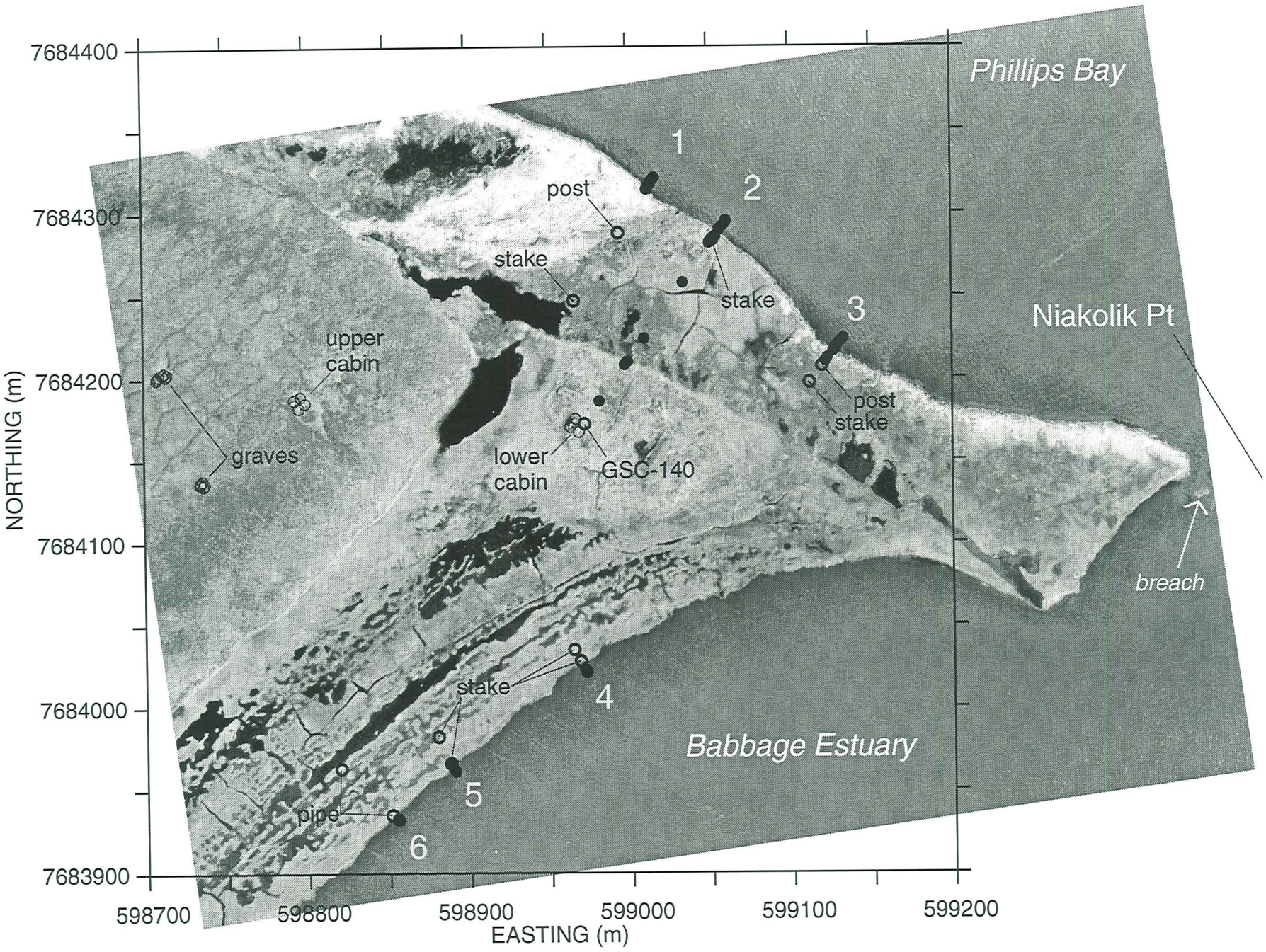

Phillips Bay
Niakolik Pt
Babbage Estuary
breach
1
2
3
4
5
6
post
stake
stake
post
stake
upper
cabin
graves
lower
cabin
GSC-140
stake
pipe
7684400
7684300
7684200
7684100
7684000
7683900
NORTHING (m)
598700
598800
598900
599000
599100
599200
EASTING (m)

Figure 10

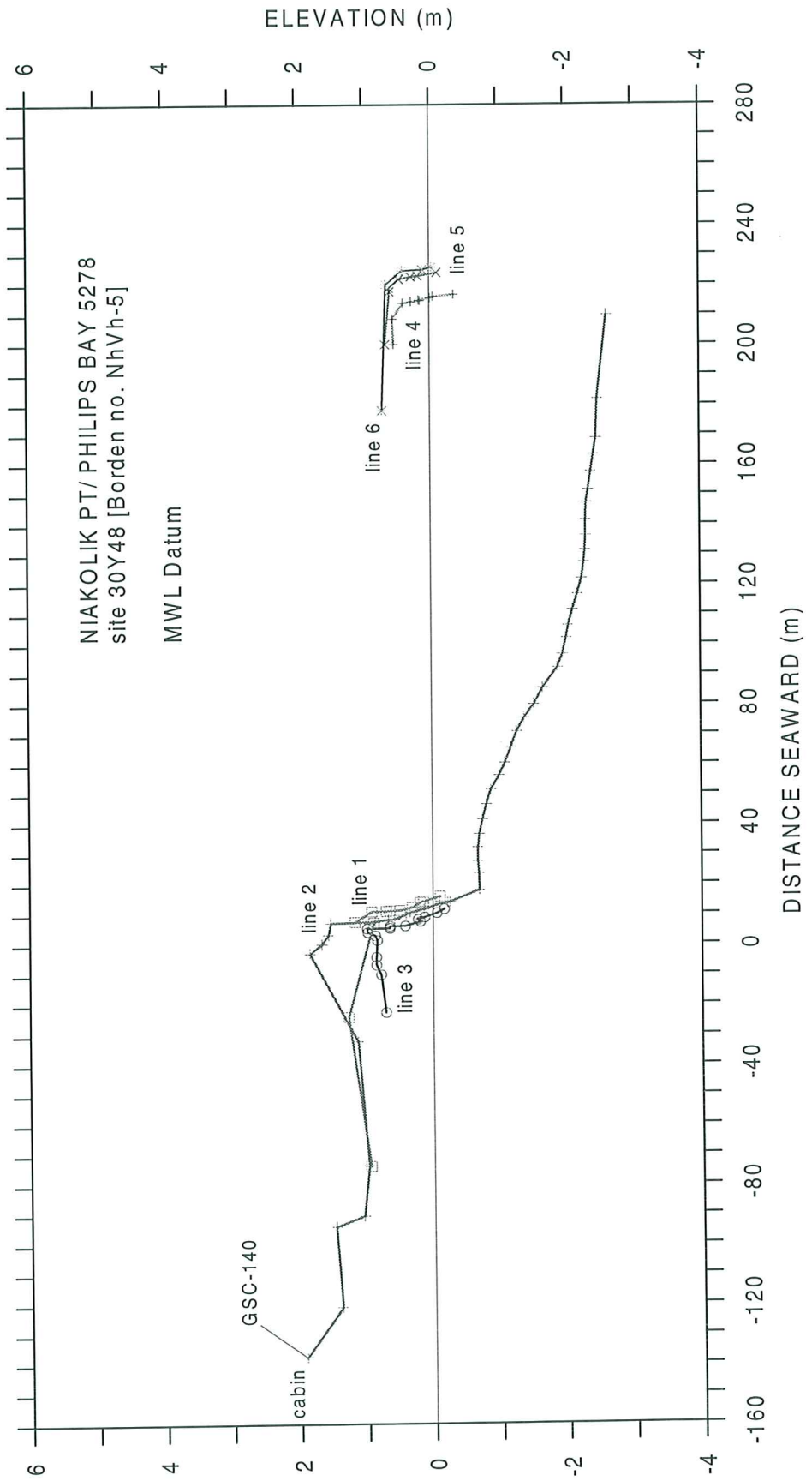

ELEVATION (m)
6
4
2
0
-2
-4
NIAKOLIK PT/ PHILIPS BAY 5278
site 30Y48 [Borden no. NhVh-5]
MWL Datum
line 6
line 4
line 5
line 2
line 1
line 3
GSC-140
cabin
-160
-120
-80
-40
0
40
80
120
160
200
240
280
DISTANCE SEAWARD (m)

Figure 11

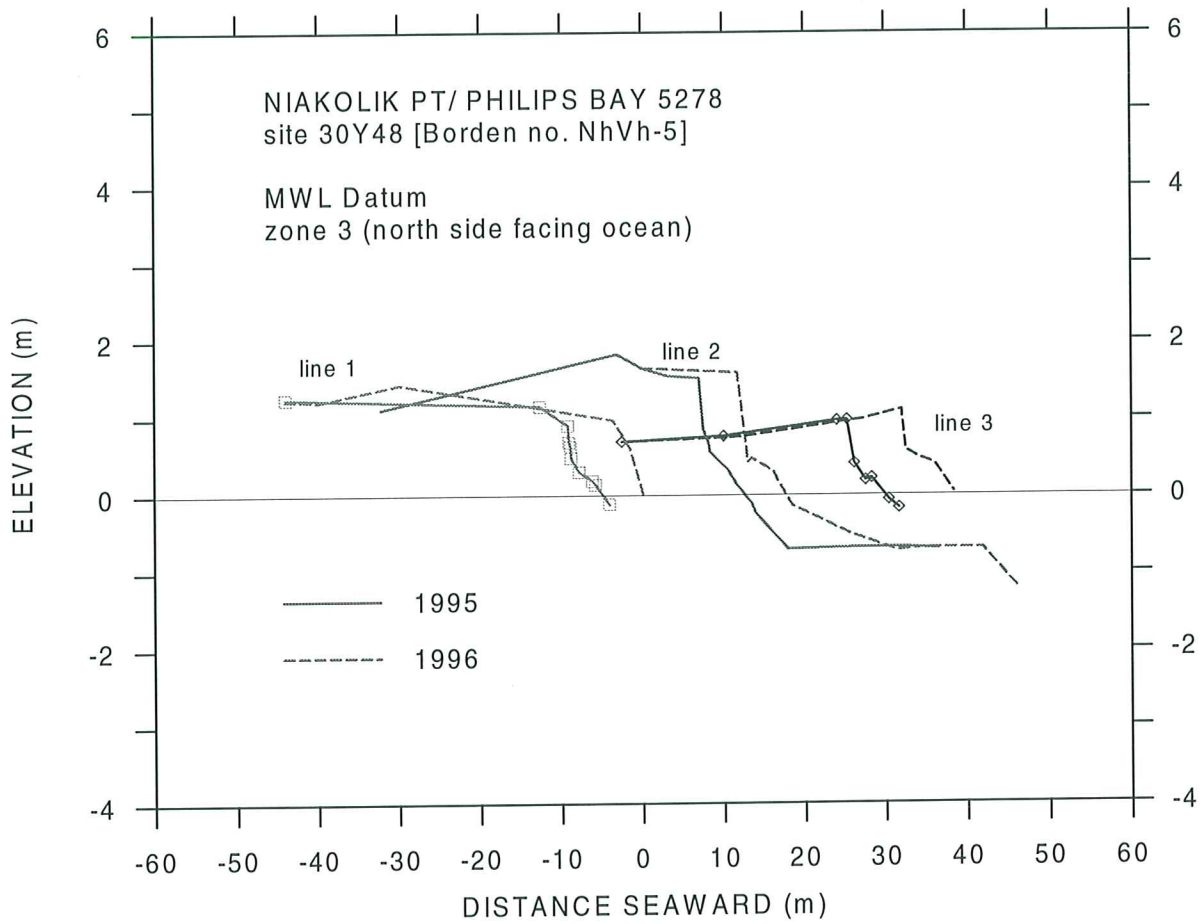

NIAKOLIK PT/ PHILIPS BAY 5278
site 30Y48 [Borden no. NhVh-5]
MWL Datum
zone 3 (north side facing ocean)
line 1
line 2
line 3
1995
1996
ELEVATION (m)
DISTANCE SEAWARD (m)
6
4
2
0
-2
-4
-60
-50
-40
-30
-20
-10
0
10
20
30
40
50
60

Figure 12

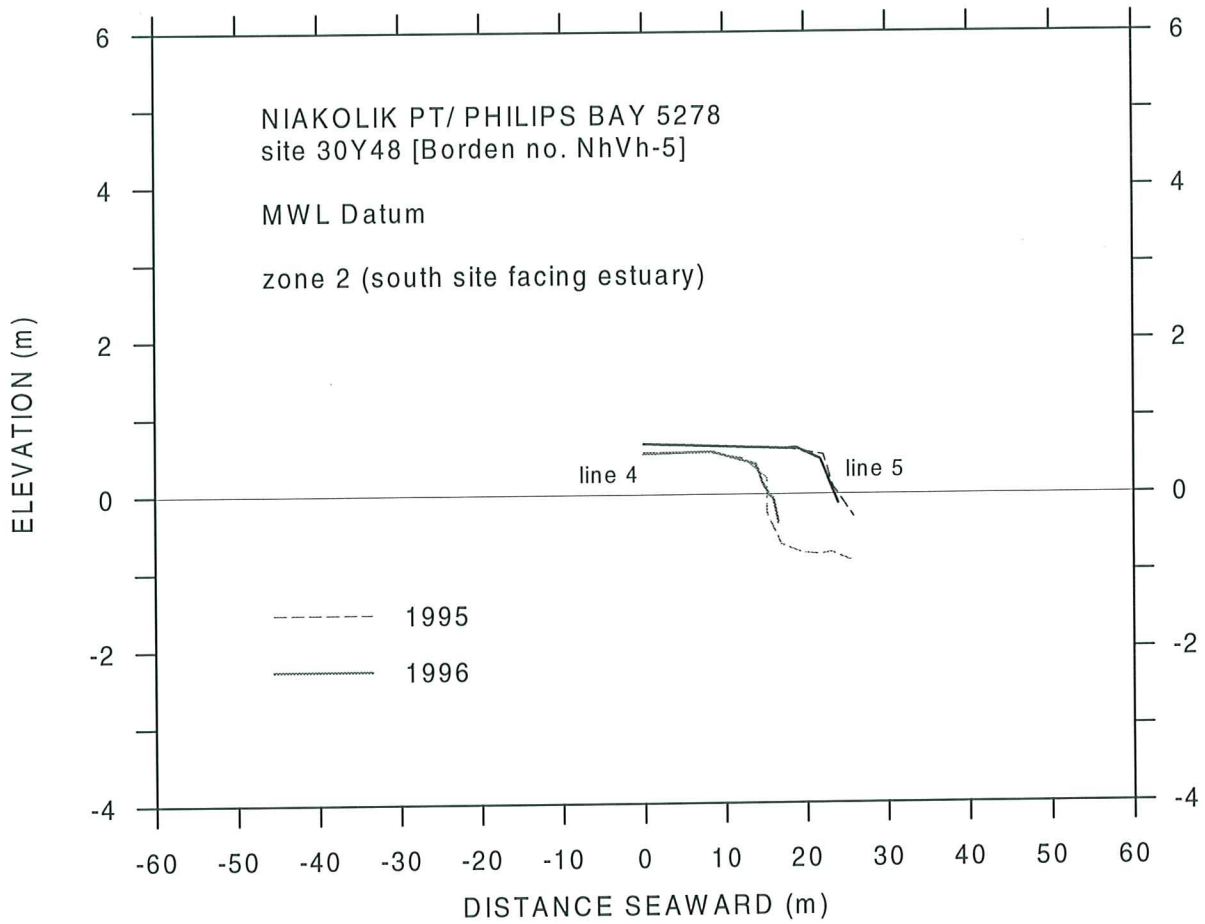

NIAKOLIK PT/ PHILIPS BAY 5278
site 30Y48 [Borden no. NhVh-5]
MWL Datum
zone 2 (south site facing estuary)
line 4
line 5
1995
1996
ELEVATION (m)
DISTANCE SEAWARD (m)
6
4
2
0
-2
-4
-60
-50
-40
-30
-20
-10
0
10
20
30
40
50
60

