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REPORT OF 1992 COASTAL SURVEYS IN THE BEAUFORT SEA

D.L. Forbes, S.M. Solomon, and D. Frobel

Geological Survey of Canada
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A contribution to the Northern Oil and Gas Action Program and the Green Plan

1995

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INTRODUCTION

This report describes field work undertaken in 1992 to investigate rates and processes of coastal change in the Canadian sector of the Beaufort Sea. The work formed part of a program entitled **Coastal Impacts of Climate Change**, funded under the Green Plan with additional funds provided by the Northern Oil and Gas Action Program (NOGAP). The field activities involved ground surveys, nearshore bathymetric surveys, and aerial photography at a number of sites from the Alaska-Yukon boundary to Atkinson Point on the Tuktoyaktuk Peninsula. We also participated in a collaborative study of coastal processes at Atkinson Point, with colleagues and students from l'Université Laval and l'Université du Québec à Rimouski.

SUMMARY

Personnel:

Steve Solomon	Atlantic Geoscience Centre
Donald Forbes	Atlantic Geoscience Centre
David Frobel	Atlantic Geoscience Centre
Paul Roy	aerial photographic contractor

Accommodations and logistical support:

Inuvik Research Centre, Science Institute of the Northwest Territories, Inuvik
Polar Continental Shelf Project, Tuktoyaktuk

Aircraft utilized:

Bell 206L helicopters C-GTLB and C-GPCX (Canadian Helicopters)
DHC Twin-Otter C-FIOJ (Aklak Air) for aerial photography

Funding and permits:

Funding under Global Change Program, Green Plan, and NOGAP
Geological Survey of Canada projects 920065 and 830007
Polar Continental Shelf Project program 298-91
Science Institute of the Northwest Territories scientific research license 12195D
Yukon Scientists and Explorers license 92-46S&E
Northern Yukon National Park permit 92-06
Inuvialuit Lands Administration permit ILA92TN37
Canadian Wildlife Service Permit A03812

OBJECTIVES

The general objective of the Coastal Impacts Program was to investigate the response of the Beaufort Sea coast to the effects of changing climate. This requires that we monitor coastal changes and understand coastal processes over a range of temporal scales. This second requirement is also part of the NOGAP mandate. The specific objectives of the 1992 field program were as follows:

1 — To resurvey monumented coastal sites (Figure 1) in order to determine rates and styles of coastal change and to core deposits in tidal flats on the west side of Richards Island (site 5390) with a view to determining sedimentation rates.

2 — To obtain low-level (1:6000) vertical air photographs with ground control at coastal survey sites (Figure 2). These were intended for digital analysis as a basis for extrapolating the ground survey results both back in time (using existing older photography) and along the coast. They were also intended as baseline photography in the event that similar-scale photographs could be obtained in future years. As it happens, we have succeeded in repeating much of the photography in 1993 and 1994, the latter following a severe storm in the fall of 1993. The aerial photography also provided a link to a satellite monitoring initiative in collaboration with the Canada Centre for Remote Sensing (CCRS) and l'Université du Québec à Rimouski (UQAR).

3 — To participate in the collection of oceanographic and sediment transport data on the beach and shoreface at Atkinson Point (Figure 1) in order to improve our understanding of nearshore sediment entrainment and transport in the Beaufort Sea.

STUDY AREA AND OTHER WORK

The study area extended from the Alaska-Yukon international boundary to Atkinson Point on the Tuktoyaktuk Peninsula (Figure 1). This includes the seaward margin of the Mackenzie Delta. Coastal sediments consist of unconsolidated but ice-bonded sands, silts, clays, and diamicts of Late Quaternary age. These form coastal bluffs up to 90 m or more in height and feed an assortment of beaches and spits with associated nearshore bars and spit platforms. Coastal bluffs expose varying proportions of ground ice, including ice wedges and thick bodies of massive ice (Mackay, 1971; Harry et al., 1988; Héquette and Barnes, 1990).

Dominant storm winds, waves and sediment transport are from the west and northwest. However, the effectiveness of the wind to generate waves during the 4 month open-water season is limited by the presence of sea-ice offshore. The ice remains within 200 km of the Mackenzie Delta coast at all times; in heavy-ice years such as 1974 and 1991, the pack ice may remain within within 20-50 km of the coast for all or most of the open-water season. Along the Yukon coast, the ice is often much closer; in heavy-ice years it remains hard ashore west of Herschel Island. The ice-limited fetch results in relatively small waves: significant wave heights are typically less than 4 m and peak periods less than 8 s in coastal waters (Pinchin et al., 1985; Solomon et al., 1993). In the vicinity of the Mackenzie Delta and in Kugmallit Bay, the very shallow slope and soft bottom of the shoreface leads to considerable wave energy dissipation and reduced wave heights at the shoreline. Along the Yukon coast and the northern part of the Tuktoyaktuk Peninsula, the shoreface slope is typically steeper, exposing the shoreline to higher-energy waves.

In spite of the restricted wave conditions and the short open-water season, many parts of the coast are retreating rapidly (Mackay, 1986). Erosion rates of 2 m a^{-1} are common and cases of up to 20 m a^{-1} have been reported (Forbes and Frobel, 1985; Harper et al., 1985; Solomon et al., 1993). Rapid coastal erosion results in part from thermal instability of the ice-bonded unconsolidated coastal bluffs. Longshore transport of material eroded from coastal bluffs produces beaches, spits, and nearshore platforms (Forbes and Frobel, 1985; Hill et al., 1990; Hill and Frobel, 1991; Ruz et al., 1992). In addition, the role of frazil- and anchor-ice entrainment and associated erosional processes on the shoreface, proposed by Reimnitz and Barnes (1987) as a major cause of coastal retreat in northern Alaska, remains to be determined in the Canadian Beaufort Sea.

Water levels are governed more by storm surges than tides. Whereas the tidal range is less than 0.5 m, storm surge levels of up to 2.4 m above mean sea level have been mapped from log debris lines (Harper et al., 1988; Forbes, 1989). Northwest winds typically cause positive surges and easterly winds cause negative surges (Henry, 1975). A variation in water level of 1 m over a 12 hour period is not unusual (Forbes, 1981; Solomon et al., 1992; Solomon and Forbes, 1993).

Measurements of coastal erosion and accretion have been made intermittently along the Beaufort coast since the 1960s. In general, cliff retreat proceeds by various combinations of mechanical erosion by waves, block failure resulting from thermal niche and wave undercutting and ice-wedge thaw, surface slips caused by active-layer detachment, and retrogressive thaw of ice-rich coastal bluffs. Retrogressive-thaw in materials with high ice content leads to rapid volume loss and mudflow transport of remaining sediment to the beach. Retreat rates are modulated by the time required for waves to erode and remove the material supplied to the beach by these processes. The relative importance of waves, thaw consolidation, and sea-ice impact for shoreface profile adjustment varies along the coast. In the Mackenzie Delta and Kugmallit Bay area, thaw consolidation and wave processes may predominate (Kurfurst and Dallimore, 1991; Solomon et al., 1993) whereas sea ice may play a greater role where the shear zone approaches the coast more closely, particularly west of Herschel Island (Reimnitz et al., 1990; Forbes and Taylor, 1994). The presence of excess and massive ice close to sea level is considered to be a cause of rapid cliff erosion in some areas. At the community of Tuktoyaktuk (Figure 3), erosion rates may be accelerated by the thaw of massive ice lenses beneath the seabed (Shah, 1978). The resulting thaw consolidation may steepen the shoreface profile, allowing more wave energy to be expended against the beach and coastal bluffs.

Spits and barrier islands along the Tuktoyaktuk Peninsula are migrating landward at rates up to 4 m a^{-1} (Héquette and Ruz, 1991). Some spits along the Yukon coast show similar behaviour (McDonald and Lewis, 1973). Rates of retreat of bluffs and barrier beaches are comparable. This suggests that, in many cases, processes leading to seaward sediment transport on the shoreface may be of primary importance (Héquette and Hill, 1993, 1995; Reimnitz and Barnes, 1987).

Since the completion of the 1992 field program, three other field programs have been completed under the same project. These included a late-winter geophysical and coring program on Richards Island and the outer Mackenzie Delta in April 1993 (ref.), repeated aerial photography of some of the 1992 airphoto sites on 24 July 1993 (in collaboration with GWNT), and a 1994 field program (Solomon, 1994), supplemented by another set of photography to document the effects of a major storm in September 1993.

DAILY LOG

26 July (JD 208): Dartmouth to Edmonton

Forbes, Frobel, Solomon travel Halifax-Toronto-Edmonton on Air Canada flights AC149 and AC135, departing YHZ at 1655 ADT, arriving YEA at 2110 MDT. Stay overnight in Leduc, Alberta.

27 July (JD 209): Edmonton to Inuvik

Party travel Edmonton-Inuvik on Canadian North flight CP444, departing YEA at 0830 MDT, arriving YEV at 1335 MDT. Begin to organize gear at Inuvik Research Centre.

28 July (JD 210): Inuvik

Organizing gear and permits in Inuvik. Test kayak-mounted echo-sounder in Mackenzie Delta channel. Meet with Larry Dyke, Terrain Sciences Division, to discuss Taglu Island studies and suitable sites for erosion monitoring. Meet with Willem van de Pypekamp, Shell Canada Limited, to discuss issues of mutual interest in the outer Mackenzie Delta. Forbes meets with Dan Frandsen, Northern Yukon National Park, to arrange permit. Solomon contacts Marshall Netherwood, Joint Environmental Impact Screening Committee, to confirm permit arrangements. Helicopter C-GTLB with pilot Steve Creagh arrives from Tuktoyaktuk around 2100 MDT.

29 July (JD 211): Yukon coast from Alaska border to Kay Point

Depart Inuvik about 1018 MDT in helicopter GTLB, refuelling at Shingle Point. Continue along coast to Alaska-Yukon boundary (**site 5010**), arriving about 1300 MDT. Coastal surveys at this site date back to the International Boundary Commission survey of 1912, with subsequent visits in 1972 (McDonald and Lewis, 1973) and 1984 (Forbes and Frobel, 1985). Present baseline and GSC benchmarks were established in 1991 (Figure 4; Solomon et al., 1992). Field party surveys a cross-shore profile on line 03 normal to the baseline from the middle benchmark (GSC-334), using theodolite and staff for the cliff and beach survey and the kayak and AGC echosounder for the nearshore profile (the bathymetric data were subsequently found to be unreliable). Airphoto targets (white cotton crosses) are placed at the two outside benchmarks on the baseline (GSC-333 and -335). The taped distance between targets is 120 m. A hand grab (**sample 001**) is collected from the pebble swash bar at the base of the subaerial beach.

The next stop is at Komakuk Beach (**site 5011**), where Gillie (1987) established a line in 1986 off the west end of the airstrip. This was resurveyed in 1991 (Solomon et al., 1992), when a second line with benchmark GSC-336 was established west of Gillie's line. Helicopter GTLB lands at Komakuk at 1607 MDT and airphoto targets are placed on Gillie's marker (steel rebar and wooden stake) and the GSC benchmark (Figure 5). The subaerial portion of line 02 (west line) is resurveyed with theodolite and staff.

Depart Komakuk Beach at 1720 MDT and continue east along the coast to Kay Point (**site 5280**). Measurements of cliff recession, spit morphology, and estuarine sedimentation in this area (Figures 6 and 7) were initiated by McDonald and Lewis (1973), Lewis (1975), Lewis and Forbes (1975), and Forbes (1981). Subsequent surveys were undertaken in 1984 by Forbes and Frobel (1985), in 1985 by Dallimore (pers. comm., 1985), and in 1986 by Gillie (1987). Field party inspects the polygon cliffs (zone 1 of Lewis and Forbes, 1975) from Kay Point southeast approximately 300 m (Figure 6A). Former reference marks near the point are missing but a number are located farther alongshore. Distance of 1.7 m is measured from the cliff top to peg 6, which is then repositioned 25.9 m from the cliff edge. Airphoto targets are placed at the repositioned peg 6 and at a marker 15 m landward of peg 6 on a bearing of 355°magnetic. Depart Kay Point at 2015 MDT and return to Inuvik about 2130.

30 July (JD 212): **Mackenzie Delta front and Kay Point**

Helicopter GTLB departs Inuvik at 1018 MDT and sets down on Mackenzie Delta front east of Ellice Island (**site 5360**) at 1108. This site (known informally as the "Ellice Island site") was established in 1986 by Gillie (1987) and resurveyed in 1991 (Solomon et al., 1992). Distances to the eroding face of the delta plain are measured from Gillie benchmark II (rebar with cap) and rebar markers "400" and "300" respectively 100 m and 200 m further east. Airphoto targets are placed 100 m apart on benchmark II and r-bar "400" (Figure 8).

Depart Ellice Island site at 1145 MDT and proceed to Tent Island (**site 5340**). This site was also established in 1986 by Gillie (1987) and resurveyed in 1991. Helicopter GTLB lands at Tent Island at 1211 MDT. We place airphoto targets on Gillie benchmark I at west end of baseline and at a 2x4 wooden stake ("100") located 100 m to the east (see Figure 4 of Solomon, 1994).

Lift off Tent Island at about 1230 MDT, stop to refuel at Shingle Point, and land at Kay Point (**site 5280**) at zone 3 of Lewis and Forbes (1975) circa 1340 MDT. This site (Figure 6A) is marked by three aluminum pipe benchmarks (J.R. Mackay anti-heave design) installed about 70 m apart on an approximate shore-parallel baseline in 1974 or 1975. A profile over the cliff and across the beach is surveyed with theodolite and staff on line 2 (middle benchmark consisting of an aluminium pipe painted blue), passing through the site of a 1976 borehole now located close to the cliff edge (Figure 6A). In addition, a nearshore profile is surveyed with the kayak and AGC sounder, positioned by theodolite (here again, the data are subsequently found to be unreliable). An airphoto target is placed at the blue pipe (Figure 6A).

After finishing at zone 3, we move out onto Kay Point spit (**site 5275**) to zone 9 of Lewis (1975). This site (Figure 7) consists of five lines established about 1 km from the north end of the spit (Figure 6B) in 1974, resurveyed 10 years later by Forbes and Frobel (1985) and two years after that by Gillie (1987). Surveys include nearshore profiles on lines 2 and 4 with the kayak (positioned by theodolite) and AGC sounder (data unusable again). A line is also run across the subaerial spit on line 4 using theodolite and staff. A white cotton cross (airphoto target) is placed on line 3 (centre line rear pipe) and driftwood crosses are constructed at the rear pipe markers on lines 1 and 5 (Figure 7). Distance between targets is 40 m (80 m between outside driftwood crosses). We are unable to resurvey the subaerial part of line 2 and have to abandon plans to survey and target zone 25, farther out the spit, because the helicopter is required in Tuktoyaktuk that evening. Depart Kay Point circa 1730, returning to Inuvik at 1915 MDT.

31 July (JD 213): **Inuvik to Tuktoyaktuk**

Finish organizing gear in Inuvik. Meet with J.R. Mackay (University of British Columbia) to discuss coastal erosion issues. Forbes, Frobel, and Solomon travel Inuvik-Tuktoyaktuk on Aklak Air flight 403, arriving YUB about 1500 MDT. Begin organizing gear at Polar Continental Shelf Project (PCSP) base.

1 August (JD 214): **Tuktoyaktuk to Atkinson Point via Tibjak Beach**

Helicopter C-GPCX takes load of gear and food to Atkinson Point camp first thing in the morning, returning with Al Todd. During this time, some effort is made to test and adjust the AGC sounder, but it soon becomes clear that it is giving no consistent results and an alternative system is needed. Ernie Sergeant and Ron Wilson (Canadian Hydrographic Service) kindly offer the use of their Micronar sounder, which is then used for the remainder of the program.

Helicopter GPCX departs Tuktoyaktuk with Forbes, Frobel, Solomon at 1042 MDT, arriving at Tibjak Beach (**site 5202**) six minutes later (Figure 1). This was the site of a detailed nearshore and beach monitoring program in 1988 (Héquette et al., 1989; Héquette and Hill, 1993, 1994). We search the entire length of the beach for survey markers, but are unable to locate any. A new baseline 200 m long bearing 175.2° magnetic is established with benchmarks GSC-492 and GSC-494 positioned at opposite ends and benchmark GSC-493 in the centre (see Figure 6 of Solomon, 1994). Five profile lines are laid out at 50 m intervals normal to the baseline. Nearshore bathymetric profiles are surveyed at each of these newly established lines with the kayak and Micronar sounder, positioned by Geodimeter. The profiles are extended up across the beach to the marsh and tundra surface behind, also using the Geodimeter system. All further nearshore and ground surveys during the field program are done in this way (see later section on coastal survey methods). Airphoto targets are placed at benchmarks GSC-492 and GSC-494 . Distance between targets is 200 m. Helicopter GPCX returns at about 1800 MDT and transfers field party to the Atkinson Point camp.

Atkinson Point (Figure 9) is the site of a joint university-government program to investigate nearshore wave processes, sediment transport, and associated beach and shoreface adjustment. In addition to ourselves, the participants include Arnaud Héquette, Marc Desrosiers, Stéphane Campeau, and Matthieu Avery of l'Université Laval, Phil Hill and Gilles Desmeules of l'Université du Québec à Rimouski, and Axys personnel Tony Ethier and Al Todd under contract from the Marine Environmental Data Service to deploy a directional Waverider buoy. The following two days are devoted to participation in this program.

