PRELIMINARY ASSESSMENT OF COASTAL EROSION BETWEEN PORT AU PORT AND STEPHENVILLE, ST. GEORGE'S BAY, WEST NEWFOUNDLAND

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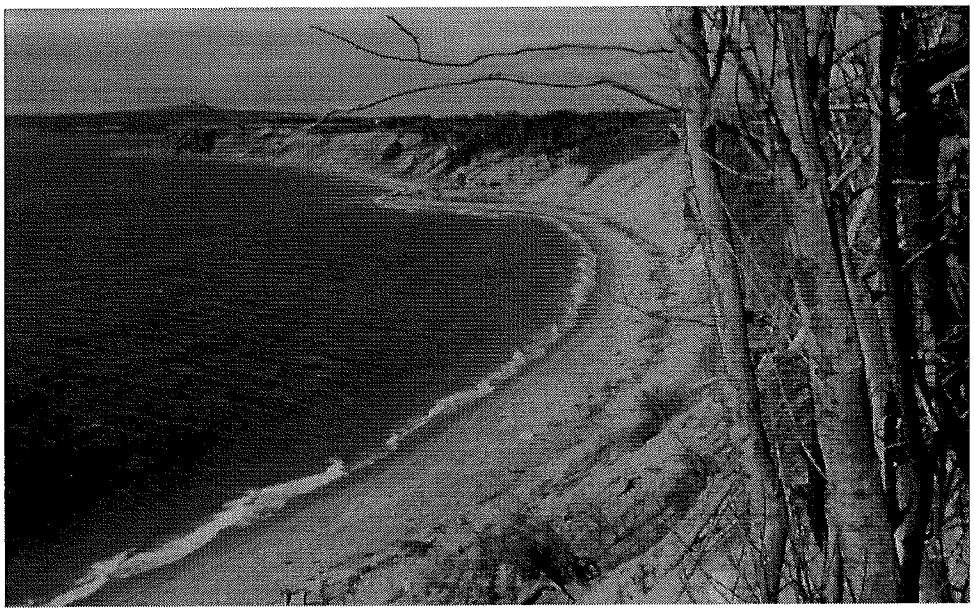

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ABSTRACT

Persistent erosion of unconsolidated cliffs up to 40 m high between Port au Port and Stephenville poses a significant erosion hazard for suburban development in this region. Historical erosion rates measured by digital photogrammetry from 1974 and 1986 air photographs ranged from 0.00 to 1.25 m/a (12 year means) at the cliff top and up to 1.21 m/a at the base of the cliffs, the highest erosion rates occurring in the area from Romaines Brook about 1 km to the west. The rates of recession were less elsewhere but remain a concern in the area of Kippens from Williams Lane east to Gadons Brook, in the area immediately east of Romaines Brook, and throughout the section from Romaines Brook west to Port au Port. The lowest rates of erosion were observed in area 3 on the west side of Kippens.

Gully development, particularly in the area west of Romaines Brook, poses a particular hazard in that area. A major retrogressive failure in early 1994 led to headwall recession of at least 60 m in a few hours to days, approaching dwellings along the main road in that area. The association of gullying and rotational slumping with a stratigraphy of permeable sands and gravels overlying marine clays and tills suggests that there is a hazard of similar failures at other locations along this coast.

RECOMMENDATIONS

- *Municipal planning practice in the communities of Kippens, Romaines, and Port au Port should take account of the hazards posed by chronic cliff recession and episodic retrogressive slope failure along the coast in this area.*

- *Building within 100 m of the present cliff line is inadvisable throughout the area. Although 100-year setback limits based on extrapolation of the observed erosion rates would be less than 100 m in some parts of the study area, accelerated erosion resulting from climate change or rising sea levels is a distinct possibility and local landslides present a danger of catastrophic failure extending up to 60 m or more landward from the cliff line.*

- *Monitoring of cliff recession rates by ground surveys should be continued at regular intervals of 2 to 3 years at a number of sites, the present network of GSC sites being an absolute minimum. At least one additional monitoring site should be established in area 3.*

- *Arrangements should be made to obtain a new set of vertical air photographs in 1995 or 1996, at a scale of 1:10,000 or better, to document the extent of the Romaines landslide and to extend the photogrammetric record of cliff recession throughout the area.*

- *Detailed geological mapping of the cliff and further study of the 1994 landslide would help clarify the risk of future landslides and where along the coast they are most likely to occur.*

INTRODUCTION

Thick deposits of unconsolidated sediments cover the coastal lowlands around St. George's Bay near Stephenville (Figure 1). Long-term erosion associated with rising relative sea levels over the past several thousand years has led to the formation of prominent cliffs along some 10 km of coast from the isthmus of Port au Port to Stephenville (Figures 2 and 3). Cliffs cut in unconsolidated sediments overlying bedrock also form the southern coast of the bay for some 40 km alongshore southwest of Flat Island (Figure 2).

Much of the Newfoundland coast is dominated by resistant bedrock outcrop with low rates of coastal erosion (Forbes, 1984). The surficial sediment cover over much of the island is thin and discontinuous (MacClintock and Twenhofel, 1940; Henderson, 1972; Brookes, 1977, 1989; Grant, 1989), but a few areas carry thicker and more extensive deposits (Liverman and Taylor, 1990a, 1990b). Where these intersect the coast they are associated with some of the most significant coastal erosion problems in Newfoundland, including the south shore of Conception Bay from Topsail west, the west coast of the Burin Peninsula near Fortune, and the north shore of St. George's Bay west of Stephenville.

The communities of Kippens, Romaines, and Port au Port have experienced progressive suburban development over the past 20 years. At first this took the form primarily of ribbon growth along the Port au Port road (Highway 460). For most of the distance this road runs parallel to the coast at least 500 m inland, except where it approaches the shore near Romaines Brook. At this point the original bridge (now abandoned) came within 150 m of the beach and the present highway bridge is 350 m from the river outlet. Between 1974 and 1986 (the two years of aerial photography employed in this study), the number of buildings in a coastal strip about 1.5 km wide increased from 432 to 649, most of them within 1 km of the cliff top. Numerous streets and laneways running south toward the cliffs appeared or were developed over the 12 years between the two sets of photography. Houses have now been built within 50 m of the cliff top at the south end of Bayview Heights on Marine Drive and within 100 m at the end of Seaside Drive in Kippens (Figure 3). Another lies within about 50 m of the cliff on a river terrace on the west side of Romaines Brook and more have been built or are under construction within about 100 m of the high cliffs a short distance further west. A large retrogressive slump early in 1994 came within a few tens of metres of a dwelling on the main road (Highway 460) in Romaines, emphasizing the potential vulnerability of structures in that area.

The rates of coastal erosion and cliff recession along this shore have not been documented previously, although the risk of slope instability was identified by M. Batterson of the Newfoundland Department of Natural Resources in 1983 when he inspected the area at the request of the local council. In view of the potential hazard for dwellings and other structures built along the top of the cliffs, the Geological Survey of Canada initiated a field monitoring program in the fall of 1991. To complement this work and extend the time-frame, we decided to undertake a photogrammetric study early in 1994. This report presents preliminary results of this study. It includes a summary of medium-term (12-year) mean recession rates between 1974 and 1986 and short-term ground measurements at five sites between 1991 and 1994. These results indicate that the rate of general cliff recession exceeds 1 m per year in some areas, while catastrophic retrogressive failure in gully depressions can proceed much more rapidly over time spans of hours to days.

METHODS

Field surveys along the Stephenville to Port au Port shore were initiated by the Geological Survey of Canada [GSC] in October 1991. Profile lines tied to GSC benchmarks were established at five sites between the Roman Catholic cemetery in Port au Port and the east side of Marine Drive in Kippens. These sites are numbered 0163 to 0167 from west to east and their locations are shown in Figures 4 to 9. One shore-normal profile was surveyed at each site, extending from the benchmark to the top of the cliff, down the cliff and across the beach. A second line on the west side of Williams Lane was added at site 0166 (Seaside Drive). Profile lines at two of the sites were run through existing provincial survey benchmarks (85G4202 at site 0165 on the east side of Romaines Brook and 85G4100 at site 0166 [line 1] at Seaside Drive). These surveys were repeated in October 1993 and again in October 1994.

The profiles were surveyed using a Geodimeter 140H total station (infrared transceiver and electronic theodolite) mounted on a tripod. Survey points were located and positioned relative to the total station instrument with a reflector target mounted on a stadia rod. The survey data were recorded in the field on a Geodat 124 data logger and later transferred via an RS232 connection to a Macintosh computer for initial data reduction and analysis. Further analyses were undertaken on PCs running DOS and on workstations running Unix.

Instrument positions in the field were determined with reference to provincial benchmarks at sites 0165 and 0166 and relative to local landmarks identifiable on the air photographs at the other sites. Site coordinates were also determined using a Magellan NavStar5000 Global Positioning System (GPS) receiver. Each GPS position was based on 32 fixes, averaged and recorded relative to the NAD 27 datum. The accuracy of these non-differential GPS positions is approximately ±50 m in both easting and northing. The accuracy of the GSC benchmark positions and survey lines based on ground surveys and photogrammetric control is estimated to be better than 2 m. Survey precision is ±0.05 m horizontally and ±0.01 m vertically. Vertical control is provided by the provincial benchmark elevations at sites 0165 and 0166 and based on tidal elevations at the other sites.

The digital photogrammetry was performed by the Eastcan Group using 1:50,000 scale aerial photography flown in 1974 and 1986. Control was derived from existing Government of Newfoundland mapping. Planimetric features were derived from diapositive images in a stereo compilation instrument interfaced to CARIS software and structured for GIS applications. Vector strings were digitized for the top and bottom of the coastal cliff in 1974 and 1986 as well as for the 1986 water line and a number of cultural features (roads, power lines, buildings, among others). The accuracy of the cliff-top and cliff-base positions is estimated to be ±1 m. Four hardcopy maps at 1:2000 scale were generated for the areas shown in Figure 1. The vector data were archived in CARIS (.ntx) and Autocad (.dxf) format on 3.5-inch diskettes.

Measurements of cliff recession were obtained from the photogrammetrically derived cliff-top and cliff-base vectors generated by The Eastcan Group. This analysis was carried out by TekMap Consulting. The vector data were imported into the public-domain Geographical Resources Analysis Support System [GRASS] software package for convenient measurement of cliff recession rates and overlay of the air photographs. Because of the large extent of the study area, the analysis was broken down into four sections equivalent to the individual 1:2000 scale maps produced by The Eastcan Group (Figure 1).

Recession measurements were made for both the cliff top and the cliff base along transects normal to the local cliff trend at approximately 50 m intervals (Figures 10 to 13). In total 190 transects were digitized between Port au Port and Stephenville, over a cumulative distance of 9.4 km. The precision of the measured distances between cliff-top and cliff-base vectors is estimated to be ±0.1 m. When combined with the estimated accuracy of the original cliff-lines (±1 m), this gives a maximum uncertainty of approximately 2.2 m for the measured recession distances from 1974 to 1986, or about

0.2 m/a averaged over the 12-year time interval.

REGIONAL SETTING

Geology of the study area

St. George's Bay occupies a funnel-shaped indentation in the coast on the south side of the Port au Port Peninsula, representing the seaward extension of a broad lowland between the Long Range highlands to the southeast and the Lewis Hills massif to the north (Figure 2). The bay expands southwestward from a width of about 4 km near Stephenville to about 40 km south of Cape St. George at the west end of the Port au Port Peninsula. A shallow sill extends south across the bay from the isthmus of Port au Port to Bank Head, enclosing two basins with maximum depths of 57 and 97 m. These basins occupy partially buried bedrock valleys more than 180 m deep that extend beneath the bayhead barriers at Stephenville and Stephenville Crossing (Shaw and Forbes, 1990b).

The St. George's Bay lowland is a broad depression formed in Carboniferous sedimentary rocks of the Codroy and Barachois Groups. These are downfaulted against anorthosites of the Indian Head ridge on the south side of Stephenville, the Long Range highlands to the southeast, and resistant rocks of the Lewis Hills to the north (Riley, 1962; Williams, 1985). The Lewis Hills massif consists of Paleozoic ophiolites of the Humber Arm Allochthon (Williams and Cawood, 1989). Intermediate and lower structural slices of volcanic and sedimentary rocks outcrop around the southern end of Port au Port Bay on the north side of the isthmus of Port au Port. Much of the Port au Port Peninsula to the west and the Table Mountain Anticline between Port au Port Bay and Romaines Brook consists of carbonate rocks of the Cambrian-Ordovician St. George and Port au Port Groups and the Ordovician Mainland Sandstone. Bedrock crops out locally along the coast between Port au Port and Stephenville. Cambrian-Ordovician carbonates of the St. George and Port au Port Groups form the base of the cliffs at Berry Head, about 1.5 km east of Port au Port (Williams and Cawood, 1989). Gypsum cliffs of the Carboniferous Codroy Group (Figure 3B of Dix and James, 1989) form the east side of Romaines Brook valley just upstream of the river mouth on the north side of the road bridge.

Unconsolidated sediments onshore record the waning phases of the last glaciation in the region as well as associated changes in relative sea level. The oldest unit is a compact lodgement till known as the St. George's River Drift (MacClintock and Twenhofel, 1940). This is overlain by deposits of the late-glacial Bay St. George Delta, which consist of bottomset muds and foreset to topset sands and gravels. These record a period of marine submergence as ice receded from the area. The highest evidence of submergence in the area is about 44 m above present sea level (Brookes et al., 1985; Grant, 1987) and dates from the end of the glaciation about 14,000 radiocarbon years before present [BP]. The ages of shells found in marine sediments onshore range from 13,700 to 12,600 radiocarbon years BP (Forbes et al., 1993). A thin veneer of early postglacial regressive marine deposits overlies the lower units in places around the margins of Port au Port and St. George's Bays (Grant, 1991).

Marine geological surveys in St. George's Bay (Forbes and Shaw, 1989) have demonstrated that a major late-glacial ice margin extended across St. George's Bay to the Port au Port isthmus in the area of the present sill. Ice-contact deposits on the sill grade seaward into glacimarine facies, suggesting a grounded tide-water ice front (Shaw and Forbes, 1990b). Small areas of high ground on Table Mountain and the Lewis Hills apparently remained free of Late Wisconsinan ice (Grant, 1987, 1991). A thick sequence of stratified subglacial, proglacial and paraglacial deposits occupies the deep bedrock valleys, which extend headward beneath the beaches at Stephenville and Stephenville Crossing (Shaw and Forbes, 1990b). Stacked units of acoustically unstratified (presumably ice-contact) deposits at least 85 m thick underlie parts of the sill (Shaw and Forbes, 1990b).

The high deltaic terraces in the area, including the gravel terrace feeding the tombolo at Port au Port, were first described by Flint (1940). This terrace, which extends eastward toward Romaines Brook, forms the foundation for much of the suburban development in the Port au Port and Romaines area. It is underlain by finer-grained glacimarine or ice-contact material in some places and by bedrock at Berry Head. A meltout (kettle) depression intersected by the present coast, about 800 m west of Romaines Brook, contains old pond deposits and other important indicators of late- and early postglacial conditions in the area (Grant, 1987). Further east, beyond Romaines Brook, the backshore terrain takes on a rolling character associated with ice-marginal deposition. The stratigraphy in the cliffs varies alongshore but can be broadly described by the section at the end of Williams Lane in Kippens (Brookes, 1989). This consists of glacial till overlain by 15 to 18 m of glacifluvial and deltaic sandy gravel with an intercalated 1 m unit of marine shell-bearing muddy sand (Figure 3).

Coastal geomorphology and oceanographic environment

The coast between Port au Port and Stephenville consists of a nearly continuous sandy gravel beach along the base of prominent coastal cliffs. The cliff height varies from less than 5 m in a kettle depression west of Romaines Brook to almost 40 m elsewhere. Surveyed cliff heights at five locations between Port au Port and Stephenville (Figure 4) range from up to 37 m (Figures 14 to 18). The cliffs are actively eroding along most of their length, but at widely varying rates. Some sections are substantially vegetated and apparently stable over time intervals of several years or more.

The beach is interrupted only at Berry Head, where the foreshore is rocky, and intermittently at Romaines Brook, where the river outlet is sometimes sealed by longshore transport (Figure 19). Beach width varies from 20 to 35 m between Port au Port and Berry Head (area 1, Figure 1), except west of site 0163, where the beach width increases to 50 to 65 m and the barrier at the isthmus is 60 to 100 m wide. From Berry Head to Romaines Brook, the beach is narrower, typically 10 to 15 m (area 2, Figure 1), but it expands to 10 to 25 m and locally to 40 m further east. The beach width is typically 15 to 20 m through Kippens (areas 3 and 4, Figure 1). The beach material is predominantly pebble-cobble gravel with a significant proportion of sand and some boulders.

The tidal range at Stephenville (Port Harmon) ranges from 1.1 m at mean tide to 1.7 m at large tide (Canadian Hydrographic Service, 1994). Storm surges may raise the water level above the high-tide level. Positive surges of about 3 m have been reported at Port aux Basques with a return period of 2.5 years (Murty et al., 1981). In addition, there is a long-term trend of rising relative sea level in the region, which may amount to as much as 0.3 m/century (Shaw and Forbes, 1990a, 1992; Carrera et al., 1990). St. George's Bay is exposed to a fetch of up to 700 m to the west and southwest and the annual significant wave height exceeds 5 m in deep water (Woodward-Clyde Consultants, 1982). The prevailing winds and the dominant wave approach direction are both from the west and southwest. Wave generation may be restricted by sea-ice cover from late December to early May. Ice cover typically exceeds 4/10 during February and March (Markham, 1980; Farmer, 1981).

OBSERVED EROSION RATES

Rates of cliff recession from photogrammetry and ground surveys

Changes in the cliff-top and cliff-base positions have been measured at each of the transects shown in

Figures 10 to 13. The location of the transects and rates of change are plotted in Figures 20 to 27 by areas as shown in Figure 1. The mean rate of retreat for the 12-year interval 1974 to 1986 is plotted as a function of distance alongshore toward the east from transect 1 at Isthmus Bay. Negative retreat rates correspond to seaward movement of the cliff base, through slumping or slope wash, and (rarely) to advance of the cliff top where material has been pushed or dumped over the edge.

