Journal of Coastal Research	8	4	926–942	Fort Lauderdale, Florida	Fall 1992

Periglacial Shoreline Erosion of a Rocky Coast: George River Estuary, Northern Quebec

Alain Fournier and Michel Allard

Centre d'études nordiques
Université Laval
Sainte-Foy, Québec G1K 7P4, Canada

ABSTRACT

FOURNIER, A., and ALLARD, M., 1992. Periglacial Shoreline Erosion of a Rocky Coast: George River Estuary, northern Quebec. *Journal of Coastal Research*, 8(4), 926–942. Fort Lauderdale (Florida), ISSN 0749-0208.

Shore erosion landforms in bedrock were observed along the estuary of George River in a macrotidal periglacial environment. Quarrying of cavities in gneissic bedrock is largely dependent on geological structure, principally on joints and foliations. Frost-riving operating in the jointed rock loosens pre-configured blocks that are thereafter mobilized by waves and sea ice. Gelifraction and frost shattering along the shore are more effective at places where streamlets flow to the shore and where fresh water seeps throughout the structure. Measurements of erosion profiles were made relative to initially glacial-sculptured intertidal outcrops. Erosional landforms were observed along the whole shoreline length of the study area which was also classified into segments according to slope angle, geographic orientation and fetch. Observations indicate that erosion is more intensive in sectors having low and medium slope angles that allow shore ice to override and where the large fetches favour wave pounding and sea-ice thrusting. The erosion takes place preferentially around the mean high tide level. The knowledge of the acting erosional processes and the resulting landforms allow the recognition of raised bedrock shoreline features associated with post-glacial, uplifted shorelines. These raised bedrock shoreline landforms correspond very well in elevation with the more conspicuous raised shorelines in Quaternary sediments in the region. Some age correlations with major dated Holocene shorelines in the eastern Canadian Arctic are suggested.

ADDITIONAL INDEX WORDS: *Erosion, frost-riving, sea ice, rock benches, raised shorelines, Ungava Bay.*

INTRODUCTION

Until very recently, little knowledge existed on the subject of shoreline erosion along rocky coasts in the periglacial environment (ALLARD and TREMBLAY, 1983a; TRENHAILE, 1987; DIONNE and BRODEUR, 1988). The exact contribution of various interacting processes such as gelifraction, wave-quarrying and shore ice pressures is still a matter of discussion because of the lack of observational data and, also, because of the poor understanding of the way each process operates along shorelines. In addition, most researchers have been, for obvious reasons, more attracted by the morphologic ultima, *i.e.*, the platforms, the strandflats (NANSEN, 1922; MOIGN, 1976; RABBOTIN, 1977; TRENHAILE, 1983; HANSOM, 1983) and the cliffs, whereas the less conspicuous but nevertheless important intermediate slope features have received little attention.

The aim of this study is to document the character of periglacial erosional processes on crystalline shores from observations of the stages of erosion sequences. These observations were made keeping in mind the complementarity of the implied processes. Two other specific questions were also addressed: (1) Does a specific level of greatest wear exist within the intertidal zone in harsh periglacial environments affected by sea ice? This question applies particularly to the study area because it has a very large tidal range. (2) Because the study area has been emerging since deglaciation, can we identify remnants of uplifted erosional strandlines and, if so, what is their potential significance in the postglacial history of the eastern Canadian Arctic?

The Study Area

The estuary of George River is located in the southeastern sector of Ungava Bay, in northern Québec (Figure 1). The study area corresponds to the middle part of the estuary where both fluvial and maritime influences are felt. Eighty-five per-

---

91009 received 28 January 1991, accepted in revision 15 December 1991

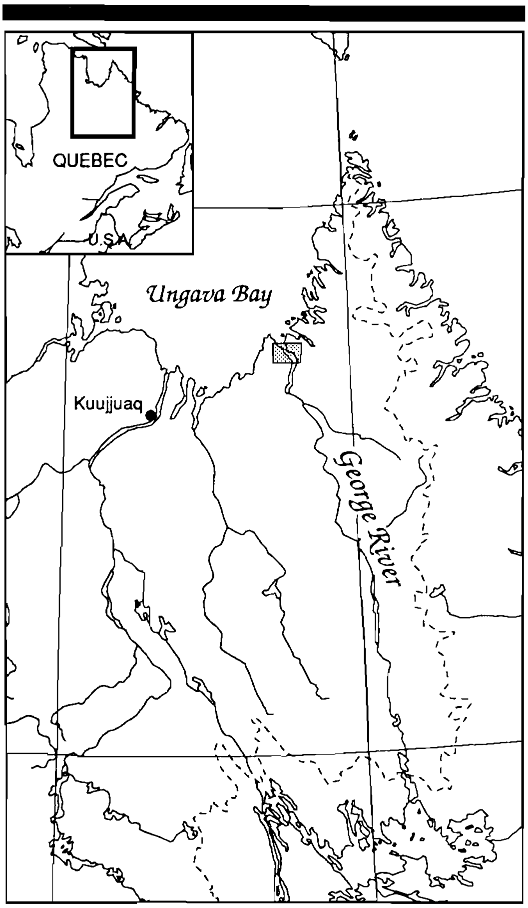

Figure 1. Location of the study area.

cent of the length of the studied shores are in bedrock; of the remaining 15%, half consists of till cliffs, half is tidal marsh.

Relief along the estuary consists of alternating elongated hills and valleys. The hills are on average 100 m high and from 1 to 5 km long with their long axis oriented either towards 310° or 332°. These directions correspond to the dominant axis of the fold hinges in the gneissic rocks which have been folded at least twice during the Hudsonian orogeny of the Proterozoic (TAYLOR, 1974). The rocky crests have asymmetrical profiles that slope steeply towards the SW and gently to the NE, somewhat paralleling the overturned folds. Due to this structural control, slopes are generally much steeper on the eastern side of the estuary than on the western shore.

Granitic and granodioritic gneiss cover most of the region. Amphiboles and biotite schists are also widespread, whereas small igneous bodies and veins of granite, diabase and gabbro are found in many places. The gneisses are composed of 40% quartz and from 20 to 30% plagioclase and potash feldspar, while amphibolites and biotites are the main accessory minerals [thin section analysis of 45 rock samples from throughout the area (FOURNIER, 1987)]. As this geology, typical of wide regions of the Canadian shield, is similar throughout the region, lithological variations or contacts within the study area cannot be invoked to explain differences in the degree of coastal erosion.

Kilometre-size fractures and lineaments exert a structural control on the shape of many indentations and reentrants along the estuary (Figure 2). A statistical analysis of metric size fractures shows that dominant directions prevail at a local scale also. Along the shorelines, the fractures are rather regularly spaced and their strikes are recurrent throughout the study area. Also, a joint plane, or sheeting, varying in depth from 30 cm to 1 m and subparallel to the relief surface is everywhere present. At most places, this subsurface plane is undulating and it tends to intercept the rock surface at the low water level (FOURNIER, 1987). The annual mean air temperature has varied between −5.4 °C and −6.5 °C over the last decade. Means for January and July are approximately −23 °C and 10 °C respectively. Precipitation amounts to 400 mm per year, of which 45% is snow. The first persistent snow cover appears during the third week of October and the last patches thaw during the second week of July. Approximately 72% of the annual winds come from the west. The mean wind velocity is about 14 km/hr (GAGNON and FERLAND, 1967; WILSON, 1971). Fetches across the estuary vary from 2 to 4 km. The downstream sector of the study area is widely exposed to winds blowing from the open sea, *i.e.*, from Ungava Bay to the north. The fluvial and tidal currents are up to 10 knots (CANADA, 1985), and the river carries large amounts of floating ice during the spring melt. Tides are semi-diurnal and the range varies from 5.5 m at neap to 13.7 m at spring (CANADA, 1990). Salinity of the surface water varies between 28 and 32‰.