2 August (JD 215): **Atkinson Point**

The plan is for the entire group to collaborate in the recovery and redeployment of two S4DW directional wave and current meters, which were installed on 24 July with data capacity for about 10-12 days. The morning is fine but moderate northwest winds are forecast and it soon becomes clear that conditions are unsuitable for the instrument recovery. Some time is devoted to preparing the optical backscatter system and streaming trap bags for sand transport measurements. After lunch, Hill, Frobel, and Forbes go out to survey the west barrier shoreline of Atkinson Point (**site 5191**), while Solomon continues working on equipment preparations. A strong northerly wind comes up during the survey, bringing fog off the water, restricting visibility, and slowing progress. Several instrument setups are required, involving use of a Zodiac inflatable boat to cross two inlets. During the evening, we finish preparing the streaming traps for possible use if the storm continues the next day.

3 August (JD 216): **Atkinson Point to Tuktoyaktuk**

As the storm has abated and the sea is calm, a major effort is made to recover the S4DW wave and current meters. By late morning, both instruments are in the cabin and the data have been downloaded to a PC notebook computer and archived on diskette. During the afternoon, these instruments are redeployed, with the addition of an optical backscatter system (OBS) at the east site. The instruments are placed 0.82 m off the seabed with OBS sensors at 0.19 m (#197), 0.35 m (#198), and 0.55 m (#199) above the seabed. Survey work for the remainder of the day includes tying in the MiniRanger ground stations and profile lines on the eastern spit of Atkinson Point (**site 5193**). Unfortunately, time runs out before the survey can be extended to lines 1 and 2 (1973 lines established by C.P. Lewis). In addition, a profile line is resurveyed across the beach and dunes at Atkinson Point (**site 5192**) in a small area of coastal dunes near the tower (Figure 9). Helicopters GPCX and GTLB arrive circa 1900 MDT to transport Forbes, Frobel, Solomon and gear to Tuktoyaktuk.

4 August (JD 217): **North Head**

Helicopter GTLB, carrying Forbes, Frobel and Solomon, departs Tuktoyaktuk about 0850 MDT for North Head (**site 5045**) on Richards Island (Figures 10 and 11). Field party is dropped off with survey and survival gear. Nearshore and beach profiles are surveyed at lines 39, GA, and 01 on the feature known informally as "Wolfe Spit". Line 39 was established in 1990 (Hill and Frobel, 1991) and resurveyed the following year, when line 01 was established (Solomon et al., 1992). Airphoto targets are placed at benchmark GSC-318 and at rebar near Dyke tripod, 92 m apart on line 39. The survey at line GA (Gillie's line NPa) is the first since it was established in 1986 (Gillie, 1987). An additional survey (line 01) is completed at line NP1 (Gillie, 1987; see Figure 2 of Solomon, 1994) on the cliffs a short distance west of the proximal end of the spit (**site 5046**). Distances to the cliff edge are measured from four other markers, two each on either side of Gillie's benchmark I. Radio contact is established with PCSP in Tuktoyaktuk at 1850 and the party is picked up by helicopter GTLB at 2000 MDT.

5 August (JD 218): **Richards Island and Beluga Bay**

Forbes, Frobel, and Solomon depart Tuktoyaktuk in helicopter GTLB shortly after 0800 MDT, to be dropped off at site known informally as "MR2 island" (**site 5040**), part of the Reindeer Islands complex along the northeast coast of Richards Island (Figure 11). Surf driven by the strong easterly wind is breaking over the bar system, making conditions unsuitable for nearshore surveys. However, profiles of the beach and inner nearshore out to wading depth are completed on each of the three 1991 lines at site 5040 and the survey is continued along the cliff edge to the northwest. We also undertake a detailed survey of the headwall and discharge channel of a large retrogressive thaw failure adjacent to the site.

On completion of this work, the survey party walks over the hill to "MR2 north" (**site 5041**), where the distance to the cliff edge is measured at line GL, equivalent to site L of Gillie (1989), originally established in 1987 and resurveyed in 1990 and 1991. A brief time is devoted to exposures of Kittigazuit Sand in a nearby gully (**samples 002 and 003**) and along the outer cliffs, while walking back to the drop-off point for lunch. Helicopter GTLB returns at 1315 and remains with the party for the rest of the day.

Stops are made at sites K and E of Gillie (1989) to remeasure the distance to the cliff edge (sites 5043 and 5044 in Figure 11). We then proceed to an area of extensive sand flats (Figure 10) located along the western shore of Richards Island in Beluga Bay (**site 5390**). A profile is surveyed from the exposed centre of the flats seaward to the water line. Three push cores (**samples 005, 006, 007**) and 2 grabs (**samples 004 and 008**) are taken along a transect across the flats. GTLB departs the sand flats at 1600 and proceeds to Taglu Island (**site 5395**). At this site (Figure 1; see also Figure 3 of Solomon, 1994), we establish a baseline along a bearing of 056°magnetic, delineated by three points at 100 m intervals marked with a set of cloth markers and a driftwood cross. Distances to the delta-front scarp are surveyed normal to the baseline from each of the three markers. Helicopter GTLB and the survey party return to Tuktoyaktuk.

6 August (JD 219): **aerial photography and surveys at Atkinson and Toker Points**

Forbes and Frobel depart Tuktoyaktuk at 0950 in helicopter GTLB, heading for Atkinson Point. The ceiling drops steadily from about 120 m (400 feet) over Tuktoyaktuk to near sea level south of Hutchison Bay, where a stop is made at Ken Swayze's archeology camp to drop off baking. About 20 km west of Atkinson Point the aircraft breaks out of the cloud into a magnificent clear sky. After a brief stop at the camp, GTLB sets down at **site 5193** on the eastern spit of Atkinson Point (Figure 9). Forbes and Frobel resurvey lines 1 and 2, the profile lines originally established in 1973 by C.P. Lewis and resurveyed in 1984 (Forbes and Frobel, 1985).

With the Atkinson Point surveys completed by 1300, GTLB proceeds west. Superb views of the coastal geomorphology are afforded by extremely low water level. At Toker Point (**site 5410**) we spot lines TP6, TP7, and TP8, established in 1986 by Gillie (1987) and land near TP8 (Figure 12). Distances to the cliff edge are measured at all three lines. GTLB then moves to Toker Point line TP11 (**site 5413**), where a full cross-shore profile is surveyed. The survey party returns to Tuktoyaktuk at about 1545.

Meanwhile, Aklak Twin-Otter C-FIOJ arrives at Tuktoyaktuk with Paul Roy at 0900 to pick up Solomon for the aerial photography (Figure 2). The weather is clear at 0700 but fog has come in by 1000. Weather reports from Shingle Point and Komakuk DEW Line stations indicate clear weather there. At 1015 the decision is made to fly west until the weather is sufficiently clear to begin taking air photographs. The first photos (1:6000 nominal scale) are obtained over Tent Island (1 line), after which lines are flown at King Point (1 line), Kay Point (3 lines), Spring River (1 line), Stokes Point (1 line), and the Alaska-Yukon border (2 lines). FIOJ lands at Komakuk Beach at 1215 to refuel, taking off again at 1245. Lines are flown at Shingle Point (1 line), Ellice Island (1 line), Big Lake to Taglu Island (1 line), and Pullen Island (3 lines). The delta sites are difficult to line up due to the lack of landmarks. FIOJ lands at Tuktoyaktuk at 1458 to refuel, taking off again at 1540. The aircraft then proceeds to North Head, where a block of 6 lines is completed. The remaining 1:6000 scale photography covers Atkinson Point (2 lines), Toker Point and Tibjak Beach (4 lines), and Topkak Marsh, Topkak Point, Tuktoyaktuk, and the mouth of East Channel of Mackenzie River (1 line each). FIOJ returns to Tuktoyaktuk at 1815 for fuel. The second phase of the air photo mission begins at 1900, when FIOJ departs Tuktoyaktuk with Roy, Solomon, and Forbes aboard to collect high-level photography (1:20,000 nominal scale) over the outer Mackenzie Delta. The haze and low sun make navigation difficult, but 7 lines of photography are completed before FIOJ returns to Tuktoyaktuk at 2115 MDT.

7 August (JD 220): **Tuktoyaktuk**

After cutting and capping Beluga Bay cores in the morning, we go out to survey profiles at Tuktoyaktuk (**site 5012**). Two beach profiles are resurveyed and nearshore profiles are obtained on the spit (Figure 3) south of the old school (benchmarks GSC-287 and GSC-289 on lines 1 and 2). Nearshore and beach profiles are also surveyed at the cemetery (1949 Dominion Land Survey benchmark and GSC-290 on line 3) and at the RCMP garage (line 4). Benchmark GSC-290 (line 3) is now located within the cemetery fence, which was moved seaward within the past year. These surveys are tied into the Canadian Hydrographic Service (CHS) benchmark 9 near the shore just north of the PCSP helicopter pads. Benchmark 9 has been tied into the benchmark in the PCSP garage by Ernie Sergeant of CHS on August 1.

During the afternoon, Solomon pays a visit to the office of the Inuvialuit Lands Administration.

8 August (JD 221): **Tuktoyaktuk**

Packing gear and working on data. A storm blows up after 1800. About four hours later, we go out to observe waves breaking against the shore protection. The water level is above the base of the protection and waves are driving driftwood logs like battering rams against the bags.

9 August (JD 222): **Inuvik**

The storm has abated overnight. After breakfast, Solomon and Forbes go out to observe shore damage. The water level has diminished by about 0.5 m and boats are stranded along the shore. The beach at lines 1 and 2 appears to be wider and flatter. There has been some undercutting and driftwood damage at lines 3 and 4.

Forbes, Frobel, and Solomon depart Tuktoyaktuk at 1115 on an Aklak flight (Islander C-GGYY), landing at the Inuvik town strip, where we are met by Les Kutny of the Inuvik Research Centre (IRC). Packing gear in the AGC warehouse at IRC during the afternoon.

10 August (JD223): **en route to Halifax**

Forbes, Frobel, and Solomon travel Inuvik-Yellowknife-Edmonton-Toronto-Halifax on NWT Air and Air Canada flights AC8952, AC126, and AC634, departing Inuvik at 0745 MDT, changing aircraft in Yellowknife, departing Edmonton at 1205 MDT, and Toronto nominally at 1915 EDT. After leaving gate 70 on time, we sit for two hours on the tarmac, waiting out a dramatic lightning storm. There is fog at Halifax but we get in on the second attempt at 0040 ADT (11 August).

METHODS AND TECHNICAL COMMENTS

Coastal surveys:

Subaerial beach and cliff surveys were carried out using a Wild T2 theodolite and 4 m graduated staff (prior to 31 July) and a Geodimeter model 140H electronic total station with Geodat model 124 data logger and reflector targets mounted on a stadia rod (from 1 August on). At some sites the beach profile lines were extended into the nearshore using a Sealight folding kayak equipped with an echosounder. Position on the echo sounding line was established by triangulation with the theodolite prior to 31 July and by range and bearing using the Geodimeter thereafter. All surveys using the Micronar sounder were positioned with the Geodimeter and have an estimated horizontal precision of better than 0.5 m.

The first nearshore surveys were attempted using a Sandpiper DL echosounder. The LED display and a digital watch face were recorded with a video camera onto VHS tape, which was synchronised with the position fixes by time. Two problems were encountered with this arrangement. The first was that the distance between the camera and the display was critical and the jostling involved in getting in and out of the kayak was sufficient to cause the display to appear out of focus on the tape. More significantly, however, the Sandpiper DL output appeared to be unstable in water depths shallower than 10 ft (3 m). Experiments comparing the Sandpiper and Micronar performance suggested that the Sandpiper DL was saturated even at the lowest gain settings. The Micronar appeared to produce satisfactory results and was used for the remainder of the surveys. Unfortunately, bathymetric data from two sites along the Yukon coast (Kay Point and the Alaska-Yukon border), acquired using the Sandpiper DL sounder, were unusable and time and funds were insufficient to repeat the surveys at those sites.

The folding kayak was used for the nearshore surveys in order to minimize the time and costs involved in acquiring this type of data. Normally nearshore profiling would be performed with a Zodiac-type rubber boat and outboard motor. This would have required two helicopter flights and at least a full day at many sites to transport and assemble the necessary gear. The Sealight folding kayak fits conveniently against the bulkhead of a Bell 206L helicopter when the aft-facing seats are removed. The kayak weighs less than 20 kg and can be assembled by one person in less than 30 minutes. It proved quite seaworthy in waves of 0.5 m and was especially stable with side-mounted sponsons attached and inflated. For positioning, a Geodimeter prism was lashed to the cockpit bulkhead approximately 0.8 m above the waterline. The echosounder transducer was lashed amidships $\leq$0.1 m below the waterline. The Miconar display was hung around the paddler's neck on a lanyard. A water resistant two-way radio was taped to the paddle and, as fix points were relayed from shore, the paddler keyed the radio and reported the depth, which was then recorded by the shore survey party. This technique permitted underway assessment of the data quality and we reran segments at slower speed where rapid changes were noted on the first pass.

The latitude and longitude of most survey instrument positions, air photo targets and some benchmarks, sample sites and other survey points were obtained using a Magellan NavStar 5000 Global Positioning System (GPS) receiver. At each GPS site, 32 readings were averaged and recorded relative to the NAD 27 datum (Appendix C). The standard deviations for these positions ranged from 1.1 to 16.9 m.

Aerial photography:

Aerial photography was performed with a Wild RC10 9 inch (229 mm) format camera and a 154 mm lens. This was borrowed from the Polar Continental Shelf Project and operated under contract by Paul Roy. Kodak Doublex aerographic black and white film (type 2405) was used. We used approximately 625 ft (190.5 m) of film for 639 photographs. A scale of 1:6000 was chosen for most of the work in order to resolve horizontal changes of less than 0.5 m. An additional series of high-level photographs (1:20,000) was shot to provide regional coverage of the outer Mackenzie Delta and several of the channels. Approximately 260 line-km of 1:6000 scale and 130 line-km of 1:20,000 scale photography were obtained. The choice of flight lines was dictated in part by the availability of ground surveys.

Ground control markers consisted of cloth or driftwood crosses a minimum of 2.4 m long (two per site). The crosses were positioned by ground survey using GPS and other survey methods outlined above. Air navigation for the photography used a combination of GPS and dead reckoning.

SITE DESCRIPTIONS AND PRELIMINARY SCIENTIFIC RESULTS

Alaska-Yukon boundary (site 5010):

This site is characterized by a narrow sandy gravel beach 10 to 15 m wide, backed by a low cliff almost 6 m high. The cliff is developed in ice-bonded pebbly muds with ice wedges, which form a distinct polygonal pattern on the backshore coastal plain (Figure 4). Minor gullying along ice wedges extends back from the cliff line. Shallow slumping along the cliff is promoted by occasional wave attack at the base and by meltwater percolation and runoff, with local development of small fans at the top of the beach. The beach slope is typically about 8° to 9° (Figure 13). Although no bathymetric data are available for the nearshore in this area, the beach profile in 1991 fell off rapidly in fine pebble gravel at a slope of 13°. Irregular pits were present around ice floes grounded in the nearshore.

McDonald and Lewis (1973) reported 43 m of erosion over 60 years between 30 July 1912 (International Boundary Commission survey) and 17 July 1972. This represents a long-term mean rate of 0.72 m a^{-1}. Forbes and Frobel (1985) returned to the site on 28 July 1984 and measured a further 10 m of erosion over 12 years, equivalent to a mean rate of 0.83 m a^{-1}. Because the boundary marker used for these surveys disappeared after 1984, we have not been able to extend this series of measurements. The 1991 and 1992 surveys showed no measurable change at the top of the cliff on line 3 although there was some reworking of the cliff face (Figure 13).

Komakuk Beach (site 5011):

This site lies immediately west of the airstrip at the Komakuk Beach DEW Line station. It is in a slightly disturbed area of dissected ice-wedge polygons. The bank here is quite low, ranging from 2.0 m at line 1 to 1.2 m at line 2 (Figure 5). The beach is 20 to 30 m wide, expanding to more than 40 m a short distance to the west. The beach slope ranges from 4° to 11°. In 1992 a low swash bar was present at the base of a wide beach at line 2, while line 1 was characterized by a low berm (Forbes et al., 1993). A thin veneer of granules and fine gravel was present on top of the bank in this area and, more conspicuously, along the coast to the east of the barrier and lagoon complex on the east side of the DEW Line station. where the profile illustrated by Forbes and Frobel (1985) was located.

Line 1 at site 5011 was established in 1986 and resurveyed in 1991 (Forbes et al., 1993), showing a mean recession of the backshore scarp amounting to 0.76 m a^{-1} over the five-year interval. This line was not resurveyed in 1992 because there appeared to have been some artificial disturbance by heavy equipment working off the end of the runway. At line 2, established in 1991, the one-year recession of the scarp was about 0.6 m but the upper beach profile showed no significant change.

Kay Point spit (site 5275):

The spit at Kay Point is about 4.4 km long, enclosing the shallow lagoon and estuary of the Babbage River (McDonald and Lewis, 1973; Lewis and Forbes, 1975; Forbes, 1981; Forbes et al., 1994). It consists of a mixture of gravel and sand, with some cobble-size material at the proximal (northeast) end near Kay Point and very little gravel at the distal end. The spit is typically between 30 and 80 m wide at the proximal end, becoming wider (up to 300 m) toward the southwest. The maximum crest elevation (relative to mean water level) is about 1.2 m (Lewis and Forbes, 1975; Forbes and Frobel, 1985) and a cap of driftwood logs with some associated aeolian sand accumulation marks the crest in many places (Figure 7).