Figure 13

Figure 14

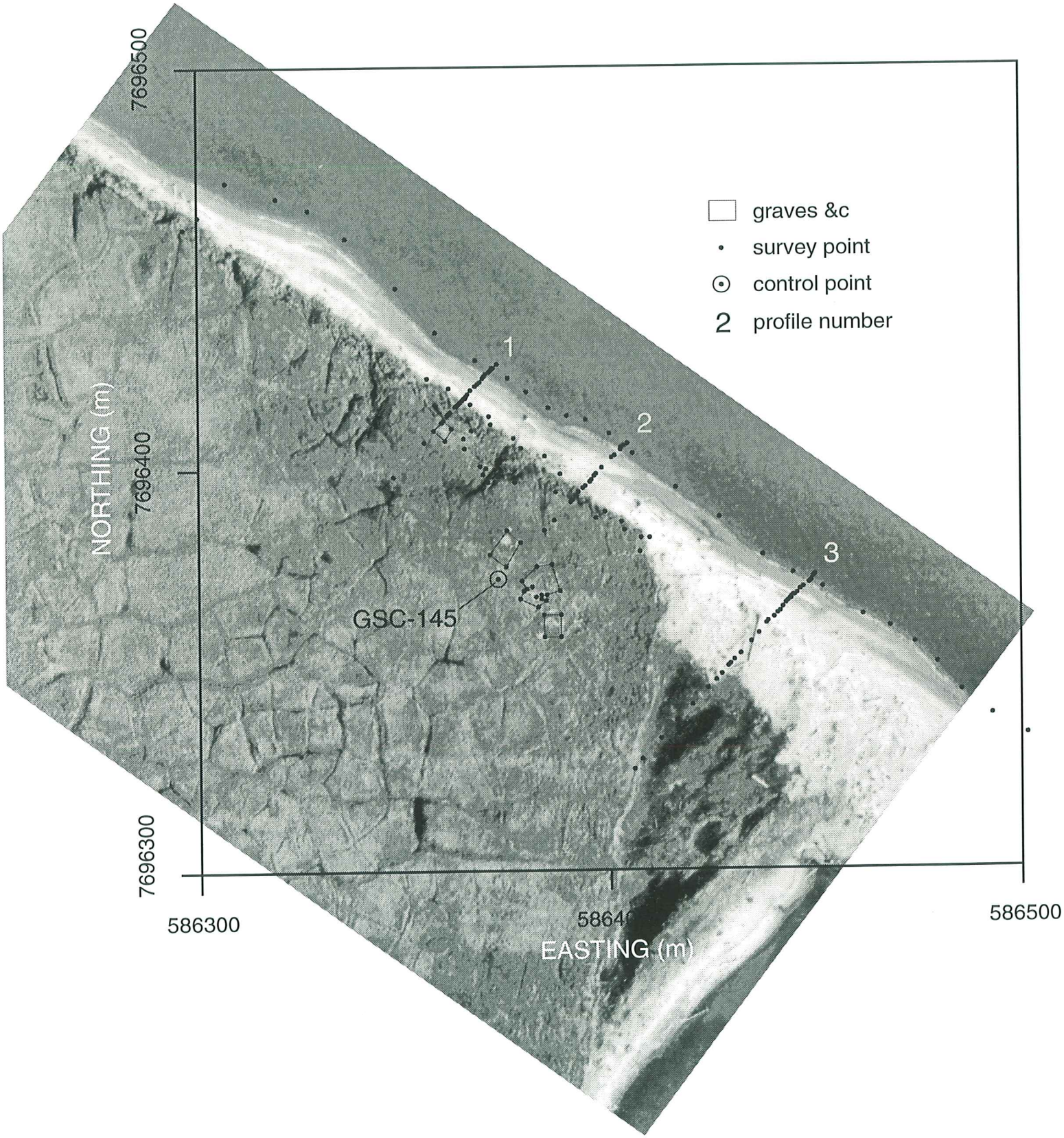

graves &c
survey point
control point
2 profile number
1
2
3
GSC-145
7696500
7696400
7696300
NORTHING (m)
586300
586500
EASTING (m)

Figure 15

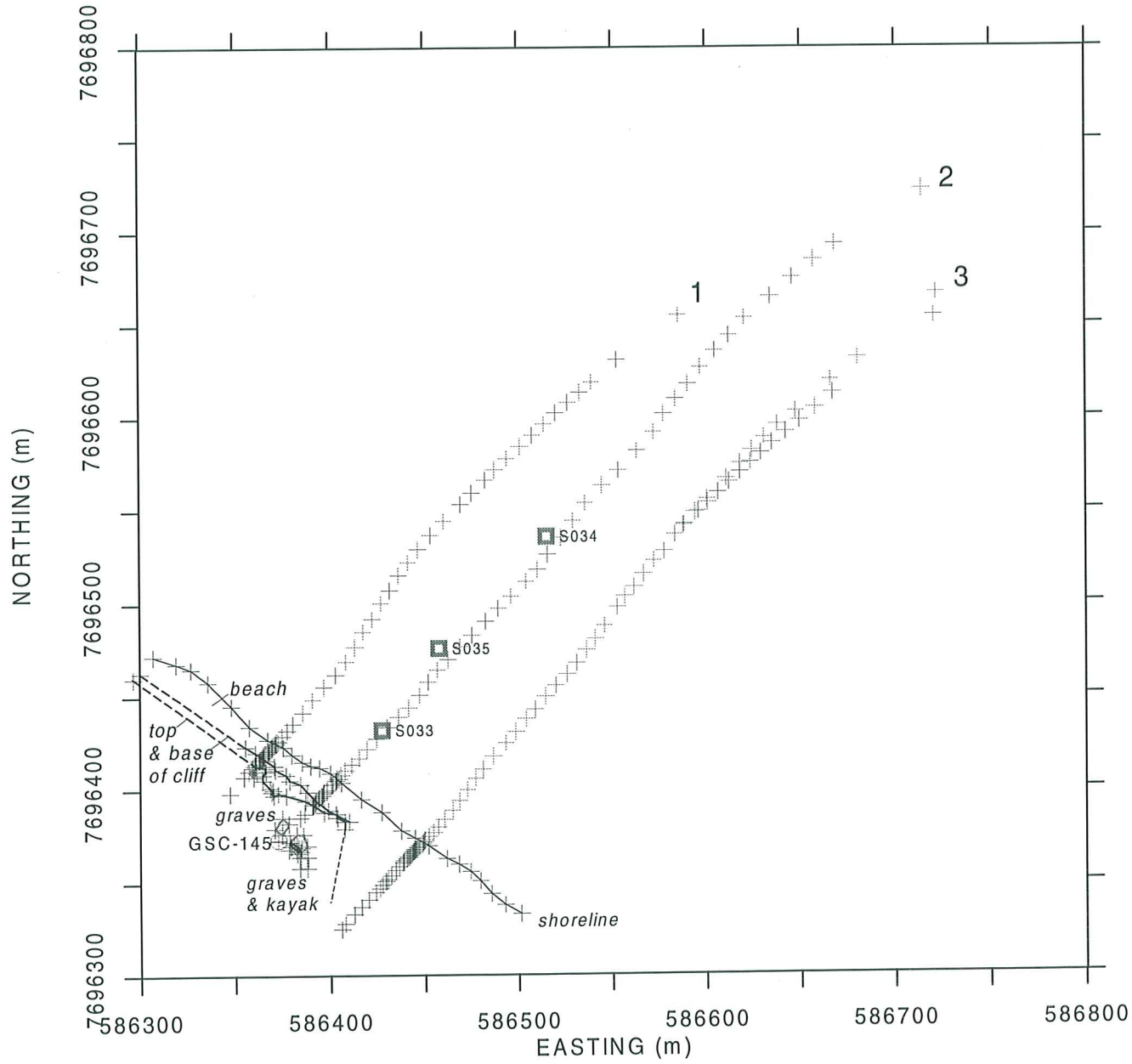

NORTHING (m)
7696800
7696700
7696600
7696500
7696400
7696300
586300
586400
586500
586600
586700
586800
EASTING (m)
1
2
3
S034
S035
S033
beach
top
& base
of cliff
graves
GSC-145
graves
& kayak
shoreline

Figure 16

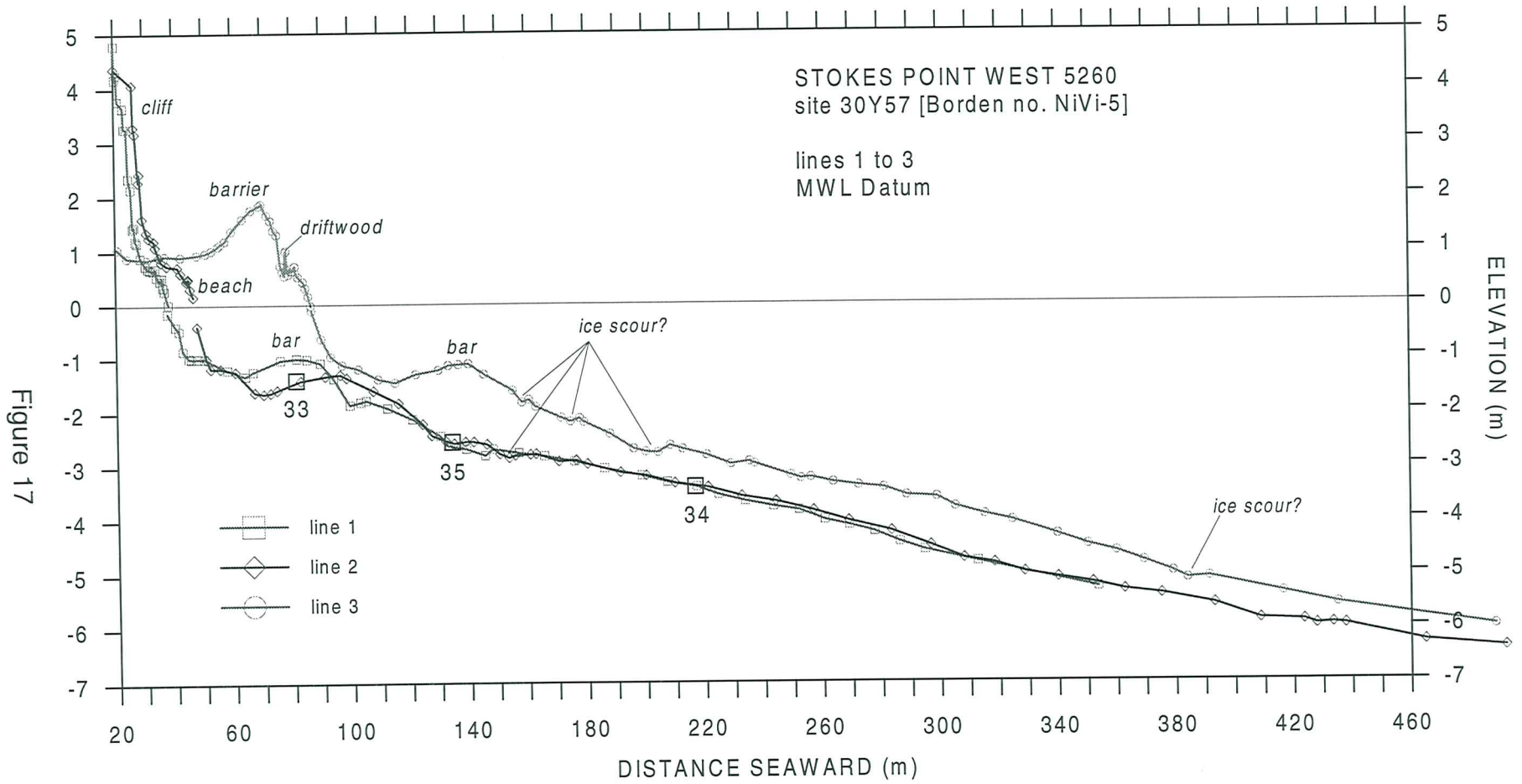

STOKES POINT WEST 5260
site 30Y57 [Borden no. NiVi-5]
lines 1 to 3
MWL Datum
cliff
barrier
driftwood
beach
bar
bar
ice scour?
ice scour?
33
35
34
line 1
line 2
line 3
DISTANCE SEAWARD (m)
ELEVATION (m)
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
20
60
100
140
180
220
260
300
340
380
420
460

Figure 17

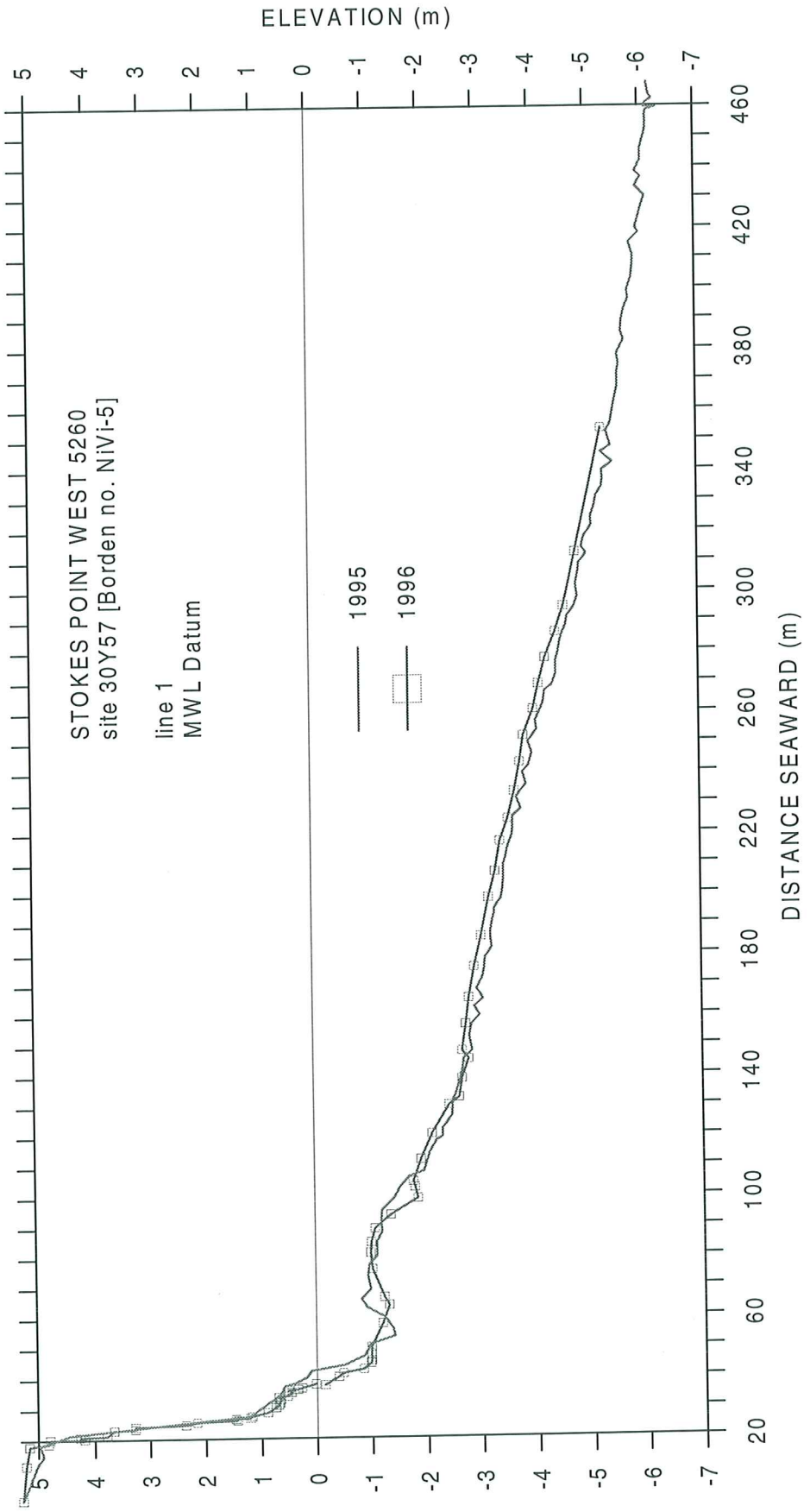

ELEVATION (m)
DISTANCE SEAWARD (m)
STOKES POINT WEST 5260
site 30Y57 [Borden no. NiVi-5]
line 1
MWL Datum
1995
1996
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
20
60
100
140
180
220
260
300
340
380
420
460