Permafrost is widespread in the bedrock above sea level (ALLARD and SEGUIN, 1987). It is about at −2.2 °C at the depth of zero annual amplitude (*ca.* 22 m). Active layer thickness is 5 m (LEVESQUE *et al.*, 1990). At a depth of one meter, the

Figure 2. Map of the study area with structural lineaments. Insert: Rose-diagrams of fractures measured on outcrops throughout the area. Orientations 1, 3 and 5 are believed to form a family related to one generation of folding (axis 310°); directions 2, 4, 5 belong to the second generation of folding (axis 332°).

rock undergoes one freeze-thaw cycle per year, the minimum and maximum temperatures at that depth being −21 °C and 6 °C. Although permafrost is absent below mean high tide level due to the warming effect of sea water, these values strongly suggest that annual frost gets down to at least that depth in the very upper part of the tidal zone where submersions are less frequent and where the ice-foot freezes onto the shore. Permafrost is also present and aggrading underneath nearby tidal marshes following the on-going isostatic uplift (ALLARD *et al.*, 1988).

The ice cover begins to form in November when floes are piled up on the shore. In December, ice cover rapidly expands over the surface of the estuary. However, a large polynia persists in the center of the study area in the narrowest stretch of the estuary due to the strong tidal currents. An icefoot complex comprising three parts extends along the rocky shores (Figure 3): (1) The icefoot *per se* is shorefast at high tide level. It is the first fringe of ice to adhere to the rock and is the last to break up. Its flat surface is usually slightly above the highest spring tide level, whereas its base is fixed to the rock at mean high sea level. (2) The "hinge-ice" is the mobile part of the icefoot complex. It is bounded landward and seaward by major tidal cracks, while one or two minor ones can be found within it. As the tide falls, hinge-ice moves downward either by translations or by jerks. At low-tide, it lies on the rock surface. (3) The "strand ice" is the wide ice surface that lies down on the boulder-strewn tidal flat at low-tide (FOURNIER, 1987).

Although it occurs unequally along the shoreline, the erosion is conspicuous because the affected rock surfaces display a shattered appearance that contrasts with the little altered, glacially polished, striated and shaped rock surfaces nearby. In eroded sectors, rock fragments are at various stages of parting from their outcrops. The debris are angular and consist of metre-size blocks and cubes, slabs (10–40 cm thick and a few squared metres in area) and splinters of various sizes (a few centimetres to about 60 cm long, with sharp edges).

METHODS

Coastal Classification

In order to ensure adequate and representative distribution of observations, the rocky shores were at first classified into 39 segments from air photo analysis and a field survey along the shoreline. The classification criteria used were: (1) the slope angle (Figure 4); (2) the sinuosity of the shoreline which varies widely from rectilinear to very indented; (3) the geographic orientation; and (4) a preliminary estimate of the state of dismantlement of the shore. By the end of the study period, a qualitative scale of shore erosion assessment was conceived and applied to the shore segments after the whole shoreline of the study area was walked and observed in detail.

Assessment of Preferential Level of Erosion

Because the observed erosional landforms were not continuous laterally over long distances and because they appeared at first look more or less randomly distributed vertically within the intertidal zone, it was decided to try some kind of statistical analysis in order to detect if any tidally controlled preferential level of erosion exists in the study area. Rock erosion was evaluated by comparing profiles on eroded outcrops with their corresponding original glacial profiles. The original profile was reconstructed from the shape of the roches moutonnées and glacial polish only a few meters beside each profile line and by linking along the profile the non-eroded remnants of the glacial surface. Twelve profiles were surveyed with an electronic level with an overall precision of ±1 cm. They are located in some specific sectors of the coast for two reasons (Figure 4). First, it is necessary to make the measurements in areas where erosion of bedrock slabs and boulders is incomplete and has left some remnants of the glacially polished surface which can be used as reference to properly calculate the eroded volume. Large tracts of shore are too densely destroyed and covered with displaced or disjointed boulders and have chaotic boulder stacks on them; this makes it impossible to determine a reference profile. This approach was used also by MATTHEWS *et al.* (1986) in a lacustrine context. Second, more profiles were surveyed near the village of Kangiqsualujjuaq and near our temporary tidal station for logistical reasons and to allow better elevation measurements relative to tidal levels.

The depth of erosion, taken from the graphical reports, is calculated perpendicularly to the rock surface, from the reconstructed original surface to the floor of the quarried areas. Altitudinal classes of 20 cm (app. 1.5% of the tidal range) were determined, down from the highest tide level, which shows by an abrupt change in lichen distribution, to the lower limit of the rock surface at the contact with the tidal flat, near mid-tide level.

Tidal Data

The tidal data used to derive a tidal level frequency curve (or tidal duration curve) (TRENHAILE and LAYZELL, 1981; CARR and GRAFF, 1982; BRODEUR and ALLARD, 1983) and to which elevation data were tied were obtained with a Neyrtec Telimnep-73 pneumatic tidal gauge that operated continuously for 35 days in July and August 1984 in the center of the study area. This short local record is coherent both in phase and in amplitude with the tidal prediction tables of Fish-

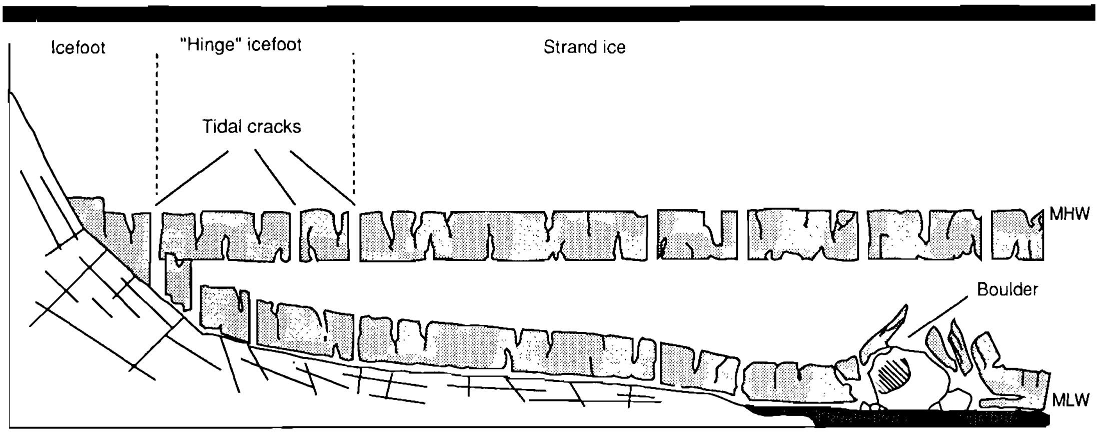

Figure 3. Icefoot components at high tide and at low tide.

eries and Ocean Canada for Ungava Bay (CANADA, 1990 and previous years).

RESULTS

Observed Erosional Features—The Quarrying Modes

The term quarrying used here refers to the combined action of numerous geomorphological processes involved in the destruction of outcrops. Quarrying successively involves separation of rock fragments, their gradual removal and the formation of erosional benches, platforms, notches and areas of concentrated erosion (ALLARD and TREMBLAY, 1983a).

(A) The most widespread mode observed in the study area is the "scaling" quarrying mode, a kind of exfoliation that produces thin flakes, laminae or scales. It affects over 75% of the intertidal outcrops. In most of the gneisses, the metamorphic hyper-stretching of the foliation has produced thin and elongated lineations in the rock. These lineations are parallel to the gneissic foliations for short distances and appear to be discontinuous and sometimes curved upward or downward. Because the foliation lies at an angle with the outcrop surface, the structurally predetermined rock fragments are thinner at their seaward extremity (Figure 5). Desquamation, disjunctive exfoliation and rock rupture by ice-pushing and ice-riving are the most apparent processes related to scaling. Two successive steps are involved.

First, the thinner part of the rock lamina is broken away, either by ice-spalling, when wind-driven floating ice loaded with fragments hammers the rock surface or by frost-shattering involving fresh water. Scaling scars are prominent where fresh water runs either as streamlets and sheet-flow over the outcrops or as groundwater seeping along structural or mineralogic discontinuities.