In area 1 (transects 1 to 56), extending from Isthmus Bay to east of Berry Head (Figures 20 and 21), the cliff top remained relatively stable during the 1974-1986 period. The maximum rate of retreat at the cliff top was 0.35 m/a at transect 51 on the east side of Berry Head. The maximum rates to the west, between Isthmus Bay and Berry Head, were 0.24 m/a at line 42 and 0.25 m/a at line 19. On the other hand, local advance of the cliff top was recorded in the area of the cemetery (transects 6 and 7) and at transects 12, 26, and 27, reflecting land clearing, quarrying, or other human intervention. The average rate of cliff-top recession in this area (excluding the modified sites) was 0.09 ± 0.01 m/a ($n = 51$) with a standard deviation of 0.09 m/a (Appendix 1). The cliff base was also relatively stable in most of the area, except in the vicinity of transects 30 to 31 and 34 to 42, where it retreated at up to 0.92 m/a (transect 37). A retreat of 0.94 m/a recorded at transect 6 may also reflect natural processes in spite of the artificially induced advance observed at the cliff-top there. Seaward advance of the cliff base was observed at transects 21 to 27, 29, and 51. The average rate of cliff base retreat (again excluding modified sites at transects 6, 7, 12, 26, and 27) was 0.19 ± 0.07 m/a with a standard deviation of 0.48 m/a (Appendix 1). Ground surveys at site 0163 (Figure 5), between transects 8 and 9, show that the cliff top there retreated 0.27 m (0.09 m/a) between October 1991 and October 1994, while the cliff base advanced seaward 0.21 m (Figure 14).

Area 2 (transects 57 to 104), extending alongshore to almost 900 m east of Romaines Brook (Figures 22 and 23), shows two distinctive patterns on either side of the river. West of Romaines Brook, there was a general trend of increasing erosion rates, for both the top and the base of the cliff, from approximately 0 m/a in the vicinity of transect 57 to about 1 m/a near transect 80. Superimposed on this trend in the cliff-top recession sequence was a cyclic variation alongshore, with peak rates of 0.81 m/a at transect 58, 1.13 m/a at transect 68, 1.07 m/a at 72, 1.25 m/a at 76, and 1.14 m/a at 79 (Figure 23). The first three peaks can be related to gully headwall recession, but there was no pronounced gullying at the last two. The cliff base advanced slowly between transects 58 and 63, but from there eastward the rate of cliff-base recession increased more or less progressively to a maximum of 1.21 m/a at transect 80. Ground surveys from 1991 to 1994 were carried out at site 0164, between transects 79 and 80 (Figure 6). These indicated a cliff-top recession rate of 0.32 m/a but retreat of the cliff base at 1.16 m/a, indicating progressive steepening of the cliff (Figure 15) as observed at transect 80 between 1974 and 1986 (Figure 23). Recession rates of about 0.5 m/a were recorded on the air photos on either side of Romaines Brook, but east of the river the cliff-top recession rates decreased to between 0.00 and 0.28 m/a. The mean cliff slope in this area was gradually decreasing as the cliff base advanced almost everywhere from transect 89 to transect 103 (Figure 23), the maximum rate being 0.46 m/a at transect 95. The 1991 to 1994 ground surveys at site 0165 (Figure 7), near transect 88, showed a comparable rate of cliff-top recession (0.20 m/a compared to 0.23 m/a at transect 88 between 1974 and 1986) but more rapid cliff-base retreat (0.70 m/a versus 0.00 m/a historically at line 88). The overall mean cliff-top and cliff-base recession rates in area 2 ($n = 48$) were 0.41 ± 0.05 m/a (standard deviation 0.37 m/a) and 0.17 ± 0.05 m/a (standard deviation 0.38 m/a), respectively (Appendix 2). In the area between the marl section (transect 73) and Romaines Brook (transect 84), the mean cliff-top recession rate between 1974 and 1986 was 0.80 ± 0.08 m/a.

Area 3 (transects 105 to 152) represents a relatively undeveloped region on the west side of Kippens (Figures 24 and 25). Here the cliff was essentially stable at the west end, where the base of the cliff was generally building seaward, but less so in the east, where there was a tendency to progressive steepening of the cliff (Figure 25). Except for the anomalous value at transect 122, rates of cliff-top retreat in area 3 ranged from -0.05 to 0.33 m/a and cliff-base erosion from -0.21 to 0.51 m/a. The overall mean rates (n = 48) were 0.08 ± 0.02 m/a (standard deviation 0.11 m/a) for the cliff top and 0.10 ± 0.03 m/a (standard deviation 0.18 m/a) for the cliff base (Appendix 3). There are no ground survey monitoring sites in area 3.

Area 4 (transects 153 to 190) extends from just west of Williams Lane in Kippens to the inactive cliff section on the west side of Stephenville east of Gadons Brook (Figures 26 and 27). This area is characterized by low to moderate cliff-top recession rates, relatively consistent alongshore, and ranging from -0.05 to a maximum of 0.33 m/a during the years 1974 to 1986. The highest rates occurred in the low boggy section west of Williams Lane and in the region from Marine Drive east. At Seaside Drive (transects 157 to 158), the 12-year mean cliff-top recession rate was 0.21 to 0.22 m/a and the 1991-1994 ground surveys at site 0166 (Figure 8) gave 0.23 m/a, suggesting a consistent pattern of erosion there (Figure 17). At Marine Drive (transects 176 to 179), the 12-year mean cliff-top recession rate ranged from 0.13 to 0.24 m/a (mean of 0.17 ± 0.03 m/a). The 1991 to 1994 ground surveys at site 0167 (Figure 9) indicated both cliff-top and cliff-base erosion rates of 0.17 m/a (Figure 18) whereas the historical (1974 to 1986) rates at adjacent transects 182 and 183 were 0.00 and 0.11 m/a at the cliff top and 0.04 and -0.07 m/a at the cliff base. The apparent long-term consistency of erosion in the Seaside Drive area is corroborated by the similarity in the rates of cliff-top and cliff-base erosion there. To the east, in the area of Marine Drive, the cliff base was stable or advancing during the years 1974 to 1986, suggesting an overall tendency toward greater stability. However, the cliff-base retreat of 0.5 m between 1991 and 1994 at site 0167 indicates that renewed undercutting can occur, creating a potential for accelerated erosion at the cliff top. The overall mean rates of cliff-top and cliff-base recession in area 4 (n = 38) for the 1974 to 1986 period were 0.13 ± 0.02 m/a (standard deviation 0.09 m/a) and 0.03 ± 0.03 m/a (standard deviation 0.17 m/a), respectively (Appendix 4).

The 1994 Romaines landslide

In late May of 1994, a large retrogressive failure propagated headward from the gully at transect 67 in Romaines (Figures 28 to 30). When visited later in June, the site remained too dangerous for detailed study because of ongoing slope activity in the headwall area. This site, about 400 m west of the marl deposit, is in an area identified by Batterson (1983) as highly vulnerable to erosion, having a history of slope instability. The cliff here consists of a lower diamict, interpreted to be probably a marine till, overlain by a thin (<1 m) unit of clay and 20 to 25 m of sand and gravel. The highly permeable sand and gravel overlying impermeable clay and till has led to the extensive gully development in this area. Heavy rain in late May presumably led to saturation at the base of the permeable sand and gravel, resulting in failure by a combination of debris torrent and rotational slumping. The torrent cut a 15 m wide channel at the former cliff line and deposited a large fan across the beach (Figures 28 to 30). In late October, trees were still visible up to 100 m seaward of the former water line (Figure 30B). Failure took place along two pre-existing gullies, resulting in the development of two large amphitheatrical depressions and leaving large slumped blocks on the gully floor (Figure 30A). The headward erosion associated with this failure was estimated at 60 m or more, bringing the headwall within 50 m of dwellings along the seaward side of the highway in Romaines (Figure 30A).

SUMMARY

Persistent erosion of unconsolidated cliffs up to 40 m high between Port au Port and Stephenville poses a significant erosion hazard for suburban development in this region. Historical erosion rates measured by digital photogrammetry from 1974 and 1986 air photographs ranged from 0.00 to 1.25 m/a (12 year means) at the cliff top and up to 1.21 m/a at the base of the cliffs, the highest erosion rates occurring in the area from Romaines Brook to about 1 km to the west. The rates of recession were less elsewhere but remain a concern in the area of Kippens from Williams Lane east to Gadons Brook, in the area immediately east of Romaines Brook, and throughout the section from Romaines Brook west to Port au Port. The lowest rates of erosion were observed in area 3 on the west side of Kippens.

Gully development, particularly in the area west of Romaines Brook, poses a particular hazard in that area. A major retrogressive failure in early 1994 led to headwall recession of at least 60 m in a few hours to days, approaching dwellings along the main road in that area. The association of gullying and rotational slumping with a stratigraphy of permeable sands and gravels overlying marine clays and tills suggests that there is a hazard of similar failures at other locations along this coast.

RECOMMENDATIONS

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- Detailed geological mapping of the cliff and further study of the 1994 landslide would help clarify the risk of future landslides and where along the coast they are most likely to occur.

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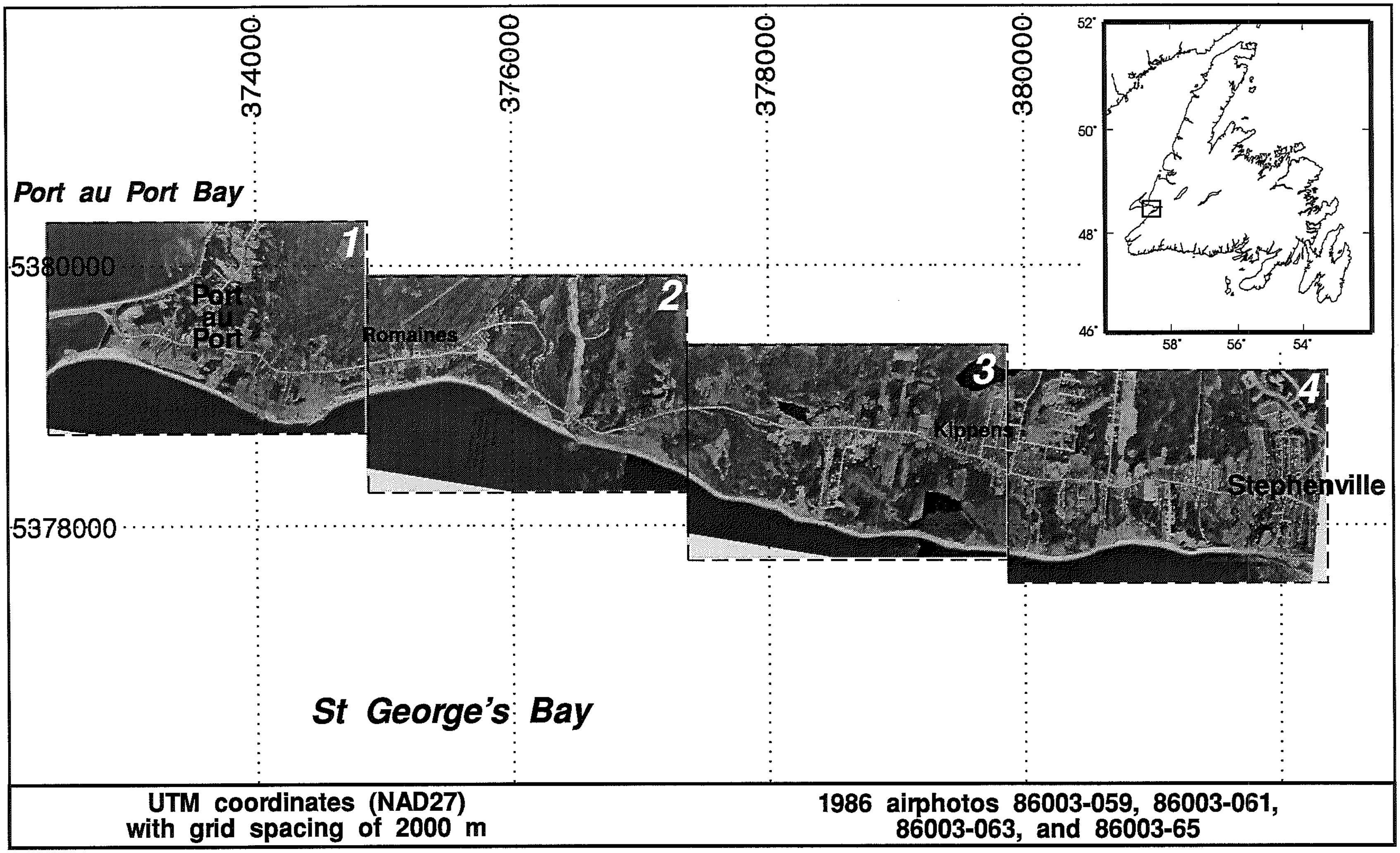

Figure 1: Study area in west Newfoundland (inset), showing the coastline between the isthmus of Port au Port and the town of Stephenville on the north shore of St. George's Bay. The coast is shown here on a mosaic of 1986 aerial photography and subdivided into four areas (ie. 1, 2, 3, & 4) as shown.

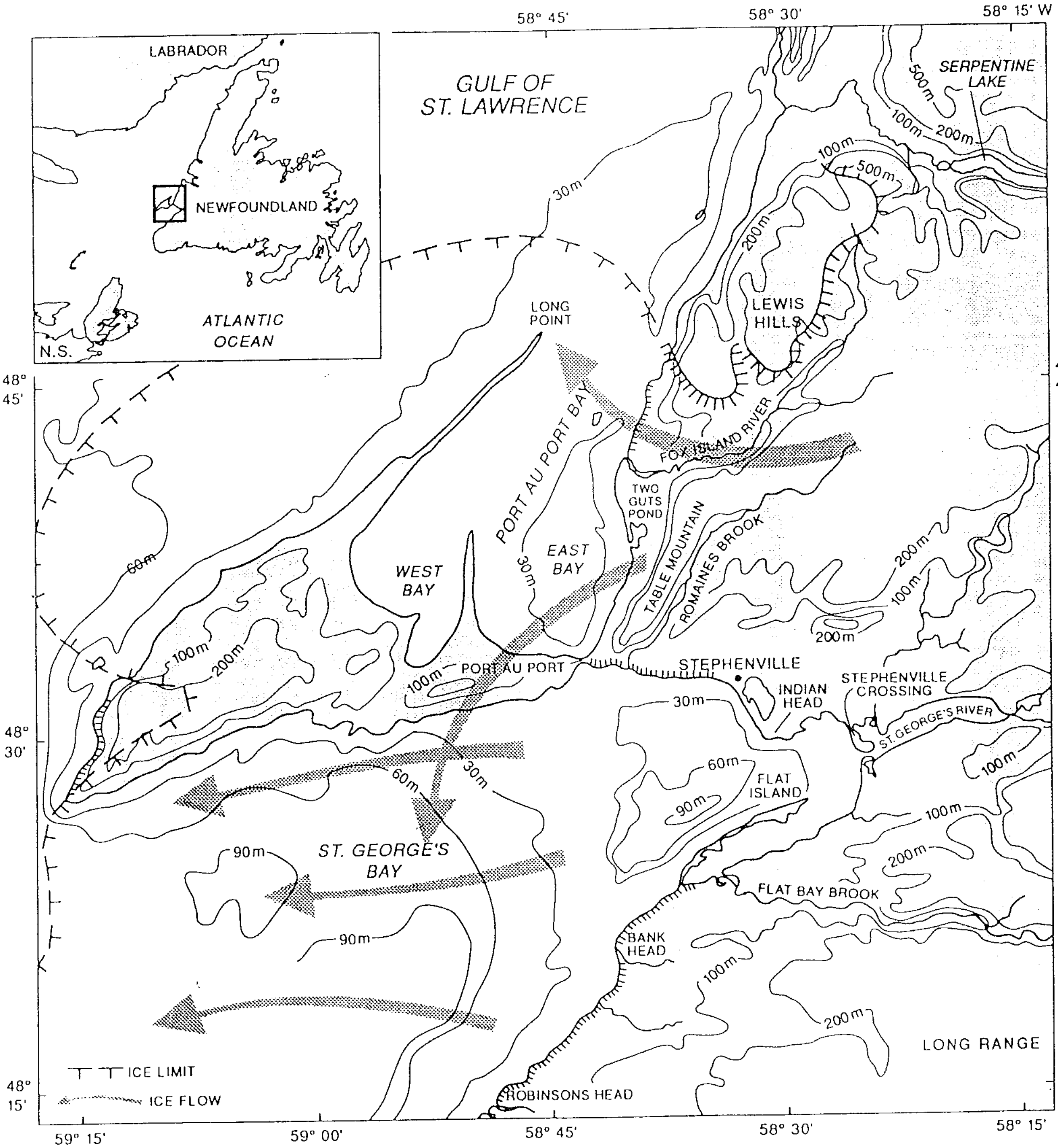

Figure 2: St. George's Bay and vicinity, west Newfoundland, showing coastal bluffs along the northern and southeastern shores of the bay, bathymetry and topography, and directions and limits of late-glacial ice movement (after Grant, 1987) [figure modified after Forbes et al., 1993].

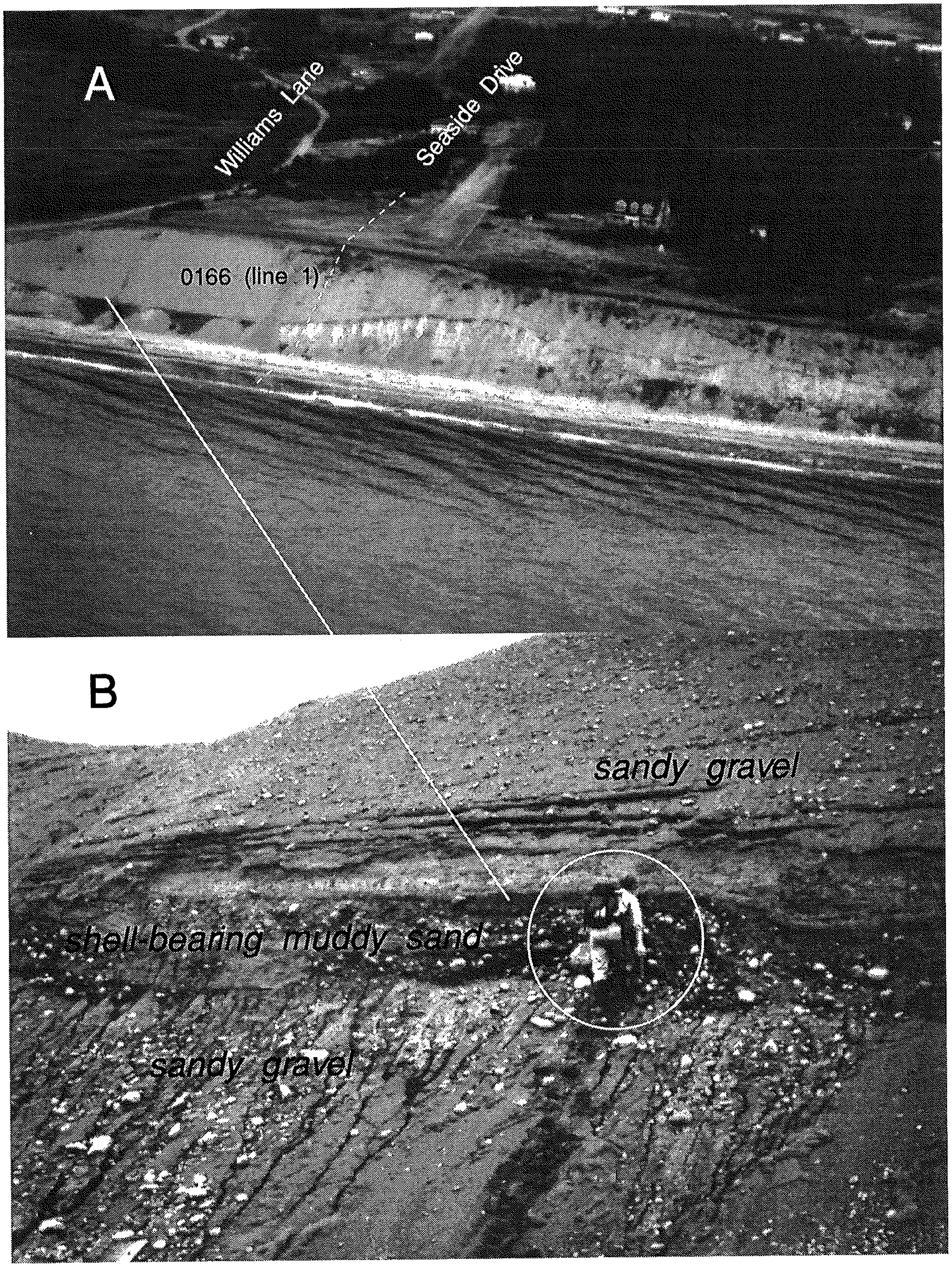

Figure 3: Coastal cliff at site 0166, Seaside Drive, Kippens.
A: Oblique aerial view in September 1985, showing general setting and stratigraphy. Broken white line is approximate position of profile. B: Close-up view from base of cliff in August 1988 (John Shaw circled for scale).