Since it was first mapped in the 1820s, the spit has migrated landward a considerable distance (Forbes, 1981). Photogrammetric analysis by Georgina Mizerovsky (in McDonald and Lewis, 1973) showed a mean landward migration of 41 m between 1952 and 1970, equivalent to a mean annual rate of 2.3 m a^{-1}. Migration occurs by extensive washover during storm surges, but the distribution of washover during any one event is uneven. Some parts of the barrier crest were completely reworked between our first surveys in the mid 1970s and a follow-up survey in 1984 (Forbes and Frobel, 1985), whereas wooden dowels marking survey lines at other locations (including zone 9) were intact, indicating little activity. Comparison of surveyed water lines in 1974, 1984, and 1992 (Figure 7) shows almost 10 m of washover on line 1 but little or no change along the backbarrier shoreline at lines 3 to 5. Net longshore transport toward the southwest along the front of the spit (Forbes, 1981) plays a part in the sediment budget and appears to be responsible for the development of irregularities in the seaward shoreline, equivalent to the longshore cell morphology documented on gravel-dominated drift-aligned beaches in other areas (e.g. Carter et al., 1990; Carter and Orford, 1991).

The spit connection at Kay Point is typically narrow and low. Tidal channels have developed there at least three times over the past 30 years, presumably initiated by channelized washover during storms. The spit may be particularly susceptible to concentrated overwashing in that area because of the rapid erosional retreat of Kay Point itself (McDonald and Lewis, 1973). There is some morphological evidence to suggest that abrupt offsets in the planform of the spit may be initiated at the proximal end as the headland retreats and then propagate alongshore over time intervals of several years.

Kay Point (site 5280):

This site has been described by Lewis and Forbes (1975) and Forbes and Frobel (1985). The outer part of the point, corresponding to segment 1 of Lewis and Forbes (1975), is a low terrace surface covered with ice-wedge polygons. The coastal cliff in this area is about 6 m high, exposing sand and sandy gravel overlain by about 1 m of peat (Lewis and Forbes, 1975). The sand beach at the base of the cliffs along the coast to the southeast becomes progressively narrower toward the point and typically vanishes altogether in the last 200 to 300 m (Figure 6A).

The dominant erosion process at this site is undercutting in combination with ice-wedge melt-out, leading to block failure by toppling of individual polygons of frozen sediment. Coastal retreat amounted to 90 m at the point between 1952 and 1970 (McDonald and Lewis, 1973), diminishing to 30 m away from the point toward the southeast. The mean recession measured between 1976 and 1984 was about 12 m or 1.5 m a^{-1} (Forbes and Frobel, 1985). Erosion measured between 1984 and 1992 amounted to 3.0 m a^{-1} on the three survey lines at zone 3. The 1976 borehole, which was almost 26 m back of the cliff edge in 1984, was only 1.3 m from the edge in 1992 (Figure 6A). A slower rate of recession was measured at peg 6, where the cliff retreated only 5 m during the 8 year interval between 1984 and 1992 (assuming that peg 6 was correctly identified).

Mackenzie Delta front (sites 5340, 5360, 5395):

The seaward margin of the subaerial delta front has been recognized to be widely erosional (e.g. Lewis and Forbes, 1975; Harper et al., 1985) although areas of extensive accumulation exist along the west side of Richards Island (Forbes and Frobel, 1985; see below) and delta progradation is occurring in some areas such as on the eastern side of Shallow Bay (Jenner and Hill, 1989). Much of the outer delta is a low-lying, almost flat, depositional plain covered with low grasses and sedges, interspersed with active and relict channels of widely varying dimensions and numerous shallow lakes and ponds

(Figure 8). The sediments underlying this surface at shallow depth consist primarily of highly organic silts that display very limited resistance to erosion when exposed and thawed along the outer delta front. These deposits form a low bank typically about 1 m high, fronted by a wide subaqueous terrace (Hill et al., 1990).

The monitoring sites at Tent Island (site 5340) and Ellice Island (site 5360) were established in 1986 by Gillie (1987). The site at Taglu Island was newly established in 1992 (this program). With limited helicopter time, we took no measurements at Tent Island in 1992, contenting ourselves with placement of the airphoto targets. However, measurements in 1991 (Solomon et al., 1992) showed erosion rates between 2.4 and 14.1 m a^{-1} between 1986 and 1991 and subsequent work has documented rates from 5.9 to 14.5 m a^{-1} between 1991 and 1994 (Solomon, 1994). At Ellice Island, where we measured rates from 4.0 to 6.5 m a^{-1} between 1986 and 1991 (Solomon et al., 1992), the 1992 measurements showed rates between 2.8 and 7.0 m a^{-1} over the previous year (1991-1992).

Beluga Bay (site 5390):

This site is on the east side of Beluga Bay along the western shore of Richards Island and is one of the principal areas of fine-sediment accretion at the front of the Mackenzie Delta. The dominant feature in this area is a wide silt bank extending more than 1.5 km from the inner shoreline to the mean water line in Beluga Bay (Figures 10 and 14). These extensive tide and storm flats, extending more than 10 km alongshore and becoming wider to the south, represent a significant sink for sediment discharged by Mackenzie Delta distributary channels between Shallow Bay and Richards Island. A vertically exaggerated profile (Figure 14) shows that the Beluga Bay bank rises to a narrow crest at an elevation of about 1.3 m (MWL datum). It has an almost linear backslope of about 0.0014 (0.08°) extending landward to a moat of the order of 100 m wide between the bank and the Richards Island shore (Figure 10). The seaward face of the bank has an identical mean slope but it is more irregular, interrupted by a broad upper sheet and a narrower ridge, both of which may represent swash accretion against the face. Small-scale sandy silt wave ripples were present on this lower section. The upper part of the seaward profile is slightly concave, possibly representing some wave reworking under storm conditions in this area, which was characterized by shallow erosional pans.

Two grabs (samples 004 and 008) and three push cores (samples 005, 006, and 007) were obtained across the profile surveyed at site 5390 (Figure 14). The cores were collected on the upper seaward face (005), at the crest (006), and midway down the backslope (007). The lengths of these cores and the observed compaction (both measured in the field) are shown in Table 1.

TABLE 1

Lengths of push cores collected on Beluga Bay flats (site 5390) and compaction measured in the field. Total depth of penetration is the sum of these values. Core locations are shown in Figure 14.

core	**length (mm)**	**compaction (mm)**	**penetration (mm)**
005	500	132	632
006	520	138	658
007	430	150	580

Cores 005 and 006 showed similar lithostratigraphy, consisting of an upper unit of laminated, olive-brown, very fine sandy coarse quartz silt with minor mica and finer silt with minor clay about 100 to 110 mm thick, overlying a faintly laminated or massive unit about 200 mm thick, consisting of well sorted quartz silt and minor clay. This middle unit had a higher water content and abundant spherical air pockets 0.1 to 2 mm in diameter. The lowermost unit in these cores had diffuse lamination defined by alternating brown and olive bands on a scale of 5 to 10 mm. Core 005 contained small pods of plant fragments in the upper unit and brown oxidation blebs near the basal 60 mm. Core 007, collected in an area of patchy grass colonization and algal growth on the middle backslope (Figure 14), had an upper unit 10 mm thick consisting of black clayey silt with oxidized organics, overlying 40 mm of black-mottled olive-green fine clayey silt with disrupted faint lamination. This was underlain, as at core sites 005 and 006, by a massive unit of well sorted silt with scattered small air pockets. From 210 mm to the base of the core, the sediment consisted of very finely and faintly laminated, olive-brown, sandy silt. Our intention had been to examine sedimentation rates in this area, but the low clay content of the cores and low ambient lead levels along the Beaufort Sea coast may preclude successful ^{210}Pb dating.

North Head (sites 5045 and 5046):

Several lines were resurveyed at North Head and on the spit extending east from the headland, known informally as "Wolfe Spit" (Figure 15). This site has been described previously by Hill et al. (1986a, 1986b), Wolfe (1989), Kurfurst and Dallimore (1989, 1991), Gillie (1989), Dallimore et al. (1991), Hill and Frobel (1991), and Solomon et al. (1992, 1994), among others. It consists of a headland with ice-rich cliffs 5 to 15 m high. Ice-rich upland tundra underlain by Kittigazuit sand and Toker Point diamict is interspersed with drained thermokarst lake basins underlain by ice-rich silts and diamicts. The latter are muddy and contain little gravel. Erosional processes include retrogressive-thaw failure, block failure, and sediment transport by waves and currents. The nearshore gradient to the 8 m isobath is about 0.0005 (0.03°), much less than at other sites remote from the Mackenzie Delta (Hill et al., 1986b). Pullen Island to the north (Figures 10 and 15) provides some protection but causes refraction of incoming waves around both sides of the island, producing orthogonal interaction locally along the coast of Richards Island under some circumstances.

The dominant storm waves in this area approach from the north and northwest. Sediments eroded from the cliffs at North Head are transported alongshore in both directions, but predominantly toward the southeast to feed the large adjacent spit complex (Figure 15). This has expanded since the first aerial photography in the 1930s and continues to do so, although extension of the spit platform may have diminished for the time being. A comparison of the 1985 and 1992 photography in Figure 15 shows some extension of the second high spit ridge (pale tone) and the development of an active outer beach/swash-bar ridge (in the area of the shore-parallel survey line indicated by + symbols in Figure 15A). This has grown on top of older spit-platform recurve structures. At the time of the 1992 survey, it had a crest elevation of about 0.7 m (MWL datum) and was cut at quasi-regular intervals by washover channels 0.2 to 0.4 m deep (Figure 16). In cross-section, the beach had a foreshore slope of about 0.004 (0.2°) rising to a small active swash bar at the front of the beach ridge, which is less than 100 m wide. A broad depression, frequently flooded (repesenting the top of the spit platform) separated this outer beach ridge from a higher washover-flat surface (in the area of Dyke's tripod, Figure 15), which appears to be an extension or incipient aggradation of the high spit.

Nearshore surveys at lines 1 and 39 show a barred profile with an inner welded-bar or low-tide terrace and two outer bars of comparable dimensions at the two sites. Beyond the outer bar crest at 105 to

125 m offshore, the profile is concave and becomes essentially flat beyond about 250 m (Figure 16). Comparison of profiles surveyed in 1990 (Hill and Frobel, 1991), 1991 (Solomon et al., 1992), and 1992 suggests that there has been some erosion and lowering of the profile during this time interval.

Tuktoyaktuk (site 5012):

Comparison of air photographs taken at the Hamlet of Tuktoyaktuk since 1968 (Solomon et al., 1993) indicates that the rapid erosion typical of the region had been effectively halted by the coastal protection measures in place in the early 1990s (Figure 17). However, this protection required annual maintenance and was suspected to be vulnerable to a major storm. We observed a short-lived (<12 hour) moderate storm and surge on the 8th of August 1992, during which the water level was above the base of the sand bags and ~0.5 m waves of about 5 s period were ramming driftwood logs against the bags. Some undercutting appeared to be occurring at the base of the revetment. Subsequent surveying (Solomon, 1994) indicated that profile steepening had occurred since the 1984 surveys predating the protection works (Forbes and Frobel, 1985). In September 1993, a major storm surge peaking at 2.15 m on the Tuktoyaktuk tide gauge caused massive damage to the sand-bag structure (Solomon, 1994).

Nearshore surveys at Tuktoyaktuk show a simple concave-upward profile, deepening abruptly from the water line to about 2 m water depth, consistent on lines 1, 2, and 3 (Figure 18). The mean slope to the 2 m isobath is between 2° and 3° on these lines but steeper at line 4. Outside this nearshore zone, the profiles are highly irregular and appear to represent a largely relict lag surface.

Tibjak Point (site 5202):

This site has been described in detail by Héquette and Hill (1993, 1995), among others. It is a relatively straight beach and bar complex facing the direction of dominant storm approach, and characterized by strong offshore flows and sediment transport under some conditions. Solomon (1994) presents a comparison of the 1992 and 1994 survey data and includes a figure showing the locations of the 1992 survey lines.

Toker Point (site 5413):

This is a complex area of irregular upland interspersed with numerous thermokarst lake basins and dissected by breached-lake embayments (Figure 12), similar in some respects to the terrain of northern Richards Island (Figure 10). A 1 km long narrow spit extends southeastward across a breached lake basin at the east side of the headland and a complex transgressive barrier with eastward-offset inlet occupies another basin on the west side. At Toker Point itself, a complex amalgamated breached-lake embayment is partially closed by opposing spits and part of the inner shoreline consists of almost flat-lying, flooded, ice-wedge polygon terrain. Gillie (1987) established five profiles on the eastern spit, three (TP6 to TP8 in Figure 12) along the cliffed section between the eastern spit and the Toker Point inlet, another on the supratidal flats on the east side of the inlet, one in an area of dunes on the west side of the inlet, and a final one (TP11 in Figure 12) a little further to the west. The lines identified in Figure 12 were revisited in 1992.

Sites TP6, TP7, and TP8 have low cliffs fronted by a sand beach of variable width and a wide, sandy, nearshore terrace. The cliff is 1.2 m high at TP6, 3.8 m at TP7, and varies from 1.8 to 2.5 m at TP8 (R. Gillie, unpublished field notes, 1986). Table 2 shows the taped distances from the 2"x2" stakes at these lines to the cliff edge in 1986 and 1992, the measured cliff retreat, and the associated mean erosion rates. These vary from 0.97 m a^{-1} at the higher TP7 site in the middle to 3.43 m a^{-1} at TP8 and 4.35 m a^{-1} at TP6. At TP11, west of the inlet, the cliff top retreated 8.9 m over the 6 years, averaging 1.49 m a^{-1} (Figure 19). The beach maintained a more or less constant slope but became narrower, essentially eliminating the wide backshore berm that was present in 1986. The low bar seen in Figure 19 in the 1992 survey data was noted qualitatively by R. Gillie (unpublished field notes, 1986).

TABLE 2

Cliff recession at Toker Point, Tuktoyaktuk Peninsula. See Figure 12 for locations. Data for 1986 is from Gillie (unpublished field notes, 1986); see also Gillie (1987).

line	**1986 x (m)**	**1992 x (m)**	**Δx (m)**	**rate (m a^{-1})**
TP6	74.6	48.5	26.1	4.35
TP7	58.0	52.2	5.8	0.97
TP8	57.0	36.4	20.6	3.43

Atkinson Point east (site 5193):

This is a wide, low, sandy spit with a linear nearshore bar, a thin but active aeolian veneer, and a steep washover slipface along the landward margin (Figure 20). Together with its western counterpart, this system is the focus of detailed study by Cloutier (1994) and Desrosiers (in prep.). Although surveys were completed on the western barrier (site 5191) and at the point, the results of most relevance to the Green Plan objectives relate to the resurvey of lines 1 and 2, originally established by C.P. Lewis in 1973. Figure 21 presents a comparison of the 1992 surveys with earlier data from 1984 (Forbes and Frobel, 1985) and 1986 (Gillie, 1987). The spit is about 320 m wide at line 1, expanding to about 460 m at line 2 (1992 data). The crest elevation in 1992 was about 0.8 m at line 1 and less at line 2. In contrast, the 1984 surveys indicate crest elevations greater than 1 m and a width of about 530 m at line 2.

Forbes and Frobel (1985) reported that line 2 had remained essentially stable since 1973. In fact, their data indicated that the barrier had accreted vertically, presumably by overtopping and aeolian transport, over the seaward 200 m of the profile, growing by up to 0.3 m at the crest, and there was a suggestion of seaward progradation although the 1973 beachface profile was incomplete. The results presented here indicate that, between 1984 and 1986, line 1 experienced erosion of the narrow crest ridge, some aggradation of the distal washover flats, and landward washover progradation of about 10 m. The beachface profile showed little change (Figure 21). At line 2, however, the beach retreated landward about 65 m during the same 2 year interval, accompanied by crestal downcutting of about 0.25 m. Most of the sediment removed in this process must have been transported alongshore or offshore because the spit at this line experienced very little washover progradation (Figure 21). By 1992, the beach at line 2 had retreated a further 22 m, with a landward washover advance of about 10 m. The crest elevation was further reduced and there was widespread downcutting of the distal washover flats. Again, though the volume involved was less than in the 1984-1986 time interval, much of the beach erosion must have been effected by longshore or offshore transport. Line 1 also experienced beachface retreat, amounting to about 12 to 15 m, between 1986 and 1992. This was accompanied by aggradation across the middle part of the profile, some downcutting toward the back, and limited washover progradation.

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Wolfe, S.A. 1989. Investigations of nearshore conditions across an aggrading coastal shoreline in permafrost, Richards Island, NWT. Unpublished M.Sc. dissertation, Queen's University, Kingston, Ontario, 188 p.