Secondly, if the remaining slab is bounded landward by a crack or a small fissure, it can be lifted by the floating ice or by the waves that inject small rock fragments or gravel in the open joints underneath the slab. The ice thereafter exerts rotational pressures upon the slab, forcing it to break at the point of weakest resistance (Figure 6). The affected outcrops are pitted with small flaky hollows with acute splinters and conchoidal edges.

(B) "Disjunction quarrying" comes second in spatial importance but produces the most conspicuous and spectacular erosional features. It takes place particularly in areas where three orthogonal fracture planes (two vertical, the other subparallel to surface) are well defined. The quarrying sequence is the following:

(1) The removal of a block from the outcrop is initiated by frost wedging helped by sea ice pressures and, less frequently, by wave pounding. The outcrops show a disjunction gradient that starts from solid but jointed and undisturbed rock, to slightly disjointed rock to lose blocks (Figure 7).

(2) The dismantling of the rock mass progresses along a "quarrying front" which can be either parallel or more or less perpendicular to the shoreline (Figure 7). When the front advances landward, sea-ice thrusting removes the blocks and

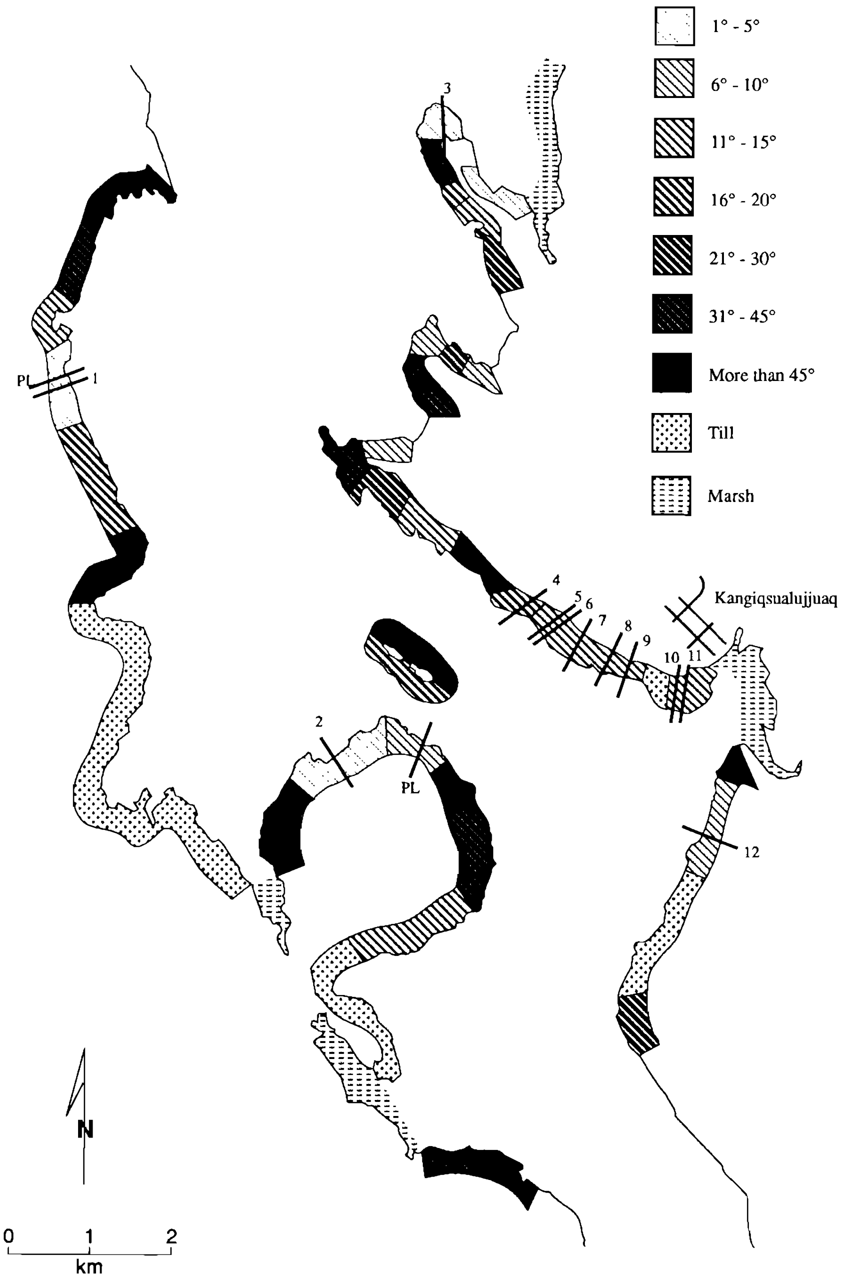

Figure 4. Shoreline classification into segments and slope classes. Nos. 1 to 12 indicate intertidal profiles. PL indicate location of profiles of Holocene rocky shorelines shown in Figure 12.

produces wide cavities that grow with time in length and depth. The front often takes the aspect of a narrow nipped and sometimes staired strip.

The removal of blocks from the first strip of outcrop, then the others, and so on continues until after a few years the width of the bench or the piling-up of boulders do not allow the ice to reach the far back of the strand. Coalescence of the

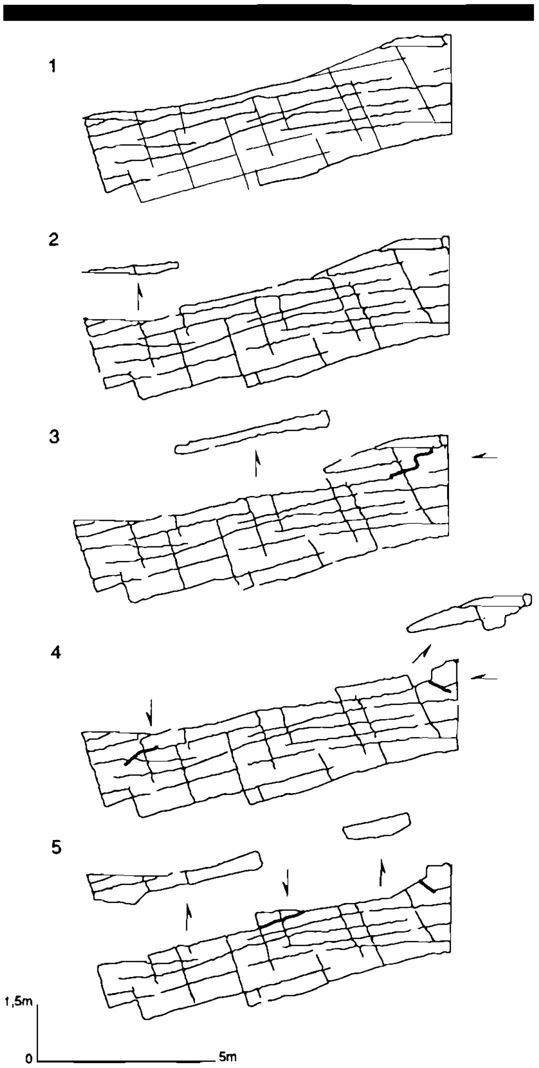

Figure 5. Schematic cross-section describing the evolution of quarrying by the "scaling" mode in jointed gneiss. Steps 2 to 5 show progressive (probably yearly) removal of slabs predefined by joints (light lines). Occasionally breaks take place in the rock at places other than along structural elements (dark lines).

larger quarried cavities leads to the formation of amphitheatres (Figure 8). Some other forms related to this mode of quarrying are also found: linear hollows, angular notches and overhangs, the two latter being very common.

(C) A third mode, which can be referred to as the "mixed quarrying mode", occurs as well, but is seemingly not as widespread. Two vertical joint planes are at first present, but slabs and splinters break along the ferro-magnesian layers of the gneissic foliation. This mode occurs only on the west shores of the estuary at places where the dip of the metamorphic foliations is roughly parallel to the slope of the strand.