Figure 18

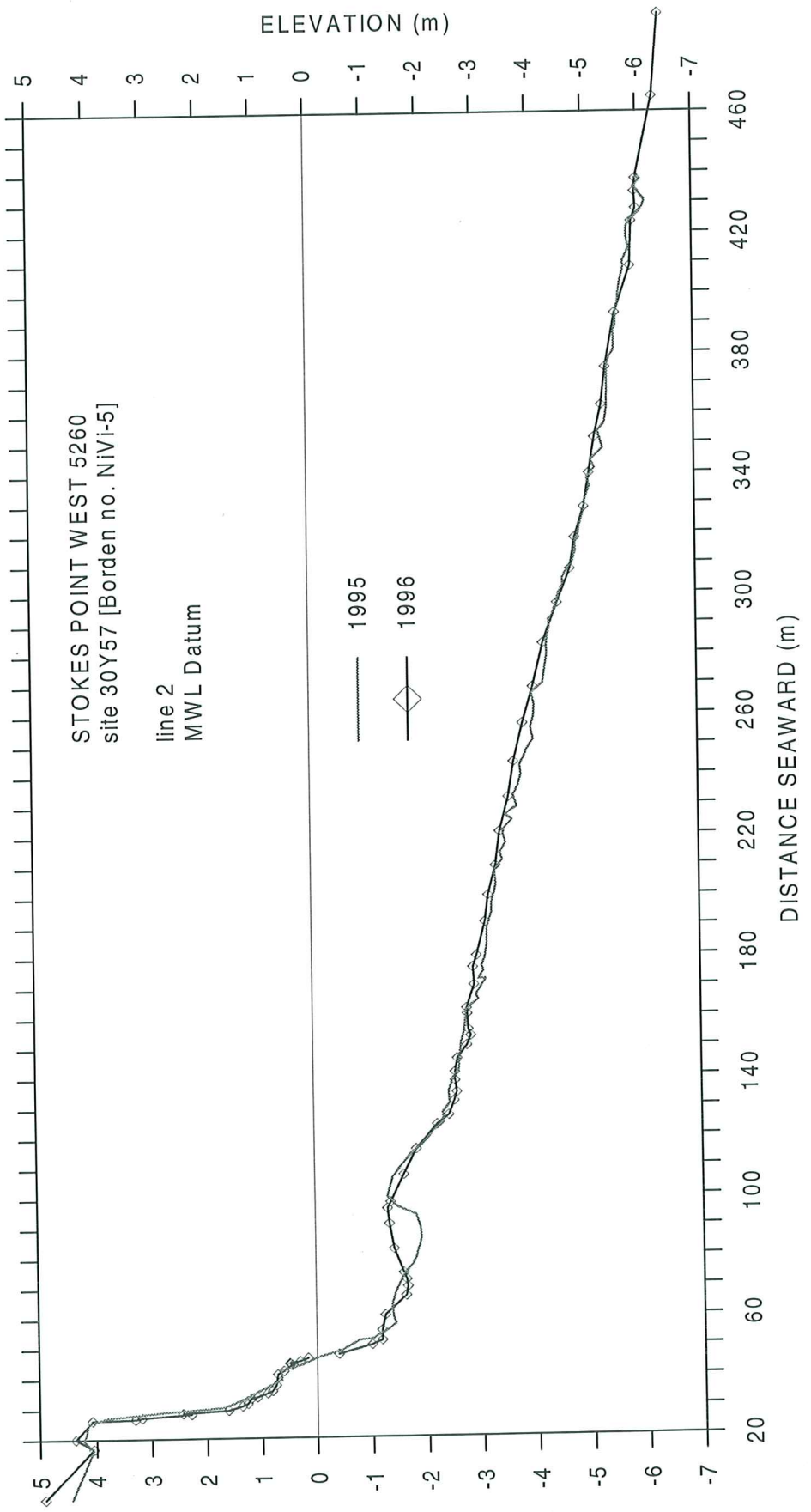

ELEVATION (m)
STOKES POINT WEST 5260
site 30Y57 [Borden no. NiVi-5]
line 2
MWL Datum
1995
1996
DISTANCE SEAWARD (m)

Figure 19

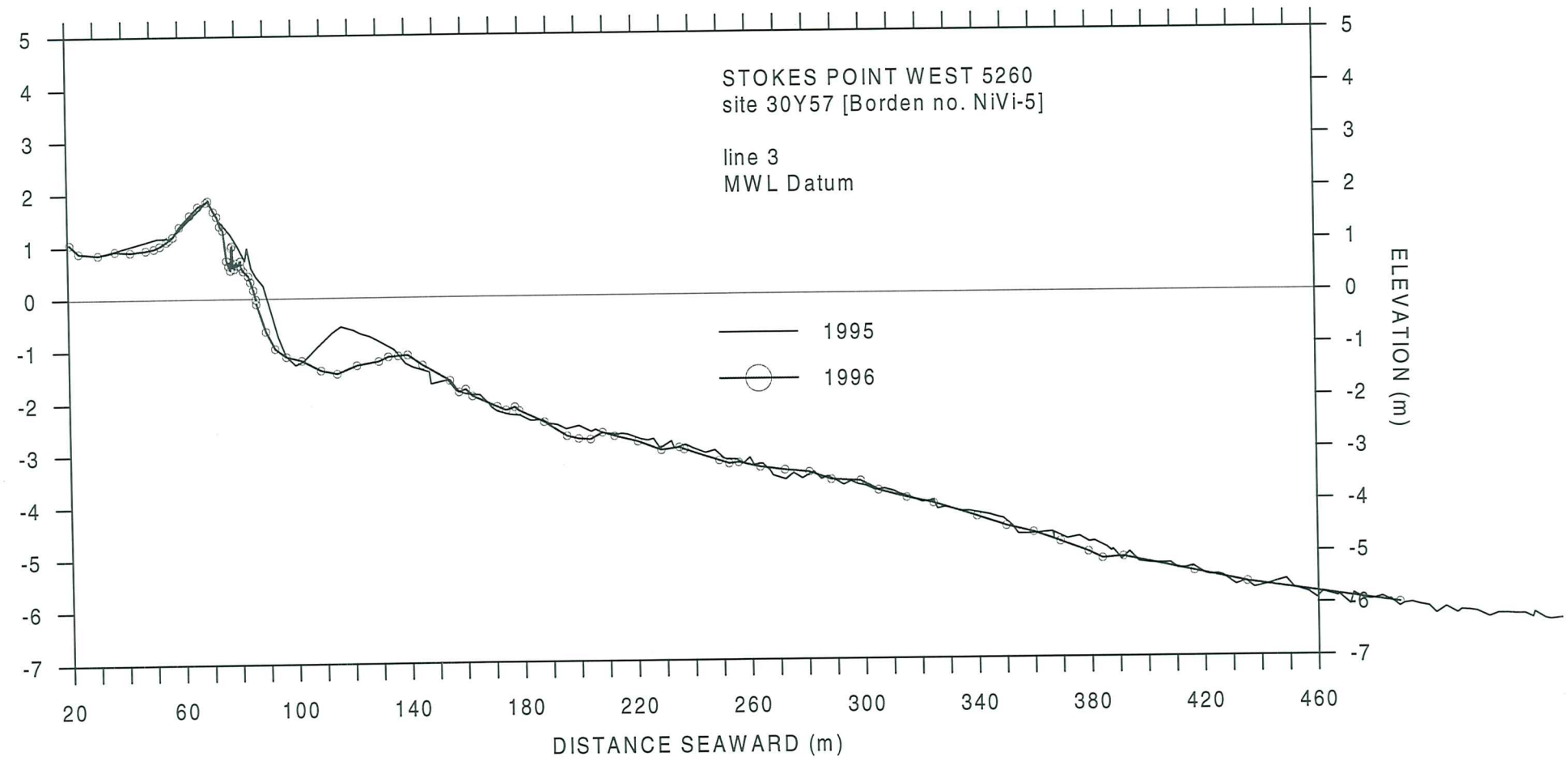

STOKES POINT WEST 5260
site 30Y57 [Borden no. NiVi-5]
line 3
MWL Datum
1995
1996
ELEVATION (m)
DISTANCE SEAWARD (m)
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
20
60
100
140
180
220
260
300
340
380
420
460

Figure 20

Figure 21

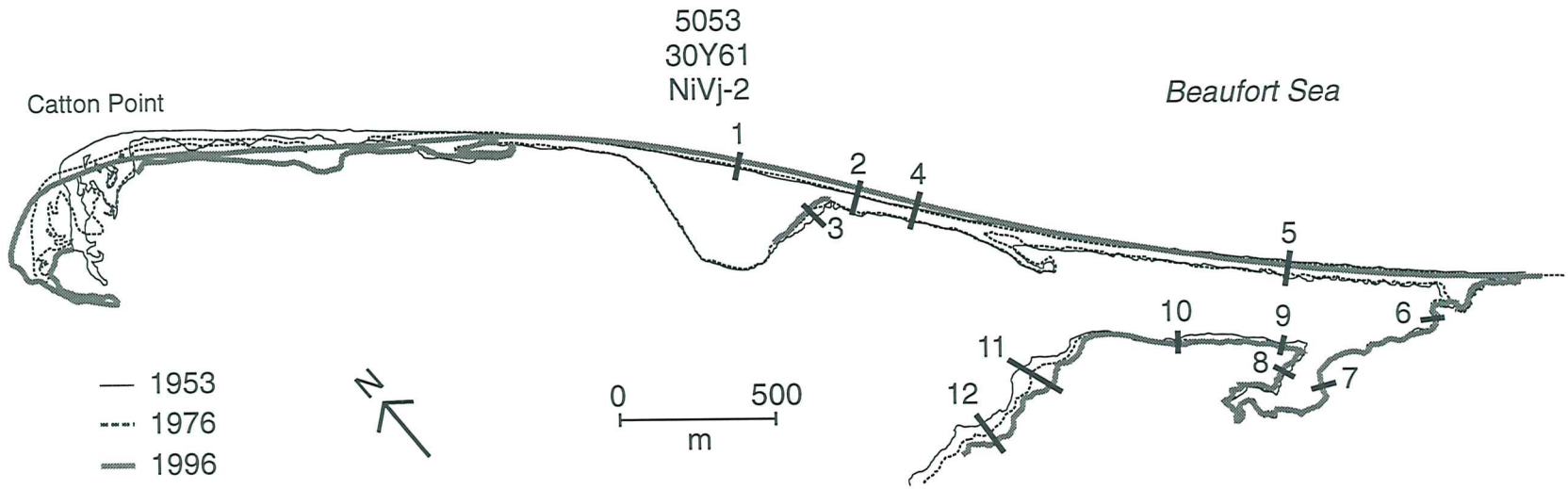

5053
30Y61
NiVj-2
Catton Point
Beaufort Sea
1
2
3
4
5
6
7
8
9
10
11
12
1953
1976
1996
N
0
500
m

Figure 22

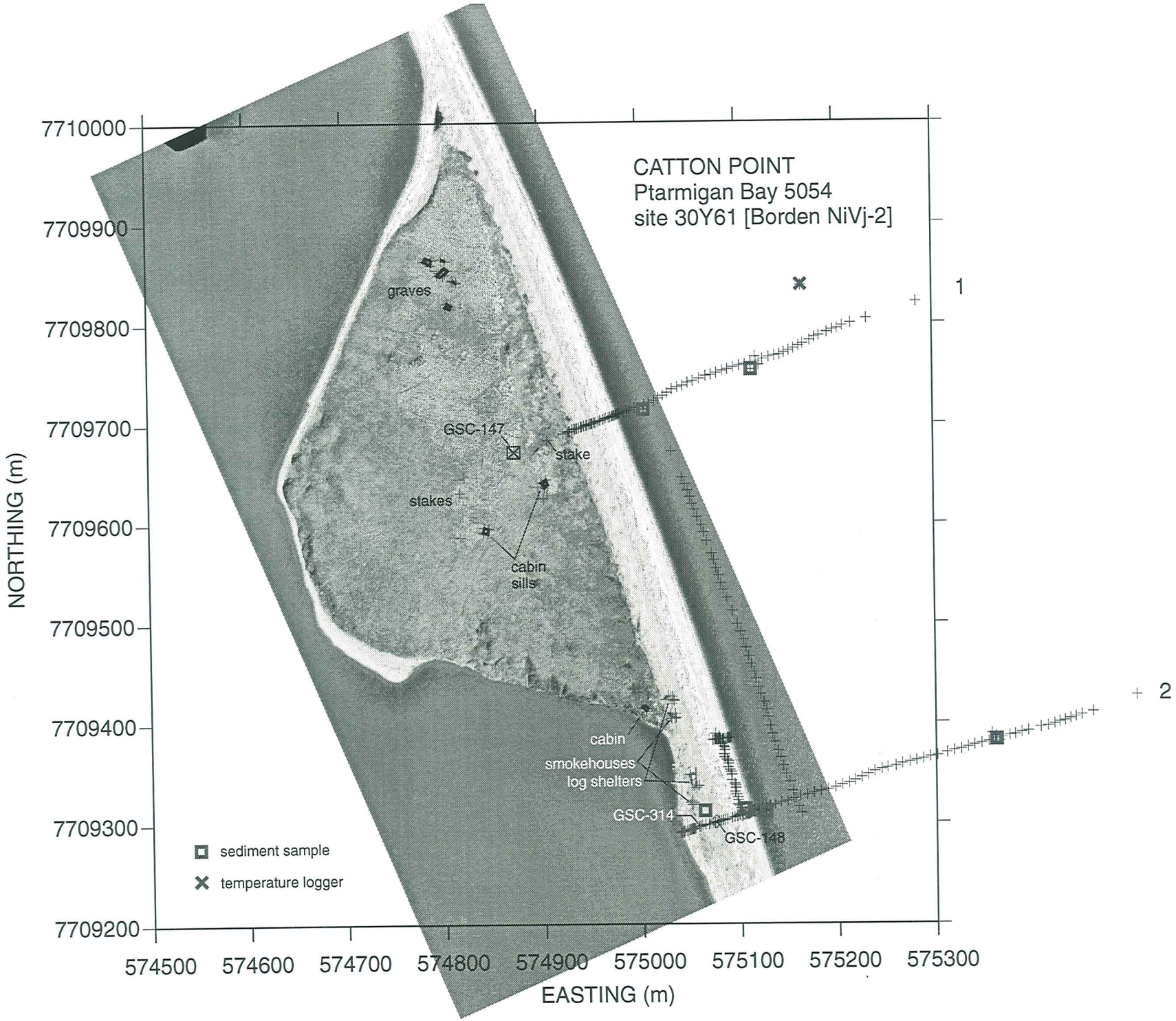

CATTON POINT
Ptarmigan Bay 5054
site 30Y61 [Borden NiVj-2]
graves
GSC-147
stake
stakes
cabin
sills
cabin
smokehouses
log shelters
GSC-314
GSC-148
1
2
sediment sample
temperature logger
NORTHING (m)
7710000
7709900
7709800
7709700
7709600
7709500
7709400
7709300
7709200
EASTING (m)
574500
574600
574700
574800
574900
575000
575100
575200
575300

Figure 23

Figure 24

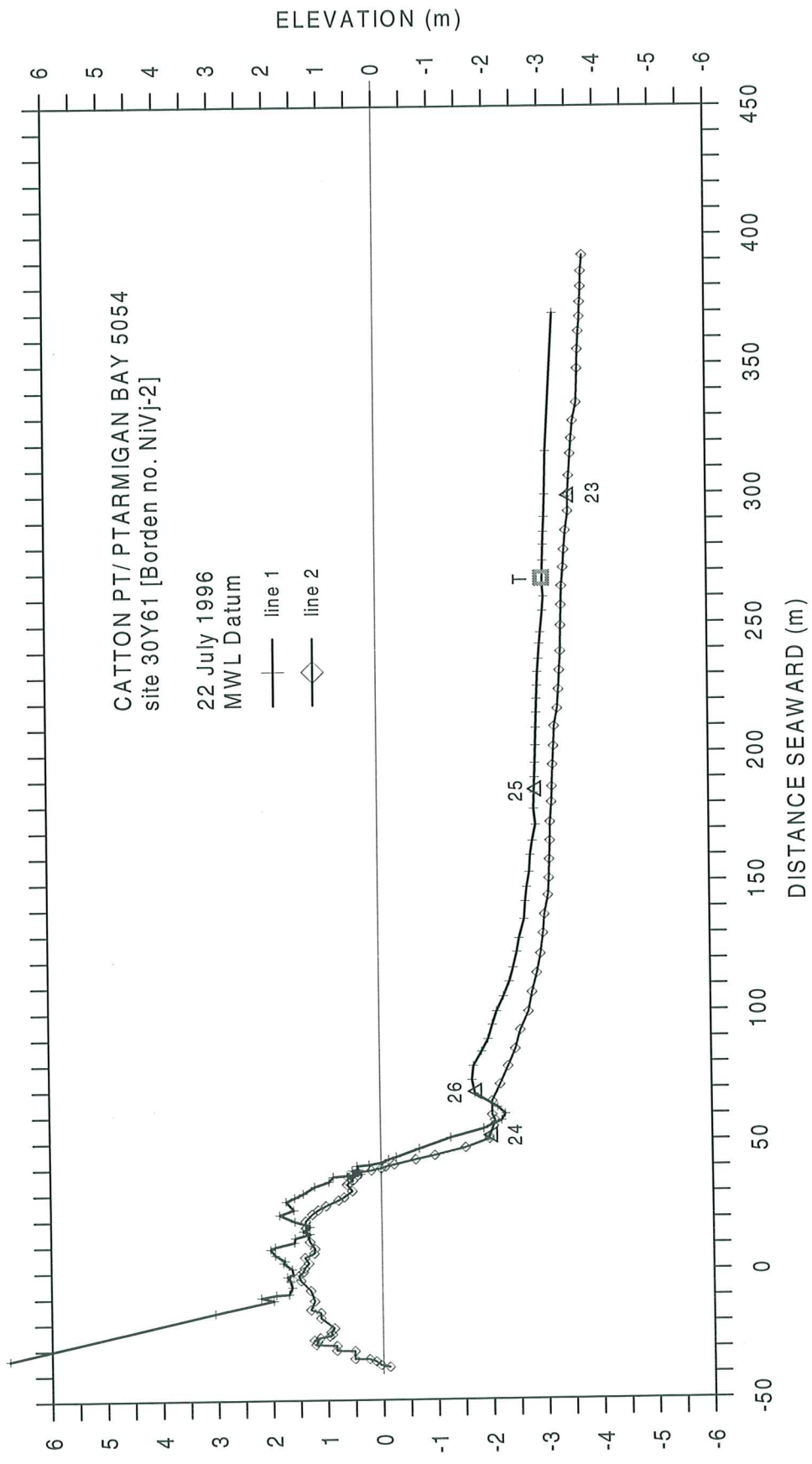

ELEVATION (m)
CATTON PT/ PTARMIGAN BAY 5054
site 30Y61 [Borden no. NiVj-2]
22 July 1996
MWL Datum
line 1
line 2
T
23
25
26
24
DISTANCE SEAWARD (m)