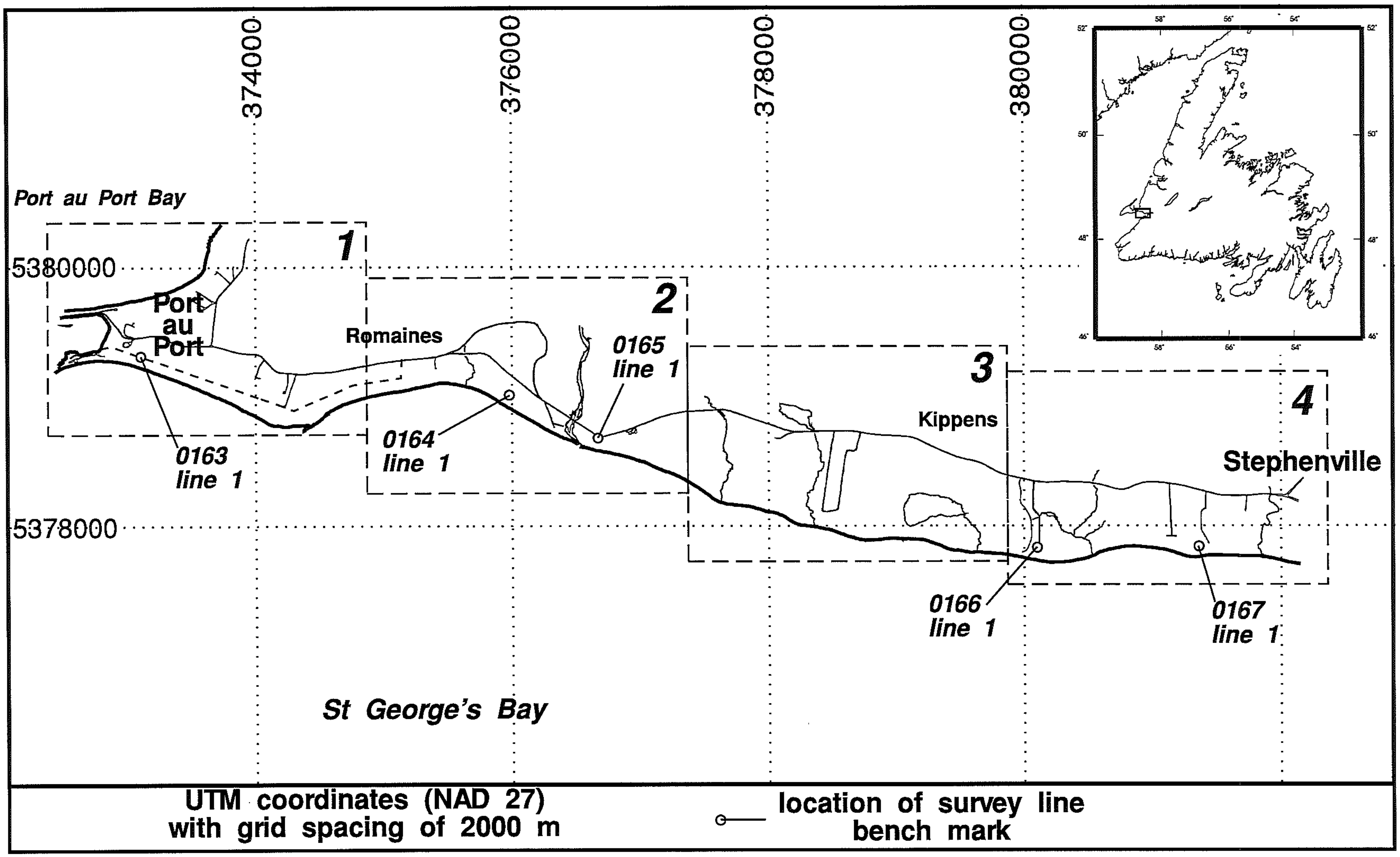

Figure 4: Locations of ground survey sites (0163 to 0167) along the north shore of St. George's Bay.

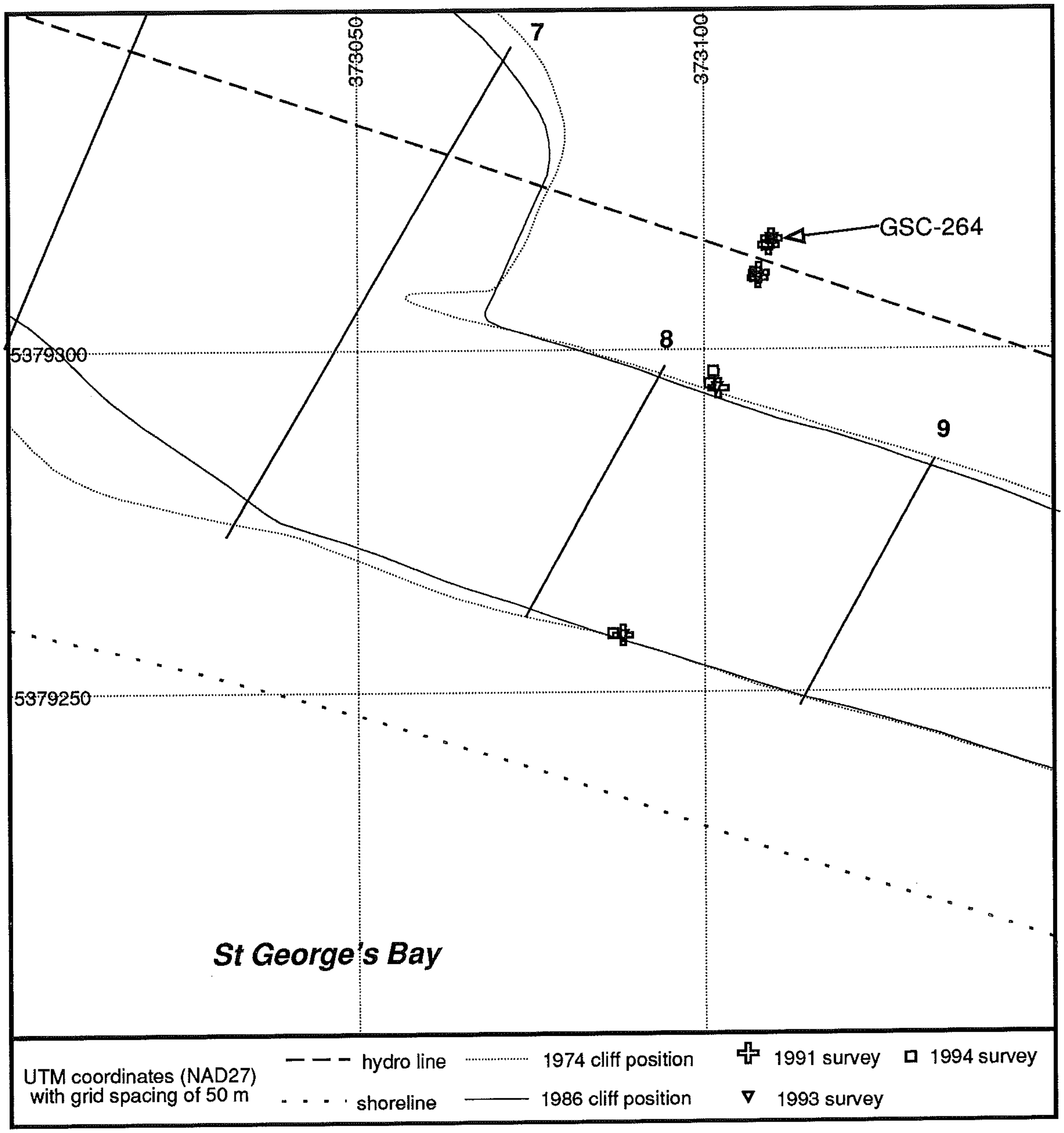

Figure 5: Detailed view of site 0163 at Port au Port cemetery, showing benchmark (GSC-264) and selected survey points, top and base of cliff in 1974 and 1986, water line in 1986, power line, and transects used for measurement of changes in cliff position. See Figure 4 for location.

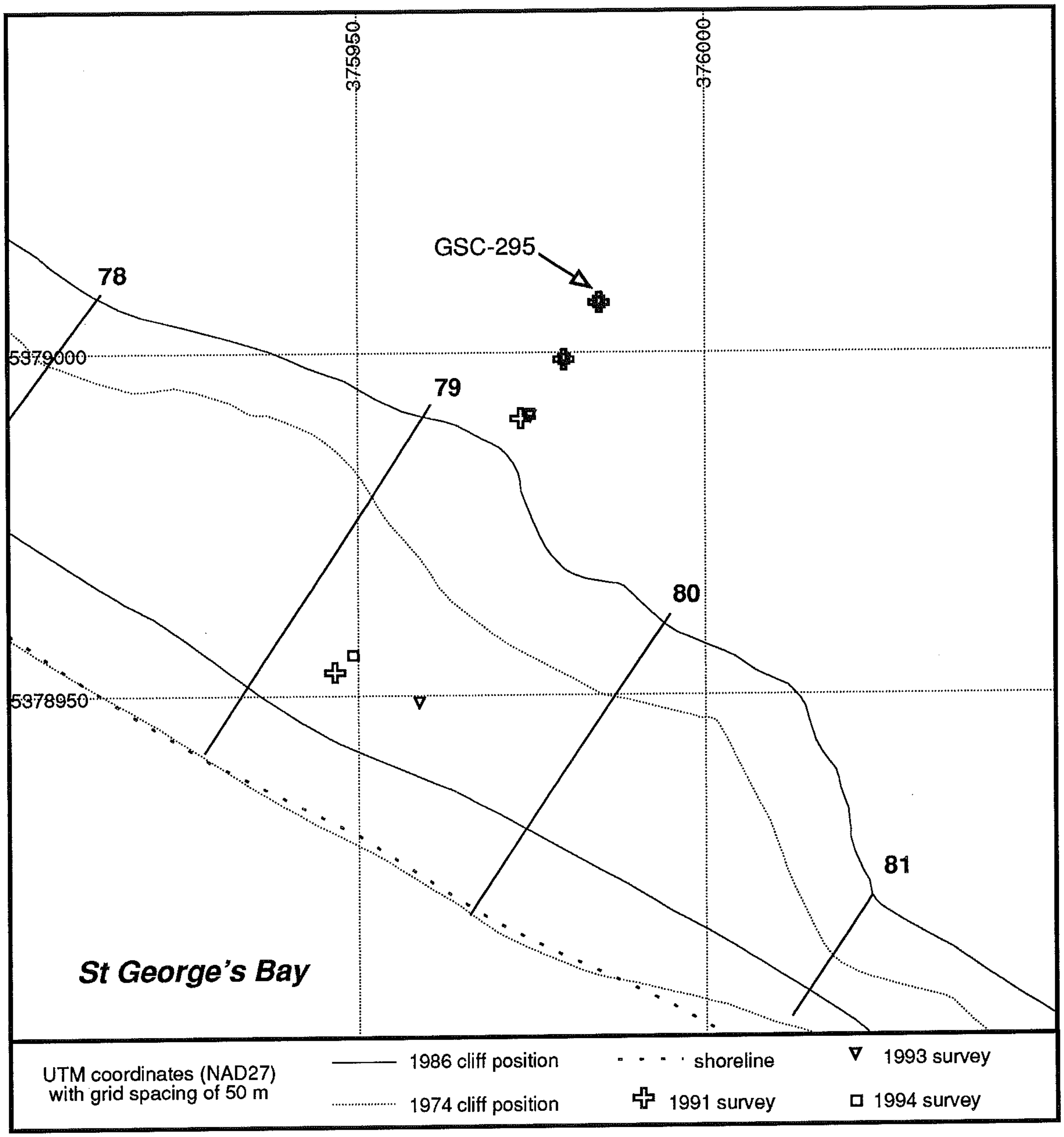

Figure 6: Detailed view of site 0164 in Romaines, showing benchmark (GSC-295) and selected survey points, top and base of cliff in 1974 and 1986, water line in 1986, and transects used for measurement of changes in cliff position. See Figure 4 for location.

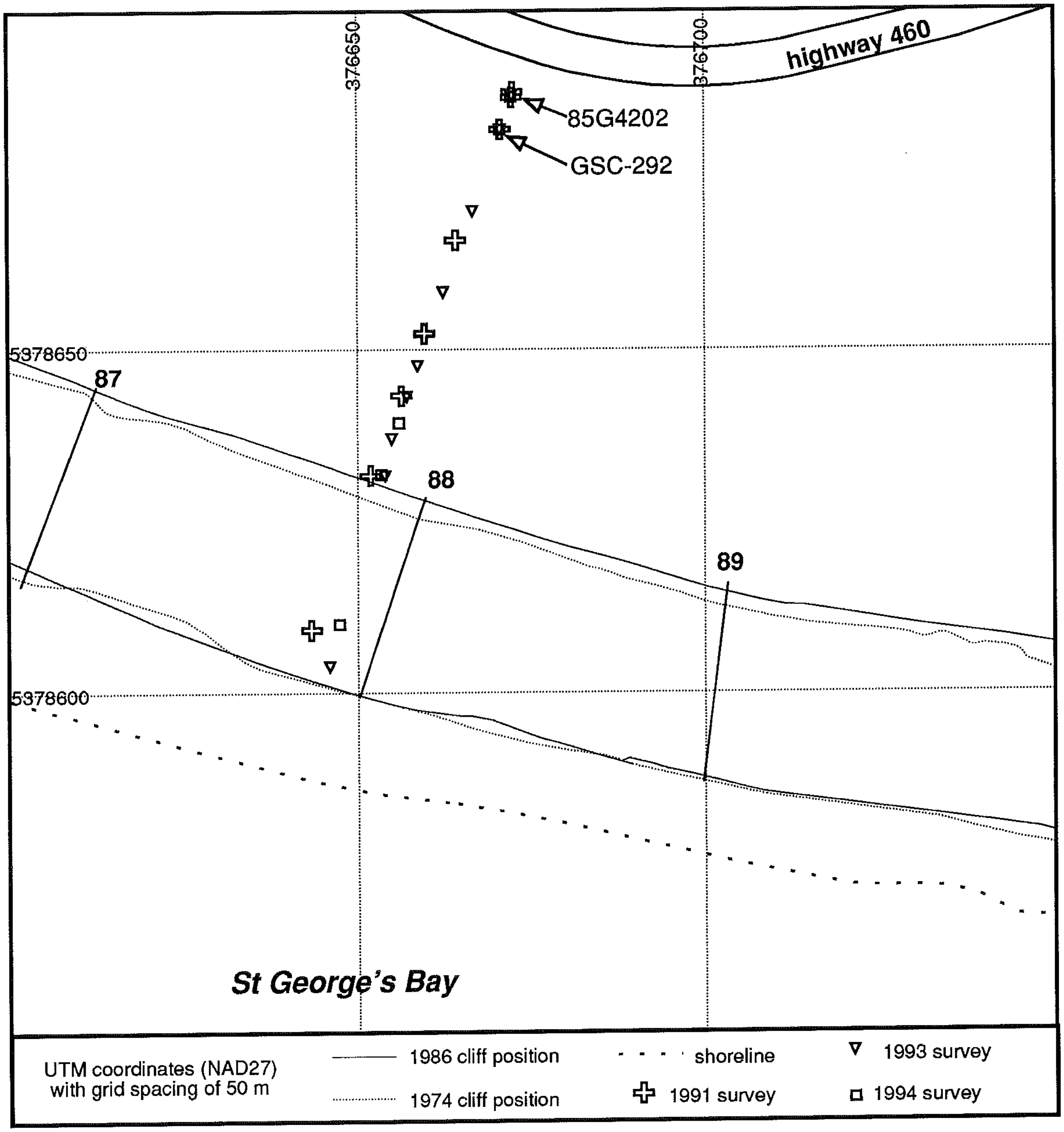

Figure 7: Detailed view of site 0165 just east of Romaines Brook, showing benchmarks (GSC-292 and Newfoundland 85G4202) with selected survey points, top and base of cliff in 1974 and 1986, water line in 1986, and transects used for measurement of changes in cliff position. See Figure 4 for location.