Regional Variations of the Processes

No long term observations are available to accurately assess the rate of erosion. At two emplacements, lines with marks at every meter were painted on the outcrops across quarrying fronts and the sites were revisited the following summer. In each case the outermost block (about 1 m^3) had been removed during spring breakup; a few new blocks had been disjointed from the outcrops, pulled out 10 cm apart or rotated. In one particular case, it had been almost impossible in 1988 to remeasure the direction of glacial striae that were observed at a site in 1986 due to extensive dismantlement of the about 100 m^2 outcrop. Hundreds of freshly broken loose blocks, one face still bearing the glacial polish, linger on the rocky shore and amidst the myriads of erratic boulders on the tidal flats. As observed outside the study area during reconnaissance expeditions, the processes also look very active along most of the Ungava Bay coast.

Within the study area, the north facing shores, opened to the Ungava Bay, have suffered much from dismantlement, particularly on capes (Figure 9). This suggests that high energy waves and wind driven ice floes, amongst other processes, play a dominant role. Segments with minor erosion either face sheltered areas or have steep rock faces. Generally, a slope angle less than 21° favours dismantlement because ice overriding is easier over more gentle slopes.

The Level of Maximum Erosion

In many regions of the world, it has been established that erosional shore platforms have planation levels at elevations where the sea level stands for longer cumulative periods of time (Trenhaile and Layzell, 1981). For macro-tidal and semi-diurnal tidal regimes, such as in Ungava Bay, the tidal level frequency curve is strongly bimodal with peaks of frequency at about the mean high water and the mean low water levels (Carr and Graff, 1982; Brodeur and Allard, 1983). An illustration of the elevation of the eroded volumes along each of the twelve profiles (Figure 10) shows that many of them present more than one level of erosion concentration. However, the sum

Figure 6. Example of scaling. The slab with glacial striations has just been dismantled.

Figure 7. Example of disjunction quarrying along a quarrying front.

Figure 8. A quarrying amphitheatre.

of all the erosion levellings indicates clearly that there exists a preferential level of wearing that lies half-way between the highest spring sea level and the mean sea level (Figure 11). Around this elevation, which corresponds to the mean still water level attained twice daily, the longer stand of the water allows marine agents to erode the shore more efficiently and for a longer period of time.

An equivalent level of erosion was not observed at the low tide level. Three reasons explain this: Few outcrops are exposed at this level where extends a very wide muddy, boulder-strewn, tidal flat (Figure 3); given the very large tidal range and those large flats, the fetch is considerably reduced at low tide and, finally, given the short time of exposition to cold air, frost related processes are virtually inactive at this level.

Raised Holocene Rock Benches

Ancient rock benches could be considered as valuable strandline indicators in so far as it can be certified that they are really the result of marine erosion. Topographic profiles were surveyed from the postglacial marine limit to the present sea level on two rocky slopes devoid of Quaternary deposits (Figure 12).

The slopes appear as a staired succession of notches, pits, amphitheaters and benches cut into layers of rock of variable thickness. It is possible, however, that marine erosion merely retouched the glacial-moulded surface and its pre-existing inequalities of profile. A sub-horizontal pseudo-stratification may explain the occurrence of some of the flat benches and therefore a high level of caution is necessary in identifying raised rocky shorelines. However no glacial features, polish or scouring marks persist at the level of the benches. These can be distinguished on the general stairs-like slope by the occurrence, at their backward limit, of rock walls or low scarps cut across many jointed rock planes (Figure 13).

The first profile (Figure 12) shows 3 well-defined levels (62 m, 30 m and 9 m) and a fourth, less continuous one (4 m). The second one comprises a series of 3 high levels (82 m, 62 m, 55 m), another of low levels (18 m, 9 m, 4 m) and a series of short and closely spaced benches, between 36 m and 25 m. All these bench levels lie at the same elevation as the major regional strandlines in Quaternary sediments (Figure 14).

Similar rock benches were observed locally at the same elevations in the study area and in the

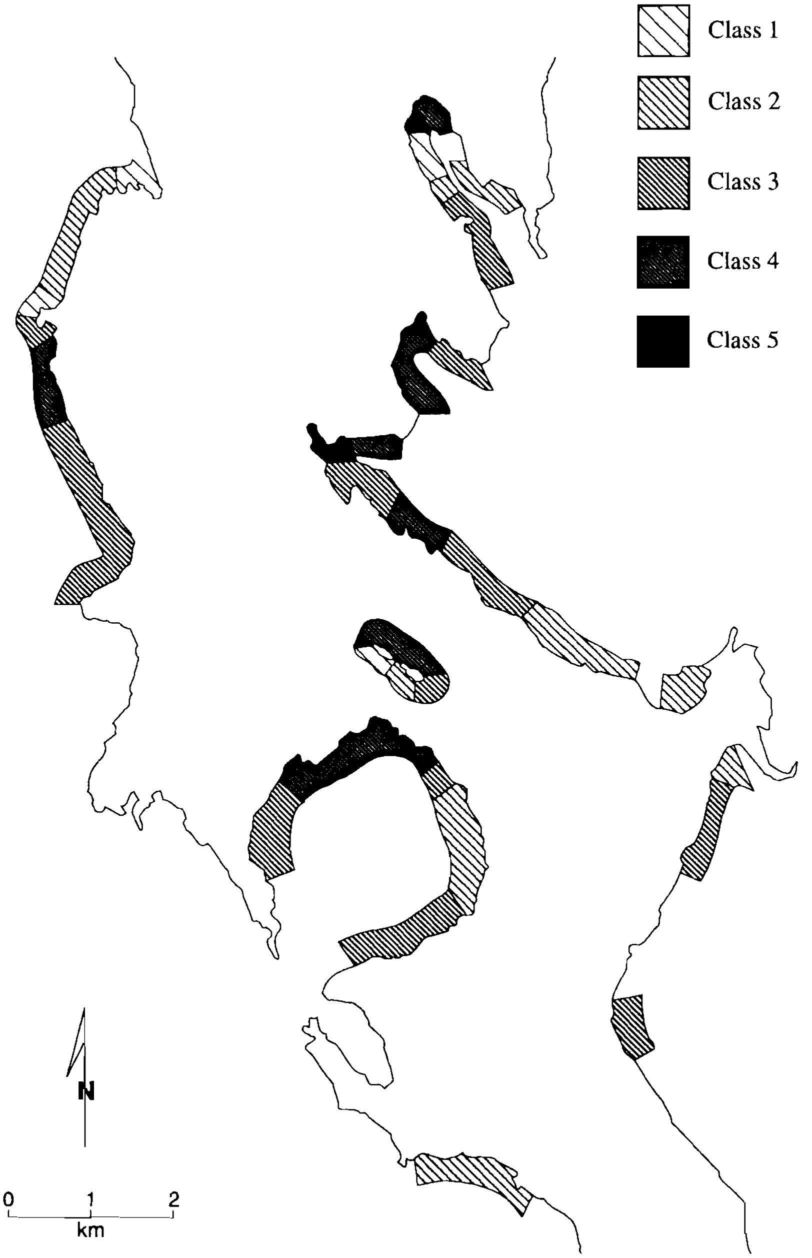

Figure 9. State of erosion and destruction of the shore segments. Class I: Glacial polish >50% of outcrop area, minor scaling. Shore ice striae present. Class 2: Glacial polish <50%, minor scaling, a little disjunction quarrying, shore ice striae abundant. Class 3: Glacial polish scarce, very abundant shore ice striae, presence of quarrying amphitheatres. Class 4: Quarrying dominant over most of the area. Class 5: Total destruction of original outcrop surface. Block chaos, very irregular profiles.