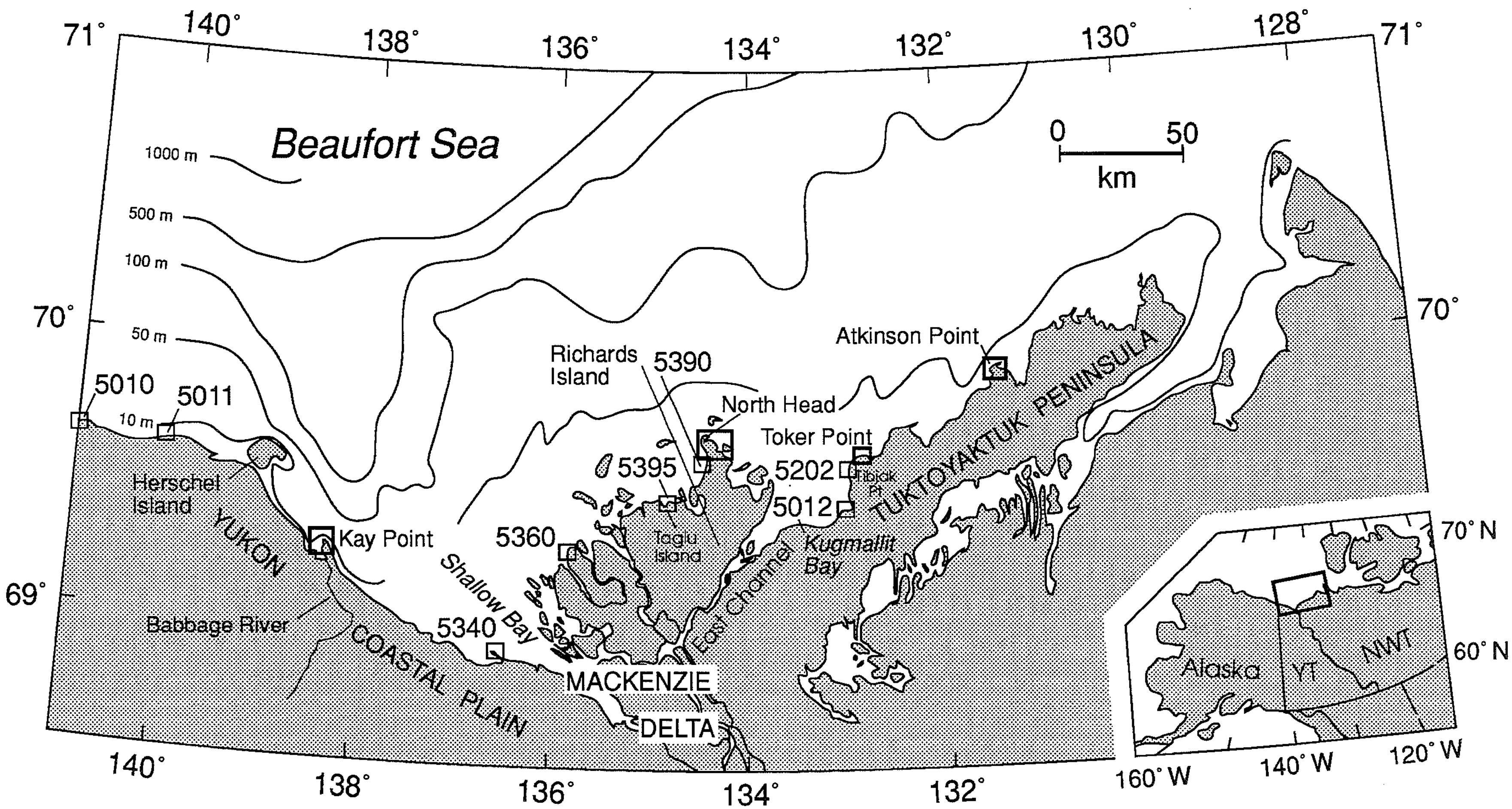

Figure 1: Beaufort Sea study area, showing coastal survey sites. Boxes at Kay Point, North Head, Toker Point and Atkinson Point show areas of detailed maps in Figures 6B, 11, 12, and 9 respectively.

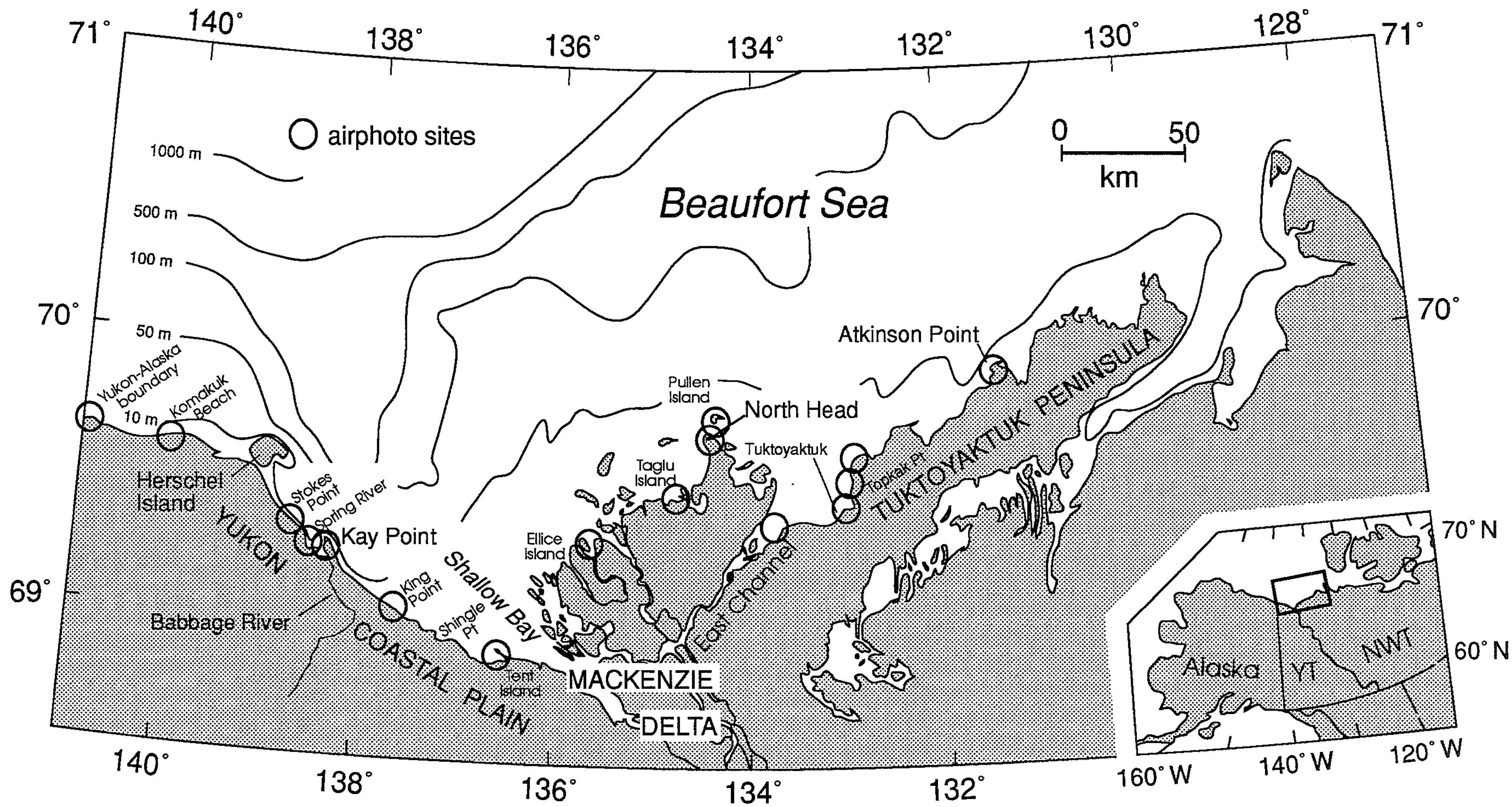

Figure 2: Sites covered by low-level (1:6000) aerial photography in 1992.

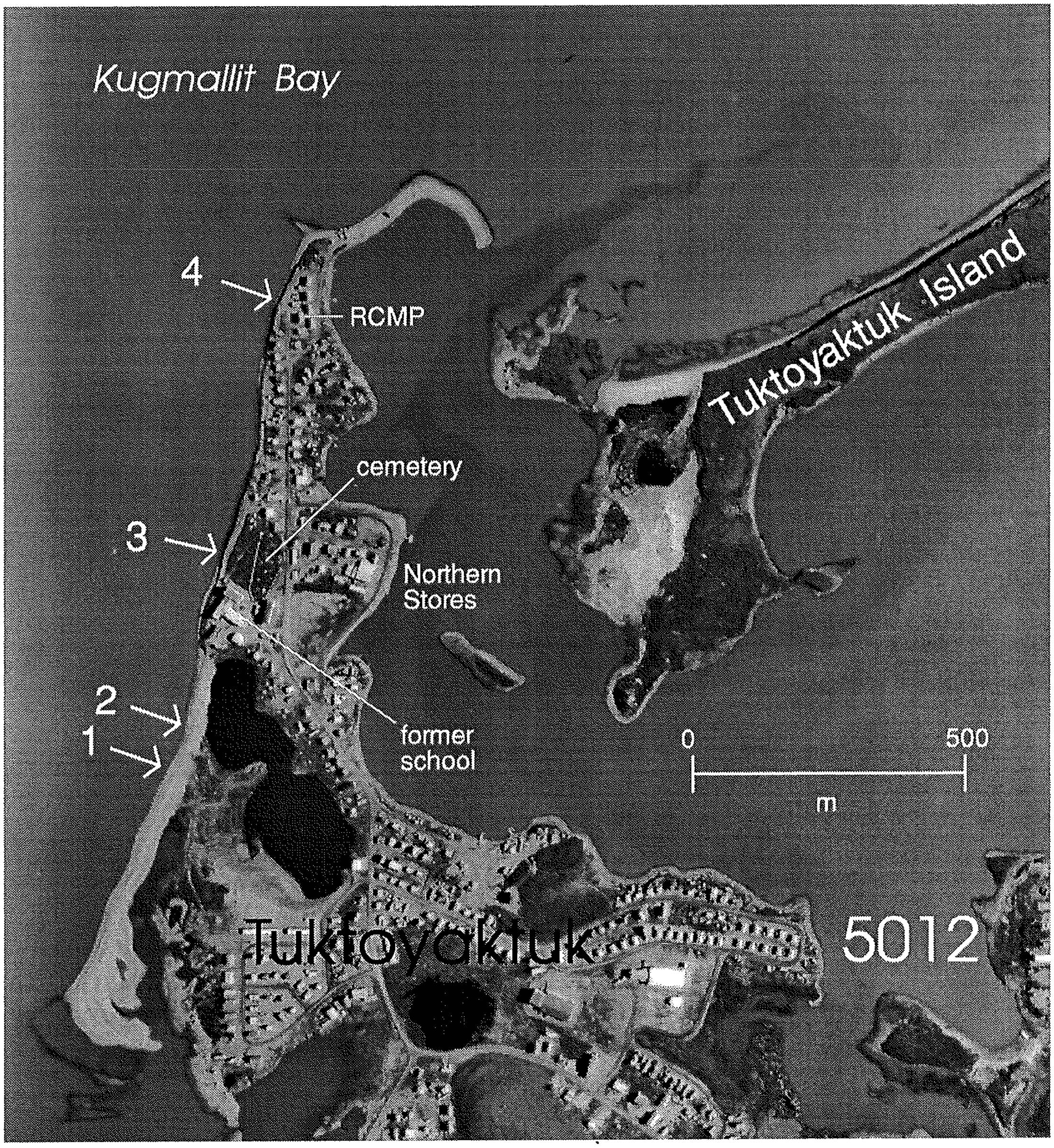

Figure 3:
Vertical airphoto of Tuktoyaktuk (site 5012) in 1993 showing eroding coast along the western shore of the peninsula and the locations of profile lines 1 to 4.

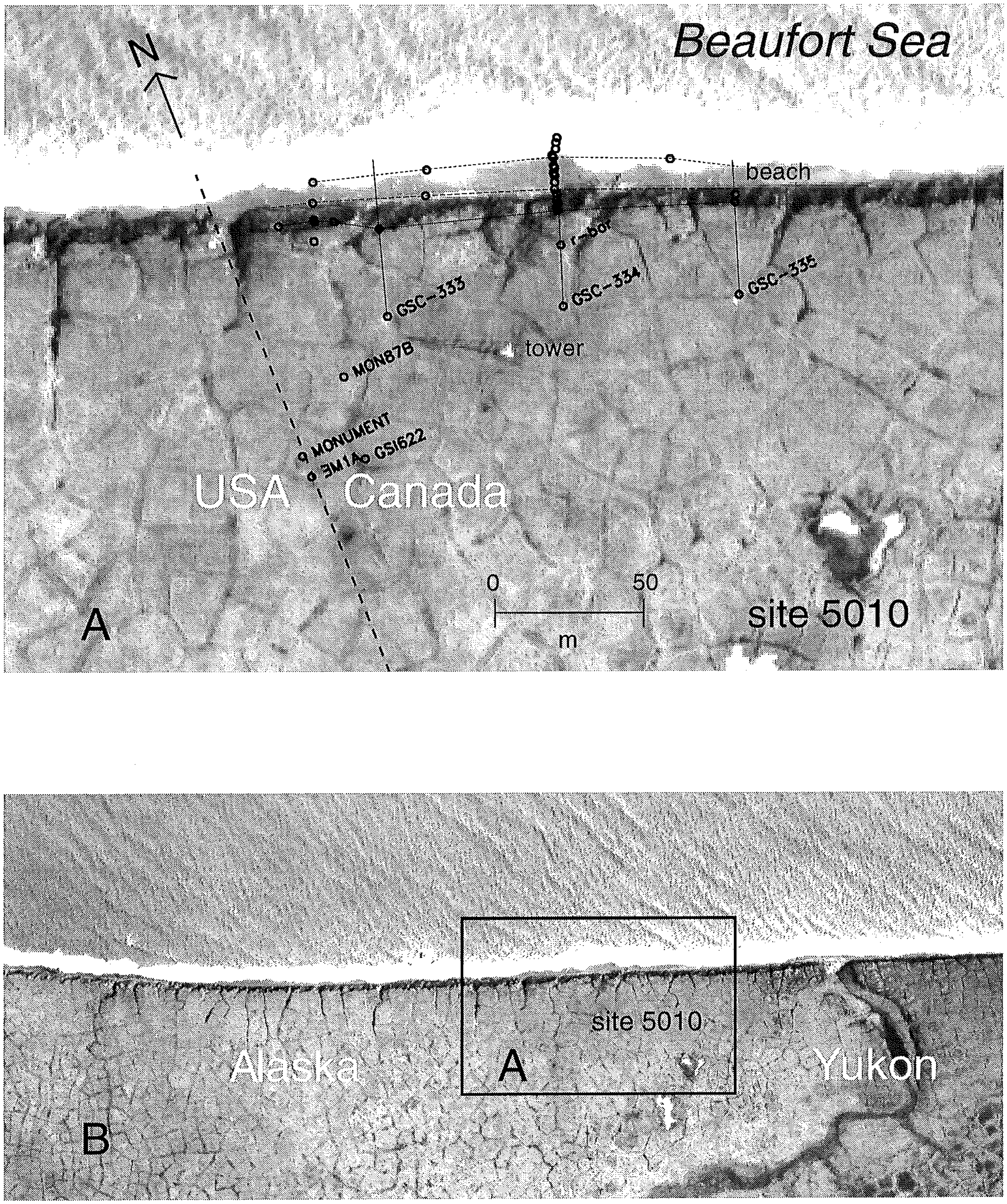

Figure 4:
Canada-USA international boundary (site 5010) on the Yukon-Alaska coast at 141°W.
A: Part of 1992 vertical airphoto 92001-132, showing the boundary (broken line) with associated monuments and survey baseline with GSC benchmarks. Circles show 1991 survey points, fine solid lines show profiles and top of cliff in 1991, fine broken lines show base of cliff and water level at time of 1991 survey (Forbes et al., 1993).
B: Expanded view of site (same photograph).

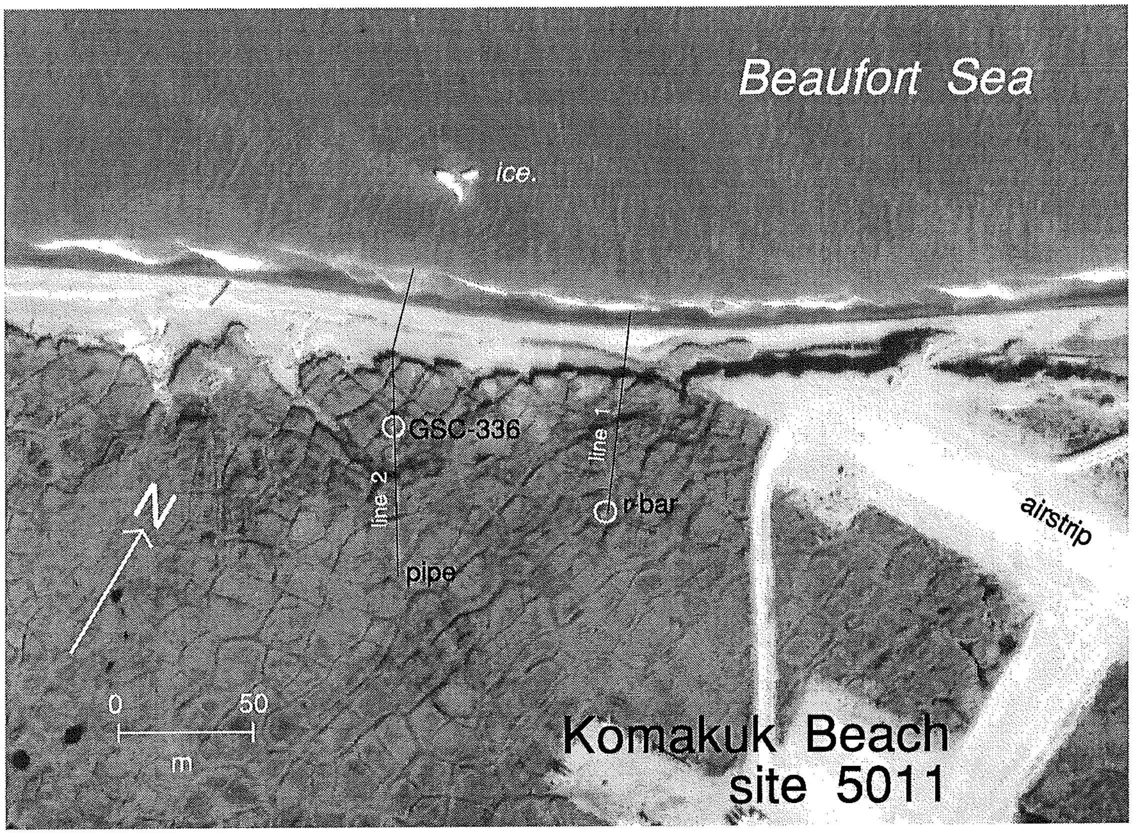

Figure 5:
Komakuk Beach (site 5011) on the Yukon coast. Part of 1992 vertical airphoto 92001-105, showing profile lines 1 and 2 (Gillie, 1987; Solomon et al., 1992) with low bank and beach at west end of airstrip.