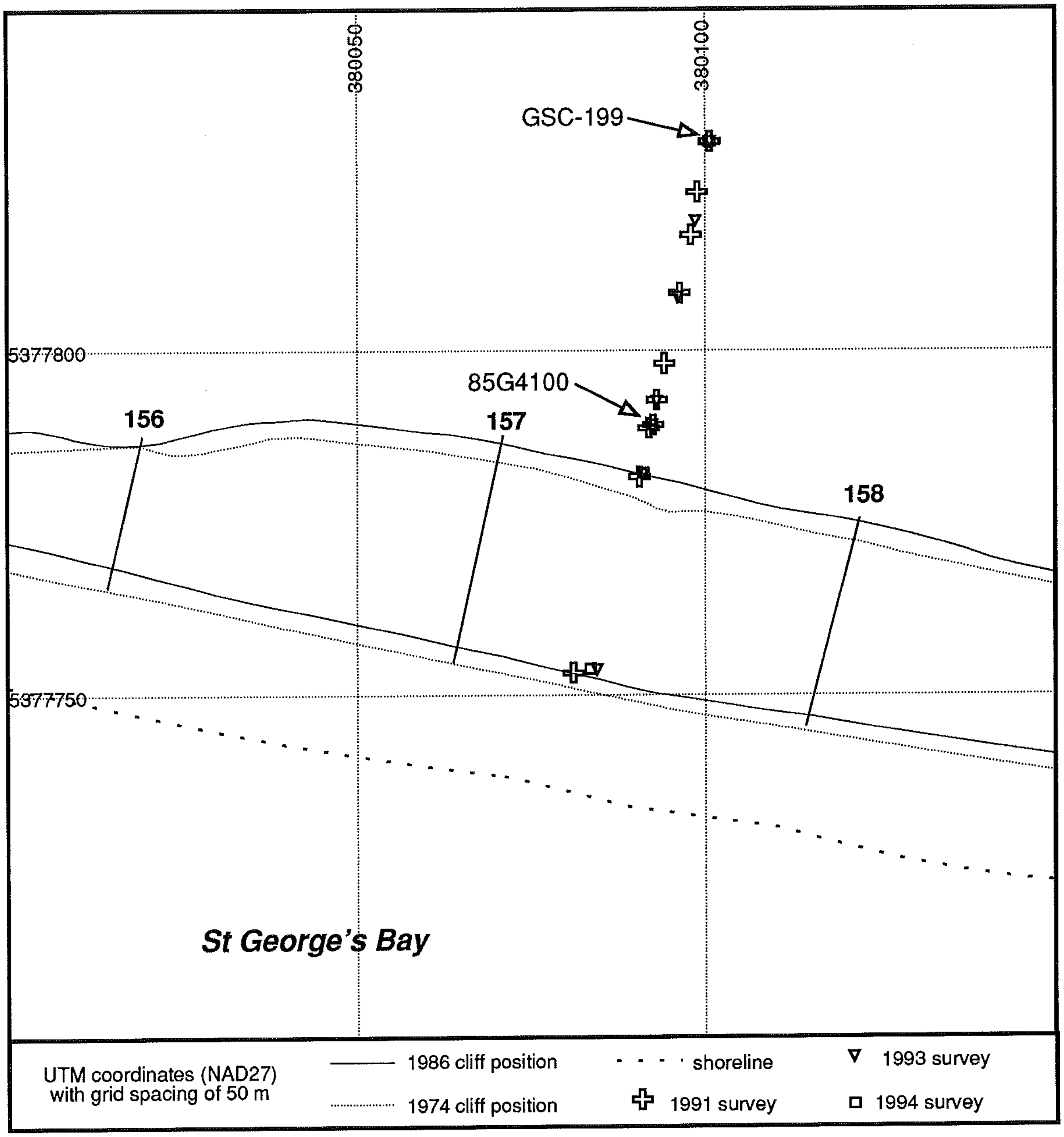

Figure 8: Detailed view of site 0166 in Kippens, showing benchmarks (GSC-199 and Newfoundland 85G4100) with selected survey points, top and base of cliff in 1974 and 1986, water line in 1986, and transects used for measurement of changes in cliff position. See Figure 4 for location.

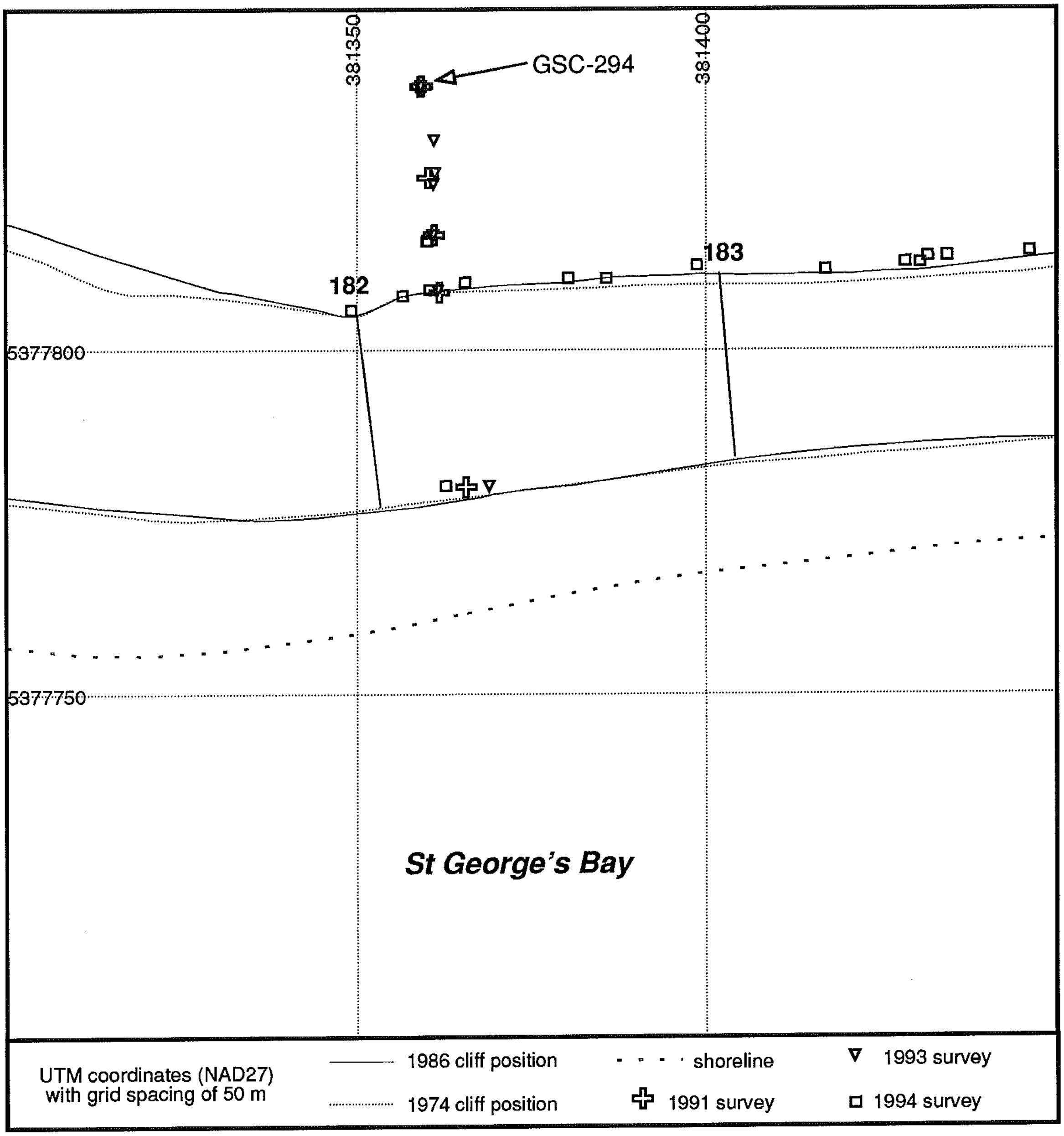

Figure 9: Detailed view of site 0167 in Kippens, showing benchmark (GSC-294) with selected survey points, top and base of cliff in 1974 and 1986, water line in 1986, and transects used for measurement of changes in cliff position. See Figure 4 for location.

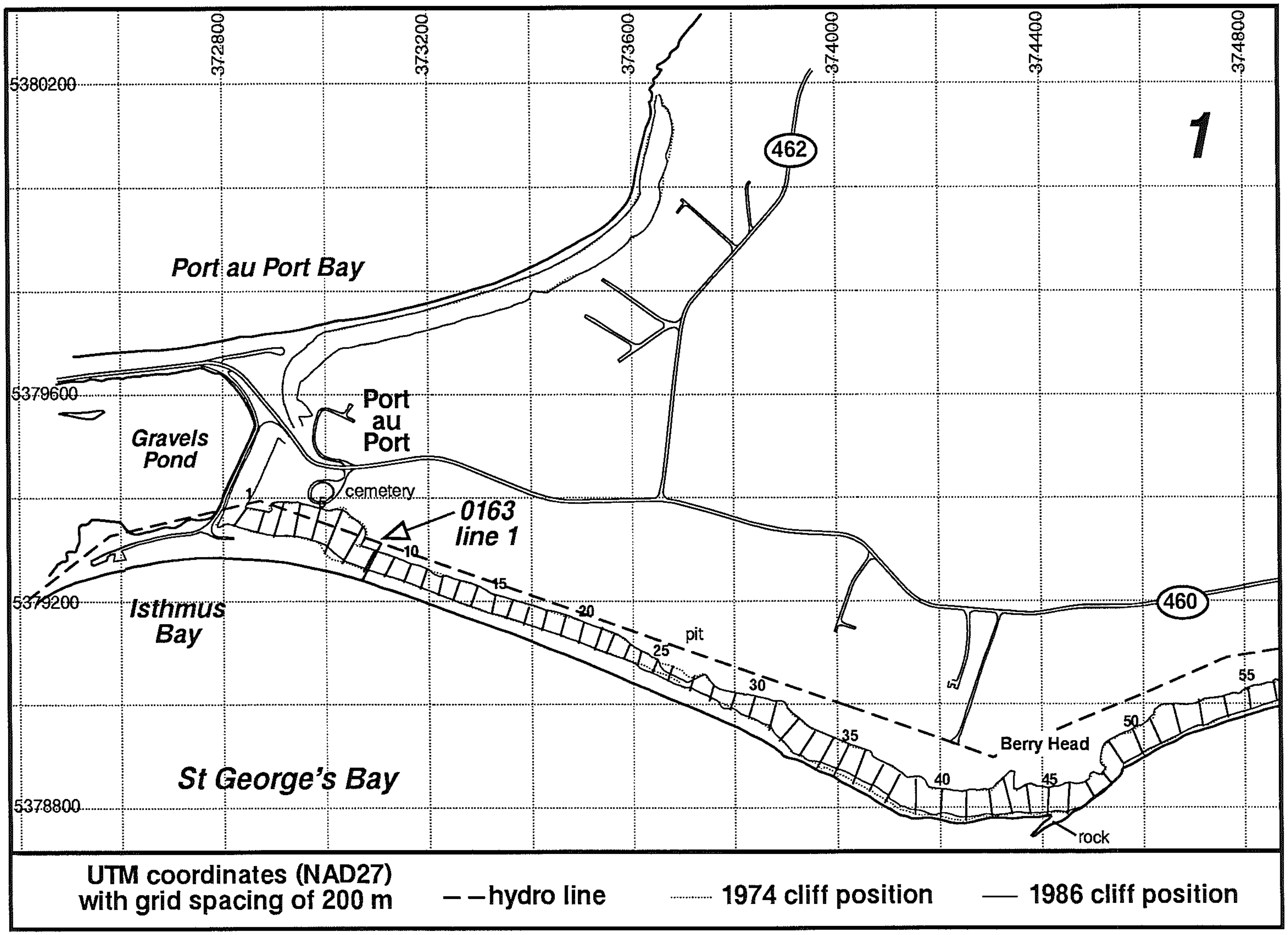

Figure 10: Cliff transects and survey site 0163 in area 1 (see Figure 1 for location).

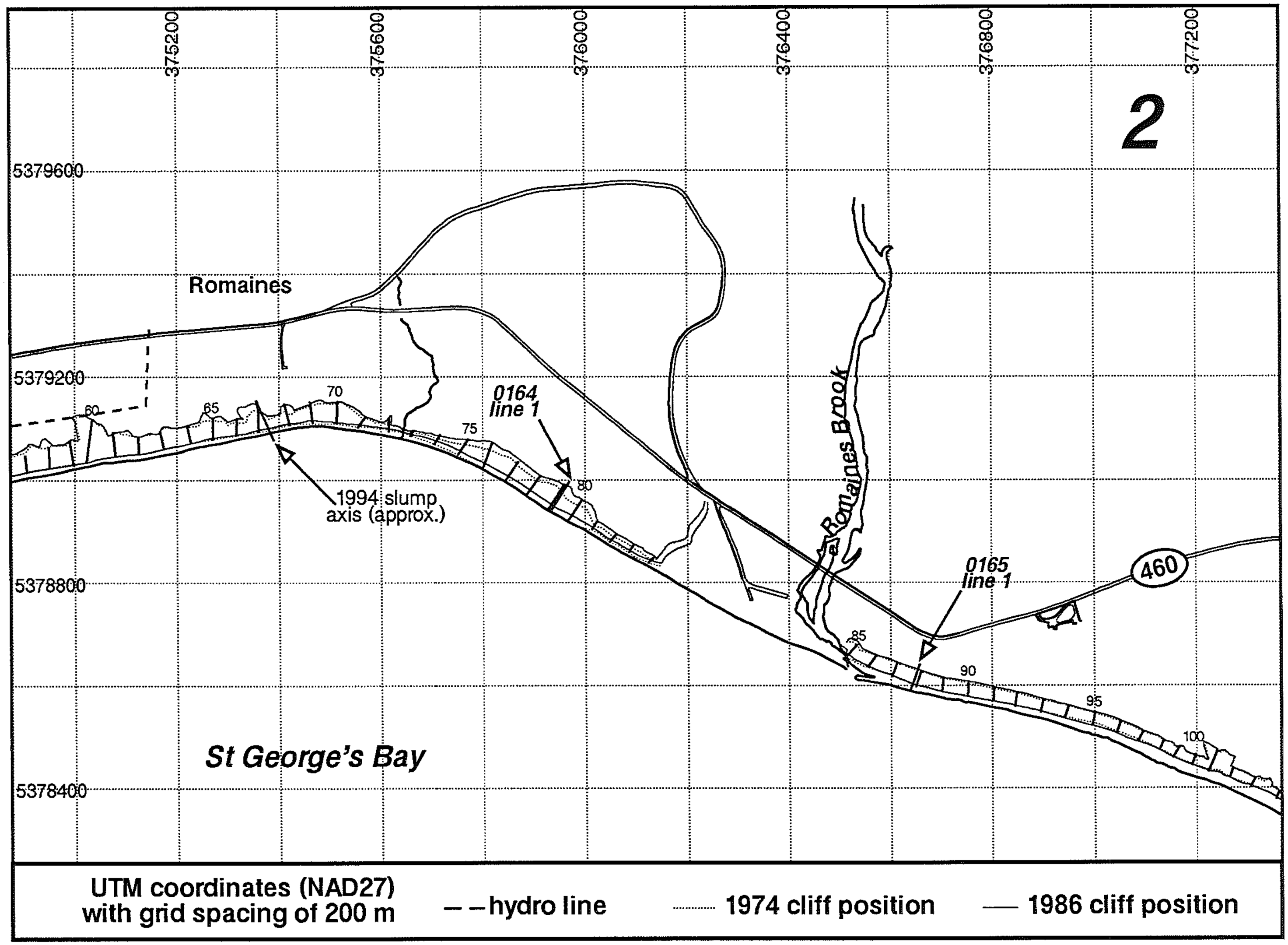

Figure 11: Cliff transects and survey sites 0164 and 0165 in area 2 (see Figure 1 for location).

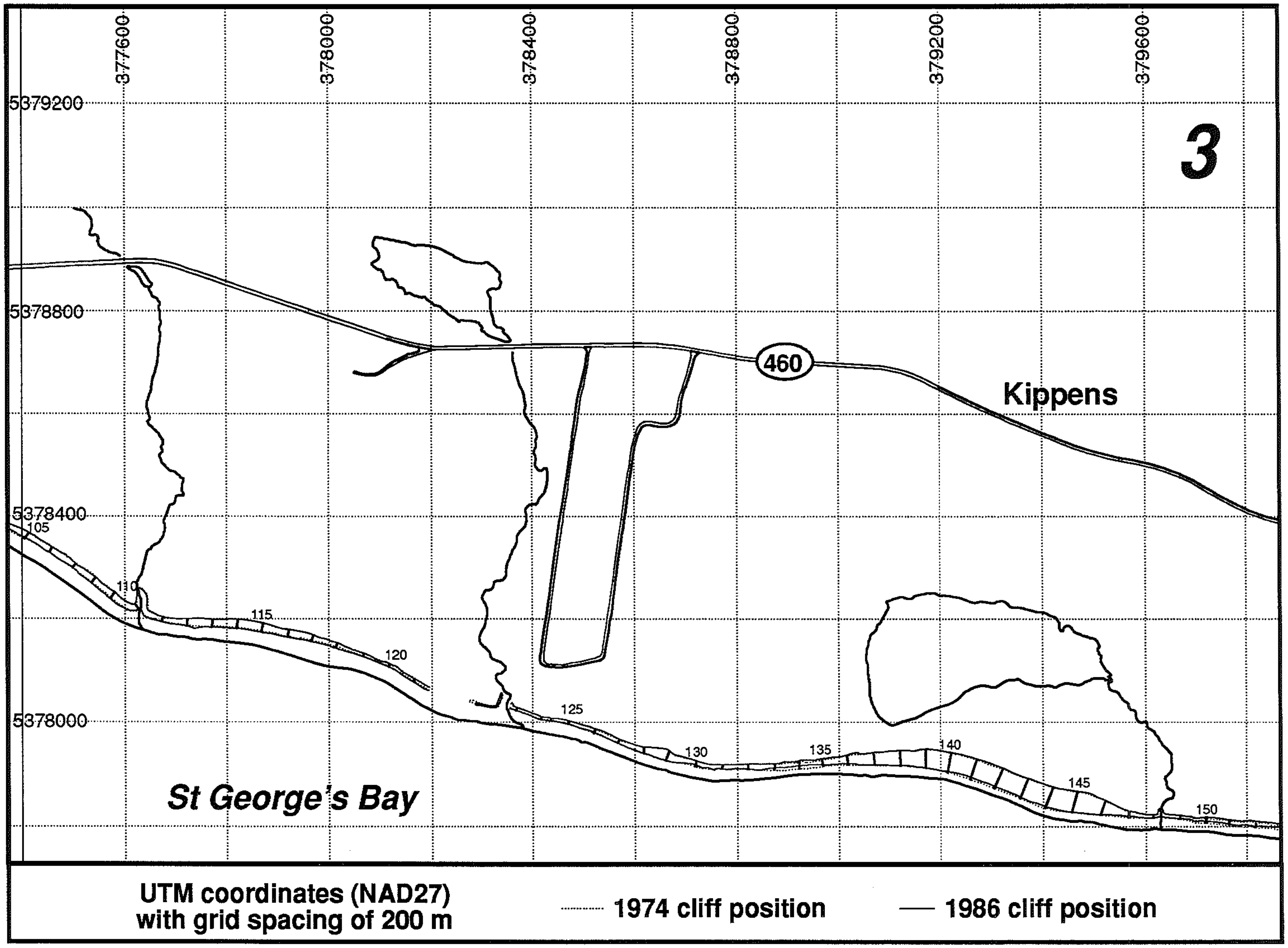

Figure 12: Cliff transects in area 3 (see Figure 1 for location).