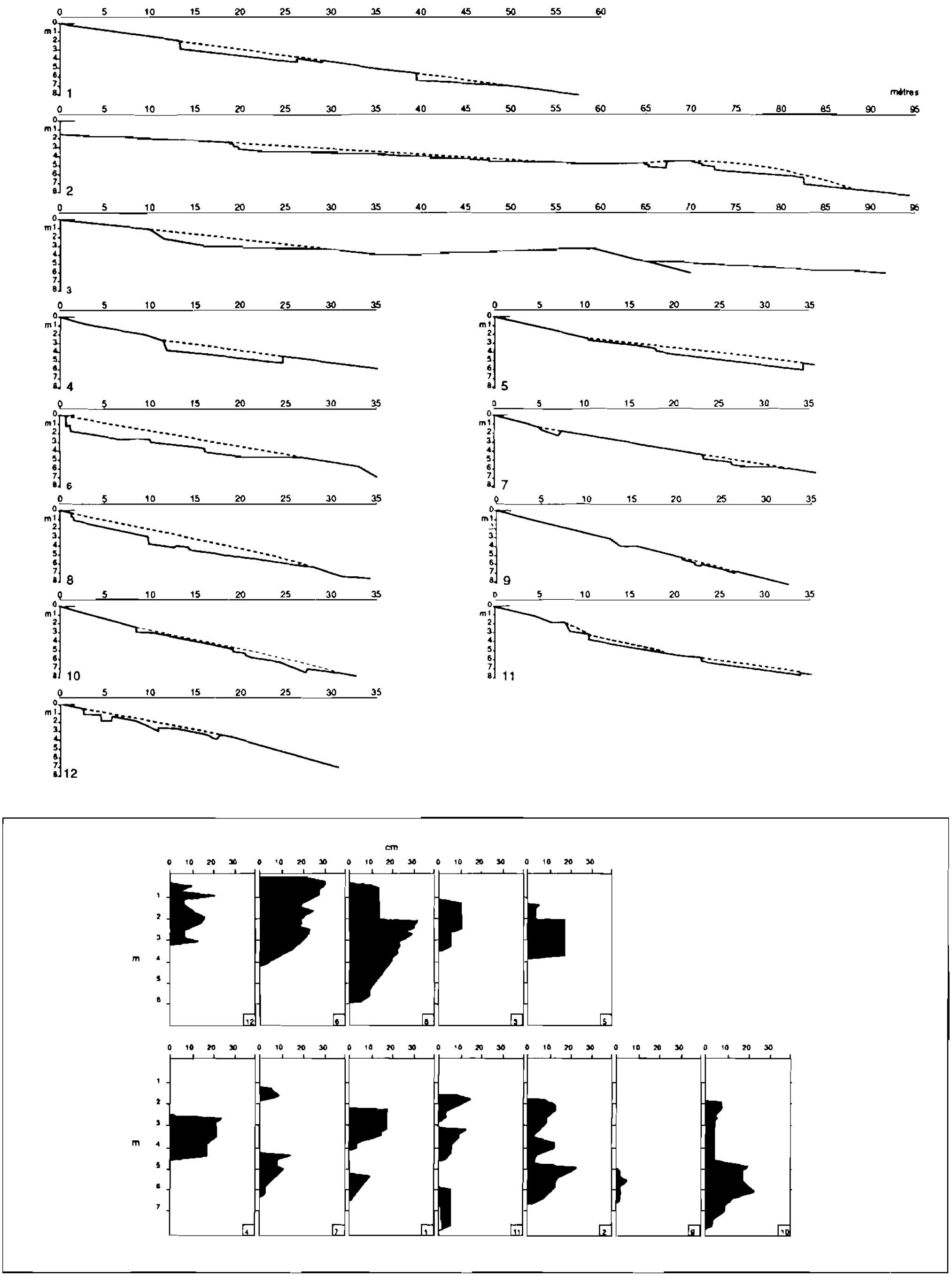

Figure 10. The twelve surveyed profiles (upper diagram) on solid rock; the dotted lines are the reconstructed original surfaces. The lower diagram shows the cross-sectional areas of eroded bedrock along the profiles vs elevation. Elevations are given in metres below large high tide level (0).

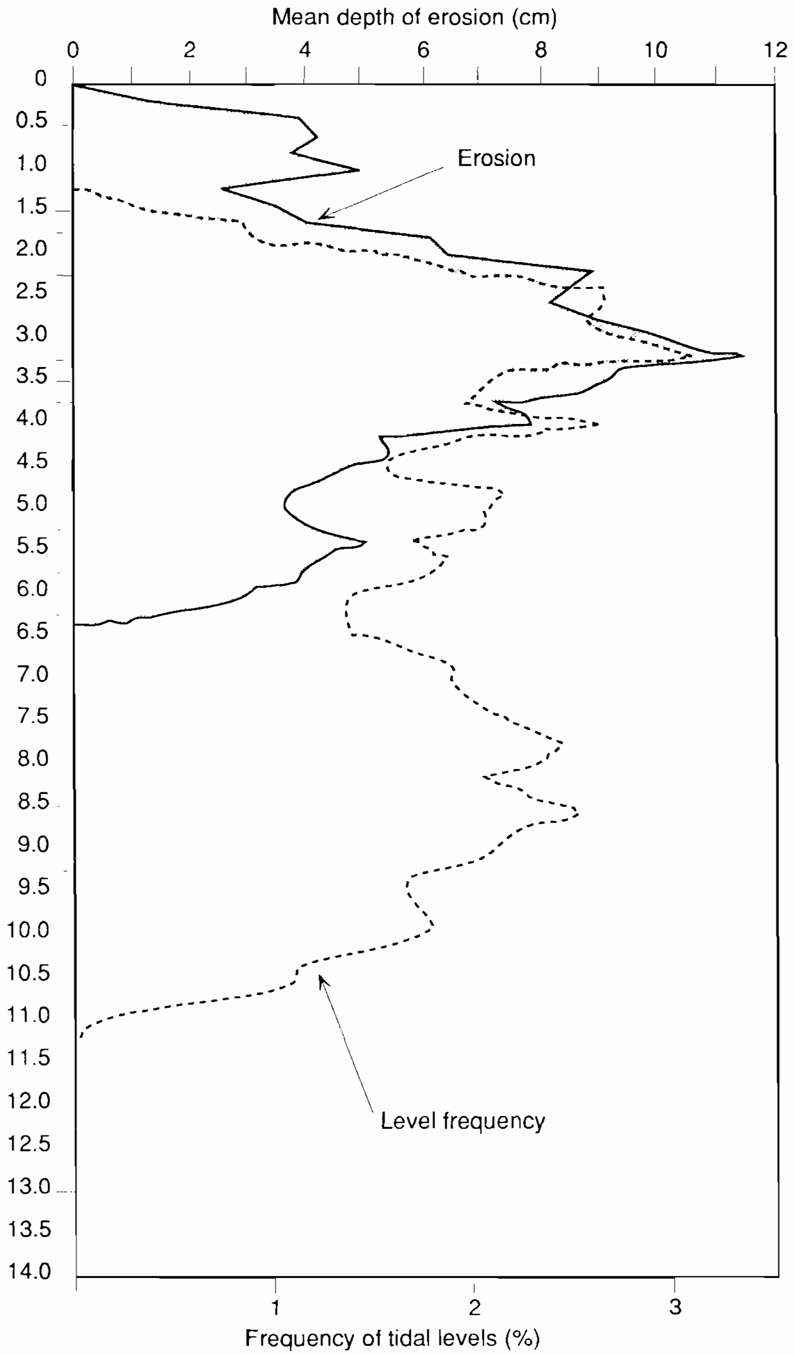

Figure 11. Plot of the mean depth of erosion on the profiles relative to the water level frequency curve (frequency in % of total time measured over 35 days in summer 1985).