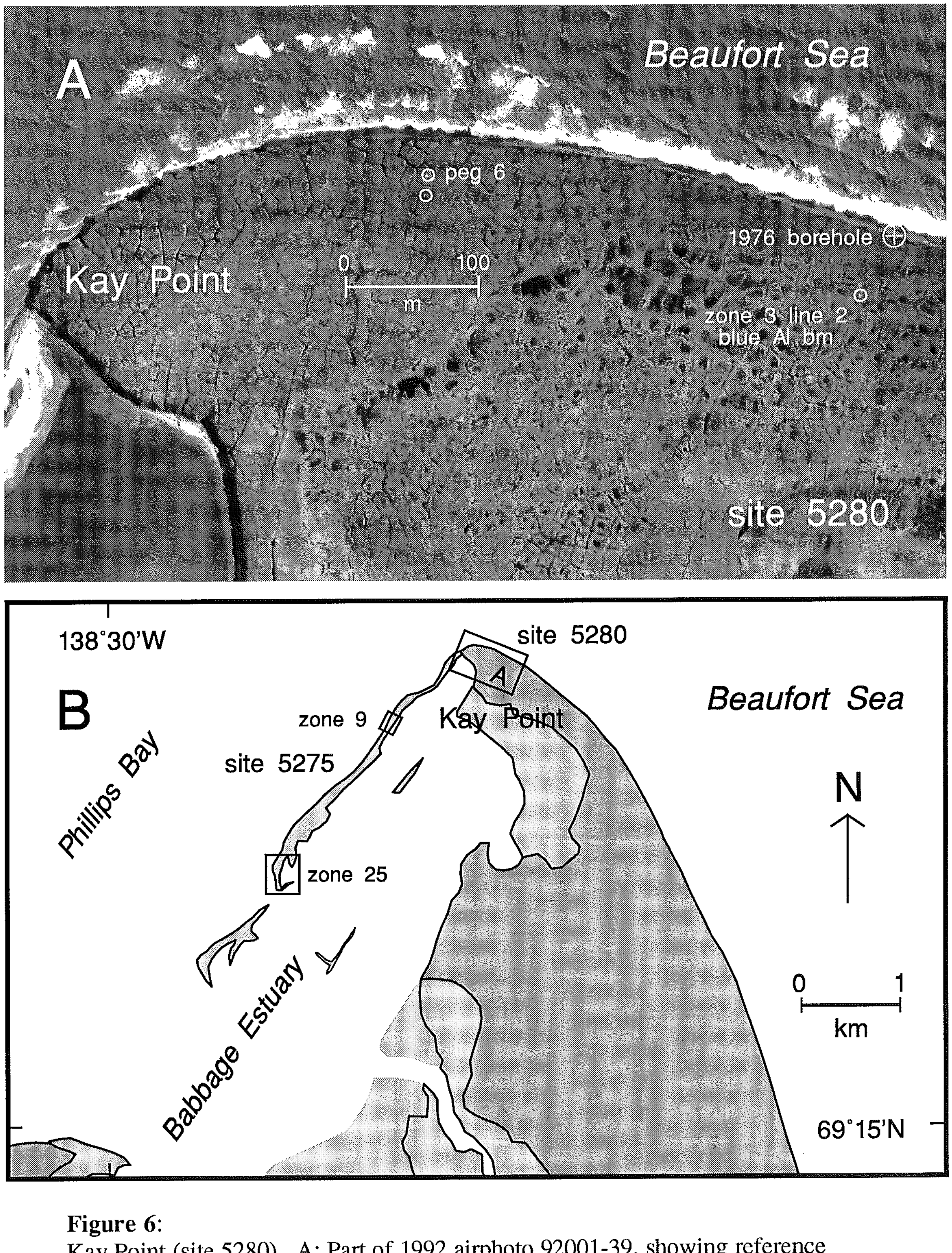

Figure 6:
Kay Point (site 5280). A: Part of 1992 airphoto 92001-39, showing reference peg 6 and line 2 of zone 3 (1992 survey line). B: Kay Point and Babbage Estuary, showing location of panel A and survey areas on Kay Point spit (site 5275). Box at zone 9 shows location of Figure 7.

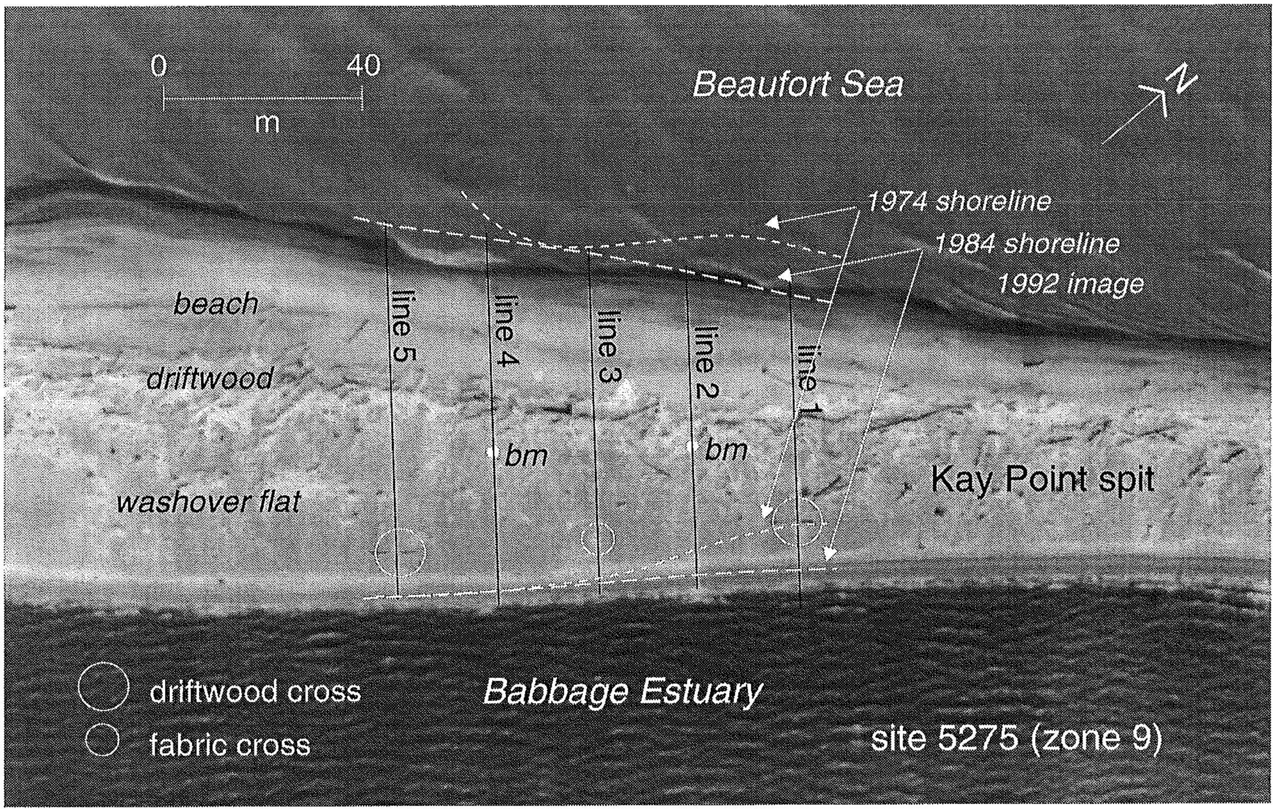

Figure 7: Kay Point spit (site 5275). Detail of 1992 airphoto 92001-47, showing targets on 1974 survey lines (see Figure 6 for location). Also shown are the surveyed positions of the 1974 and 1984 shorelines (Lewis and Forbes, 1975; Forbes and Frobel, 1985).

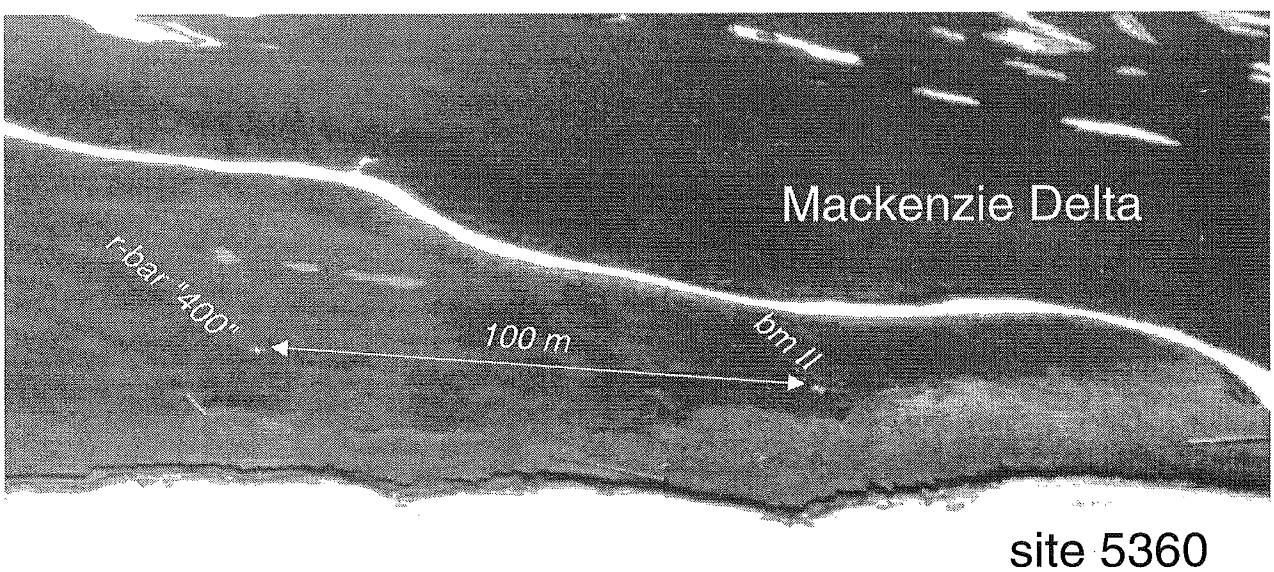

Figure 8: Oblique view of site 5360 (Ellice Island), showing low silt bank at seaward edge of Mackenzie Delta plain and airphoto targets at bm "II" and r-bar "400" (Gillie, 1987). Note driftwood logs strewn over washover flats immediately landward of the bank. See Figure 5 of Solomon (1994) for detailed location. [DLF/ 30 July 1992]

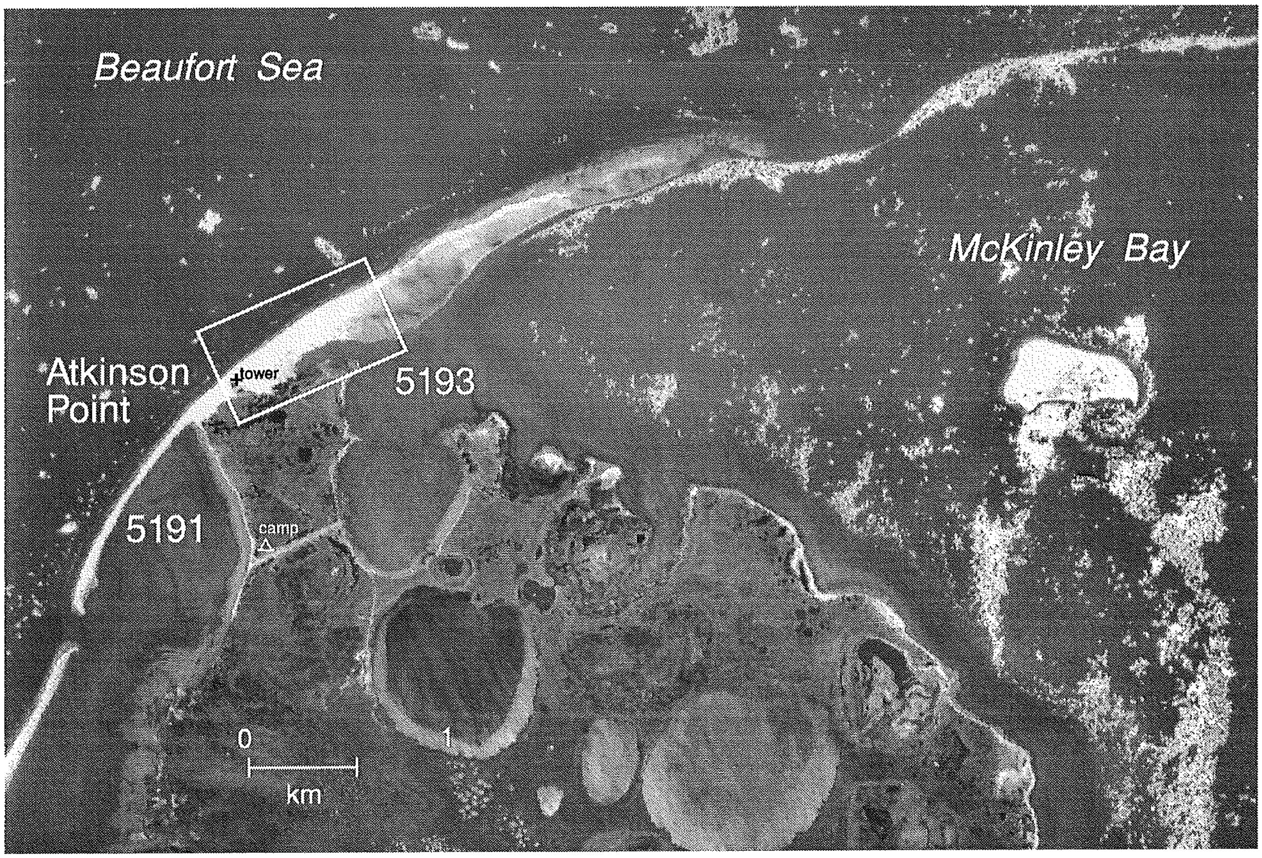

Figure 9:
Atkinson Point, showing western barrier (site 5191) and eastern spit (site 5193) with location of camp. Box indicates area shown in Figure 20. Part of 1985 vertical airphoto A26755-228.

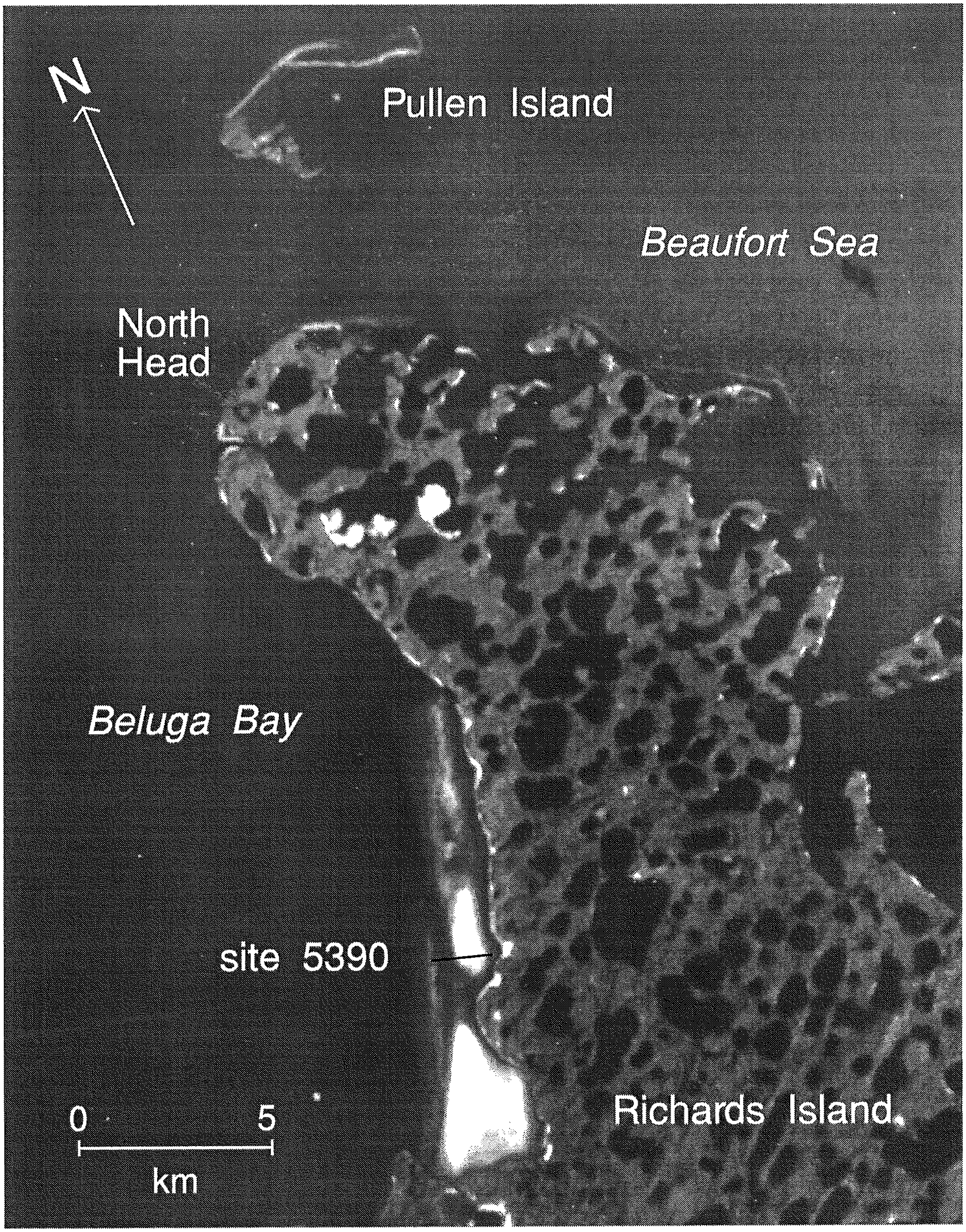

Figure 10:
Northern Richards Island, showing North Head, Beluga Bay flats (site 5390), and Pullen Island to the north. LANDSAT image acquired 23 July 1986.