Figure 25

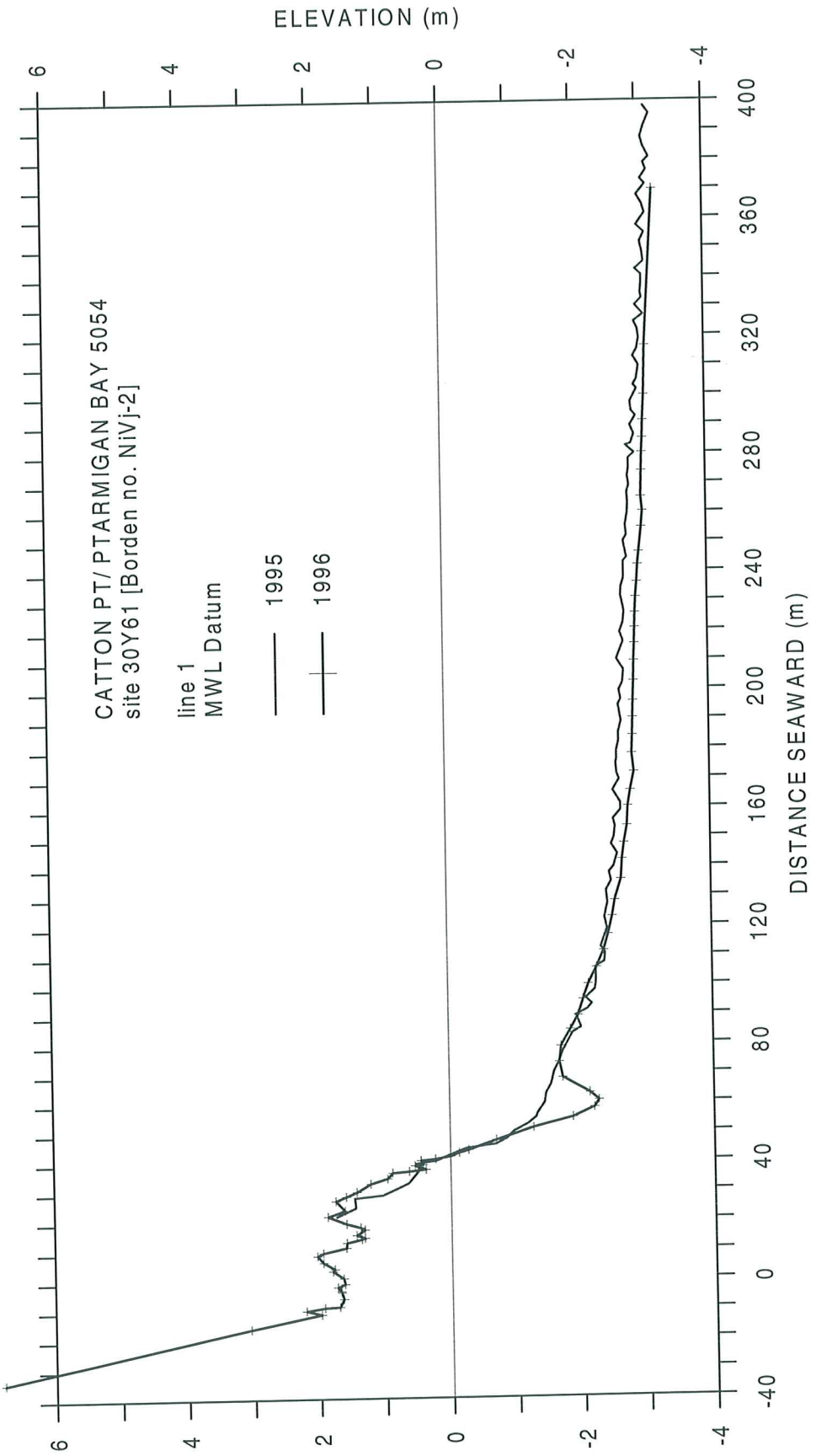

ELEVATION (m)
6
4
2
0
-2
-4
CATTON PT/ PTARMIGAN BAY 5054
site 30Y61 [Borden no. NiVj-2]
line 1
MWL Datum
1995
1996
-40
0
40
80
120
160
200
240
280
320
360
400
DISTANCE SEAWARD (m)

Figure 26

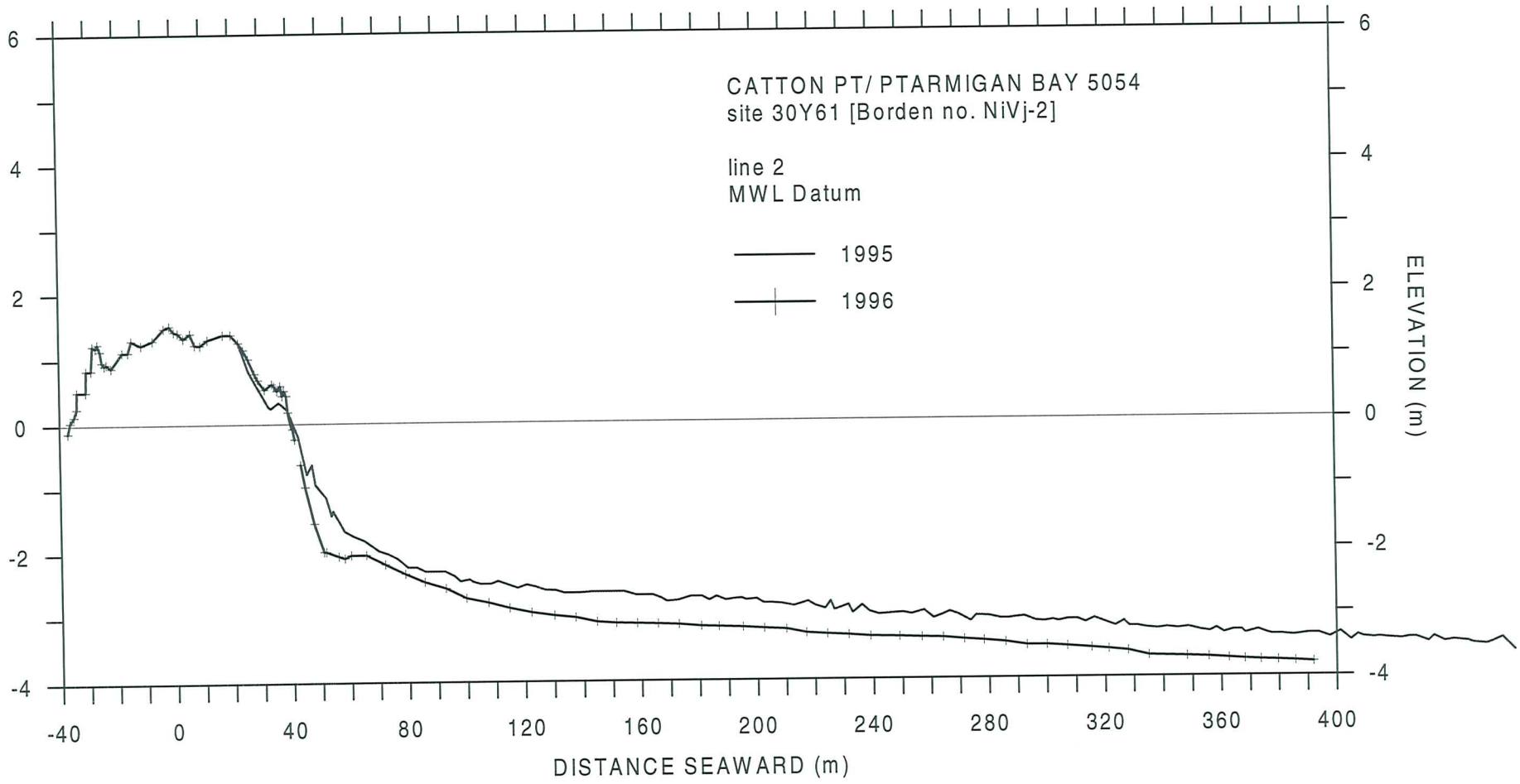

CATTON PT/ PTARMIGAN BAY 5054
site 30Y61 [Borden no. NiVj-2]
line 2
MWL Datum
1995
1996
6
4
2
0
-2
-4
-40
0
40
80
120
160
200
240
280
320
360
400
DISTANCE SEAWARD (m)
ELEVATION (m)

Figure 27

NUNALUK SPIT 5053
site 30Y94 [Borden NjVk-1]
NORTHING (m)
7717640
7717600
7717560
7717520
7717480
EASTING (m)
[WGS84]
555680
555720
555760
555840
stake
stake
stakes
post
cabin
21/A56
GSC-143
post
stake

Figure 28

Figure 29

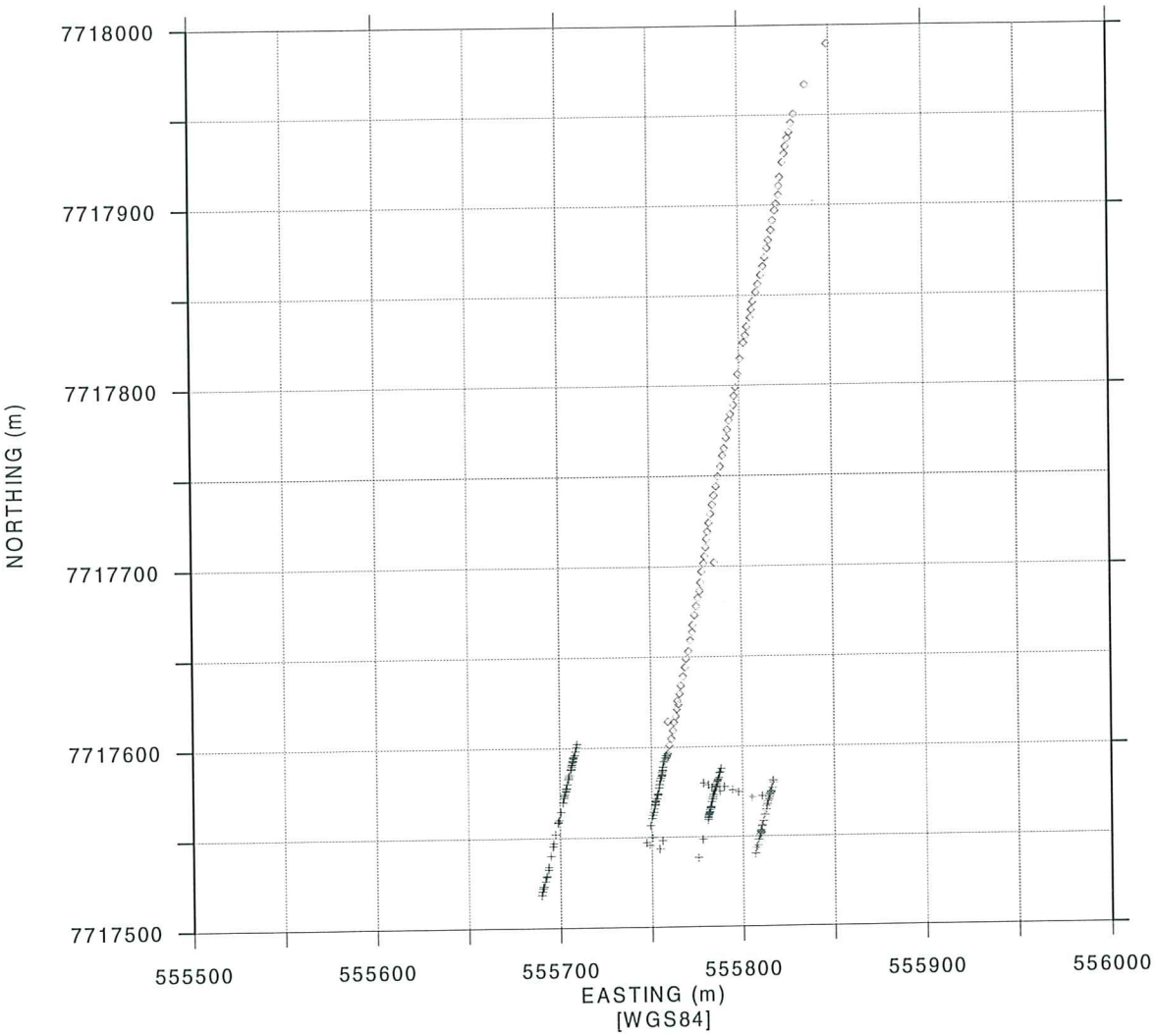

7718000
7717900
7717800
7717700
7717600
7717500
NORTHING (m)
555500
555600
555700
555800
555900
556000
EASTING (m)
[WGS84]

Figure 30

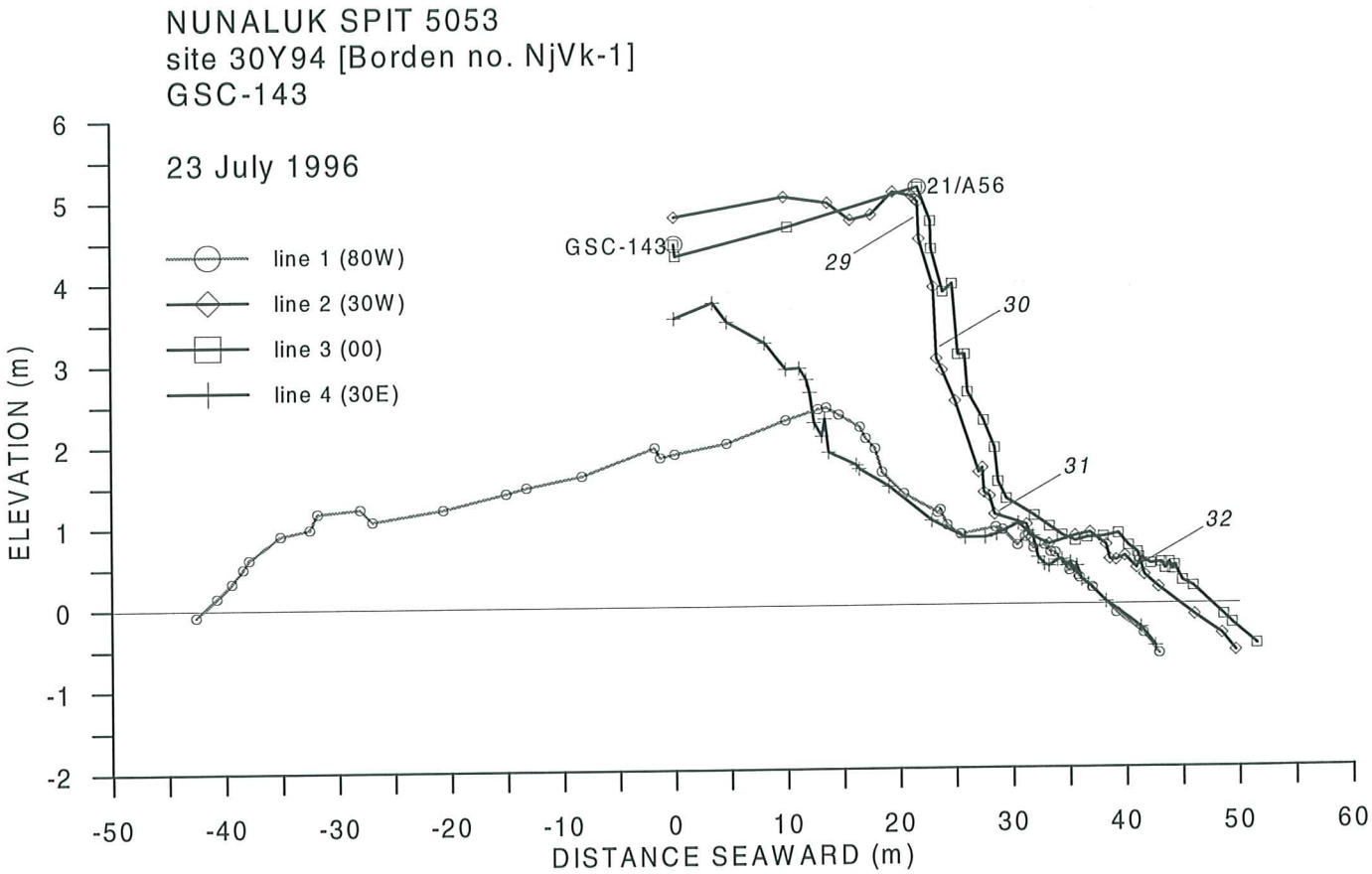

NUNALUK SPIT 5053
site 30Y94 [Borden no. NjVk-1]
GSC-143
23 July 1996
line 1 (80W)
line 2 (30W)
line 3 (00)
line 4 (30E)
GSC-143
21/A56
29
30
31
32
ELEVATION (m)
DISTANCE SEAWARD (m)
6
5
4
3
2
1
0
-1
-2
-50
-40
-30
-20
-10
0
10
20
30
40
50
60