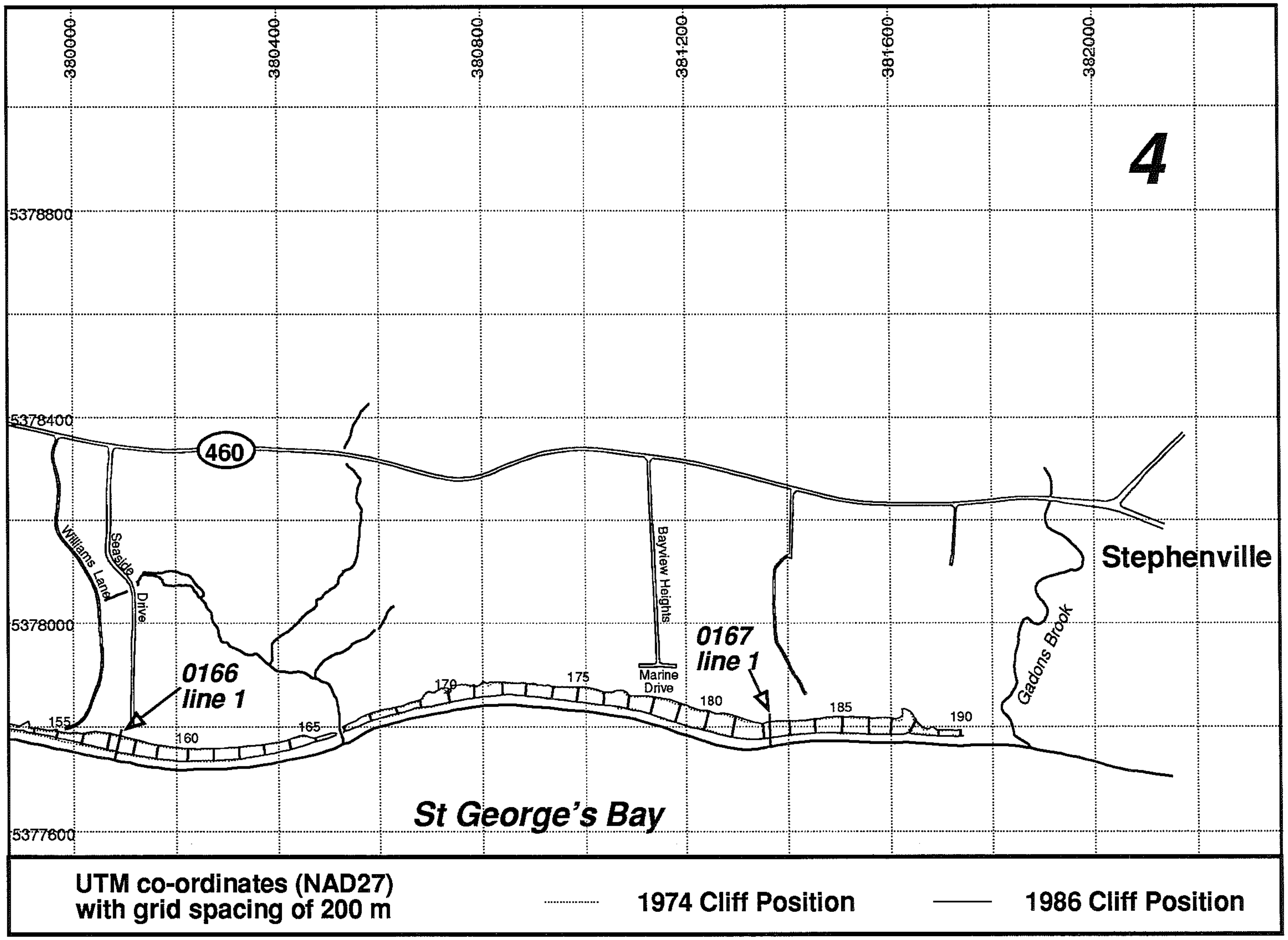

Figure 13: Cliff transects and survey sites 0166 and 0167 in area 4 (see Figure 1 for location).

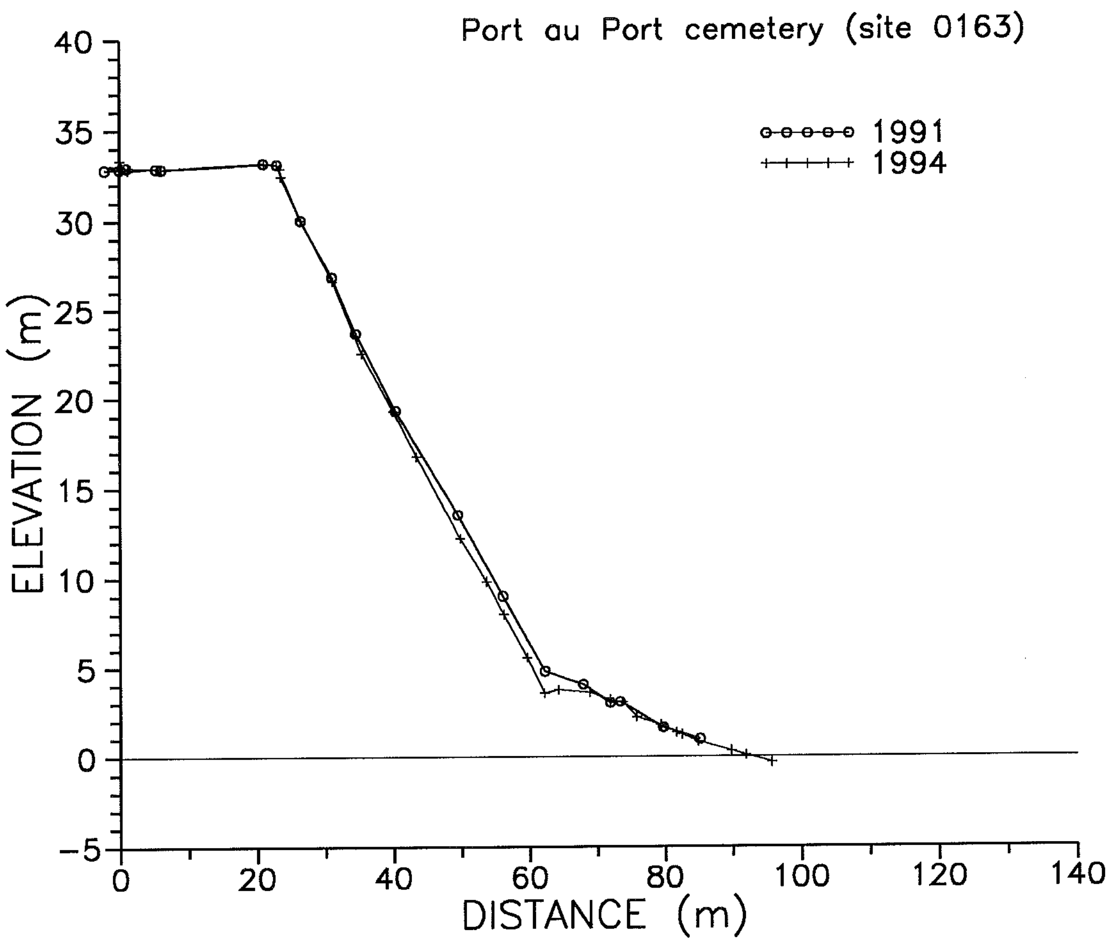

Figure 14: Cliff and beach profiles surveyed at Port au Port cemetery (site 0163) in 1991 and 1994 (see Figure 4 for location).

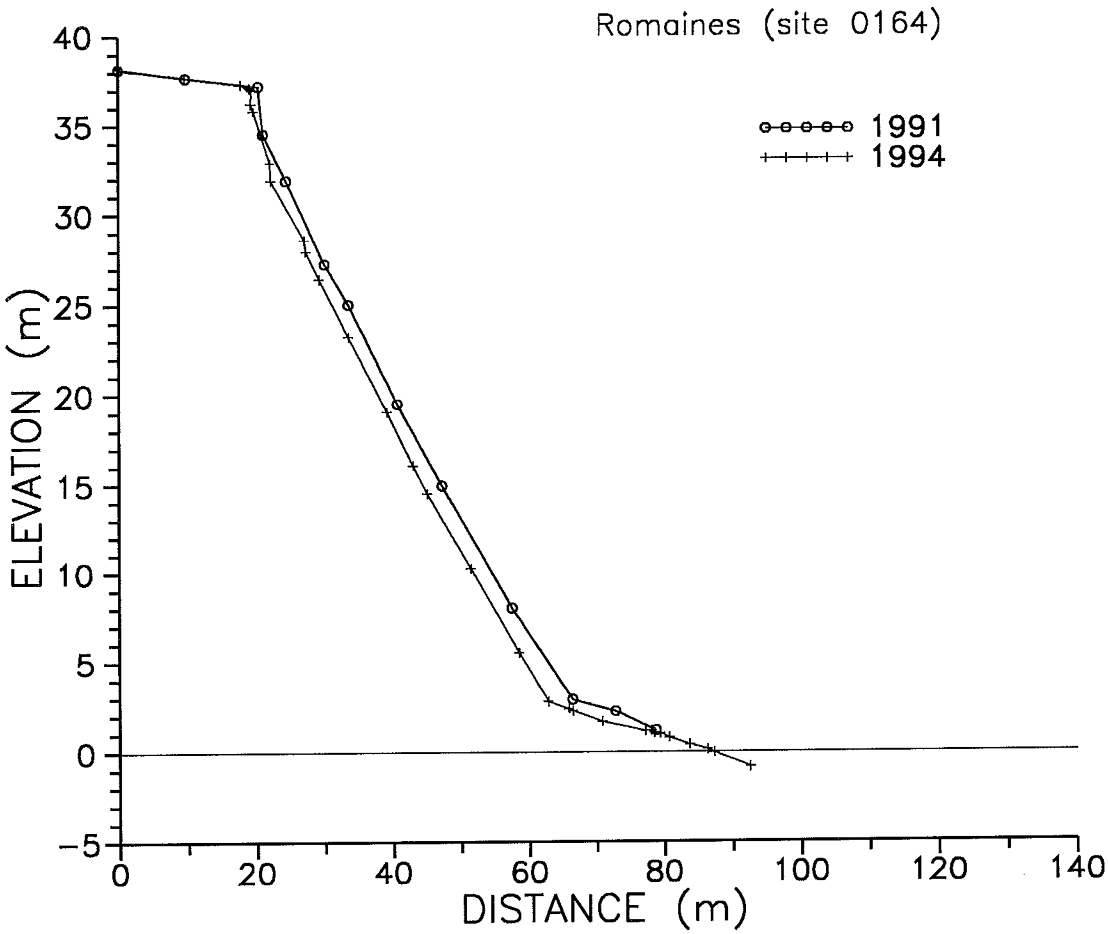

Figure 15: Cliff and beach profiles surveyed at Romaines (site 0164) in 1991 and 1994 (see Figure 4 for location).

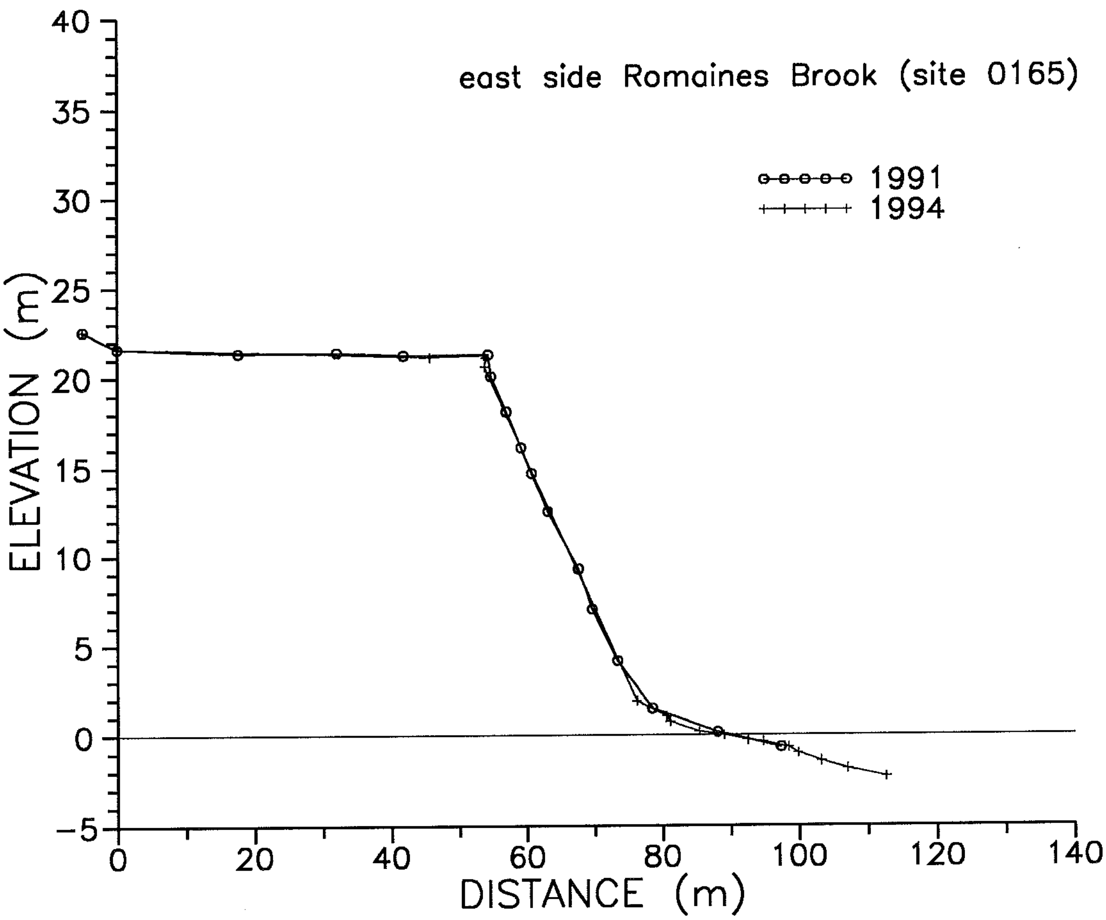

Figure 16: Cliff and beach profiles surveyed east of Romaines Brook (site 0165) in 1991 and 1994 (see Figure 4 for location).

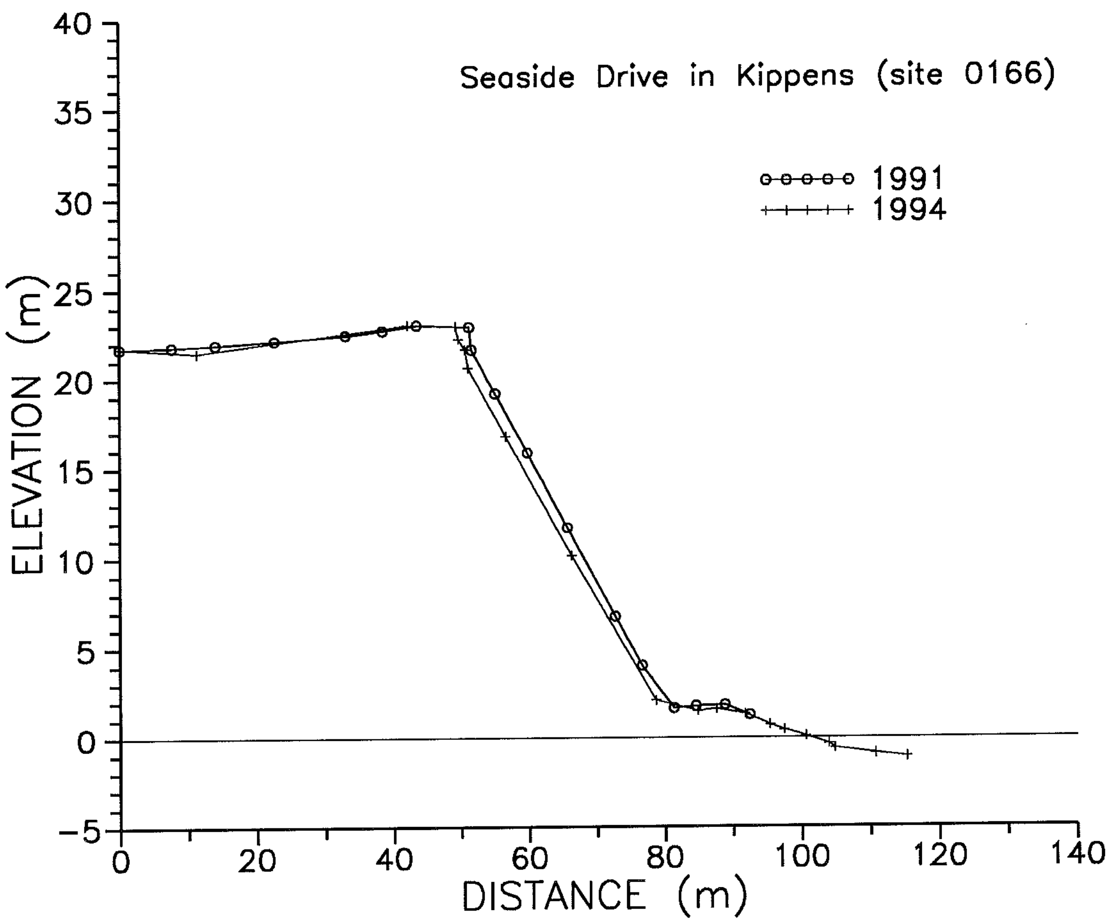

Figure 17: Cliff and beach profiles surveyed at Seaside Drive in Kippens (site 0166) in 1991 and 1994 (see Figure 4 for location).