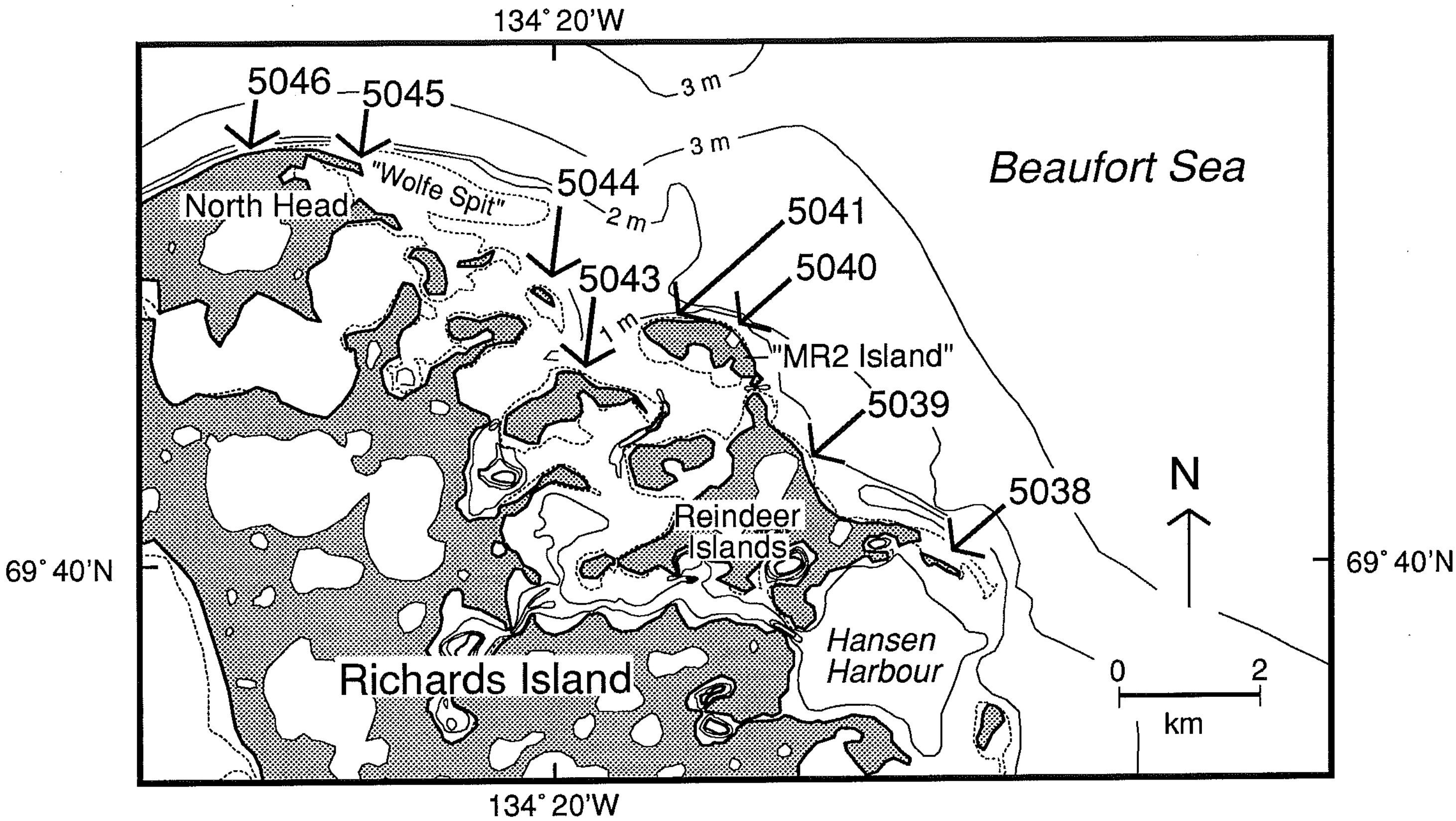

Figure 11:
Northernmost part of Richards Island between North Head and Hansen Harbour (area of detailed studies in 1990 and 1991). Locations of coastal monitoring sites along the outer coast and in the outer part of the embayment system between Reindeer Islands and North Head.

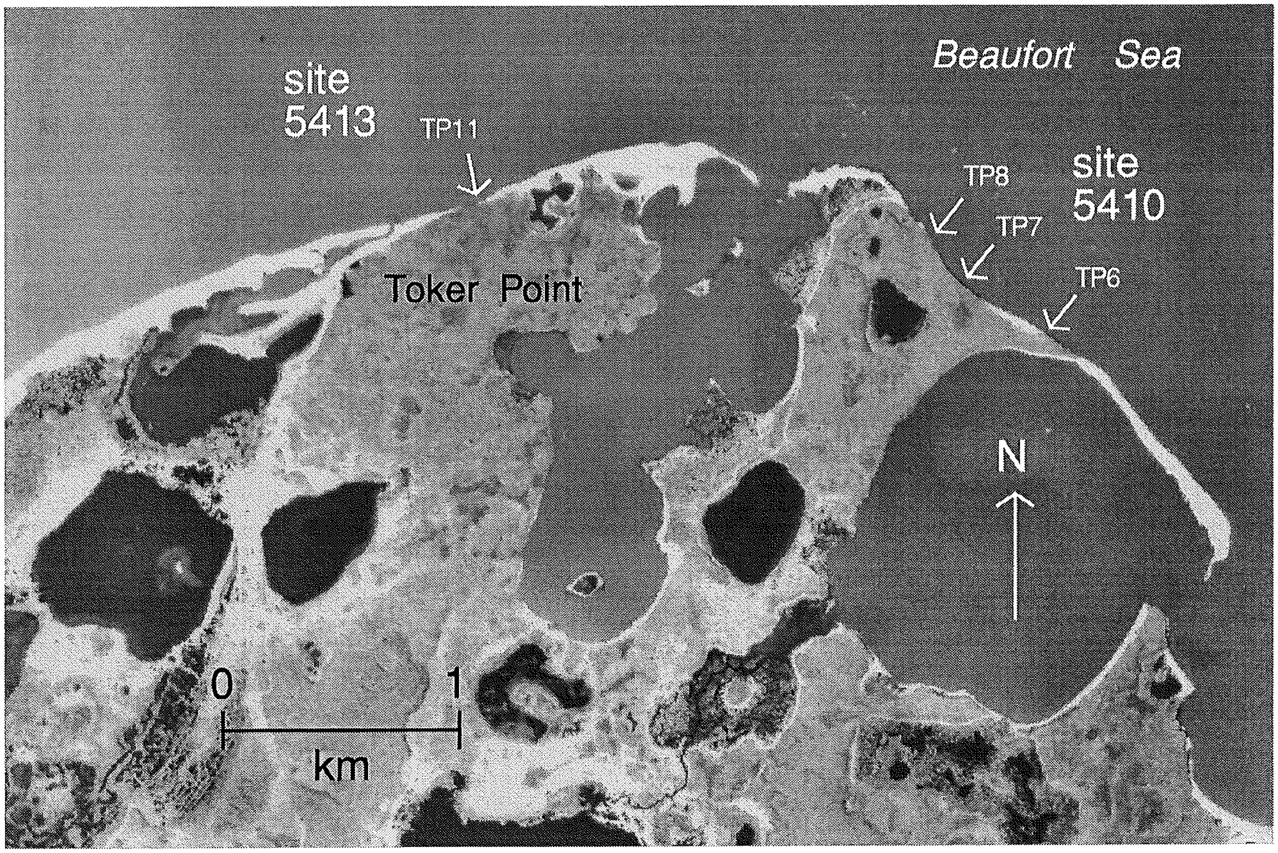

Figure 12:
Toker Point area, showing erosion monitoring sites.
Part of 1972 airphoto A22884-198 (NAPL Ottawa).

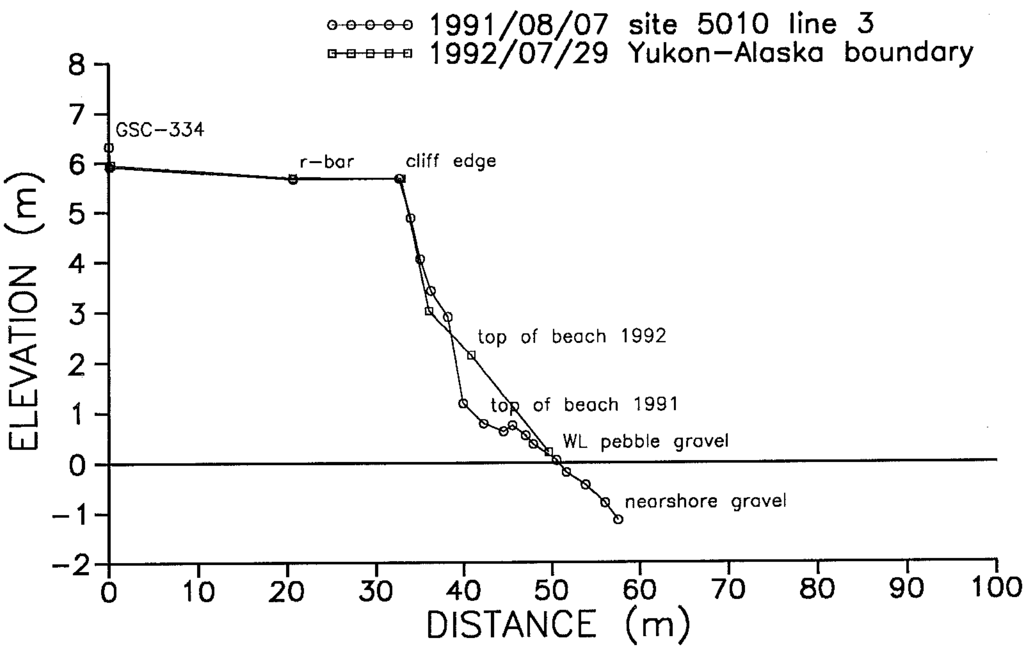

Figure 13:

Cliff and beach profiles at the Alaska-Yukon boundary (site 5010) in 1991 and 1992.

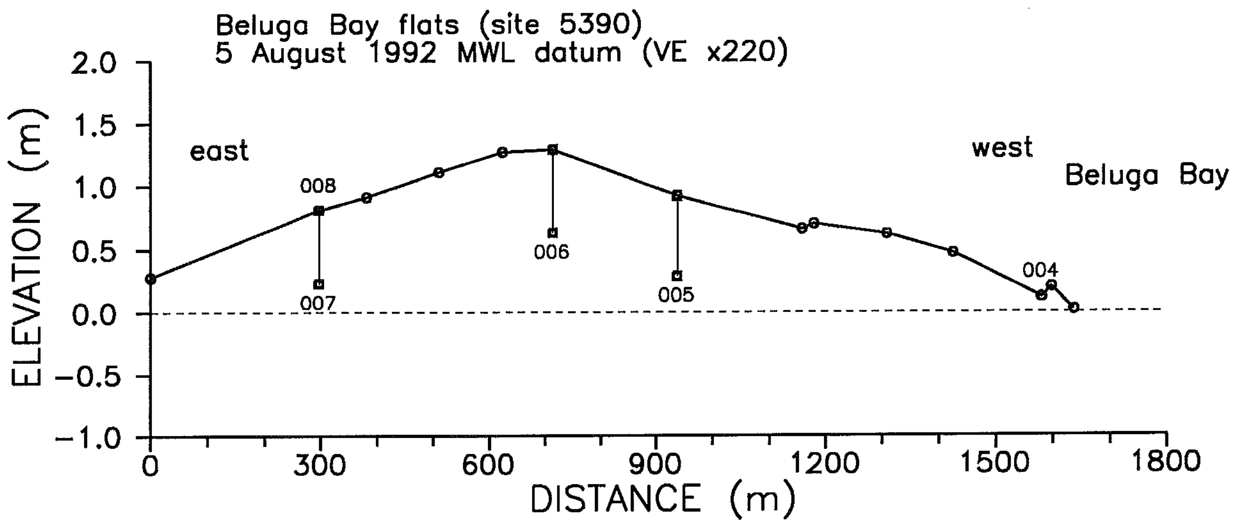

Figure 14: Profile across Beluga Bay flats (site 5390), showing grab and core locations.

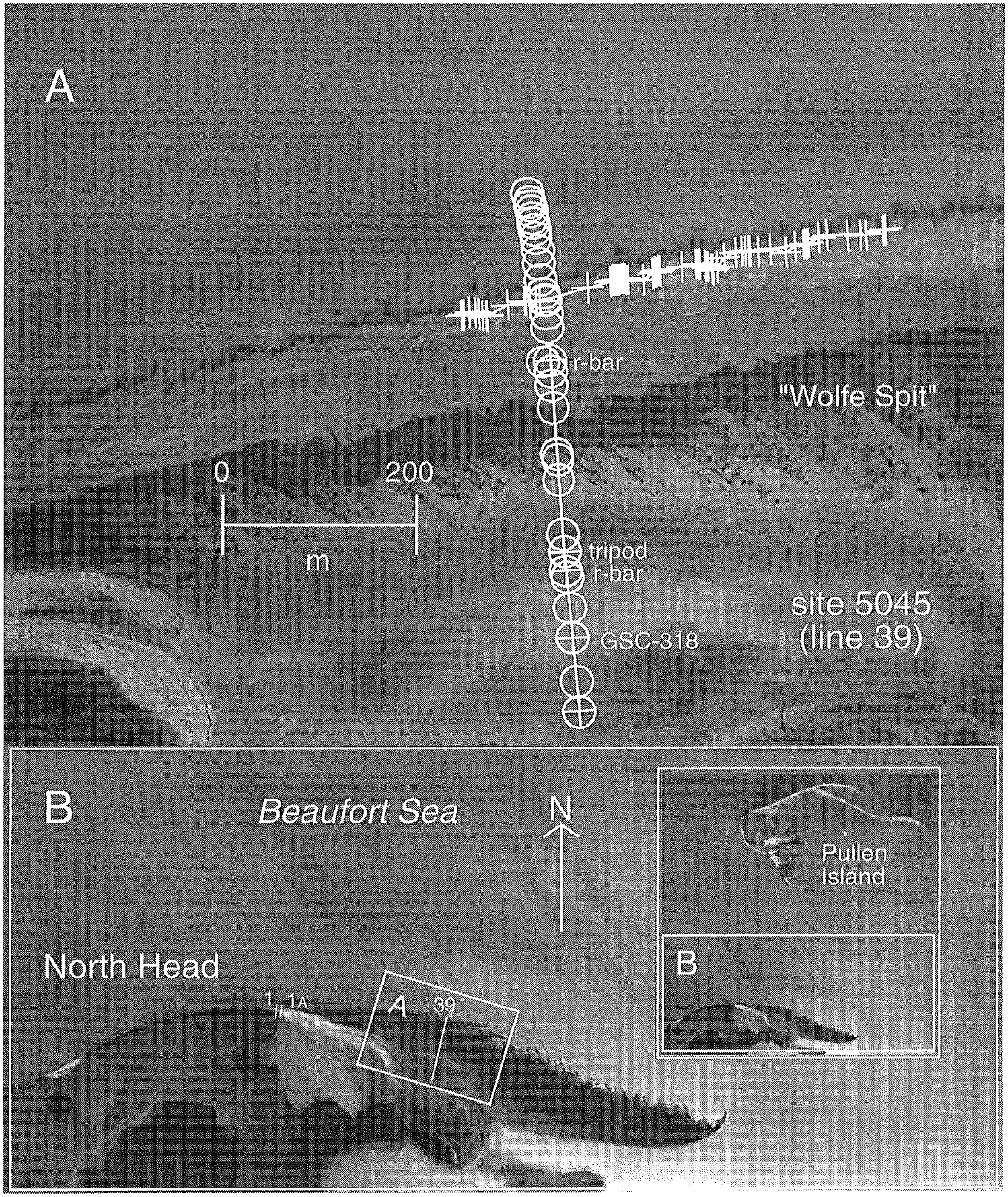

Figure 15:
North Head and "Wolfe Spit", showing locations of lines 1 (Solomon et al., 1992), 1A (Gillie, 1989), and 39 (Hill and Frobel, 1990). Note double spit storm ridge, new beach ridge to seaward with transverse bar structures, wide washover flats, and recurve structures with washover-generated megaripples in swales. A: part of airphoto 92002-14 [1992]. B: part of airphoto A26754-224 [1985] (NAPL Ottawa).