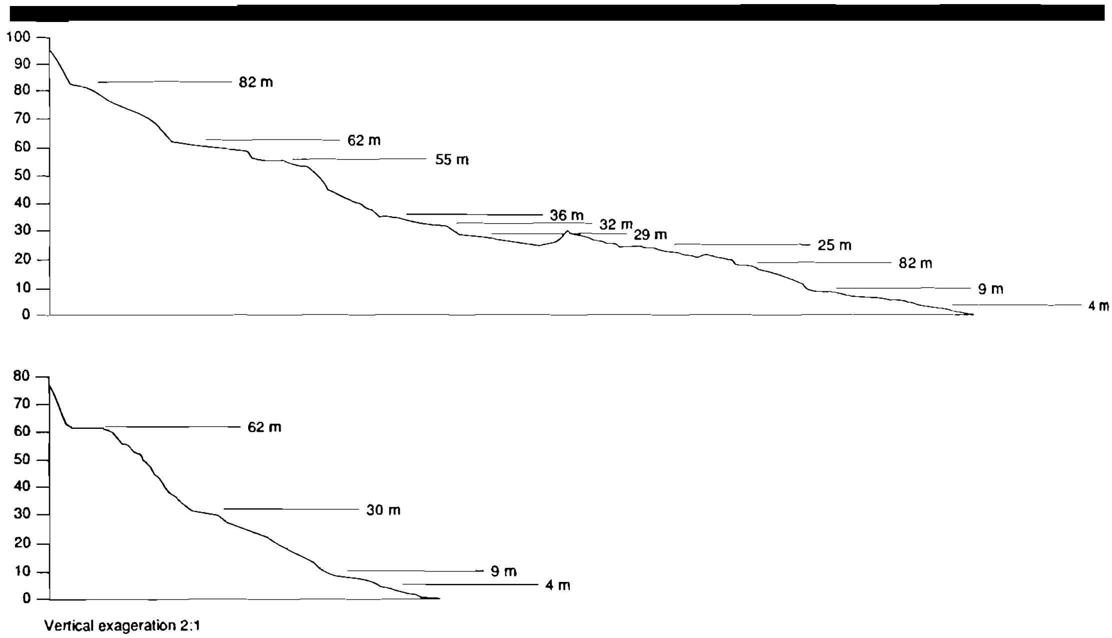

Figure 12. Two surveyed profiles from post-glacial marine limit to actual sea level, showing raised rock benches.

surrounding region. The ages of the shorelines shown on Table 1 are derived from the regional post-glacial emergence curve (Allard *et al.*, 1989). Emergence rate was 4.5 m/century from 7,400 BP to about 6,000–5,800 BP; around that date, it decreased drastically. Since then the rate has been 0.5 m/century. The decrease of the land uplift rate started when the sea was at the actual elevation of 36 m; this explains the closer vertical spacing of strandlines below that elevation. Table 1 shows the possible chronological correspondence of George River rock benches with the prominent Holocene strandlines of the eastern Canadian Arctic.

DISCUSSION AND CONCLUSION

Because frost penetrates deeply into the intertidal rock, gelifraction and frost wedging are certainly important mechanisms for the pre-quarrying that separates the blocks from the outcrops. The action of these processes is strongly enhanced where freshwater streamlets flow to the shoreline. The key factors that favour the quarrying of rock and erosion along the estuary of George River are the generally favourable geological structure, a low or medium slope angle and exposure to long fetches or strong currents. When two intertidal outcrops have similar slopes, then the longer fetch is the main factor that makes the difference in the rate of dismantlement.

The fastened icefoot, as observed in spring, does not play a dominant role in removal and transport of blocks and slabs. In many instances, and particularly in sheltered locations, it melts *in situ*. Nevertheless, its presence may ease deep frost penetration in the rock by forming a thermal barrier to sporadic warming by tide water. The mobile parts of the icefoot complex and moving icefloes at freeze-up and break-up do override rocky slopes in the intertidal zone and have sufficient energy to push, slide or carry loose blocks.

The few subhorizontal flat benches observed along the modern shores result from quarrying on shore segments that already possess sub-horizontal fracture planes. Despite the fact that the shore benches recently formed are structurally controlled, the existence of a tidally regulated preferential level of erosion along the shore suggests that "true" erosional platforms could start to form if the coast was vertically stable.

The occurrence of raised Holocene rock benches correlated to major strandlines of the eastern Canadian Arctic suggests that either eustatic standstills (or slowings of emergence rate) or pe-

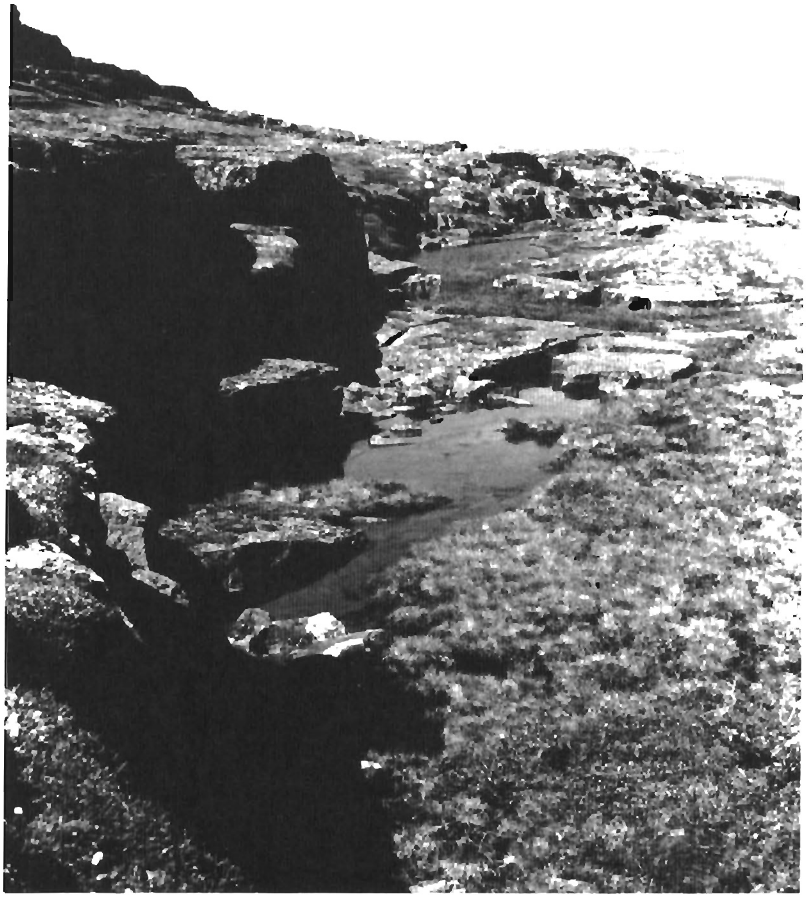

Figure 13. A raised rock bench; elevation is 62 m.

riods of increased storminess were sufficient to initiate horizontal cutting of bedrock. A study of the same type of erosional landforms in basalts on the southeastern Hudson Bay coast by ALLARD and TREMBLAY (1983b) could not recognize any well defined rocky strandline that could be correlated with unconsolidated strandlines. Three reasons were then proposed for this absence of correlation: (1) emergence in Hudson Bay has been, up to the present, too fast (1 cm/year) to allow time for erosion to cut some horizontal benches; (2) tidal range is small (1–2 m) and the erosional processes are dominated by thrusting of sea ice across the whole width of the intertidal zone; and (3) the major unconsolidated strandlines are probably related to periods characterized by larger ice-free seasons with increased storminess rather than with eustatic standstill. In George River Estuary, the environment is quite different. The major unconsolidated strandlines are marked by deltas (at the higher elevations), high erosional bluffs and raised tidal flats. Tidal range is very large and emergence rate is much slower. Therefore, it is probable that periods of increased storminess during the Holocene would have had enough time to cut embryonic platforms around mean high tide level. Whatever the case, relative standstills or stormy periods, a good regional knowledge of the erosional landforms and study of their spatial distribution and elevation could