Figure 31

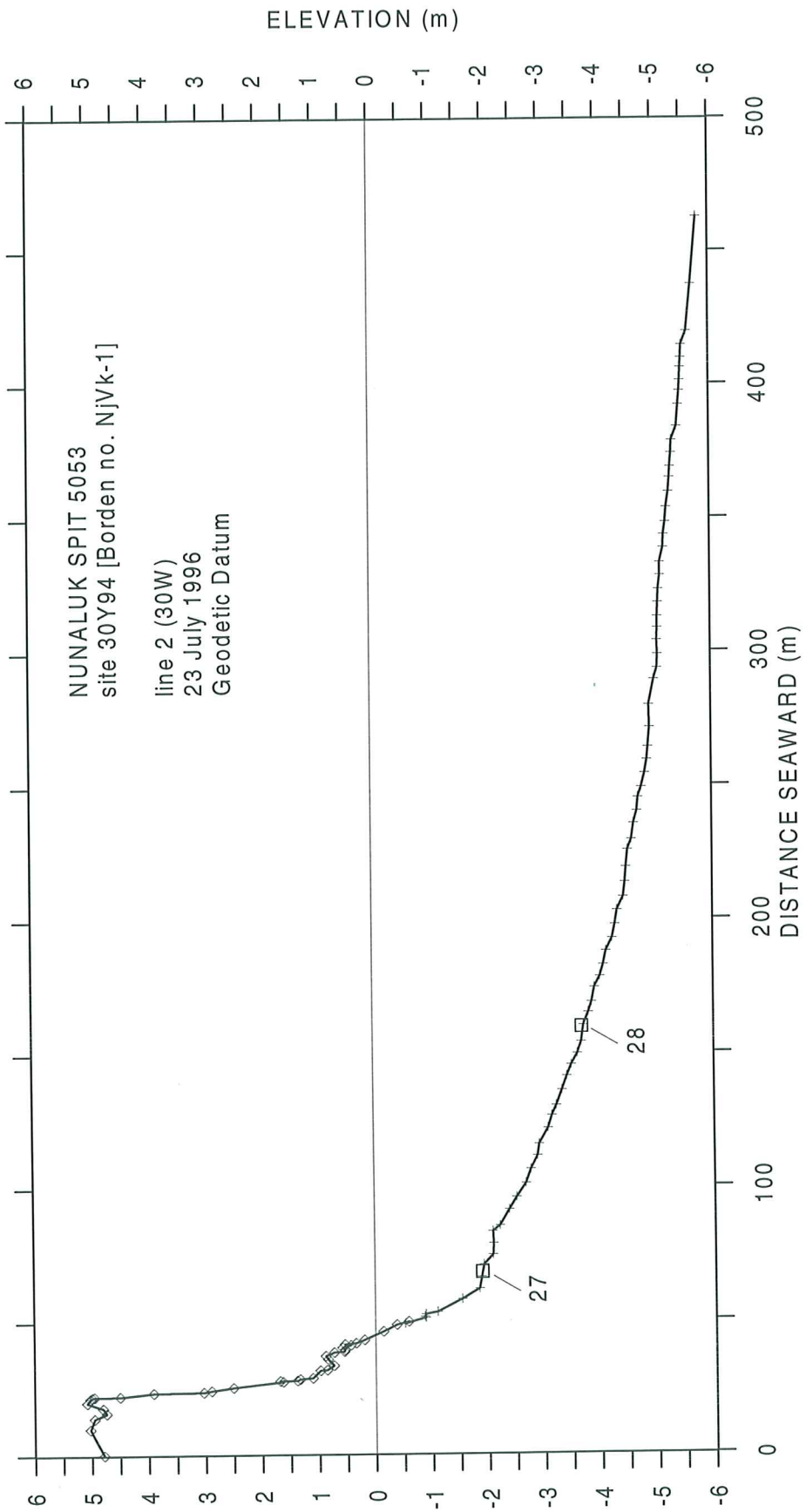

ELEVATION (m)
NUNALUK SPIT 5053
site 30Y94 [Borden no. NjVk-1]
line 2 (30W)
23 July 1996
Geodetic Datum
27
28
DISTANCE SEAWARD (m)

Figure 32

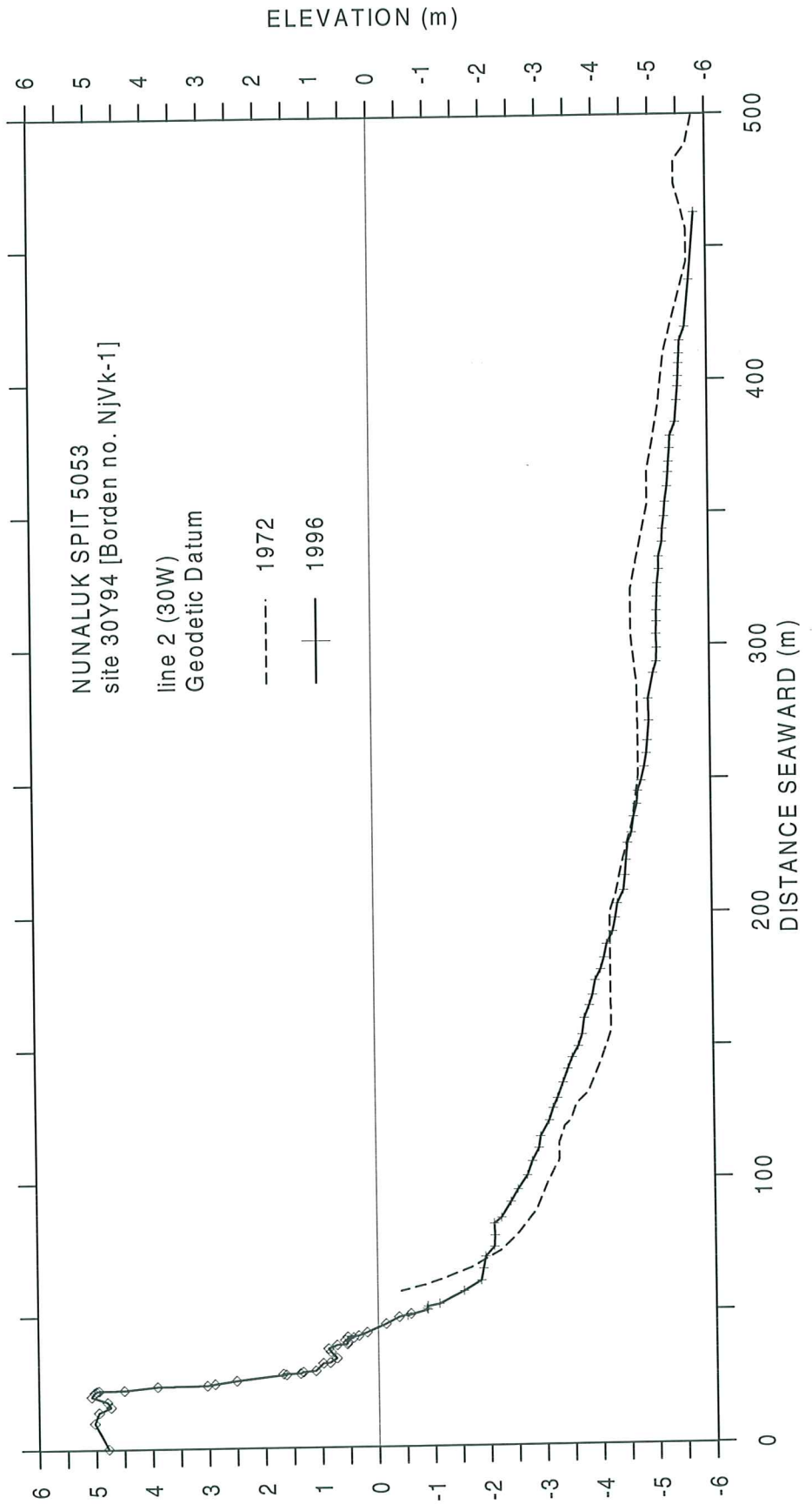

ELEVATION (m)
NUNALUK SPIT 5053
site 30Y94 [Borden no. NjVk-1]
line 2 (30W)
Geodetic Datum
1972
1996
DISTANCE SEAWARD (m)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
100
200
300
400
500

Figure 33

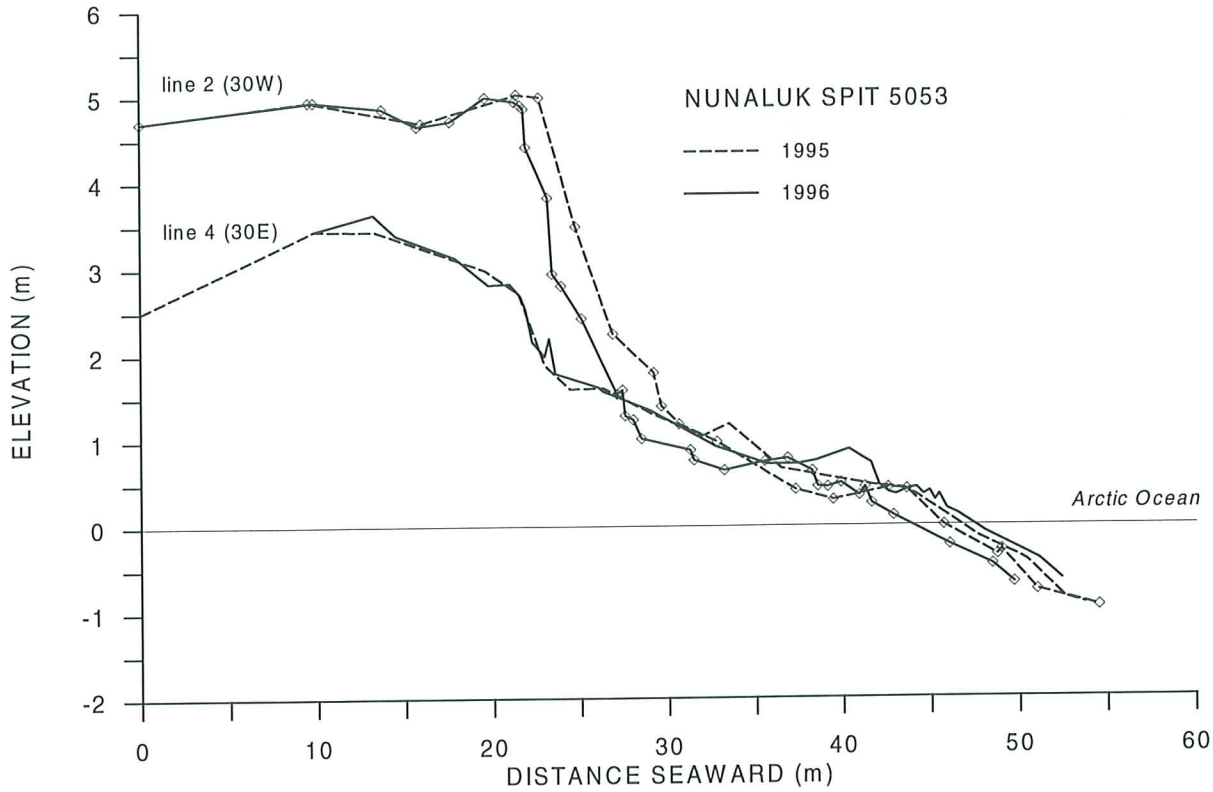

NUNALUK SPIT 5053
1995
1996
line 2 (30W)
line 4 (30E)
Arctic Ocean
ELEVATION (m)
DISTANCE SEAWARD (m)
6
5
4
3
2
1
0
-1
-2
0
10
20
30
40
50
60

Figure 34

Appendix I

PHOTOGRAMMETRIC ANALYSIS OF COASTAL EROSION AT FIVE SITES IN IVVAVIK NATIONAL PARK

Contract report to
Geological Survey of Canada (Dartmouth)
and
Parks Canada (Inuvik)

R. Covill

Tekmap Consulting
Windsor Junction,
Nova Scotia

NIAKOLIK POINT

Photos Scanned:

1944 600 DPI
1952 600 DPI
1970 400 DPI
1974 600 DPI
1985 600 DPI
1992 400 DPI
1996 400 DPI (2)

- 1996 image(s) added to GRASS dataset.
- All images are rectified to the 1992 photography.
- Despite numerous rectification control points, the 1996 images proved difficult to rectify due to parallax errors. For this reason two images were used to cover the area. In this way, good rectification was achieved in the area of the survey lines. The thermokarst section to the west still shows rectification problems.
- The cliff base was digitized using the distinct vegetation boundary.
- The high-water line was digitized. In zone 3 (outer shore), the high-water line is distinguished by the bright white line in the sand. In zone 2 (inner shore), it is distinguished by the land/water boundary.
- The six field survey lines were superimposed on the dataset and measurements were made at these sites for all available years.
- Lines 1 to 3 are in zone 3 (outer shore) and lines 4 to 6 in zone 2 (inner shore).
- Results show that the spit was breached between 1992 and 1996.
- Lines 1 to 3 show the highest retreat rates (4.9 to 6.8 m/a) between 1992 and 1996.

Niakolik Point
shoreline

measured retreat
(m/yr)

line	**1952 - 1970**	**1970 - 1974**	**1974- 1985**	**1985- 1992**	**1992- 1996**
1	0.55	-1.45	1.34	1.81	6.83
2	0.47	0.58	0.65	0.76	5.01
3	0.60	4.76	2.34	1.87	4.88
4	1.28	-0.56	1.15	0.70	1.11
5	1.63	-0.63	0.99	1.34	1.54
6	1.99	-0.63	1.31	0.61	1.09

The negative retreat values measured for the 1970-1974 interval are attributable to the low resolution of the 1974 image.

NIAKOLIK

Shoreline and Cliff Base
1952, 1970, 1992, & 1996

Legend
1996
1992
1970
1952
Grid spacing is 250 m

Shoreline is displayed as a solid line.
Cliff base is displayed as a dashed line.

The 1974 and 1985 vector data is not shown.

STOKES POINT WEST

Photos Scanned: 1954 600 DPI
1970 400 DPI
1985 600 DPI
1992 400 DPI
1996 400 DPI

- 1996 image added to GRASS dataset.
- All images are rectified to the 1970 photography.
- The cliff base was digitized using the distinct vegetation boundary.
- The cliff base in the 1970 image is partially obscured by shadow giving a possible false impression of its location.
- The cliff top was digitized using the active break in slope as the boundary.
- The beach crest was digitized using the debris boundary as a guide. This is easily discernible on the 1992 and 1996 images and shows up well in stereo.
- Due to poor image resolution the beach crest was not digitized on the 1954 image.
- The three field survey lines were superimposed on the dataset and measurements were made at these sites for all available years. These survey lines are marked 1, 2, and 3.
- A fourth line (marked *slump)* was added on the west side of the site. This picks up the active retrogressive thaw failure visible since 1985.