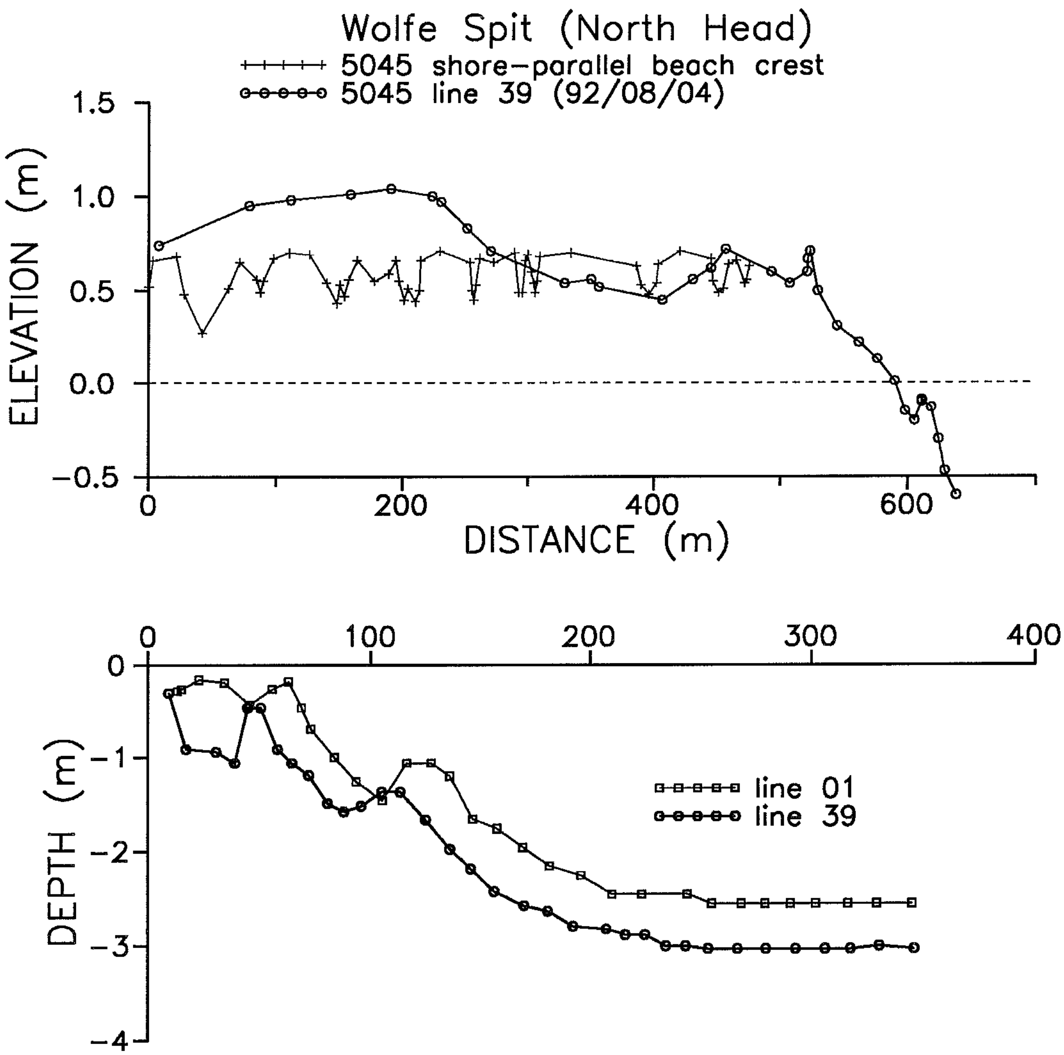

Figure 16:
Beach and nearshore profiles at "Wolfe Spit". Top: Shore-normal and shore-parallel beach profiles at line 39. Bottom: Nearshore profiles at lines 1 and 39. See Figure 15 for locations.

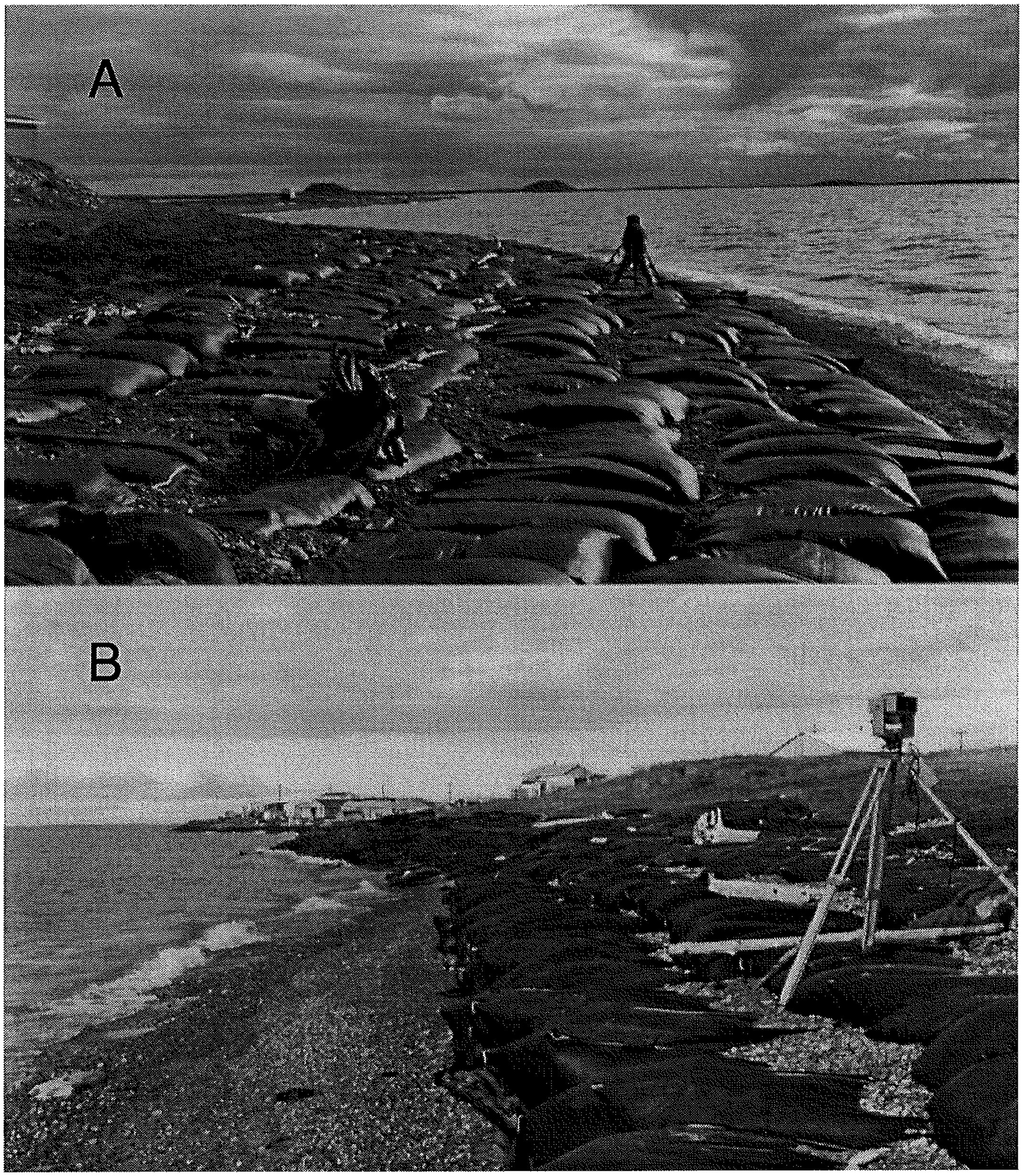

Figure 17:
Two ground views of the beach and shore protection at Tuktoyaktuk in 1991. A: Looking south from in front of the abandoned schoolhouse toward the spit (Ibyuk and Split Hill pingos in the distance). B: Looking north from the beach at line 3 (in front of the cemetery). Note mixed sand-gravel beach and sandbag revetment, more or less intact, with driftwood resting on the revetment. [DLF/ 8 August 1991]

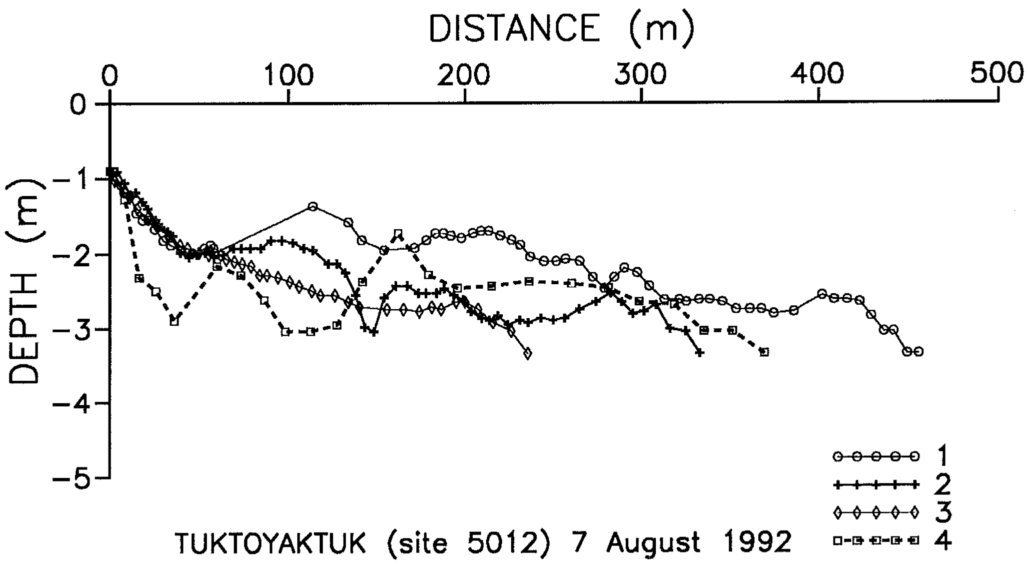

Figure 18: Shoreface profiles at Tuktoyaktuk (see Figure 3 for locations).

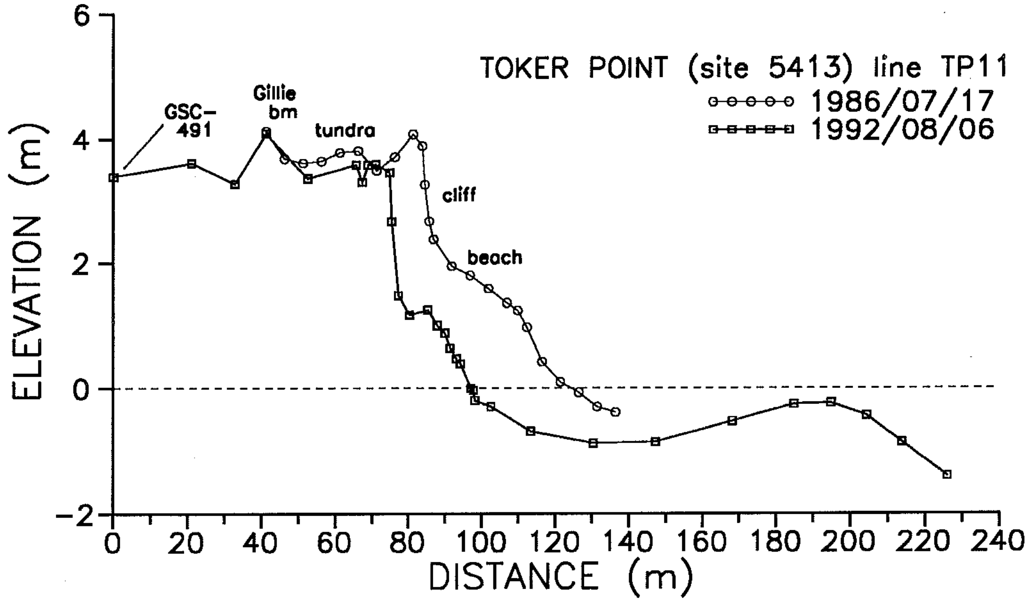

Figure 19: Cliff and beach surveys at Toker Point (site 5413/ TP11) in 1986 and 1992. See Figure 12 for location.

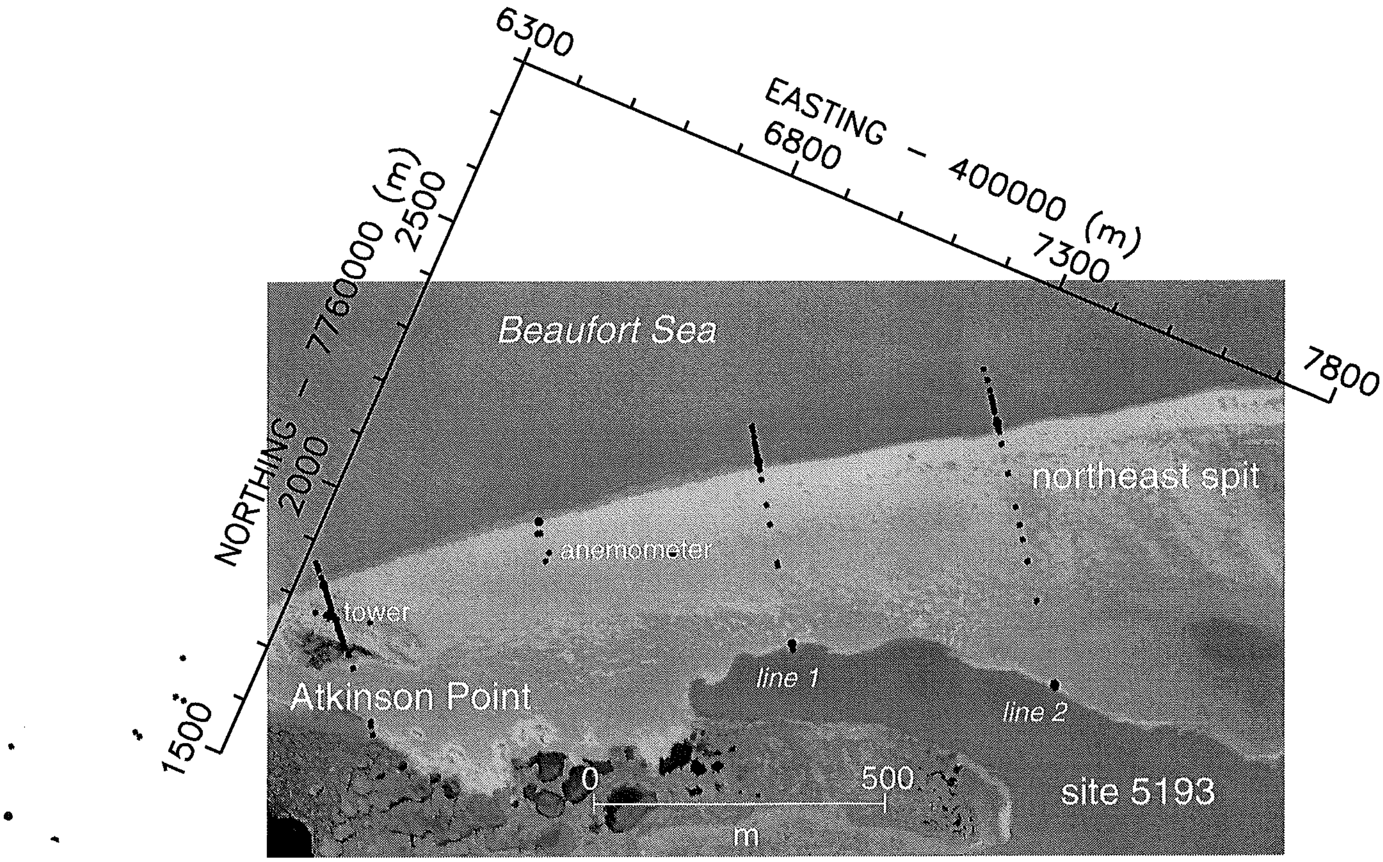

Figure 20:
Atkinson Point (site 5192) and the proximal end of the northeast spit (site 5193), showing 1992 survey points on a line at the point (site 5192 at the tower) and two lines on the spit (lines 1 and 2) originally established in 1973. Mosaic of 6 August 1992 airphotos.

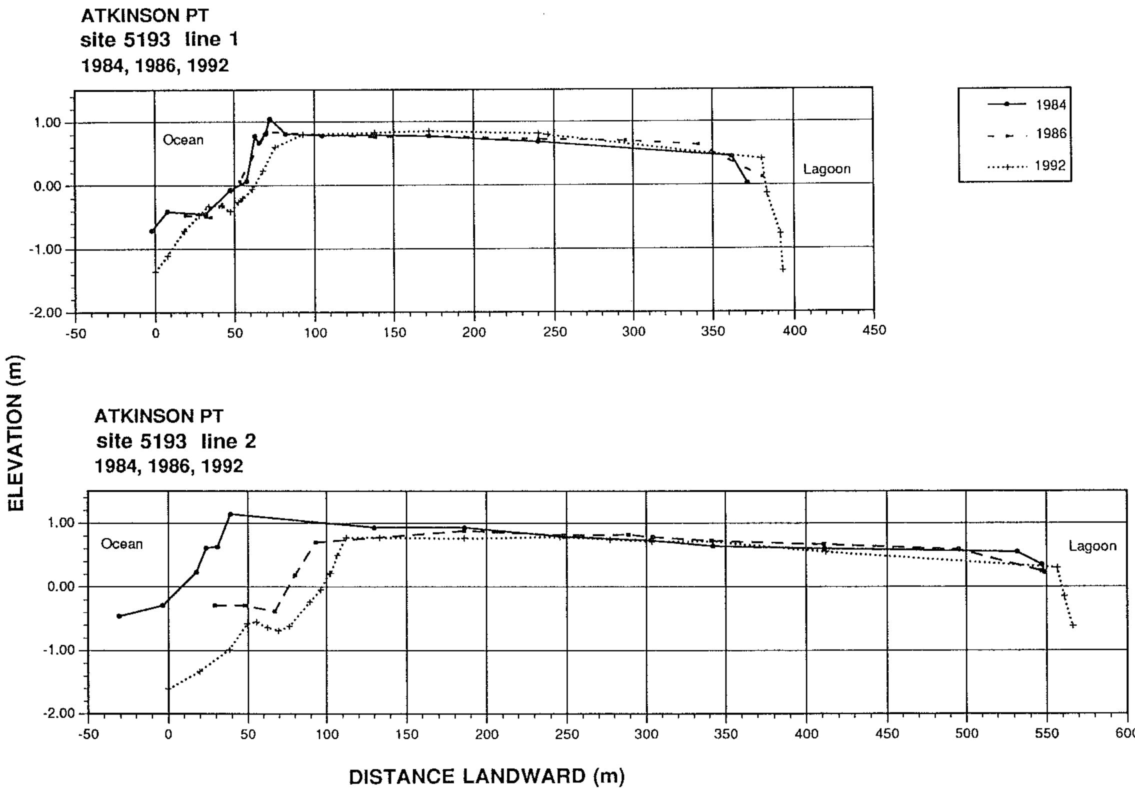

Figure 21:
Profiles across northeast spit (site 5193) at Atkinson Point on lines 1 and 2 in 1984 (Forbes and Frobel, 1985), 1986 (Gillie, 1987), and 1992. See Figure 20 for line locations.