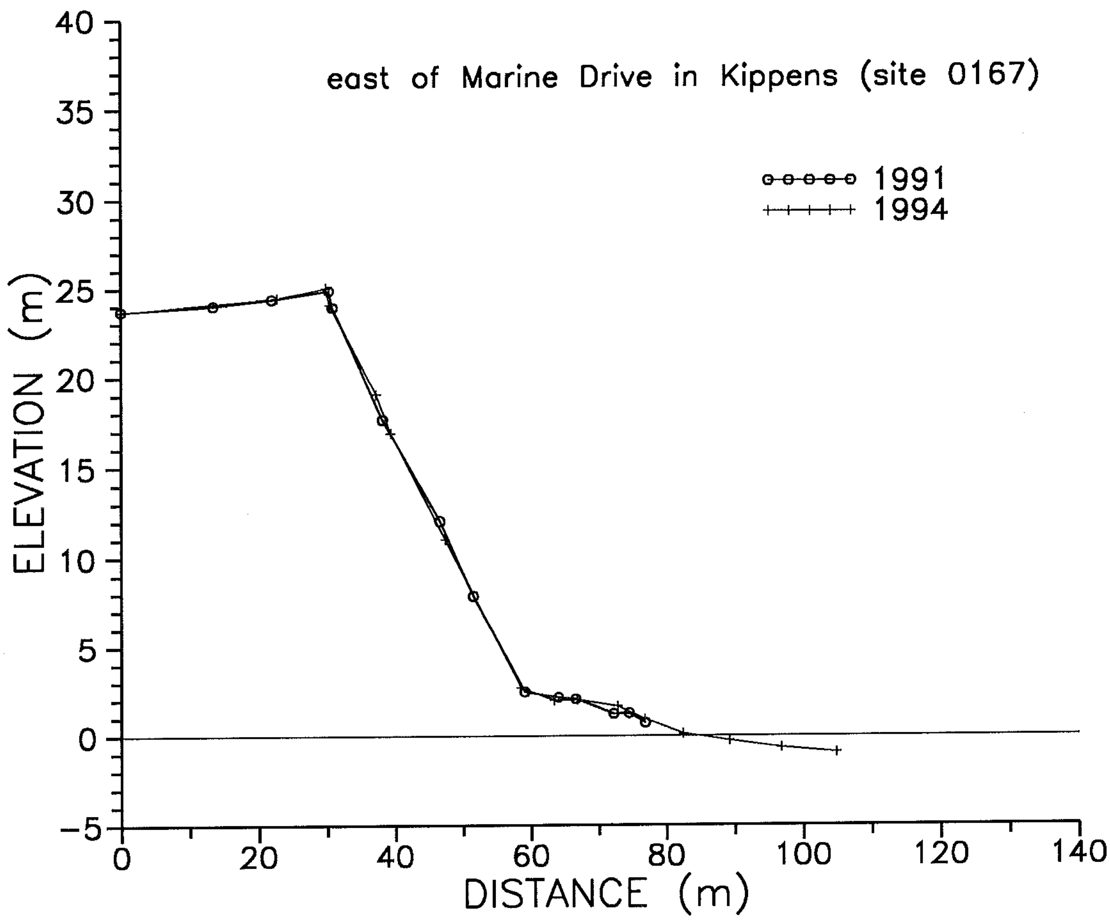

Figure 18: Cliff and beach profiles surveyed east of Marine Drive in Kippens (site 0167) in 1991 and 1994 (see Figure 4 for location).

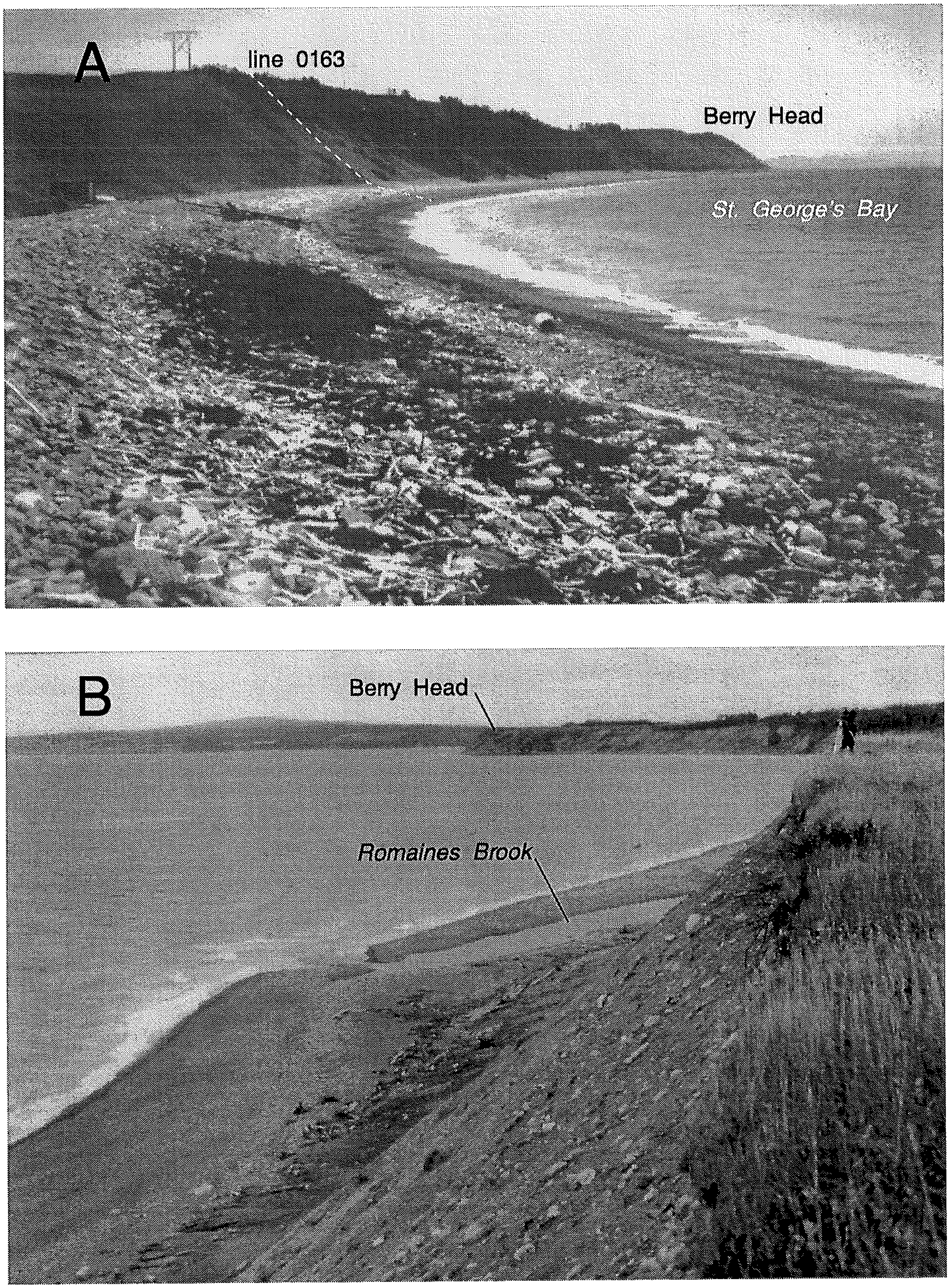

Figure 19: Ground views of the cliffs and beach at Port au Port and Romaines Brook. A: Looking east from the isthmus toward Berry Head, showing the survey line at site 0163. B: Looking west from the top of the cliff at site 0165 showing the partially blocked outlet of Romaines Brook (October 1994).

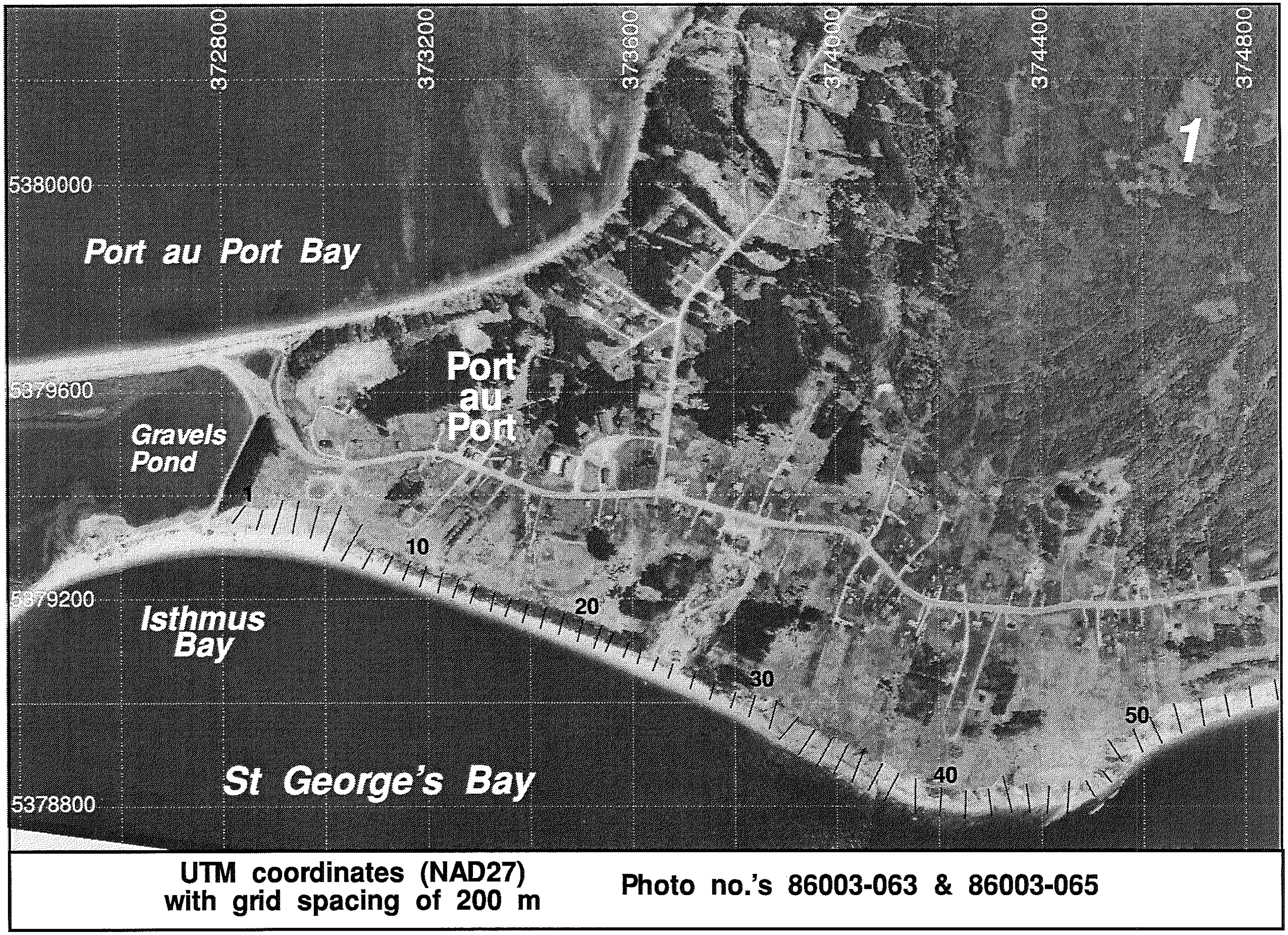

Figure 20: Transects superimposed on 1986 air photographs for area 1.

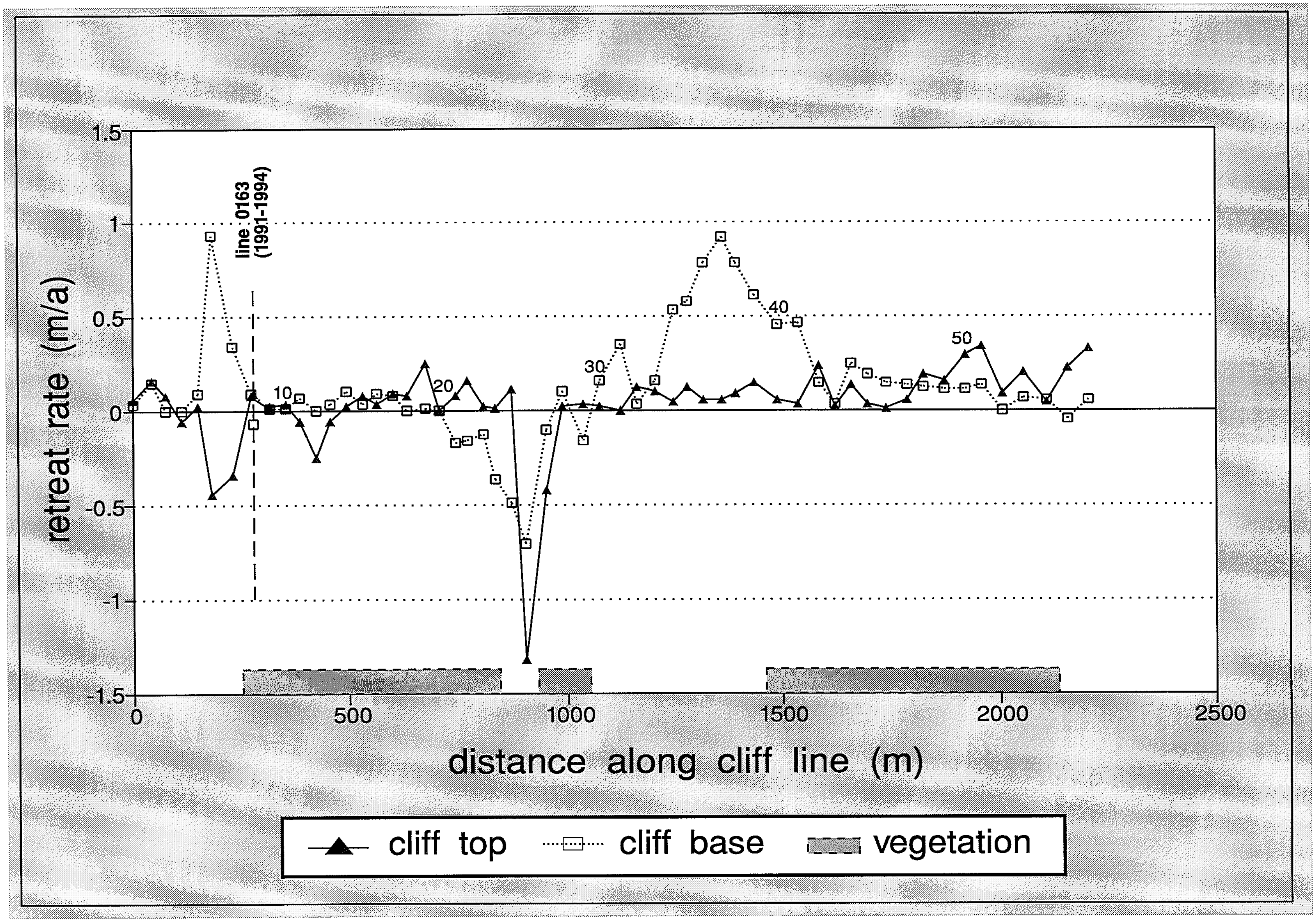

Figure 21: Cliff retreat as a function of distance alongshore in area 1.

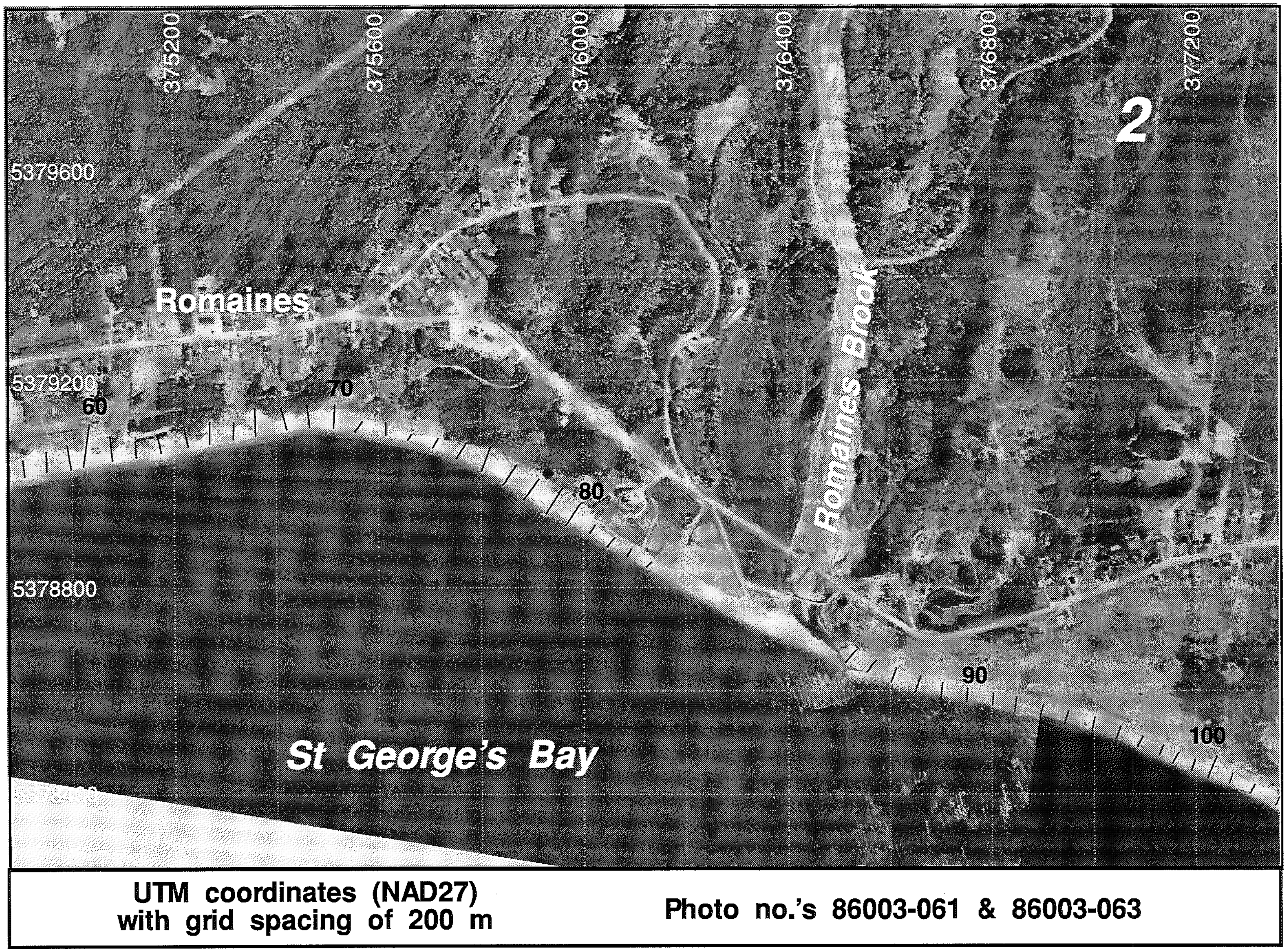

Figure 22: Transects superimposed on 1986 air photographs for area 2.