STOKES POINT

CLIFF TOP
measured retreat (m/yr)

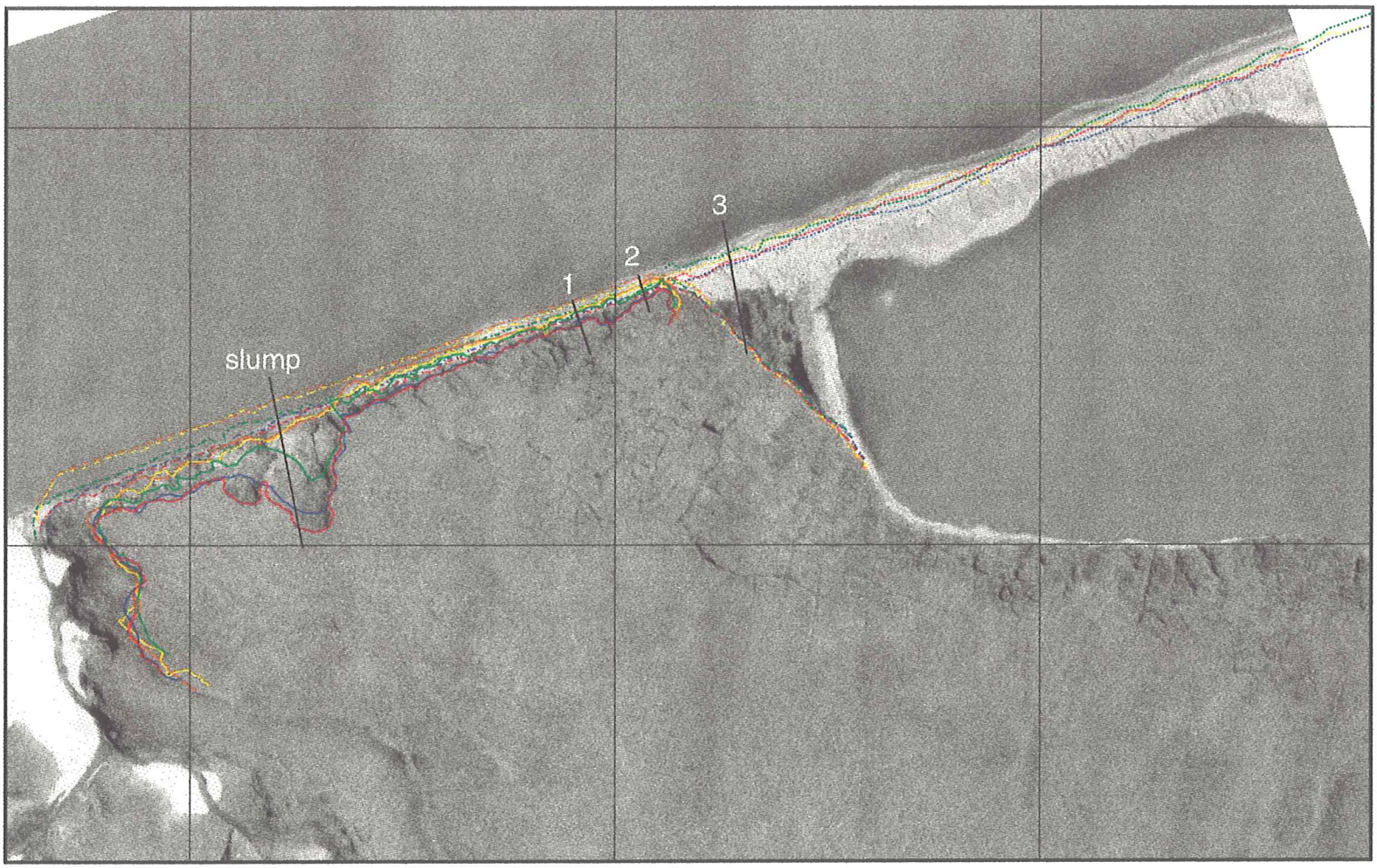
line	**1954 -1970**	**1970 -1985**	**1985-1992**	**1992-1996**
slump	0.05	0.81	2.89	2.43
1	-0.05	0.05	0.73	0.71
2	0.00	0.21	0.51	0.22
3	no cliff			

CLIFF BASE
measured retreat (m/yr)

line	**1954 -1970**	**1970 -1985**	**1985-1992**	**1992-1996**
slump	0.00	0.56	0.24	0.84
1	0.09	0.35	0.06	0.35
2	0.16	0.31	0.30	0.27
3	no cliff			

STOKES POINT

Cliff Edge, Cliff Base, and Spit Crest
1954, 1970, 1985, 1992, & 1996



Legend
1996
1992
1985
1970
1954
Grid spacing is 250 m

Cliff edge is displayed as a solid line.
Cliff base is displayed as a dashed line.
Spit crest is displayed as a dotted line.

Note: No spit crest vector is available for 1954.

CATTON POINT
(PTARMIGAN BAY)

Photos Scanned: 1953 600 DPI
1970 400 DPI (2)
1976 600 DPI
1996 400 DPI (2)

- 1996 image(s) added to GRASS dataset.
- All images are rectified to the 1970 photography.
- The cliff base was digitized using the distinct vegetation boundary.
- The beach crest was digitized using the debris boundary as a guide. This is easily discernible on the 1996 images and shows up well in stereo.
- The two field survey lines were superimposed on the dataset and measurements were made at these sites for all available years. These survey lines are marked 1 and 2.
- A third transect (line 3) was added on the south side of the site, adjacent to the cabin, in order to pick up a site of notable erosion.
- The negative results recorded for crest retreat at lines 1 & 2 indicate that the beach is prograding.
- Measurements taken on the southern lagoon shoreline between 1970 and 1996 show a maximum retreat of 75 m (2.87 m/a).

CATTON POINT

CLIFF BASE
measured retreat (m/yr)

line	**1953-1970**	**1970-1976**	**1976-1996**
1	0.00	0.00	0.00
3	0.75	1.15	0.19

No cliff on line 2.

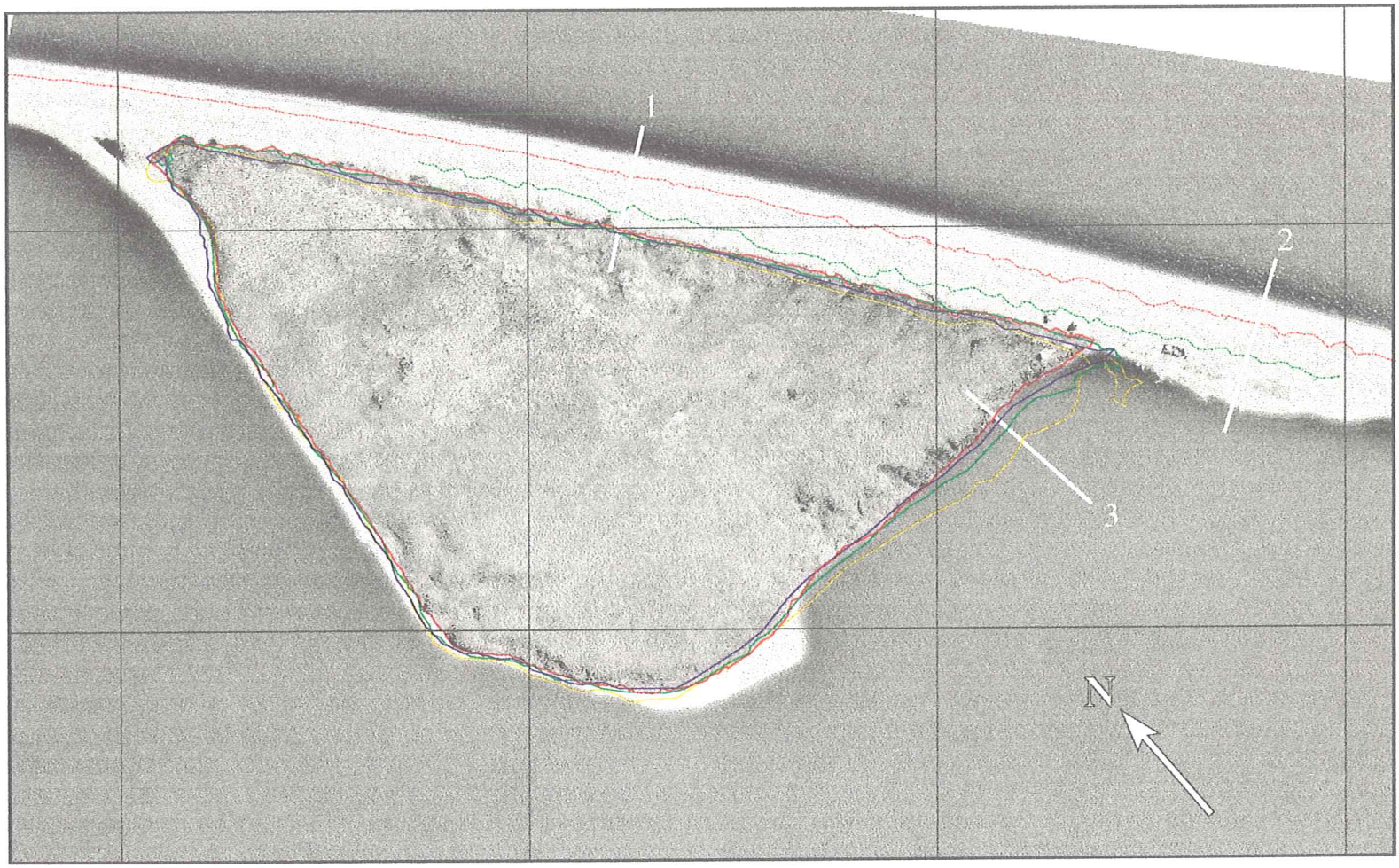
BEACH CREST
measured retreat (m/yr)

line	**1953-1970**	**1970-1976**	**1976-1996**
1	-0.36	0.00	-0.39
2	-0.17	0.00	-0.42
3	-0.86	-1.09	-0.35

Negative values indicate that the beach crest is building seaward.

CATTON POINT

Cliff Base and Beach Crest for 1953, 1970, 1976, and 1996



Legend
1996
1976
1970
1953
Grid spacing is 250 m

Cliff base is displayed as a solid line.
Spit crest is displayed as a dotted line.

NUNALUK SPIT

Photos Scanned:
1952 600 DPI
1970 400 DPI
1976 600 DPI
1996 400 DPI (2)

- 1996 image(s) added to GRASS dataset.
- Images were first rectified to each other to cover a larger area with more control points.
- All images are rectified to the 1970 photography.
- The cliff base was digitized using the vegetation boundary.
- The cliff top on the ocean side was digitized using the active break in slope.
- The spit crest was digitized using a distinct white/gray boundary as a guide. This is easily discernible on the 1996 images and shows up well in stereo.
- The four field survey lines were superimposed on the dataset and measurements were made at these sites for all available years. These are marked 1, 2, 3, and 4.
- The low resolution of the 1952 and 1976 images makes it difficult to distinguish features in the same detail as on the 1970 and 1996 images.

Nunaluk Spit

CLIFF TOP
measured retreat (m/yr)

line	1952 - 1970	1970 - 1976	1976 - 1996
1	no cliff		
2	1.07	1.64	0.15
3	1.02	2.55	0.03
4	2.03	1.59	0.33

CLIFF BASE
measured retreat (m/yr)

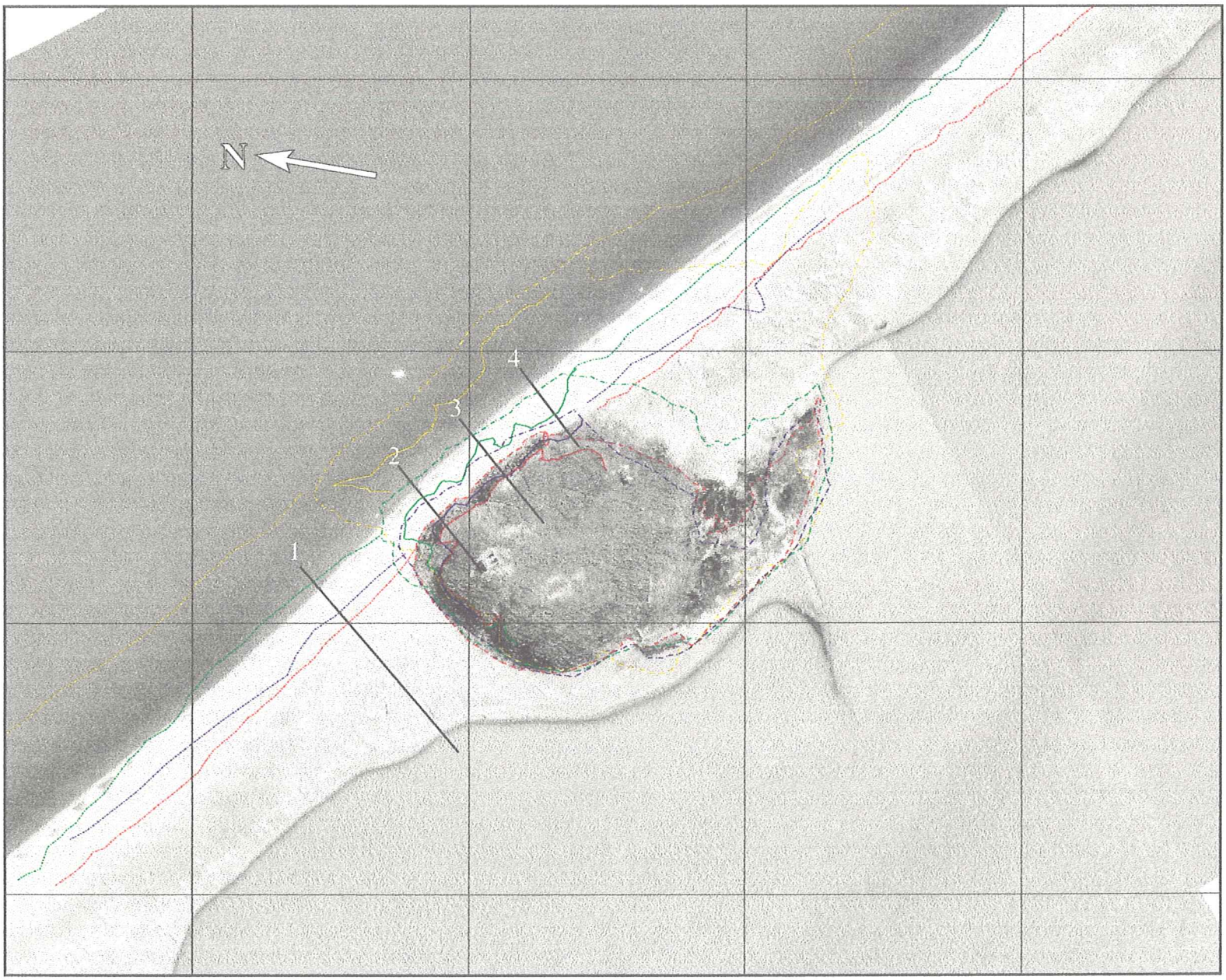
line	1952 - 1970	1970 - 1976	1976 - 1996
1	no cliff		
2	1.32	1.56	0.33
3	1.40	1.47	0.26
4	1.87	2.07	0.28

SPIT CREST
measured retreat (m/yr)

transect	1952 - 1970	1970 - 1976	1976 - 1996
1	1.37	2.43	0.26

NUNALUK

Cliff Edge, Cliff Base, and Spit Crest
1952, 1970, 1976, & 1996



Legend
1996
1976
1970
1952
Grid spacing is 100 m

Cliff edge is displayed as a solid line.
Cliff base is displayed as a dashed line.
Spit crest is displayed as a dotted line.

CLARENCE LAGOON

Photos Scanned: 1976 600 DPI
1992 400 DPI (2)
1996 400 DPI (2)

- 1996 image(s) added to GRASS dataset.
- All images are rectified to the 1992 photography.
- Excellent rectification and feature clarity on 1992 and 1996 images.
- The cliff base was digitized using the distinct vegetation boundary.
- The cliff top was digitized using the active break in slope as the boundary.
- The high water line was digitized using the bright white line in the sand as a boundary. This feature is potentially affected by changing water levels.
- The high water line was digitized to provide a qualitative representation of the spit on the east side of the inlet.
- The three field survey lines were superimposed on the dataset and measurements were made at these sites for all available years. These survey lines are labeled 1, 2, and 3.
- Two more transects were added to pick up the retrogressive thaw failure (RTF) zone west of the survey lines. The are marked RTF-4 and RTF-5.
- The apparent negative retreat recorded at the cliff edge on transect 3 for the 1976-1992 interval is attributable to the low resolution of the 1976 image and difficulty in accurately choosing the cliff edge.