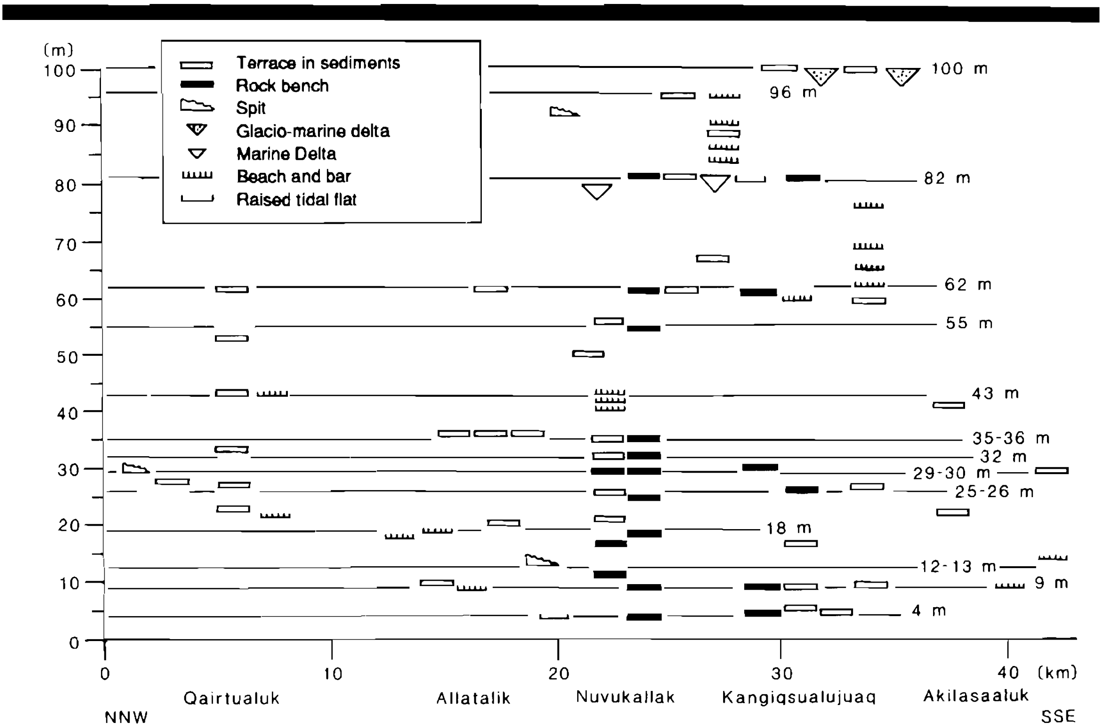

Figure 14. Altitudinal concordance of raised quarried rock benches with Holocene strandlines in Quaternary sediments along a north-south transect of the George River Estuary.

Table 1. *Possible age correlations of the raised rocky shorelines of George River with other dated shorelines in the eastern Canadian Arctic.*

George River		Eastern Canadian Arctic		
Elevation	Age B.P. (^{14}C years)	Elevation	Location	References
82 m	6900	158 m	Ottawa Islands	Andrews and Falconer, 1969
62 m	6500	ca 90 m	Ottawa Islands	Andrews and Falconer, 1969
		64 m	Southern shore of Hudson Strait	Mathews, 1967
55 m	6300	55 m	Southern shore of Hudson strait	Mathews, 1967
44 m	6050	30–31 m	Southern shore of Hudson strait	Mathews, 1967
32–36 m	5700–5800	55–60 m	West Coast of Ungava Bay	Lauriol, 1982
24–26 m	4700–5300	55 m	Ottawa Islands	Andrews and Falconer, 1969
		22–30 m	Northern Ellesmere Island	Stewart and England, 1983
		22 m	Southern Ellesmere Island	Blake, 1975
18 m	3900	12 m	Hudson Strait	Mathews, 1967
		25–30 m	West coast of Ungava Bay	Lauriol, 1982
12–13 m	3100–3400	25 m	Ottawa Islands	Andrews and Falconer, 1969
9 m	2450			
4 m	1200	5 m	Ottawa Islands	Andrews and Falconer, 1969

help the correlation of raised strandlines and drawing of isobase maps.

The study of these shoreline features may also have a practical interest: in the process of locating potential sites for jetties or docking facilities in regions like the estuary of George River, a survey of zones of active quarrying and dismantlement concentration could clearly indicate the sectors subject to strong attack by waves and ice. That could inspire site selection and the choice of engineering design of harbour facilities in order to minimize the cost of maintenance during service.

ACKNOWLEDGEMENTS

The authors express their thanks to students who provided help in the field, particularly to Mr. Yvon Pelletier. Fieldwork was based in the village of Kangiqsualujjuaq where we appreciated the friendship of the community. Care and maintenance of our boat was provided by Mr. Jean-Guy St-Aubin's Atelier Felix. Funding came from NSERC (Canada), Fonds FCAR (Québec) and the Northern Scientific Training Program of the Department of Indian and Northern Affairs of Canada. Dr. J.C. Dionne and Y. Bégin from Université Laval kindly commented on preliminary versions of the manuscript. The thoughtful comments of Dr. Daniel F. Belknap (University of Maine) and another anonymous reviewer of the journal were very helpful to improve the paper.

LITERATURE CITED

Allard, M.; Fournier, A.; Gahe, E., and Seguin, M.K., 1989. Le Quaternaire de la côte sud-est de la baie d'Ungava, Québec nordique. *Géographie physique et Quaternaire*, 43, 325–336.

Allard, M. and Seguin, M.K., 1987. Le pergélisol au Québec nordique: bilan et perspectives. *Géographie physique et Quaternaire*, 41, 141–152.

Allard, M.; Seguin, M.K., and Pelletier, Y., 1988. Shoreline permafrost in Kangiqsualujjuaq Bay, Ungava, Québec. *In:* Senneset, K. (ed.), *Permafrost, Fifth International Conference, Proceedings,* volume 1. Trondheim, Norway: Tapir, pp. 113–118.

Allard, M. and Tremblay, G., 1983a. Les processus d'érosion littorale périglaciaire de la région de Poste-de-la-Baleine et des îles Manitounuk sur la côte est de la mer d'Hudson, Canada. *Zeitschrift für Geomorphologie,* Supplement Band, 47, 27–60

Allard, M. and Tremblay, G., 1983b. La dynamique littorale des îles Manitounuk durant l'Holocène. *Zeitschrift für Geomorphologie,* Supplement Band, 47, 61–95.

Andrews, J.T. and Falconer, G., 1969. Late-glacial and post-glacial history and emergence of the Ottawa Islands, Hudson Bay: Evidence on the deglaciation of Hudson Bay. *Canadian Journal of Earth Sciences,* 6, 1263–1276.

Blake, W., Jr., 1975. Radiocarbon age determinations and postglacial emergence at Cape Storm, Southern Ellesmere Island, Arctic, Canada. *Geografiska Annaler,* 57A, 1–71.

Brodeur, D. and Allard, M., 1983. Les plates-formes littorales de l'Ile-aux-Coudres, moyen estuaire du Saint-Laurent, Québec. *Géographie physique et Quaternaire,* 37, 179–195.

Canada, 1985. *Rivière George, Baie d'Ungava/Ungava Bay.* Department of Fisheries and Oceans, Canadian Hydrographic Service, Map No. 5335, 1:30000.

Canada, 1990. *Canadian Tide and Current Tables. Volume 4: Arctic and Hudson Bay.* Fisheries and Ocean Canada, 49p. Annual publication.

Carr, A. and Graff, J., 1982. The tidal immersion factor and shore platforms development: A discussion. *Transactions of the Institute of British Geographers,* 7, 240–245.

Dionne, J.C. and Brodeur, D., 1988. Erosion des plates-formes rocheuses littorales par affouillement glaciel. *Zeitschrift für Geomorphologie,* 32, 101–115.

Fournier, A., 1987. Les processus d'érosion périglaciaire des estrans rocheux de l'estuaire du George, Québec nordique. Thèse de maîtrise, Université Laval, Ste-Foy, Canada, Département de géographie, 194p.