APPENDICES

APPENDIX A

Table A1: **Sample inventory**

sample[a]	type	material	elevation	latitude	longitude	site
1	grab	gravel	~ 0 m	69°38.75	140°59.70	5010 Yukon-Alaska boundary
2	section	sand	~ 8 m	69°41.99	134°16.67	5041 Reindeer Islands
3	section	silt/sand	~ 8 m	69°41.99	134°16.67	5041 Reindeer Islands
4	grab	silt	~ 0 m	69°36.73	134°28.25	5390 Beluga Bay
5	core	silt	~ 0 m	69°36.73	134°27.52	5390 Beluga Bay
6	core	silt	~ 0 m	69°36.74	134°27.24	5390 Beluga Bay
7	core	silt	~ 0 m	69°36.73	134°26.58	5390 Beluga Bay
8	grab	silt	~ 0 m	69°36.73	134°26.58	5390 Beluga Bay
9	grab	sand	~ 2 m	69°28.40	131°25.83	5191 Atkinson Point
A11-A53[b]	trap	sand	~ -1 m	69°56.9	131°26.9	5192 Atkinson Point
B11-B53[b]	trap	sand	~ -1 m	69°56.9	131°26.9	5192 Atkinson Point

[a] sample numbers omit leading digits 92303-00

[b] sample numbers omit leading digits 92303:
30 streaming trap samples (two sets of 3 replicates at 5 levels)
A directed onshore
B directed alongshore toward northeast

set 1A:	A11	A21	A31	A41	A51
set 2A:	A12	A22	A32	A42	A52
set 3A:	A13	A23	A33	A43	A53
set 1B:	B11	B21	B31	B41	B51
set 2B:	B12	B22	B32	B42	B52
set 3B:	B13	B23	B33	B43	B53

Table A2: **Sample descriptions**

1

Yukon-Alaska boundary at coastline
site 5010 line 02
beach
pebble gravel
swash bar

2

Reindeer Islands (northeast Richards Island)
site 5041 near line GL (Gillie L)
cliff exposure
Kittigazuit Formation
faintly-laminated fine-medium sand
00-25 mm above contact with interlaminated finer unit (sample 3)

3

Reindeer Islands (northeast Richards Island)
site 5041 near line GL (Gillie L)
cliff exposure
Kittigazuit Formation
massive silt and/or fine sand
10 ± 5 mm fine unit in east-dipping body of fine-medium sand (sample 2)

4

Beluga Bay (western shore of Richards Island)
site 5390 line 01
tidal flat
silt
surface sediment on lower flat near low-water line

5

Beluga Bay (western shore of Richards Island)
site 5390 line 01
tidal flat
silt
lower middle flat in shallow-scour zone
core length 0.50 m
compaction on coring 0.132 m (a further 0.025 m contraction after 36 hours)

6

Beluga Bay (western shore of Richards Island)
site 5390 line 01
tidal flat
silt
upper middle flat in drying zone
core length 0.52 m
compaction on coring 0.138 m (a further 0.070 m contraction after 36 hours)

Table A2 (continued)

7

Beluga Bay (western shore of Richards Island)
site 5390 line 01
tidal flat
silt
upper flat in algal mat zone
core length 0.43 m
compaction on coring 0.150 m (a further 0.030 m contraction after 36 hours)

8

Beluga Bay (western shore of Richards Island)
site 5390 line 01
tidal flat
silt
surface sediment at core 7

9

Atkinson Point (eastern spit)
site 5191 line 01
barrier crest
sand
washover flats extensively reworked by wind at surface
sample taken 10-30 mm below wind-rippled surface (below drying front)

A

Atkinson Point
site 5192 line 01
beach nearshore
shoreward sand transport under waves during storm of 13 August 1992
5-minute samples at 5 levels from A1 at base to A5 approx. 0.7 m above sea bed

B

Atkinson Point
site 5192 line 01
beach nearshore
alongshore sand transport under waves during storm of 13 August 1992
5-minute samples at 5 levels from B1 at base to B5 approx. 0.7 m above sea bed

APPENDIX B

Table B1: **Survey inventory** (from west to east)

location	site	line	day[1]	method[2]	description
Yukon coast					
Yukon-Alaska border	5010	01	211	+	cliff
	5010	02	211	TH	cliff and beach
	5010	03	211	+	cliff
Komakuk Beach	5011	02	211	TH+	low cliff and beach
	5011	01	211	+	low cliff (disturbed)
Kay Point spit (zone 9)	5275	05	212	+	barrier beach
	5275	04	212	TH	barrier beach
	5275	03	212	+	barrier beach
	5275	01	212	+	barrier beach
Kay Point (zone 3)	5280	p6?	211	T++	cliff
	5280	02	212	TH	cliff and beach
Mackenzie Delta					
Tent Island	5340	I	212	+	delta front
	5340	"100"	212	+	delta front
"Ellice Island"	5360	II	212	T+	delta front
	5360	"400"	212	T+	delta front
	5360	"300"	212	T	delta front
Taglu Island	5395	01	218	T+	delta front
	5395	02	218	T+	delta front
	5395	03	218	T+	delta front
Richards Island					
Beluga Bay	5390	01	218	TT	sand flat
North Head	5046	GI	217	TT	cliff
	5046	01 (NP1)	217	TT	cliff and beach

Table B1 (continued)

location	site	line	day[1]	method[2]	description
***Richards Island** (continued)*					
"Wolfe Spit"	5045	01	217	TT/ES	beach and nearshore
	5045	GA	217	TT	beach
	5045	39	217	TT/ES++	beach and nearshore
"Pipeline Harbour"	5043	GE	218	T	cliff
"Pipeline Harbour"	5042	GK	218	T	cliff
Reindeer Islands	5041	GL	218	T	cliff
("MR2 Island")	5040	02	218	TT	beach
	5040	03	218	TT	beach
	5040	04	218	TT	beach
Tuktoyaktuk Peninsula					
Tuktoyaktuk	5012	01	220	TT/ES	beach and nearshore
	5012	02	220	TT/ES	beach and nearshore
	5012	03	220	TT/ES	beach and nearshore
	5012	04	220	TT/ES	beach and nearshore
Tibjak Beach	5202	03	214	TT/ES+	beach and nearshore
	5202	04	214	TT	beach
	5202	05	214	TT/ES+	beach and nearshore
	5202	06	214	TT	beach
	5202	07	214	TT/ES+	beach and nearshore
Toker Point	5413	11 (TP11)	219	TT++	beach
	5410	08 (TP8)	219	T	cliff
	5410	07 (TP7)	219	T	cliff
	5410	06 (TP6)	219	T	low cliff
Atkinson Point west	5193	06	215	TT	barrier beach
	5193	07	215	TT	barrier beach
	5193	08	215	TT	barrier beach
Atkinson Point	5192	01	216	TT	dune and beach

Table B1 (continued)

location	site	line	day[1]	method[2]	description
Tuktoyaktuk Peninsula *(continued)*					
Atkinson Point east	5191	01	219	TT	barrier beach
	5191	02	219	TT	barrier beach

[1] See daily log for corresponding dates.
[2] Codes defined as follows:

+ — airphoto target
T — tape
TH — theodolite (Wild T2) and staff
TT — electronic total station (Geodimeter 140H) and target
ES — digital echosounder (Micronar) on kayak

APPENDIX C

Table C1: **GPS positions**

site	description		latitude	longitude	utm zone	easting (m)	northing (m)	s[1] (m)
Yukon-Alaska border (**site 5010**)								
	instrument[2]		69°38.7743	140°59.6805	7	500207	7726247	6.5
	instrument (ES)[3]		69°38.7855	140°59.7556	7	500158	7726268	3.8
	bm GSC-334	(line 02)	69°38.7541	140°59.7018	7	500193	7726209	3.6
	bm GSC-333 +	(line 01)	69°38.7580	140°59.7259	7	500178	7726216	9.0
	bm GSC-335 +	(line 03)	69°38.7679	140°59.6128	7	500251	7726235	7.7
Komakuk Beach (**site 5011**)								
	bm GSC-336 +	(line 02)	69°35.7489	140°11.3196	7	531570	7720833	6.0
	rebar +	(line 01)	69°35.7719	140°11.1750	7	531663	7720877	16.9
Kay Point spit zone 9 (**site 5275**)								
	pipe (zone 9) +	(line 03)	69°17.4147	138°24.5814	7	602209	7688710	2.0
	pipe (zone 9) +	(line 01)	69°17.4418	138°24.5977	7	602196	7688758	2.8
Kay Point (**site 5280**)								
	peg p6?		69°17.7913	138°22.8973	7	603286	7689456	2.0
	repos[4] p6 +		69°17.7630	138°22.8317	7	603331	7689406	3.6
	new p6-2 +		69°17.7806	138°22.9035	7	603283	7689436	1.6
	pipe (zone 3)	(line 01)	69°17.6387	138°22.5110	7	603552	7689184	5.2
	pipe (zone 3) +	(line 02)	69°17.6809	138°22.5458	7	603525	7689261	4.9
	pipe (zone 3)	(line 03)	69°17.6585	138°22.4195	7	603610	7689223	5.0
	1976 drill hole	(line 02)	69°17.6661	138°22.3709	7	603642	7689239	7.0
	instrument (ES)[3]		69°17.6485	138°22.3239	7	603674	7689207	4.1
	repos[4] (zone 4)	(line 01)	69°17.5714	138°22.1905	7	603768	7689068	2.2
	repos[4] 12		69°17.4660	138°21.9427	7	603939	7688879	4.9
	repos[4] 11		69°17.4645	138°21.9367	7	603943	7688877	2.9
Tent Island (**site 5340**)								
	bm I +		68°54.9393	136°36.7962	8	435235	7645629	4.7
	stake "100" +		68°54.9626	136°36.6421	8	435339	7645669	2.0

Table C1 (continued)

site	description		latitude	longitude	utm zone	easting (m)	northing (m)	s[1] (m)
"Ellice Island" (**site 5360**)								
	bm II +		69°17.3359	135°51.2872	8	466262	7686637	3.6
	rebar "400" +		69°17.4084	135°51.2752	8	466272	7686772	6.6
Taglu Island (**site 5395**)								
	instrument[2]		69°28.3936	134°55.3108	8	503059	7706955	3.3
	rebar +	(line 01)	69°28.3970	134°55.3004	8	503065	7706962	2.7
	rebar +	(line 03)	69°28.3953	134°55.0127	8	503253	7706959	6.0
Beluga Bay (**site 5390**)								
	instrument[2]		69°36.7713	134°27.4699	8	521080	7722617	7.7
	sample 5-core		69°36.7322	134°27.5214	8	521047	7722544	2.9
	sample 6-core		69°36.7429	134°27.2482	8	521224	7722566	4.2
	sample 6-core		69°36.7302	134°26.5774	8	521659	7722546	4.4
North Head —"Wolfe Spit" (**site 5045**)								
	instrument[2&3]	(line 39)	69°43.2214	134°22.6513	8	524080	7734635	2.0
	bm GSC-318 +	(line 39)	69°43.1904	134°22.7934	8	523989	7734576	1.6
	rbar @ tripod +	(line 39)	69°43.2385	134°22.7591	8	524010	7734666	1.9
	instrument[2&3]	(line 01)	69°43.4834	134°24.8628	8	522649	7735108	2.6
	bm GSC-311	(line 01)	69°43.4979	134°24.8702	8	522644	7735135	4.0
"MR2 Island" & "Pipeline Harbour" (**sites 5040-5043**)								
	instrument[2]	(line 02)	69°42.0175	134°14.9915	8	529045	7732453	1.6
	bm GSC-308	(line 02)	69°41.9846	134°14.9878	8	529049	7732392	2.6
	bm GSC-317	(line GL)	69°41.9933	134°16.6702	8	527963	7732395	5.7
	front stake	(line GL)	69°42.0266	134°16.6765	8	527958	7732457	2.9
	bm GSC-316	(line GK)	69°41.6129	134°18.7399	8	526635	7731673	1.6
	bm GSC-276	(line GE)	69°42.3013	134°19.2619	8	526284	7732948	6.4

Table C1 (continued)

site	description		latitude	longitude	utm zone	easting (m)	northing (m)	s[1] (m)
Tuktoyaktuk (**site 5012**)								
	instrument[2&3]	(line 01)	69°26.8296	133°02.4366	8	576762	7705276	4.0
	bm GSC-287	(line 01)	69°26.8130	133°02.3190	8	576840	7705247	4.2
	bm GSC-288	(line 02)	69°26.8215	133°02.3409	8	576825	7705263	1.9
	instrument[2&3]	(school)	69°27.0538	133°02.2174	8	576892	7705697	2.7
	bm GSC-289	(line 03)	69°26.8660	133°02.3629	8	576808	7705345	2.7
	bm GSC-290	(line 03)	69°27.0864	133°02.2286	8	576883	7705757	11.6
	bm 1949[5]	(line 03)	69°27.0679	133°02.2015	8	576902	7705723	5.7
	instrument[2&3]	(near RCMP)	69°27.3101	133°02.0673	8	576975	7706176	4.9
	instrument[2]	(tie CHS9)	69°26.5476	133°02.3569	8	576831	7704753	3.4
	bm CHS-9	(near PCSP)	69°26.3937	133°02.1983	8	576944	7704471	4.3
Tibjak Beach (**site 5202**)								
	instrument[2]		69°35.3746	132°59.4207	8	578209	7721214	6.4
	bm GSC-492 +	(line 03)	69°35.3677	132°59.3356	8	578265	7721203	6.2
	bm GSC-494 +	(line 07)	69°35.2774	132°59.5003	8	578163	7721031	7.3
Toker Point (**sites 5413 & 5410**)								
	instrument[2]	(line 11)	69°39.0665	132°51.5824	8	583051	7728244	3.0
	GSC BM 491+	(line 11)	69°39.0566	132°51.5678	8	583061	7728226	5.2
	bm Gillie +	(line 11)	69°39.0784	132°51.5807	8	583051	7728276	11.8
	bm Gillie	(line 08)	69°39.0155	132°48.6341	8	584961	7728217	2.2
	bm Gillie	(line 07)	69°38.9296	132°48.4374	8	585093	7728062	1.4
	bm Gillie	(line 06)	69°38.7890	132°47.9999	8	585386	7727811	2.6
Atkinson Point (**sites 5191-5193**)								
	instrument[2] 1 near tower		69°56.8835	131°26.8721	9	406347	7761785	2.8
	legal survey marker		69°56.8973	131°26.7188	9	406446	7761807	1.1
	instrument[2] 3		69°55.9758	131°28.5975	9	405179	7760144	5.8
	instrument[2] 5		69°55.5352	131°28.8647	9	404975	7759332	2.8
	instrument[2] on hut		69°56.0053	131°26.0124	9	406830	7760132	2.8
	rebar on sand flat		69°57.0666	131°26.0201	9	406904	7762103	4.2
	anemometer		69°57.0254	131°26.3697	9	406678	7762036	1.3
	instrument[2] on sand flat		69°57.1686	131°25.8346	9	407030	7762288	1.6
	pipe west line	(line 01)	69°57.1358	131°25.8347	9	407027	7762227	6.8
	bm GSC-495	(line 01)	69°57.1017	131°25.7525	9	407077	7762162	11.8

[1] standard deviation (32 readings)
[2] instrument position
[3] instrument position for echosounding
[4] repositioned marker
[5] 1949 Dominion Land Survey benchmark
+ airphoto target (cloth or driftwood cross)

APPENDIX D

Table D1: **Airphoto inventory**

Roll 92001

Altitude 3100 feet (945 m)
Nominal scale 1:6000

frames	line/direction	site
1-9	1/W	Tent Island
10-19	1/NW	King Point
20-36	3/NW	Kay Point
37-43	2/SE	Kay Point
44-55	1/SW	Kay Point
56-61	1a/W	Kay Point
62-76	1/NW	Spring River
77-95	1/NW	Stokes Point
96-109	1/W	Komakuk Beach
110-125	1/W	Yukon-Alaska border
126-142	1/E	Yukon-Alaska border
143-156	1/E	Shingle Point
157-167	1/NE	Ellice Island
168-192	2/E	Ellice Island
193-209	3/E	Ellice Island
210-218	3/E	Ellice Island
219-238	1/E	Big Lake
239-246	2/W	Big Lake
247-251	1/N	Pullen Island
252-260	2/W	Pullen Island
261-268	3/E	Pullen Island

Roll 92002

Altitude 3100 feet (945 m)
Nominal scale 1:6000

frames	line/direction	site
1-17	2/NW	North Head
18-43	3/SE	North Head
44-73	4/NW	North Head
74-104	5/SE	North Head
105-121	6/SW	North Head
122-130	1/NE	North Head
131-158	6/SE	North Head
159-175	1/NE	Atkinson Point

Table D-1 (continued)

Roll 92002 (continued)

frames	line/direction	site
176-190	2/SW	Atkinson Point
191-201	2/SW	Tibjak to Toker Point
202-219	1/S	Tibjak to Toker Point
220-232	2/S	Topkak Point
233-241	1/N	Topkak Point
242-254	1/S	Tuktoyaktuk
255-269	1/NW	East Channel

Roll 92003

Altitude 10,100 feet (3079 m)
Nominal scale 1:20,000

frames	line/direction	site
19-44	2/E	Mackenzie Delta
45-56	7/S	Mackenzie Delta
57-69	3/N	Mackenzie Delta
70-80	4/S	Mackenzie Delta
81-89	5/N	Mackenzie Delta
90-102	6/S	Mackenzie Delta