CLARENCE LAGOON

CLIFF TOP
measured retreat (m/yr)

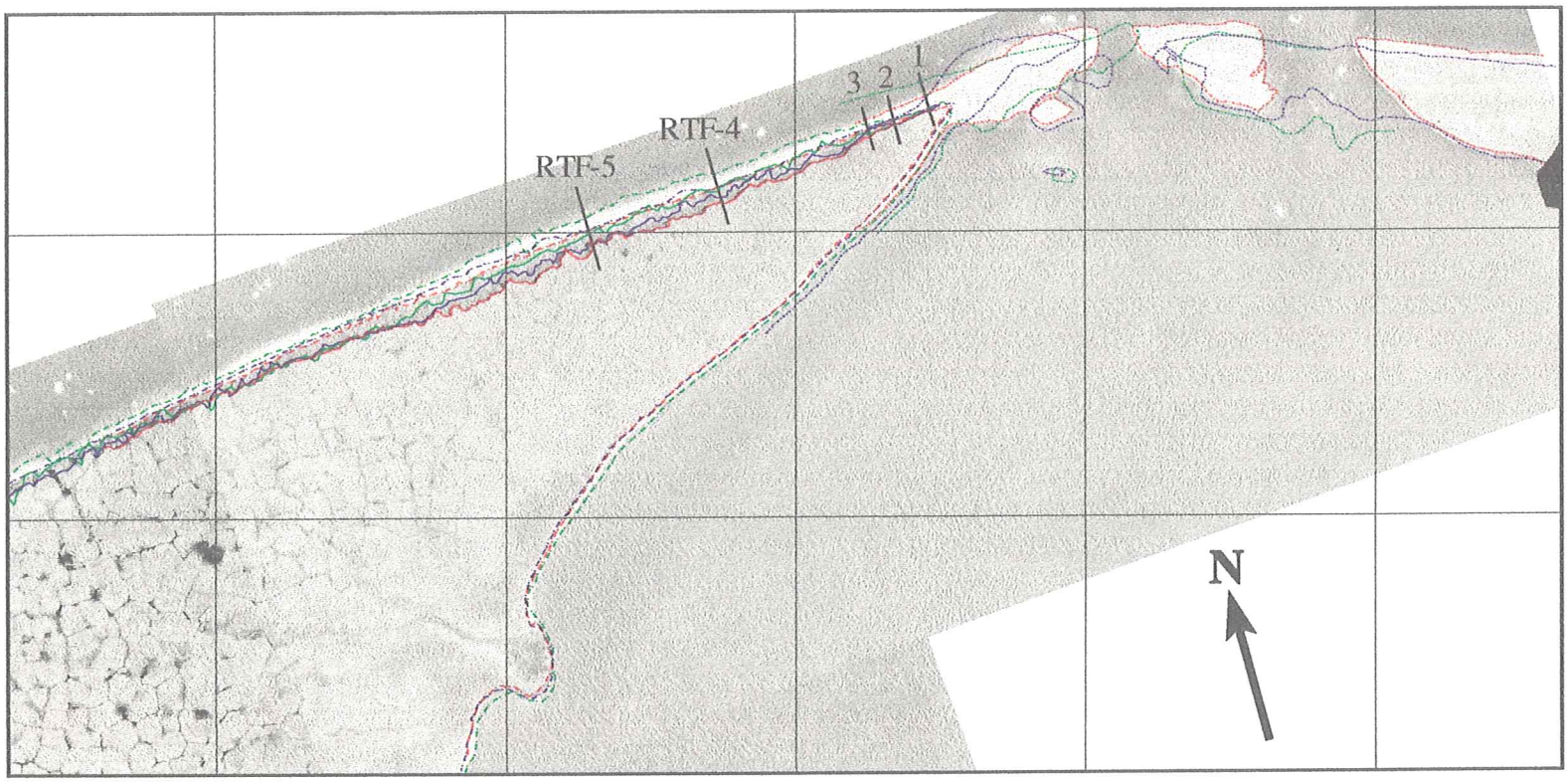
line	**1976-1992**	**1992-1996**
1	0.08	0.29
2	0.00	0.00
3	-0.26	1.64
RTF-4	0.41	1.51
RTF-5	0.49	0.00

CLIFF BASE
measured retreat (m/yr)

line	**1976-1992**	**1992-1996**
1	0.00	0.66
2	0.00	0.26
3	0.21	0.48
RTF-4	0.75	0.24
RTF-5	0.66	0.15

CLARENCE LAGOON

Cliff-edge, cliff-base, and high-water line
1976, 1992, and 1996



Legend
1996
1992
1976
Grid spacing is 250 m

Shoreline is displayed as a solid line.
Cliff base is displayed as a dashed line.

The 1974 and 1985 vector data is not shown.

Appendix II

SEDIMENT SAMPLE SUMMARY AND GRAIN-SIZE DISTRIBUTIONS

IVVAVIK NATIONAL PARK

1996

sample	site	site	line	easting	northing	elev.	date	material	location
no.		no.	no.	(m WGS84)		(m MSL)			
-023	Catton Point	5054	2	575362.18	7709382.47	-3.30	22-Jul-96	fine sand	nearshore
-024	Catton Point	5054	2	575125.37	7709311.44	-1.70	22-Jul-96	fine sand	nearshore
-025	Catton Point	5054	1	575115.02	7709753.67	-2.90	22-Jul-96	fine sand	nearshore
-026	Catton Point	5054	1	575005.31	7709714.40	-1.70	22-Jul-96	fine sand	nearshore
-027	Nunaluk Point	5053	30W	555759.31	7717614.00	-2.10	23-Jul-96	pebbly fine sand	nearshore
-028	Nunaluk Point	5053	30W	555785.41	7717702.18	-4.00	23-Jul-96	silty fine sand	nearshore
-029	Nunaluk Point	5053	30W	555809.98	7717551.88	2.63	23-Jul-96	organic muddy sand	cliff face
-030	Nunaluk Point	5053	30W	555809.64	7717552.04	2.26	23-Jul-96	ice-bonded mud	cliff face
-031	Nunaluk Point	5053	30W	555809.94	7717553.30	1.89	23-Jul-96	sand	beach
-032	Nunaluk Point	5053	30W	555814.89	7717573.27	0.55	23-Jul-96	fine pebble gravel	beach
-033	Stokes Point wes	5260	2	586427.44	7696432.46	-2.00	24-Jul-96	medium sand	nearshore
-034	Stokes Point wes	5260	2	586515.28	7696535.57	-4.00	24-Jul-96	fine sand	nearshore
-035	Stokes Point wes	5260	2	586458.03	7696476.09	-3.00	24-Jul-96	medium sand	nearshore
-036	Catton Point	5054	2	575062.99	7709312.00	1.43	26-Jul-96	pebble gravel	beach
-037	Catton Point	5054	2	575104.55	7709313.95	0.50	26-Jul-96	pebble gravel	beach

Catton Point 96303 **-023**

5054 -02 lab 10474

nearshore fine sand

elevation -3.30

APERTURE (mm)	(ϕ)	MID-PT (ϕ)	MASS (cum %)	(%)
16.0000	-4.0	-3.50	0.00	0.00
8.0000	-3.0	-2.50	0.00	0.00
4.0000	-2.0	-1.50	0.00	0.00
2.8000	-1.5	-1.25	0.00	0.00
2.0000	-1.0	-0.75	0.01	0.01
1.4000	-0.5	-0.25	0.02	0.01
1.0000	0.0	0.25	0.02	0.00
0.7100	0.5	0.75	0.02	0.00
0.5000	1.0	1.25	0.02	0.00
0.3500	1.5	1.75	0.02	0.00
0.2500	2.0	2.25	0.63	0.61
0.1800	2.5	2.75	49.91	49.28
0.1250	3.0	3.25	88.75	38.84
0.0900	3.5	3.75	93.68	4.92
0.0625	4.0	4.25	95.01	1.34
0.0442	4.5	4.75	95.74	0.73
0.0313	5.0	5.25	96.24	0.51
0.0221	5.5	5.75	96.57	0.32
0.0156	6.0	6.25	96.87	0.31
0.0110	6.5	6.75	97.10	0.23
0.0078	7.0	7.25	97.39	0.29
0.0055	7.5	7.75	97.64	0.25
0.0039	8.0	8.25	97.91	0.27
0.0028	8.5	8.75	98.16	0.25
0.0020	9.0	9.25	98.35	0.19
0.0014	9.5	9.75	98.54	0.19
0.0010	10.0	10.25	98.76	0.22
0.0007	10.5	10.75	98.91	0.15
0.0005	11.0	12.00	99.98	1.06
SUM				99.98

mean	3.27 ϕ	0.103 mm
m2	1.67	
sorting	1.29 ϕ	
m3	10.74	
skewness	4.99 ϕ	
m4	83.96	
kurtosis	30.21 ϕ	

Catton Point 96303 **-024**

5054 -02 lab 10475

nearshore fine sand

elevation -1.70

APERTURE (mm)	(ϕ)	MID-PT (ϕ)	MASS (cum %)	(%)
32.0000	-5.0	-4.75	0.00	0.00
22.6274	-4.5	-4.25	0.00	0.00
16.0000	-4.0	-3.75	0.00	0.00
11.3137	-3.5	-3.25	0.00	0.00
8.0000	-3.0	-2.75	0.00	0.00
5.6569	-2.5	-2.25	0.00	0.00
4.0000	-2.0	-1.75	0.00	0.00
2.8284	-1.5	-1.25	0.00	0.00
2.0000	-1.0	-0.75	0.00	0.00
1.4000	-0.5	-0.25	0.01	0.01
1.0000	0.0	0.25	0.01	0.00
0.7100	0.5	0.75	0.01	0.00
0.5000	1.0	1.25	0.05	0.04
0.3500	1.5	1.75	2.76	2.71
0.2500	2.0	2.25	32.67	29.91
0.1800	2.5	2.75	88.46	55.79
0.1250	3.0	3.25	96.93	8.48
0.0900	3.5	3.75	97.84	0.91
0.0625	4.0	4.25	98.14	0.29
0.0442	4.5	4.75	98.35	0.22
0.0313	5.0	5.25	98.55	0.20
0.0221	5.5	5.75	98.72	0.16
0.0156	6.0	6.25	98.82	0.10
0.0110	6.5	6.75	98.90	0.08
0.0078	7.0	7.25	99.01	0.10
0.0055	7.5	7.75	99.10	0.09
0.0039	8.0	8.25	99.19	0.09
0.0028	8.5	8.75	99.25	0.07
0.0020	9.0	9.25	99.32	0.07
0.0014	9.5	9.75	99.40	0.08
0.0010	10.0	10.25	99.48	0.08
0.0007	10.5	10.75	99.54	0.06
0.0005	11.0	12.00	99.99	0.45
SUM				99.99

mean	2.73 ϕ	0.151 mm
m2	0.83	
sorting	0.91 ϕ	
m3	5.38	
skewness	7.06 ϕ	
m4	44.95	
kurtosis	64.53 ϕ	

Catton Point 96303 **-025**

5054 -01 lab 10476

nearshore fine sand

elevation -2.90

APERTURE (mm)	(ϕ)	MID-PT (ϕ)	MASS (cum %)	(%)
32.0000	-5.0	-4.75	0.00	0.00
22.6274	-4.5	-4.25	0.00	0.00
16.0000	-4.0	-3.75	0.00	0.00
11.3137	-3.5	-3.25	0.00	0.00
8.0000	-3.0	-2.75	0.00	0.00
5.6569	-2.5	-2.25	0.00	0.00
4.0000	-2.0	-1.75	0.00	0.00
2.8284	-1.5	-1.25	0.00	0.00
2.0000	-1.0	-0.75	0.01	0.01
1.4000	-0.5	-0.25	0.03	0.01
1.0000	0.0	0.25	0.03	0.00
0.7100	0.5	0.75	0.03	0.00
0.5000	1.0	1.25	0.03	0.00
0.3500	1.5	1.75	0.03	0.00
0.2500	2.0	2.25	3.14	3.11
0.1800	2.5	2.75	69.83	66.69
0.1250	3.0	3.25	92.71	22.88
0.0900	3.5	3.75	96.03	3.32
0.0625	4.0	4.25	96.78	0.76
0.0442	4.5	4.75	97.16	0.37
0.0313	5.0	5.25	97.47	0.31
0.0221	5.5	5.75	97.67	0.20
0.0156	6.0	6.25	97.85	0.19
0.0110	6.5	6.75	98.07	0.22
0.0078	7.0	7.25	98.27	0.20
0.0055	7.5	7.75	98.47	0.20
0.0039	8.0	8.25	98.63	0.16
0.0028	8.5	8.75	98.75	0.12
0.0020	9.0	9.25	98.88	0.13
0.0014	9.5	9.75	99.00	0.13
0.0010	10.0	10.25	99.13	0.13
0.0007	10.5	10.75	99.25	0.12
0.0005	11.0	12.00	100.00	0.75
SUM				100.00

mean	3.07 ϕ	0.119 mm
m2	1.21	
sorting	1.10 ϕ	
m3	8.05	
skewness	6.02 ϕ	
m4	64.48	
kurtosis	43.77 ϕ	

Catton Point 96303 **-026**

5054 -01 lab 10477

nearshore fine sand

elevation -1.70

APERTURE (mm)	(ϕ)	MID-PT (ϕ)	MASS (cum %)	(%)
32.0000	-5.0	-4.75	0.00	0.00
22.6274	-4.5	-4.25	0.00	0.00
16.0000	-4.0	-3.75	0.00	0.00
11.3137	-3.5	-3.25	0.00	0.00
8.0000	-3.0	-2.75	1.06	1.06
5.6569	-2.5	-2.25	1.06	0.00
4.0000	-2.0	-1.75	1.38	0.32
2.8284	-1.5	-1.25	1.60	0.22
2.0000	-1.0	-0.75	1.79	0.19
1.4000	-0.5	-0.25	1.99	0.19
1.0000	0.0	0.25	1.99	0.00
0.7100	0.5	0.75	1.99	0.00
0.5000	1.0	1.25	2.38	0.39
0.3500	1.5	1.75	11.99	9.61
0.2500	2.0	2.25	68.11	56.12
0.1800	2.5	2.75	97.25	29.15
0.1250	3.0	3.25	98.87	1.62
0.0900	3.5	3.75	99.28	0.41
0.0625	4.0	4.25	99.40	0.11
0.0442	4.5	4.75	99.48	0.08
0.0313	5.0	5.25	99.53	0.05
0.0221	5.5	5.75	99.57	0.03
0.0156	6.0	6.25	99.59	0.03
0.0110	6.5	6.75	99.63	0.03
0.0078	7.0	7.25	99.65	0.03
0.0055	7.5	7.75	99.68	0.03
0.0039	8.0	8.25	99.71	0.02
0.0028	8.5	8.75	99.73	0.03
0.0020	9.0	9.25	99.76	0.03
0.0014	9.5	9.75	99.78	0.02
0.0010	10.0	10.25	99.80	0.03
0.0007	10.5	10.75	99.83	0.03
0.0005	11.0	12.00	100.00	0.16
SUM				100.00

mean	2.32 ϕ	0.200 mm
m2	0.78	
sorting	0.88 ϕ	
m3	0.48	
skewness	0.70 ϕ	
m4	28.07	
kurtosis	46.64 ϕ	

Nunaluk Spit 96303 **-027**

5053 -02 lab 10478

nearshore pebbly fine sand

elevation -2.10

APERTURE (mm)	(ϕ)	MID-PT (ϕ)	MASS (cum %)	(%)
32.0000	-5.0	-4.75	0.00	0.00
22.6274	-4.5	-4.25	0.00	0.00
16.0000	-4.0	-3.75	0.00	0.00
11.3137	-3.5	-3.25	1.50	1.50
8.0000	-3.0	-2.75	1.50	0.00
5.6569	-2.5	-2.25	1.61	0.11
4.0000	-2.0	-1.75	1.66	0.05
2.8284	-1.5	-1.25	1.95	0.29
2.0000	-1.0	-0.75	2.24	0.29
1.4000	-0.5	-0.25	2.50	0.27
1.0000	0.0	0.25	2.64	0.14
0.7100	0.5	0.75	3.53	0.89
0.5000	1.0	1.25	7.66	4.12
0.3500	1.5	1.75	19.65	12.00
0.2500	2.0	2.25	67.88	48.23
0.1800	2.5	2.75	95.68	27.79
0.1250	3.0	3.25	97.78	2.10
0.0900	3.5	3.75	98.22	0.44
0.0625	4.0	4.25	98.41	0.19
0.0442	4.5	4.75	98.46	0.05
0.0313	5.0	5.25	98.53	0.07
0.0221	5.5	5.75	98.59	0.07
0.0156	6.0	6.25	98.69	0.10
0.0110	6.5	6.75	98.81	0.11
0.0078	7.0	7.25	98.91	0.10
0.0055	7.5	7.75	99.02	0.12
0.0039	8.0	8.25	99.14	0.12
0.0028	8.5	8.75	99.25	0.10
0.0020	9.0	9.25	99.34	0.09
0.0014	9.5	9.75	99.43	0.09
0.0010	10.0	10.25	99.50	0.07
0.0007	10.5	10.75	99.59	0.09
0.0005	11.0	12.00	99.97	0.39
SUM				99.97

mean	2.29 ϕ	0.204 mm
m2	1.54	
sorting	1.24 ϕ	
m3	3.20	
skewness	1.67 ϕ	
m4	68.23	
kurtosis	28.74 ϕ	