Gagnon, R.M. and Ferland, M., 1967. *Climat du Québec septentrional.* Québec, Ministère des richesses naturelles, M.P. 10, 107p.

Hansom, J.D., 1983. Shore-platform development in the South Shetland Islands, Antarctica. *Marine Geology,* 53, 211–229.

Lauriol, B., 1982. Géomorphologie quaternaire du sud de la Baie d'Ungava. *Paléo-Québec,* 15, 174p.

Lévesque, R.; Allard, M.; Seguin, M.K., and Pilon, J., 1990. Données préliminaires sur le régime thermique du pergélisol dans quelques localités du Nunavik, Québec. *Permafrost-Canada, Proceedings of the Fifth Canadian Permafrost Conference.* Nordicana No. 54, Centre d'études nordiques. Université Laval, pp. 207–214.

Matthews, B., 1967. Late Quaternary emergence in Northern Ungava, Québec. *Arctic,* 20, 176–202.

Matthews, J.A.; Dawson, A.G., and Shakesbury, R.A., 1986. Late shoreline development, frost weathering and rock platform erosion in a alpine periglacial environment, Jotunheimen, southern Norway. *Boreas,* 15, 33–50.

Moign, A., 1976. L'action des glaces flottantes sur le littoral et les fonds marins du Spitsberg central et nord-occidental. *Revue de géographie de Montréal,* 30, 51–64.

Nansen, F., 1922. *The Strandflat and Isostasy,* 1. Kristiana, Norway: Kommission his Jacob Dybwad, 313p.

Rabbotin, J.L., 1977. *Vestvagoy (Lofoten), Contribution à l'étude des modes et modelés d'élaboration actuelle du strandflat.* Mémoire de maîtrise, Université de Paris-Sorbonne, Institut de géographie, 281p.

Stewart, T.G. and England, J., 1983. Holocene sea-ice variations and paleoenvironmental change, northernmost Ellesmere Island, N.W.T., Canada. *Arctic and Alpine Research,* 15, 1–17.

Taylor, F.C., 1974. Reconnaissance geology of a part of the Precambrian shield, northeastern Québec, northern Laborador and Northwest Territories. *Geological Survey of Canada, Paper 74-21,* 9p.

Trenhaile, A.S., 1987. *The Geomorphology of Rock Coasts.* Oxford: Clarendon Press, 384p.

Trenhaile, A.S., 1983. The development of shore platforms in high latitudes. *In:* Smith, D.E. and Dawson, A.G. (eds.), *Shorelines and Isostasy*. Institute of British Geographers, special publication No. 16, London: Academic, pp. 77–96.

TRENHAILE, A.S. and LAYZELL, M.G., 1981. Shore platform morphology and the tidal duration factor. *Transactions of the Institute of British Geographers*, 6, 82–102.

WILSON, C.W., 1971. *Le climat du Québec*. Atlas climatique, lère partie, Ottawa, Service météorologique.

□ RÉSUMÉ □

Des formes d'érosion littorales rocheuses ont été étudiées le long des rives de l'estuaire de la rivière George dans un environnement périglaciaire et macro-tidal. Le débitage de fragments rocheux et l'excavation de cavités dans le gneiss sont contrôlés en grande partie par la structure géologique, principalement les joints et les foliations. L'action de la gélifraction sur le roc jointif disloque des blocs pré-figurés qui sont ensuite déplacés par les vagues et les glaces de mer. La gélifraction et l'éclatement au gel sur le littoral sont plus actifs là où coulent des ruisselets et où de l'eau douce suinte à travers la structure. Des mesures de l'érosion le long de profils topographiques, en comparaison avec les surfaces à polis glaciaires non altérés, ont été effectuées. Les formes d'érosion furent observées sur tout le littoral de la région étudiée, lequel a aussi été classifié en segments suivant la pente, l'orientation géographique et le fetch. Les observations révèlent que l'érosion est plus intense dans les secteurs à pentes faibles et moyennes sur lesquelles peuvent monter les glaces flottantes ainsi que dans les secteurs à grand fetch fortement attaqués par les vagues et chevauchés par les poussées de glace marine. L'érosion est concentrée principalement autour du niveau des hautes mers moyennes. La connaissance de ces processus d'érosion et des formes qui en résultent permet l'identification de formes comparables inactives et maintenant soulevées par le relèvement isostatique post-glaciaire. En fait, les formes littorales rocheuses soulevées correspondent très bien en altitude avec les paléo-rivages dans les sédiments quaternaires de la région. Des corrélations chronologiques avec les rivages dominants et bien datés de l'Holocène dans l'Arctique de l'est sont aussi proposées.

□ ZUSAMMENFASSUNG □

Im Anstehenden ausgebildete Formen der Küstenerosion wurden im makrotidalen, periglazialen Milieu des George River-Ästuars untersucht. Das Herausarbeiten von Hohlformen im gneishaltigen Gestein ist zum großen Teil an geologische Strukturen, vor allem Klüfte und Schieferungen, gebunden. Frostsprengung, die in geklüftetem Gestein arbeitet, lockert vorgeformte Blöcke, die danach von Wellen und Meereis bewegt werden. Frostverwitterung ist an der Küste dort wirksam, wo Gerinne zum Meer fließen und wo Süßwasser durch die Strukturen sickert. An ursprünglich glazial überprägtem, intertidal anstehendem Gestein wurden Erosionsprofile gemessen und die Erosionsformen entlang der gesamten Küstenlinie des Untersuchungsgebietes studiert. Dazu wurde die Küste nach Neigung, geographischer Exposition und Brandung in verschiedene Abschnitte eingeteilt. Die Ergebnisse zeigen, daß die Erosion in denjenigen Küstenabschnitten stärker wirkt, die geringe und mittlere Neigungswinkel haben, weil das Küsteneis sie überformen kann, und dort, wo eine lange Brandung Wellenschlag und Druck durch Meereis begünstigt. Die Erosion findet vorzugsweise im Bereich des mittleren Tidehochwassers statt. Die Kenntnis über die wirksamen Erosionsprozesse und die sich daraus ergebenden Formen erlaubt es, gehobene Küstenformen im Anstehenden, die zu postglazial herausgehobenen Küsten gehören, zu entdecken. Diese stimmen in ihrer Höhenlage sehr gut mit den weniger zweifelsfrei erkennbaren gehobenen Strandlinien in quartären Sedimenten überein. Schließlich werden einige Alterskorrelationen mit bedeutenden datierten holozänen Strandlinien der östlichen kanadischen Arktis vorgeschlagen.—*Helmut Brückner, Department of Geography, University of Marburg, Deutschhausstr. 10, D-3550 Marburg, Germany.*

□ RESUMEN □

En el estudio del Río George, ambiente periglacial de macromarea, se observó una forma de erosión terrestre costera en elk fondo rocoso. Las cavidades en las canteras de fondo rocoso gneísico son dependientes de la estructura geológica, en especial de las juntas y de las foliaciones.

Formas erosivas se observaron a lo largo de toda la costa del área estudiada, la cual se clasificó en segmentos de acuerdo al ángulo de la pendiente, a la orientación geográfica y al campo de acción del viento (fetch). Las observaciones indican que la erosión es más intensa en los sectores donde los ángulos de las pendientes son pequeños y medios, tal que permitan que el hielo pase por encima de la playa y donde los fetchs importantes favorecen el accionar de las olas y el empuje del hielo marino. La erosión se produce preferiblemente cerca del nivel de las pleamares medias. El conocimiento de la actuación de los procesoserosivos y las formas terrestres resultantes permiten reconocer las características del fondo rocoso elevado de la costa, asociado con las costas emergentes postglaciales. Estos fondos rocosos se corresponden muy bien con las costas más importantes de sedimentos del Cuaternario de la región. Se han sugerido ciertas correlaciones en edad con las principales costas fechadas durante el Holoceno en el Artico del este Canadiense.—*Néstor W. Lanfredi, CIC-UNLP, La Plata, Argentina.*