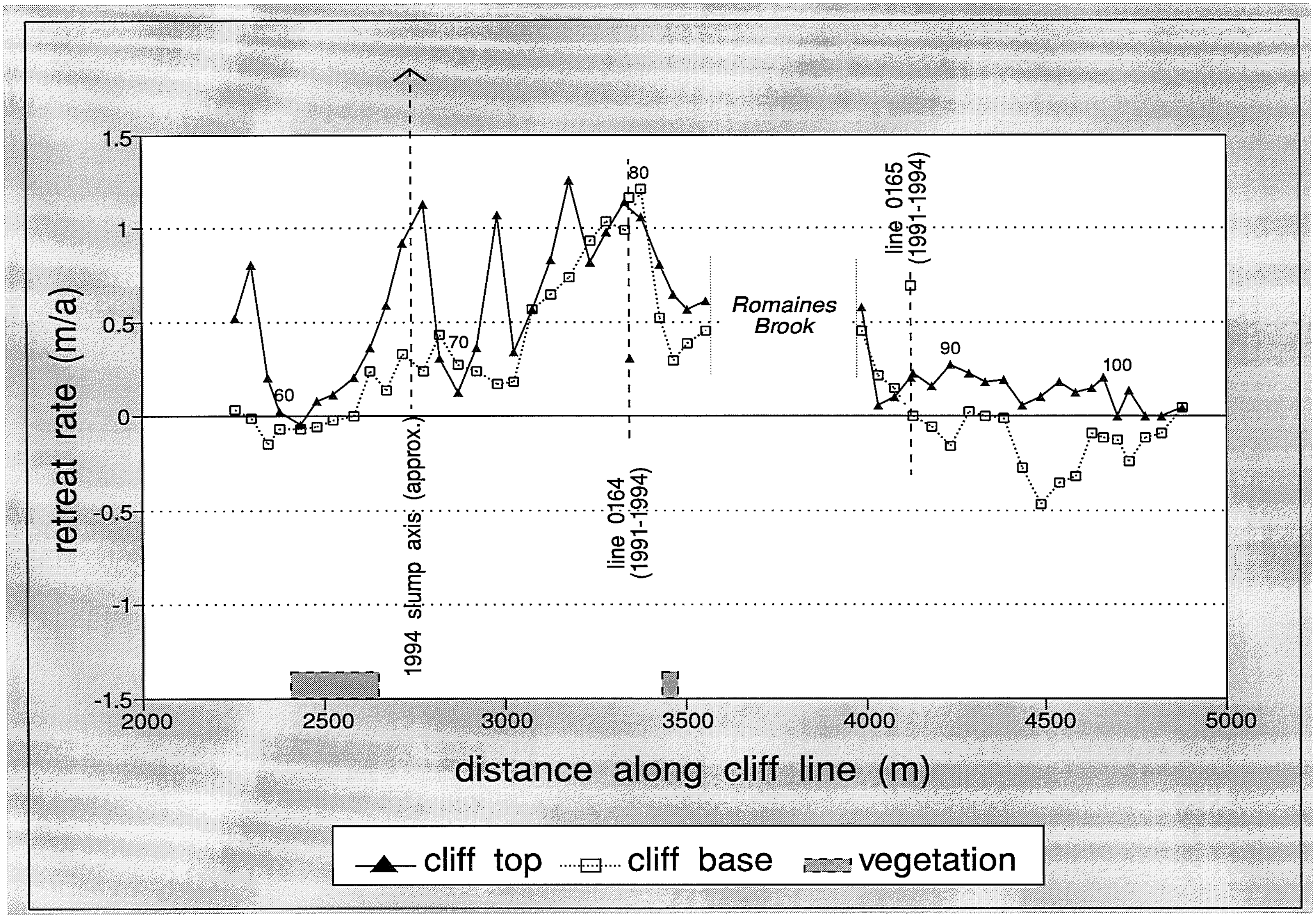

Figure 23: Cliff retreat as a function of distance alongshore in area 2.

Figure 24: Transects superimposed on 1986 air photographs for area 3.

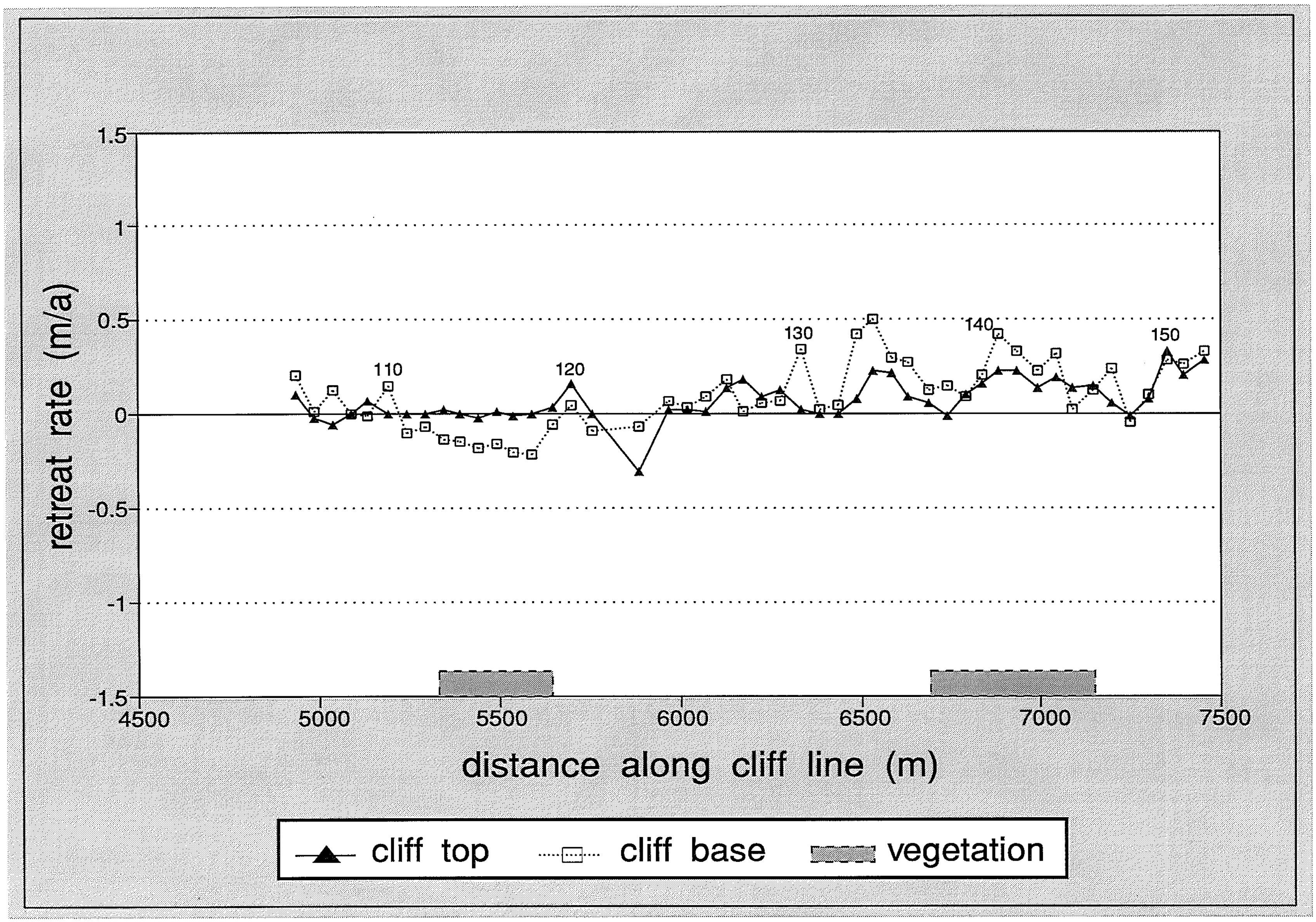

Figure 25: Cliff retreat as a function of distance alongshore in area 3.

Figure 26: Transects superimposed on 1986 air photographs for area 4.

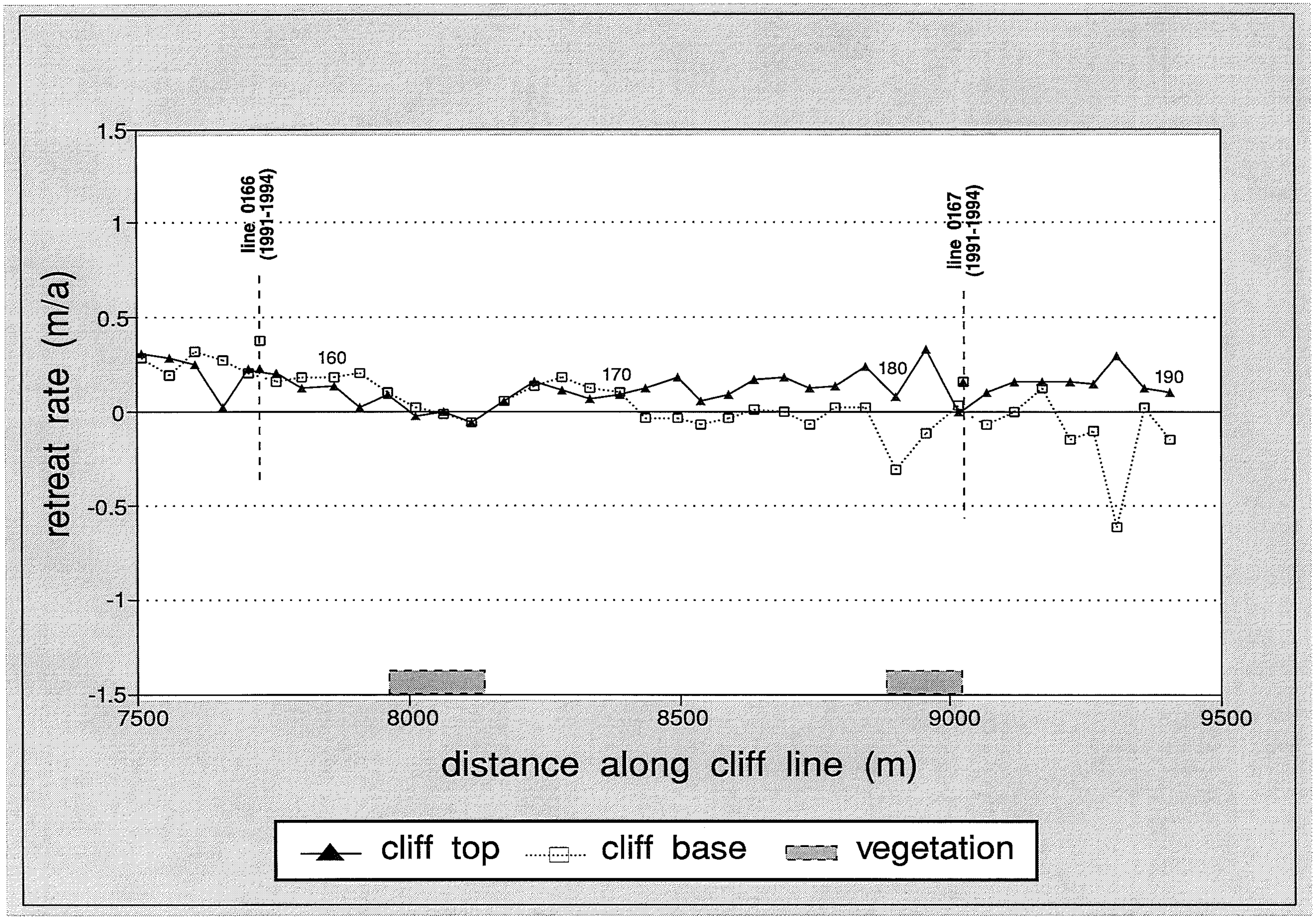

Figure 27: Cliff retreat as a function of distance alongshore in area 4.

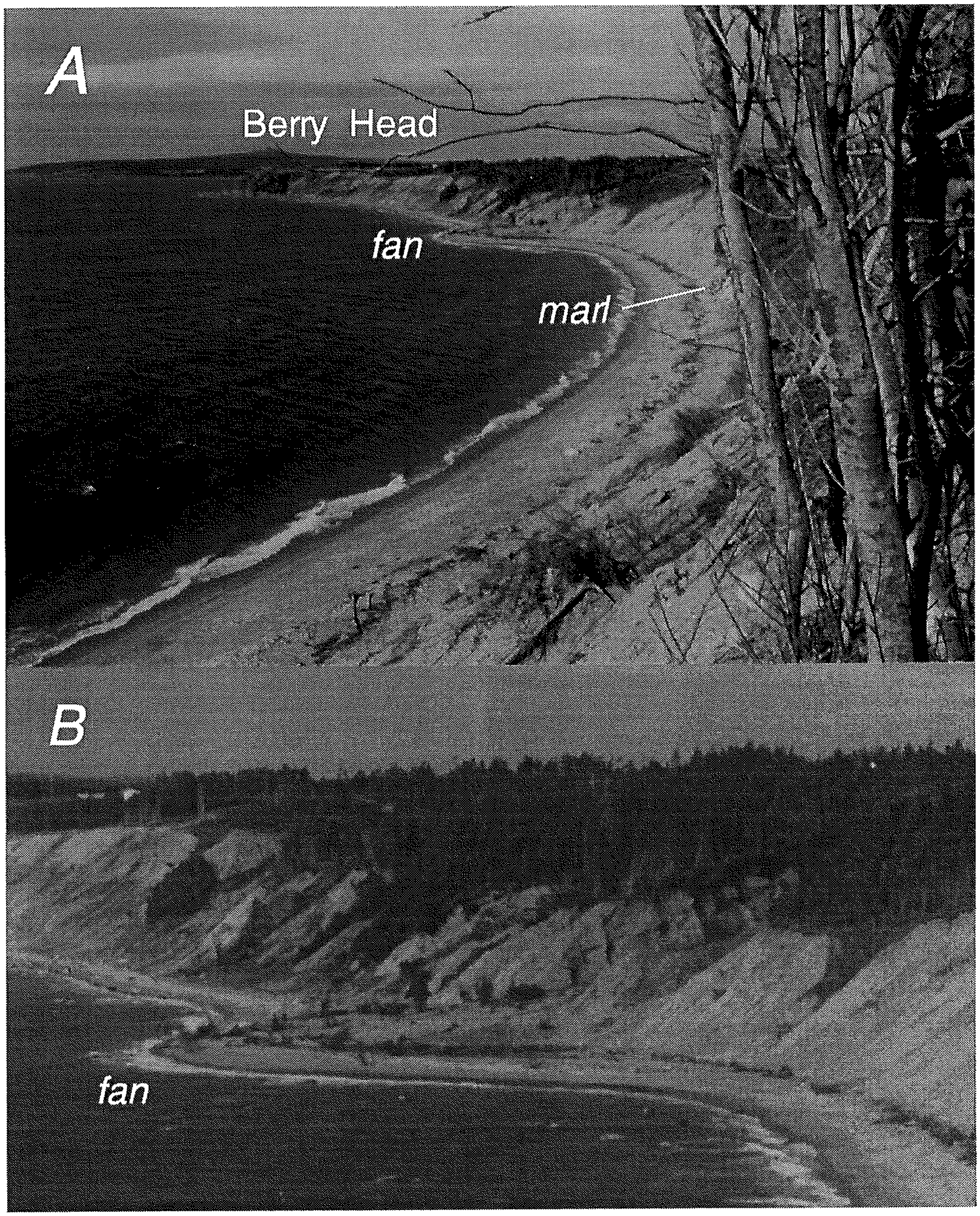

Figure 28: View west to the 1994 landslide fan from the top of cliff at site 0164 in Romaines. A: General view to the marl section and landslide fan with Berry Head in the background. B: Close-up of the fan and gullies in the area of the landslide.

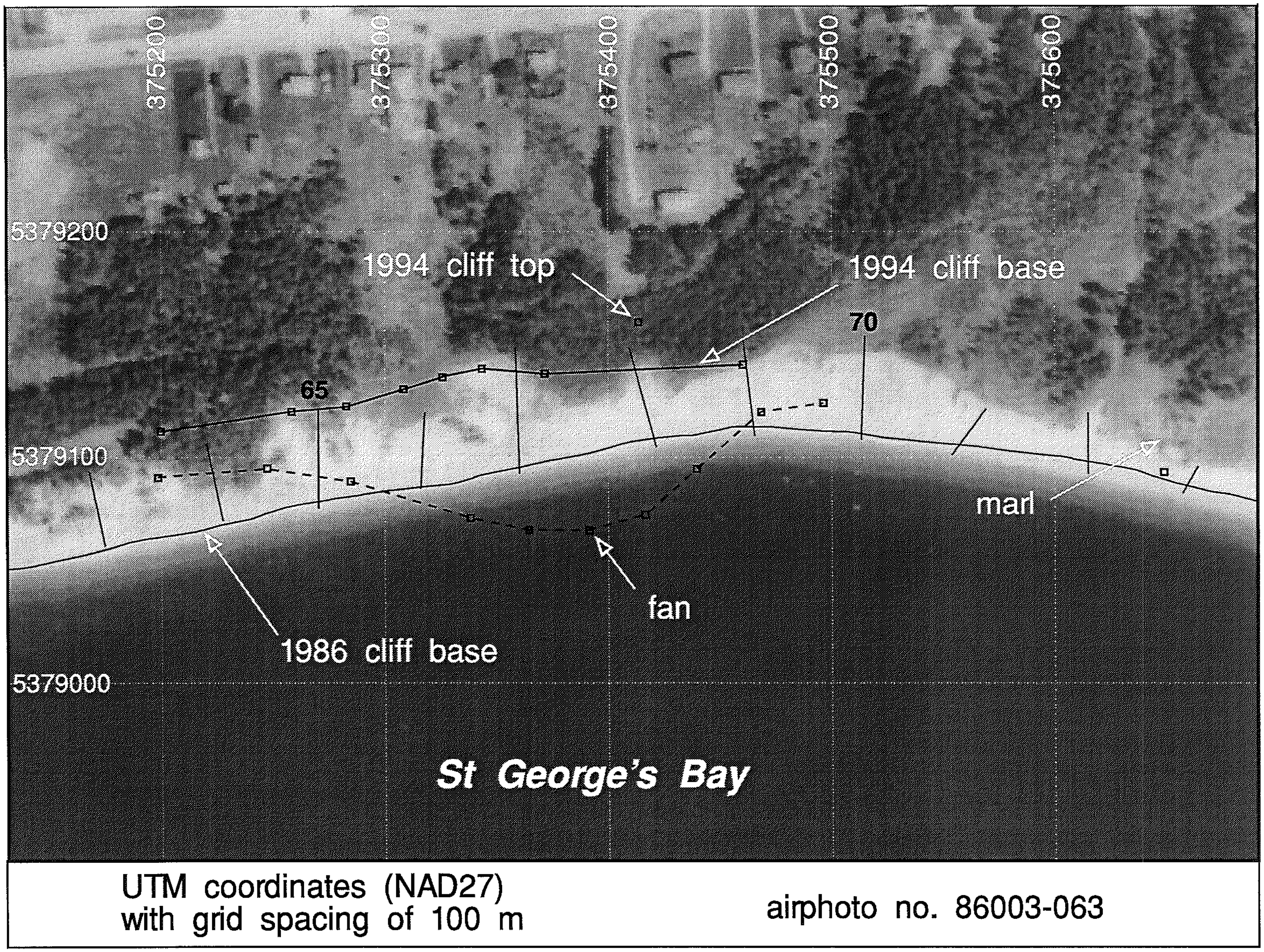

Figure 29: Detail of 1986 air photograph in the area of the 1994 landslide.