Nunaluk Spit 96303 **-028**

5053 -02 lab 10479

nearshore silty sand

elevation -4.00

APERTURE (mm)	(ϕ)	MID-PT (ϕ)	MASS (cum %)	(%)
32.0000	-5.0	-4.75	0.00	0.00
22.6274	-4.5	-4.25	0.00	0.00
16.0000	-4.0	-3.75	0.00	0.00
11.3137	-3.5	-3.25	0.00	0.00
8.0000	-3.0	-2.75	0.00	0.00
5.6569	-2.5	-2.25	0.00	0.00
4.0000	-2.0	-1.75	0.19	0.19
2.8284	-1.5	-1.25	0.24	0.04
2.0000	-1.0	-0.75	0.25	0.01
1.4000	-0.5	-0.25	0.30	0.05
1.0000	0.0	0.25	0.30	0.00
0.7100	0.5	0.75	0.30	0.00
0.5000	1.0	1.25	0.92	0.61
0.3500	1.5	1.75	2.76	1.84
0.2500	2.0	2.25	17.32	14.56
0.1800	2.5	2.75	69.63	52.31
0.1250	3.0	3.25	84.79	15.16
0.0900	3.5	3.75	87.97	3.17
0.0625	4.0	4.25	89.18	1.21
0.0442	4.5	4.75	90.56	1.38
0.0313	5.0	5.25	91.79	1.23
0.0221	5.5	5.75	92.59	0.80
0.0156	6.0	6.25	93.32	0.73
0.0110	6.5	6.75	93.80	0.48
0.0078	7.0	7.25	94.52	0.72
0.0055	7.5	7.75	95.36	0.84
0.0039	8.0	8.25	96.05	0.70
0.0028	8.5	8.75	96.63	0.58
0.0020	9.0	9.25	97.09	0.46
0.0014	9.5	9.75	97.50	0.42
0.0010	10.0	10.25	97.84	0.34
0.0007	10.5	10.75	98.22	0.37
0.0005	11.0	12.00	100.00	1.78
SUM				99.99

mean	3.32 ϕ	0.100 mm
m2	3.39	
sorting	1.84 ϕ	
m3	19.25	
skewness	3.08 ϕ	
m4	151.30	
kurtosis	13.14 ϕ	

Nunaluk Spit 96303 **-029**

5053 -02 lab 10481

cliff muddy sand

elevation 2.63

APERTURE (mm)	(ϕ)	MID-PT (ϕ)	MASS (cum %)	(%)
32.0000	-5.0	-4.75	0.00	0.00
22.6274	-4.5	-4.25	0.00	0.00
16.0000	-4.0	-3.75	0.00	0.00
11.3137	-3.5	-3.25	0.00	0.00
8.0000	-3.0	-2.75	0.00	0.00
5.6569	-2.5	-2.25	0.00	0.00
4.0000	-2.0	-1.75	0.09	0.09
2.8284	-1.5	-1.25	0.32	0.24
2.0000	-1.0	-0.75	0.79	0.46
1.4000	-0.5	-0.25	1.51	0.72
1.0000	0.0	0.25	1.82	0.31
0.7100	0.5	0.75	3.38	1.56
0.5000	1.0	1.25	6.42	3.04
0.3500	1.5	1.75	10.90	4.48
0.2500	2.0	2.25	15.86	4.96
0.1800	2.5	2.75	21.10	5.24
0.1250	3.0	3.25	25.60	4.51
0.0900	3.5	3.75	28.74	3.14
0.0625	4.0	4.25	30.92	2.18
0.0442	4.5	4.75	33.84	2.92
0.0313	5.0	5.25	38.06	4.21
0.0221	5.5	5.75	42.06	4.00
0.0156	6.0	6.25	46.38	4.33
0.0110	6.5	6.75	49.95	3.57
0.0078	7.0	7.25	53.43	3.48
0.0055	7.5	7.75	57.42	3.99
0.0039	8.0	8.25	61.13	3.71
0.0028	8.5	8.75	64.13	3.00
0.0020	9.0	9.25	67.22	3.09
0.0014	9.5	9.75	69.67	2.45
0.0010	10.0	10.25	73.27	3.60
0.0007	10.5	10.75	76.37	3.10
0.0005	11.0	12.00	99.77	23.40
SUM				99.77

mean	7.01 ϕ	0.008 mm
m2	14.65	
sorting	3.83 ϕ	
m3	-5.13	
skewness	-0.09 ϕ	
m4	367.58	
kurtosis	1.71 ϕ	

Nunaluk Spit 96303 **-030**

5053 -02 lab 10482

cliff ice-bonded mud

elevation 2.26

APERTURE (mm)	(ϕ)	MID-PT (ϕ)	MASS (cum %)	(%)
32.0000	-5.0	-4.75	0.00	0.00
22.6274	-4.5	-4.25	0.00	0.00
16.0000	-4.0	-3.75	1.93	1.93
11.3137	-3.5	-3.25	3.56	1.63
8.0000	-3.0	-2.75	5.30	1.74
5.6569	-2.5	-2.25	5.97	0.67
4.0000	-2.0	-1.75	7.51	1.54
2.8284	-1.5	-1.25	9.09	1.58
2.0000	-1.0	-0.75	11.10	2.01
1.4000	-0.5	-0.25	13.32	2.22
1.0000	0.0	0.25	14.27	0.95
0.7100	0.5	0.75	17.34	3.07
0.5000	1.0	1.25	22.39	5.05
0.3500	1.5	1.75	29.43	7.04
0.2500	2.0	2.25	37.74	8.31
0.1800	2.5	2.75	42.55	4.81
0.1250	3.0	3.25	45.75	3.21
0.0900	3.5	3.75	48.42	2.67
0.0625	4.0	4.25	49.52	1.10
0.0442	4.5	4.75	52.42	2.90
0.0313	5.0	5.25	57.96	5.53
0.0221	5.5	5.75	63.02	5.06
0.0156	6.0	6.25	67.25	4.23
0.0110	6.5	6.75	70.76	3.52
0.0078	7.0	7.25	73.00	2.24
0.0055	7.5	7.75	74.92	1.92
0.0039	8.0	8.25	77.34	2.42
0.0028	8.5	8.75	78.91	1.57
0.0020	9.0	9.25	80.49	1.58
0.0014	9.5	9.75	81.95	1.46
0.0010	10.0	10.25	83.28	1.33
0.0007	10.5	10.75	84.62	1.33
0.0005	11.0	12.00	100.00	15.38
SUM				100.00

mean	4.81 ϕ	0.036 mm
m2	19.69	
sorting	4.44 ϕ	
m3	14.53	
skewness	0.17 ϕ	
m4	825.23	
kurtosis	2.13 ϕ	

Nunaluk Spit 96303 **-031**

5053 -02 lab 10483

beach sand

elevation 1.89

APERTURE (mm)	(ϕ)	MID-PT (ϕ)	MASS (cum %)	(%)
32.0000	-5.0	-4.75	0.00	0.00
22.6274	-4.5	-4.25	0.00	0.00
16.0000	-4.0	-3.75	0.00	0.00
11.3137	-3.5	-3.25	0.00	0.00
8.0000	-3.0	-2.75	0.35	0.35
5.6569	-2.5	-2.25	0.71	0.36
4.0000	-2.0	-1.75	0.78	0.07
2.8284	-1.5	-1.25	0.83	0.05
2.0000	-1.0	-0.75	1.03	0.20
1.4000	-0.5	-0.25	2.24	1.21
1.0000	0.0	0.25	4.53	2.29
0.7100	0.5	0.75	26.70	22.16
0.5000	1.0	1.25	78.44	51.75
0.3500	1.5	1.75	97.07	18.63
0.2500	2.0	2.25	98.97	1.90
0.1800	2.5	2.75	99.44	0.48
0.1250	3.0	3.25	99.56	0.11
0.0900	3.5	3.75	99.62	0.06
0.0625	4.0	4.25	99.73	0.11
0.0442	4.5	4.75	99.77	0.04
0.0313	5.0	5.25	99.79	0.02
0.0221	5.5	5.75	99.81	0.02
0.0156	6.0	6.25	99.82	0.02
0.0110	6.5	6.75	99.83	0.01
0.0078	7.0	7.25	99.84	0.01
0.0055	7.5	7.75	99.86	0.02
0.0039	8.0	8.25	99.87	0.01
0.0028	8.5	8.75	99.88	0.01
0.0020	9.0	9.25	99.90	0.01
0.0014	9.5	9.75	99.91	0.01
0.0010	10.0	10.25	99.92	0.01
0.0007	10.5	10.75	99.93	0.01
0.0005	11.0	12.00	100.00	0.07
SUM				100.00

mean	1.21 ϕ	0.432 mm
m2	0.47	
sorting	0.69 ϕ	
m3	1.05	
skewness	3.25 ϕ	
m4	15.31	
kurtosis	68.76 ϕ	

Nunaluk Spit 96303 **-032**

5053 -02 lab 10484

beach gravel

elevation -0.55

APERTURE (mm)	(ϕ)	MID-PT (ϕ)	MASS (cum %)	(%)
32.0000	-5.0	-4.75	0.00	0.00
22.6274	-4.5	-4.25	1.15	1.15
16.0000	-4.0	-3.75	5.82	4.66
11.3137	-3.5	-3.25	14.81	8.99
8.0000	-3.0	-2.75	30.41	15.60
5.6569	-2.5	-2.25	52.43	22.03
4.0000	-2.0	-1.75	79.57	27.14
2.8284	-1.5	-1.25	96.33	16.76
2.0000	-1.0	-0.75	99.92	3.59
1.4000	-0.5	-0.25	99.99	0.06
1.0000	0.0	0.25	99.99	0.00
0.7100	0.5	0.75	99.99	0.00
0.5000	1.0	1.25	99.99	0.00
0.3500	1.5	1.75	99.99	0.00
0.2500	2.0	2.25	100.00	0.01
0.1800	2.5	2.75	100.00	0.00
0.1250	3.0	3.25	100.00	0.00
0.0900	3.5	3.75	100.00	0.00
0.0625	4.0	4.25	100.00	0.00
0.0442	4.5	4.75	100.00	0.00
0.0313	5.0	5.25	100.00	0.00
0.0221	5.5	5.75	100.00	0.00
0.0156	6.0	6.25	100.00	0.00
0.0110	6.5	6.75	100.00	0.00
0.0078	7.0	7.25	100.00	0.00
0.0055	7.5	7.75	100.00	0.00
0.0039	8.0	8.25	100.00	0.00
0.0028	8.5	8.75	100.00	0.00
0.0020	9.0	9.25	100.00	0.00
0.0014	9.5	9.75	100.00	0.00
0.0010	10.0	10.25	100.00	0.00
0.0007	10.5	10.75	100.00	0.00
0.0005	11.0	12.00	100.00	0.00
SUM				100.00

mean	-2.15 ϕ	4.444 mm
m2	0.59	
sorting	0.77 ϕ	
m3	-0.20	
skewness	-0.43 ϕ	
m4	0.98	
kurtosis	2.81 ϕ	

Stokes Point W 96303 **-033**

5260 -02 lab 10485

nearshore medium sand

elevation -2.00

APERTURE (mm)	(ϕ)	MID-PT (ϕ)	MASS (cum %)	(%)
32.0000	-5.0	-4.75	0.00	0.00
22.6274	-4.5	-4.25	0.00	0.00
16.0000	-4.0	-3.75	0.00	0.00
11.3137	-3.5	-3.25	0.00	0.00
8.0000	-3.0	-2.75	0.14	0.14
5.6569	-2.5	-2.25	0.68	0.54
4.0000	-2.0	-1.75	1.06	0.38
2.8284	-1.5	-1.25	1.52	0.46
2.0000	-1.0	-0.75	2.19	0.67
1.4000	-0.5	-0.25	2.97	0.78
1.0000	0.0	0.25	3.34	0.37
0.7100	0.5	0.75	4.69	1.35
0.5000	1.0	1.25	12.01	7.32
0.3500	1.5	1.75	49.27	37.26
0.2500	2.0	2.25	88.86	39.59
0.1800	2.5	2.75	97.59	8.73
0.1250	3.0	3.25	98.55	0.96
0.0900	3.5	3.75	99.03	0.48
0.0625	4.0	4.25	99.29	0.26
0.0442	4.5	4.75	99.41	0.12
0.0313	5.0	5.25	99.48	0.07
0.0221	5.5	5.75	99.52	0.04
0.0156	6.0	6.25	99.55	0.03
0.0110	6.5	6.75	99.57	0.02
0.0078	7.0	7.25	99.59	0.02
0.0055	7.5	7.75	99.62	0.03
0.0039	8.0	8.25	99.64	0.02
0.0028	8.5	8.75	99.67	0.03
0.0020	9.0	9.25	99.69	0.03
0.0014	9.5	9.75	99.71	0.02
0.0010	10.0	10.25	99.74	0.03
0.0007	10.5	10.75	99.77	0.03
0.0005	11.0	12.00	99.98	0.22
SUM				99.98

mean	1.97 ϕ	0.255 mm
m2	0.88	
sorting	0.94 ϕ	
m3	1.97	
skewness	2.38 ϕ	
m4	32.40	
kurtosis	41.67 ϕ	

Stokes Point W 96303 **-034**

5260 -02 lab 10486

nearshore fine sand

elevation -4.00

APERTURE (mm)	(ϕ)	MID-PT (ϕ)	MASS (cum %)	(%)
32.0000	-5.0	-4.75	0.00	0.00
22.6274	-4.5	-4.25	0.00	0.00
16.0000	-4.0	-3.75	0.00	0.00
11.3137	-3.5	-3.25	0.00	0.00
8.0000	-3.0	-2.75	0.71	0.71
5.6569	-2.5	-2.25	0.71	0.00
4.0000	-2.0	-1.75	0.77	0.06
2.8284	-1.5	-1.25	0.83	0.06
2.0000	-1.0	-0.75	0.92	0.09
1.4000	-0.5	-0.25	1.09	0.17
1.0000	0.0	0.25	1.09	0.00
0.7100	0.5	0.75	1.09	0.00
0.5000	1.0	1.25	1.48	0.39
0.3500	1.5	1.75	4.96	3.48
0.2500	2.0	2.25	12.85	7.89
0.1800	2.5	2.75	76.59	63.74
0.1250	3.0	3.25	94.28	17.70
0.0900	3.5	3.75	97.53	3.25
0.0625	4.0	4.25	98.26	0.73
0.0442	4.5	4.75	98.69	0.43
0.0313	5.0	5.25	98.91	0.22
0.0221	5.5	5.75	98.98	0.07
0.0156	6.0	6.25	99.04	0.06
0.0110	6.5	6.75	99.11	0.06
0.0078	7.0	7.25	99.15	0.05
0.0055	7.5	7.75	99.21	0.06
0.0039	8.0	8.25	99.27	0.06
0.0028	8.5	8.75	99.32	0.05
0.0020	9.0	9.25	99.37	0.06
0.0014	9.5	9.75	99.42	0.05
0.0010	10.0	10.25	99.49	0.07
0.0007	10.5	10.75	99.54	0.05
0.0005	11.0	12.00	99.97	0.44
SUM				99.98

mean	2.84 ϕ	0.140 mm
m2	1.02	
sorting	1.01 ϕ	
m3	3.17	
skewness	3.10 ϕ	
m4	46.54	
kurtosis	45.14 ϕ	

Stokes Point W 96303 **-035**

5260 -02 lab 10487

nearshore medium sand

elevation -3.00

APERTURE (mm)	(ϕ)	MID-PT (ϕ)	MASS (cum %)	(%)
32.0000	-5.0	-4.75	0.00	0.00
22.6274	-4.5	-4.25	0.00	0.00
16.0000	-4.0	-3.75	1.07	1.07
11.3137	-3.5	-3.25	1.07	0.00
8.0000	-3.0	-2.75	1.89	0.82
5.6569	-2.5	-2.25	2.40	0.51
4.0000	-2.0	-1.75	3.11	0.71
2.8284	-1.5	-1.25	4.02	0.91
2.0000	-1.0	-0.75	5.16	1.14
1.4000	-0.5	-0.25	6.51	1.35
1.0000	0.0	0.25	6.83	0.32
0.7100	0.5	0.75	8.96	2.13
0.5000	1.0	1.25	11.05	2.09
0.3500	1.5	1.75	16.13	5.08
0.2500	2.0	2.25	50.99	34.86
0.1800	2.5	2.75	90.90	39.91
0.1250	3.0	3.25	96.27	5.37
0.0900	3.5	3.75	98.05	1.78
0.0625	4.0	4.25	98.63	0.58
0.0442	4.5	4.75	99.03	0.40
0.0313	5.0	5.25	99.22	0.19
0.0221	5.5	5.75	99.28	0.07
0.0156	6.0	6.25	99.33	0.04
0.0110	6.5	6.75	99.36	0.04
0.0078	7.0	7.25	99.39	0.03
0.0055	7.5	7.75	99.45	0.05
0.0039	8.0	8.25	99.47	0.03
0.0028	8.5	8.75	99.51	0.04
0.0020	9.0	9.25	99.56	0.05
0.0014	9.5	9.75	99.59	0.04
0.0010	10.0	10.25	99.64	0.05
0.0007	10.5	10.75	99.70	0.06
0.0005	11.0	12.00	99.99	0.29
SUM				99.98

mean	2.27 ϕ	0.207 mm
m2	1.92	
sorting	1.38 ϕ	
m3	-1.15	
skewness	-0.43 ϕ	
m4	61.74	
kurtosis	16.80 ϕ	