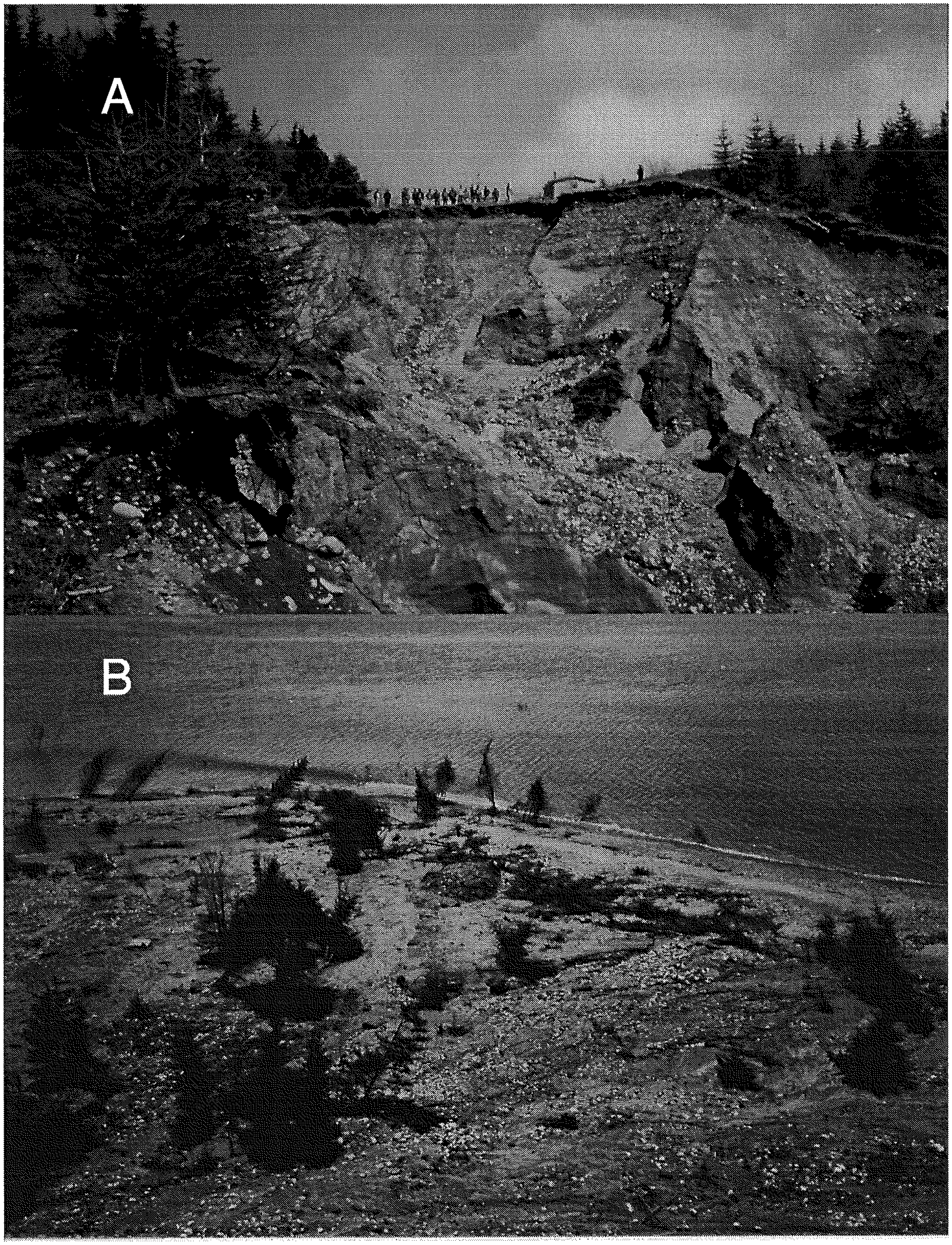

Figure 30: Two views of the 1994 landslide in Romaines taken a few weeks after the event. A: Looking up at the headwall with slumped blocks in the foreground and house beyond (note people at top of cliff for scale). B: Looking down at the fan, showing transported trees lying across the fan and in the water in the background.

APPENDIX 1
Area 1 measurements

Transects		1974 to 1986				1991 to 1994	
		Cliff Top		Cliff Base		Cliff Top	Cliff Base
Transect No.	Cummulative distance (m)	Retreat (meters)	Retreat Rate (m /yr)	Retreat (meters)	Retreat Rate (m / yr)	Retreat Rate (m / yr)	Retreat Rate (m / yr)
1	0.00	0.70	0.06	0.38	0.03		
2	41.09	1.99	0.17	1.82	0.15		
3	73.66	0.90	0.08	0.00	0.00		
4	110.53	-0.66	-0.06	0.00	0.00		
5	148.83	0.31	0.03	1.16	0.10		
6	183.72	-5.35	-0.45	11.29	0.94		
7	229.08	-4.01	-0.33	4.19	0.35		
8	271.76	0.95	0.08	1.17	0.10		
8a	280.29					0.09	-0.07
9	314.82	0.25	0.02	0.19	0.02		
10	351.57	0.47	0.04	0.19	0.02		
11	385.44	-0.62	-0.05	0.86	0.07		
12	420.59	-2.90	-0.24	0.00	0.00		
13	453.13	-0.59	-0.05	0.41	0.03		
14	489.16	0.32	0.03	1.21	0.10		
15	528.99	0.90	0.08	0.41	0.03		
16	561.75	0.47	0.04	1.12	0.09		
17	596.39	1.11	0.09	1.03	0.09		
18	633.12	0.92	0.08	0.00	0.00		
19	670.59	2.99	0.25	0.19	0.02		
20	709.02	0.00	0.00	0.00	0.00		
21	745.07	0.95	0.08	-2.00	-0.17		
22	771.44	1.89	0.16	-1.88	-0.16		
23	807.36	0.20	0.02	-1.52	-0.13		
24	835.99	0.18	0.02	-4.37	-0.36		
25	870.48	1.39	0.12	-5.89	-0.49		
26	903.56	-15.82	-1.32	-8.49	-0.71		
27	951.12	-5.06	-0.42	-1.21	-0.10		
28	993.33	0.28	0.02	1.29	0.11		
29	1038.08	0.47	0.04	-1.89	-0.16		
30	1076.84	0.28	0.02	1.97	0.16		
31	1120.94	0.00	0.00	4.22	0.35		
32	1162.63	1.50	0.13	0.38	0.03		
33	1206.69	1.22	0.10	2.03	0.17		
34	1246.17	0.59	0.05	6.38	0.53		
35	1280.74	1.49	0.12	6.92	0.58		
36	1316.59	0.79	0.07	9.46	0.79		

APPENDIX 1
Area 1 measurements

Transects		1974 to 1986				1991 to 1994	
		Cliff Top		Cliff Base		Cliff Top	Cliff Base
Transect No.	Cummulative distance (m)	Retreat (meters)	Retreat Rate (m /yr)	Retreat (meters)	Retreat Rate (m / yr)	Retreat Rate (m / yr)	Retreat Rate (m / yr)
37	1356.80	0.71	0.06	11.00	0.92		
38	1393.77	1.18	0.10	9.49	0.79		
39	1437.03	1.77	0.15	7.40	0.62		
40	1487.06	0.79	0.07	5.58	0.47		
41	1535.55	0.35	0.03	5.63	0.47		
42	1583.40	2.84	0.24	1.77	0.15		
43	1620.32	0.32	0.03	0.41	0.03		
44	1658.54	1.59	0.13	3.12	0.26		
45	1697.43	0.44	0.04	2.34	0.20		
46	1736.76	0.18	0.02	1.77	0.15		
47	1784.43	0.71	0.06	1.66	0.14		
48	1825.11	2.31	0.19	1.47	0.12		
49	1872.68	1.90	0.16	1.36	0.11		
50	1920.33	3.58	0.30	1.40	0.12		
51	1961.30	4.15	0.35	1.64	0.14		
52	2008.67	1.14	0.10	0.00	0.00		
53	2057.76	2.45	0.20	0.82	0.07		
54	2108.77	0.53	0.04	0.69	0.06		
55	2157.40	2.78	0.23	-0.56	-0.05		
56	2209.63	3.93	0.33	0.68	0.06		

APPENDIX 2
Area 2 measurements

Transects		1974 to 1986				1991 to 1994	
		Cliff Top		*Cliff Base*		*Cliff Top*	*Cliff Base*
Transect No.	Cummulative distance (m)	Retreat (meters)	Retreat Rate (m / yr)	Retreat (meters)	Retreat Rate (m / yr)	Retreat Rate (m / yr)	Retreat Rate (m / yr)
57	2255.67	6.30	0.53	0.46	0.04		
58	2301.33	9.74	0.81	-0.15	-0.01		
59	2347.54	2.47	0.21	-1.66	-0.14		
60	2380.10	0.30	0.03	-0.74	-0.06		
61	2431.65	-0.48	-0.04	-0.87	-0.07		
62	2478.92	0.92	0.08	-0.60	-0.05		
63	2526.76	1.36	0.11	-0.33	-0.03		
64	2579.88	2.47	0.21	0.00	0.00		
65	2628.29	4.41	0.37	2.93	0.24		
66	2674.88	7.15	0.60	1.63	0.14		
67	2718.57	11.10	0.93	3.97	0.33		
68	2776.09	13.53	1.13	2.86	0.24		
69	2823.55	3.76	0.31	5.25	0.44		
70	2874.55	1.53	0.13	3.22	0.27		
71	2924.85	4.43	0.37	2.90	0.24		
72	2978.44	12.88	1.07	2.09	0.17		
73	3026.82	4.09	0.34	2.26	0.19		
74	3077.54	6.75	0.56	6.80	0.57		
75	3129.07	10.05	0.84	7.88	0.66		
76	3181.74	15.02	1.25	8.93	0.74		
77	3236.82	9.90	0.83	11.16	0.93		
78	3286.12	11.80	0.98	12.41	1.03		
79	3336.46	13.66	1.14	11.98	1.00		
79a	3346.61					0.32	1.16
80	3382.25	12.69	1.06	14.47	1.21		
81	3428.85	9.71	0.81	6.35	0.53		
82	3472.96	7.76	0.65	3.53	0.29		
83	3513.25	6.81	0.57	4.69	0.39		
84	3559.58	7.42	0.62	5.46	0.46		
85	3993.27	6.99	0.58	5.46	0.46		
86	4037.13	0.76	0.06	2.59	0.22		
87	4083.15	1.23	0.10	1.83	0.15		
87a	4127.48					0.20	0.70
88	4134.47	2.79	0.23	0.00	0.00		
89	4182.32	1.98	0.17	-0.60	-0.05		
90	4233.85	3.32	0.28	-1.92	-0.16		
91	4284.63	2.77	0.23	0.29	0.02		

APPENDIX 2

Area 2 measurements

Transects		1974 to 1986				1991 to 1994	
		Cliff Top		Cliff Base		Cliff Top	Cliff Base
Transect No.	Cummulative distance (m)	Retreat (meters)	Retreat Rate (m / yr)	Retreat (meters)	Retreat Rate (m / yr)	Retreat Rate (m / yr)	Retreat Rate (m / yr)
92	4330.43	2.12	0.18	0.00	0.00		
93	4382.52	2.36	0.20	-0.15	-0.01		
94	4431.92	0.68	0.06	-3.32	-0.28		
95	4486.89	1.25	0.10	-5.55	-0.46		
96	4538.60	2.18	0.18	-4.17	-0.35		
97	4584.52	1.56	0.13	-3.85	-0.32		
98	4629.33	1.83	0.15	-1.05	-0.09		
99	4661.54	2.51	0.21	-1.37	-0.11		
100	4698.53	0.00	0.00	-1.52	-0.13		
101	4734.56	1.73	0.14	-2.80	-0.23		
102	4776.98	0.00	0.00	-1.30	-0.11		
103	4825.15	0.00	0.00	-1.05	-0.09		
104	4878.82	0.64	0.05	0.60	0.05		

APPENDIX 3
Area 3 measurements

Transects		1974 to 1986			
		Cliff Top		*Cliff Base*	
Transect No.	Cummulative distance (m)	Retreat (meters)	Retreat Rate (m / yr)	Retreat (meters)	Retreat Rate (m / yr)
105	4933.95	1.29	0.11	2.48	0.21
106	4987.94	-0.32	-0.03	0.13	0.01
107	5043.37	-0.61	-0.05	1.44	0.12
108	5089.45	0.00	0.00	0.00	0.00
109	5136.88	0.82	0.07	-0.18	-0.02
110	5191.75	0.00	0.00	1.79	0.15
111	5246.03	0.00	0.00	-1.13	-0.09
112	5295.21	0.00	0.00	-0.88	-0.07
113	5345.20	0.20	0.02	-1.63	-0.14
114	5393.21	0.00	0.00	-1.75	-0.15
115	5442.39	-0.32	-0.03	-2.15	-0.18
116	5494.81	0.14	0.01	-1.89	-0.16
117	5543.04	-0.14	-0.01	-2.40	-0.20
118	5591.45	0.00	0.00	-2.52	-0.21
119	5647.67	0.46	0.04	-0.73	-0.06
120	5701.52	2.01	0.17	0.53	0.04
121	5757.93	0.00	0.00	-1.07	-0.09
122	5888.68	-3.72	-0.31	-0.88	-0.07
123	5968.68	0.32	0.03	0.84	0.07
124	6020.79	0.20	0.02	0.45	0.04
125	6075.84	0.14	0.01	1.12	0.09
126	6128.77	1.69	0.14	2.12	0.18
127	6178.78	2.17	0.18	0.12	0.01
128	6231.30	1.16	0.10	0.73	0.06
129	6278.98	1.54	0.13	0.88	0.07
130	6335.31	0.29	0.02	4.08	0.34
131	6388.99	0.00	0.00	0.25	0.02
132	6438.95	0.00	0.00	0.62	0.05
133	6490.20	1.01	0.08	5.11	0.43
134	6539.66	2.70	0.23	6.12	0.51
135	6586.66	2.64	0.22	3.53	0.29
136	6636.88	1.19	0.10	3.24	0.27
137	6688.82	0.72	0.06	1.50	0.13
138	6740.72	-0.14	-0.01	1.75	0.15
139	6790.68	1.31	0.11	1.13	0.09
140	6837.19	1.93	0.16	2.45	0.20
141	6885.20	2.70	0.23	5.09	0.42

APPENDIX 3

Area 3 measurements

Transects		1974 to 1986			
		Cliff Top		*Cliff Base*	
Transect No.	Cummulative distance (m)	Retreat (meters)	Retreat Rate (m / yr)	Retreat (meters)	Retreat Rate (m / yr)
142	6937.25	2.78	0.23	4.02	0.34
143	6990.63	1.62	0.14	2.79	0.23
144	7041.71	2.34	0.20	3.87	0.32
145	7094.10	1.62	0.14	0.25	0.02
146	7148.71	1.75	0.15	1.52	0.13
147	7200.64	0.74	0.06	2.89	0.24
148	7249.45	-0.14	-0.01	-0.51	-0.04
149	7302.71	1.02	0.09	1.25	0.10
150	7354.81	3.93	0.33	3.38	0.28
151	7400.60	2.50	0.21	3.14	0.26
152	7453.40	3.38	0.28	3.90	0.33

APPENDIX 4
Area 4 measurements

Transects		1974 to 1986				1991 to 1994	
		Cliff Top		Cliff Base		Cliff Top	Cliff Base
Transect No.	Cummulative distance (m)	Retreat (meters)	Retreat Rate (m / yr)	Retreat (meters)	Retreat Rate (m / yr)	Retreat Rate (m / yr)	Retreat Rate (m / yr)
153	7507.99	3.78	0.32	3.39	0.28		
154	7559.09	3.39	0.28	2.28	0.19		
155	7604.33	3.03	0.25	3.86	0.32		
156	7654.88	0.29	0.02	3.33	0.28		
157	7705.75	2.68	0.22	2.48	0.21		
157a	7725.92					0.23	0.38
158	7757.68	2.57	0.21	1.98	0.17		
159	7802.86	1.48	0.12	2.26	0.19		
160	7863.36	1.62	0.14	2.12	0.18		
161	7912.67	0.29	0.02	2.52	0.21		
162	7963.37	1.06	0.09	1.26	0.11		
163	8012.65	-0.29	-0.02	0.31	0.03		
164	8064.82	0.00	0.00	-0.14	-0.01		
165	8115.97	-0.60	-0.05	-0.63	-0.05		
166	8177.82	0.74	0.06	0.71	0.06		
167	8230.97	1.97	0.16	1.63	0.14		
168	8284.95	1.38	0.12	2.20	0.18		
169	8333.79	0.88	0.07	1.45	0.12		
170	8390.03	1.17	0.10	1.34	0.11		
171	8439.43	1.45	0.12	-0.39	-0.03		
172	8495.53	2.20	0.18	-0.42	-0.04		
173	8540.31	0.74	0.06	-0.77	-0.06		
174	8591.90	1.06	0.09	-0.37	-0.03		
175	8641.35	2.05	0.17	0.13	0.01		
176	8693.83	2.18	0.18	0.00	0.00		
177	8743.56	1.52	0.13	-0.83	-0.07		
178	8792.19	1.65	0.14	0.29	0.02		
179	8844.43	2.86	0.24	0.29	0.02		
180	8903.34	0.92	0.08	-3.62	-0.30		
181	8957.84	3.95	0.33	-1.34	-0.11		
182	9016.19	0.00	0.00	0.42	0.04		
182a	9026.36					0.17	0.17
183	9069.00	1.31	0.11	-0.79	-0.07		
184	9118.34	1.89	0.16	0.00	0.00		
185	9171.09	2.03	0.17	1.58	0.13		
186	9223.09	1.89	0.16	-1.71	-0.14		
187	9265.33	1.80	0.15	-1.19	-0.10		

APPENDIX 4
Area 4 measurements

Transects		1974 to 1986				1991 to 1994	
		Cliff Top		*Cliff Base*		*Cliff Top*	*Cliff Base*
Transect No.	Cummulative distance (m)	Retreat (meters)	Retreat Rate (m / yr)	Retreat (meters)	Retreat Rate (m / yr)	Retreat Rate (m / yr)	Retreat Rate (m / yr)
188	9306.85	3.51	0.29	-7.37	-0.61		
189	9359.57	1.43	0.12	0.26	0.02		
190	9403.68	1.31	0.11	-1.71	-0.14		