Holocene emergence along the Ellesmere Island coasts of northernmost Baffin Bay

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Investigations into the Quaternary geology of parts of Ellesmere Island (76° to 79°45'N) and North-West Greenland have been carried out by the writer over the last 25 years (Fig. 1). The aim of this work has been to elucidate the glacial history of this vast region, with considerable emphasis being placed on establishing chronologies for events during and since the last glaciation. One of the main research topics has been to document the emergence of the land from the sea in Holocene time. This emergence, as elsewhere in glaciated terrain (e.g., see Walcott 1972; Sørensen 1979; Mangerud et al. 1992) is interpreted as being the result of rebound following the removal of a much thicker load of glacier ice over the region in Late Wisconsinan time than is present today.

Three major reports on Holocene emergence have been published up to now. Two deal with the raised beaches at Cape Storm (and South Cape Fiord) on the south coast of Ellesmere Island (Blake, 1970, 1975a), and the third report provides an analysis of data from Cape Herschel on the east-central coast, close to both the Prince of Wales Icefield and to Inglefield Land, Greenland (Blake 1992a). The present paper includes both the curve for Cape Herschel, modified by the addition of an age determination from Inglefield Land, and a new emergence curve for Piliravijuk Bay in inner Makinson Inlet. The latter site is situated approximately mid-way between Cape Storm and Cape Herschel (Fig. 1).

Following publication of the original paper, in which the concept of a Late Wisconsinan Innuitian Ice Sheet was proposed (Blake 1970), a considerable debate arose. The leading advocate of a restricted Late Wisconsinan ice cover over the Queen Elizabeth Islands, based on fieldwork in northernmost Ellesmere Island, has been J. England (1976, 1978, 1987, 1990). The controversy continues to the present day, as is evident from a series of maps and summaries published within the last decade by Prest (1984), Dyke & Prest (1987), Fulton (1989), Hodgson (1989, 1991) and Lemmen & England (1992).

Geophysical data which can most easily be explained by the presence of a significant thickness of ice over the Queen Elizabeth Islands have been presented by Tushingham (1991).

Geological setting

The three sites occupy somewhat different geologic positions with regard to both bedrock and the proximity of present-day ice caps: (1) Cape Storm is situated in the Interior Platform, comprised of gently northward-dipping lower Paleozoic sedimentary rocks, mainly carbonates (Kerr 1970), although the outer part of nearby South Cape Fiord is within the Franklinian Mobile Belt; (2) Piliravijuk Bay, near the head of the western arm of Makinson Inlet, is also in the Interior Platform, but is only 20 km west of outcrops of the Archean basement; and (3) Cape Herschel lies near the northern edge of the Canadian Shield (Christie 1962a; Frisch 1984a, b; Okulitch 1991; Trettin 1991). As is shown in Fig. 1, the raised beaches at Cape Storm are situated some 35 km to the west and southwest of the nearest outlet glaciers from the Sydkap Ice Cap (although smaller ice caps are closer), and the Piliravijuk Bay site is 25 km west-southwest of the nearest outlet glaciers of the Prince of Wales Icefield, the largest of the glacier – ice cap complexes in the southern half of Ellesmere Island (cf. Fig. 2). Cape Herschel, on the other hand, is located within the narrow
(<5 km) ice-free zone on the east side of the same icefield, facing Smith Sound and Greenland (Fig. 1).

Prior to the surge of geological activity in the post-World War II era, when R. L. Christie of the GSC reconnoitered much of the east coast by dog sledge (Christie 1962a, b), by far the most significant work carried out in the southern half of Ellesmere Island was that of the Second Norwegian Arctic Expedition in the 'Fram' 1898–1902, under the leadership of Otto Svedrup. This magnificently successful expedition made many important observations and collections, including extensive dredge samples of living marine molluscs and cirripeds (Grieg 1909). These samples have provided invaluable reference material for correcting radiocarbon-age determinations on molluscs of Holocene age (cf. Mangerud & Gulliksen 1975; Blake 1975a, b, 1979).
Curiously enough, the geologist with the ‘Fram’ Expedition, Per Schei, despite the location of the expedition’s first wintering base (1898–1899) in Rice Strait (Fig. 1), an area of especially well-developed glacial sculpture, stated (Schei 1903, pp. 64–65):

After examining the unglaciated parts of the region with the view to discovering whether they may possibly have been subjected to glaciation at some earlier period, I arrived at results of a negative character. I nowhere observed roches moutonnées, neither did I observe strie or scourings. Nay, further, I did not perceive any loose materials that could with any degree of likelihood be ascribed to the effects of glacier ice. Moreover, in several places I noticed marine terraces at a great height above the sea, running immediately in front of the existing glaciers, and in such a position that it is scarcely conceivable that they could have been formed with the sea at its corresponding elevation if there had existed glaciation of even the same intensity as that which now obtains, to say nothing of a greater intensity. I believe I may venture to say, that in those regions the existing glaciation represents a maximum, such as has never been attained before, and if this conclusion should turn out to be sound, it is one, I need hardly say, of considerable importance from the point of view of physical as well as of biological geography.

I have no ready explanation for Schei’s conclusions and, as quoted above, Schei (1903) did note the presence of marine molluscs and terraces high above present sea level. His observations, including many extracted from his diaries, were published by Holtedahl (1917). Schei’s record of a terrace at 105 m on Pim Island is similar to the highest elevation at which I collected Holocene shells nearby, on the west side of Rice Strait (Blake 1992a).

As illustrated in Figs. 3 and 4, Pim Island and the Cape Herschel peninsula are characterized by intense glacial scouring, including polished surfaces and sculptured features in the Archean orthopyroxene granites (Blake 1977). Similar spectacular features have been carved in biotite granite on Bowman Island in Makinson Inlet (Blake 1978), as shown in Figs. 5 to 7. Bowman Island has Paleozoic erratics, derived from the terrane to the west and north, on its top at 570 m a.s.l. As water depths to the north of the island range from 400 m to over 600 m (Sadler 1973), a glacier thickness of at least 1200 m would be required to fill the fiord and transport debris to the top.

Evidence for the Late Wisconsinan age of the glacial sculpture at Pim Island/Cape Herschel and on the opposite shore of Smith Sound, in Inglefield Land, Greenland, has been presented in a series of papers (Blake 1977, 1992a, b; Blake et al. 1992), and the same reasoning for Late Wisconsinan age is applicable to Makinson Inlet. In a preliminary report after the 1977 field season I illustrated the landscape features there and noted the contrast between the extremely fine glacial sculpture on
Fig. 3. View west at a sculptured bedrock knob on the plateau of Pim Island near its southeast corner, elevation ~440 m. This striated granite outcrop displays the typical rounded stoss side (to the right) and plucking on the lee side (left). Ice of the 'Smith Sound Ice Stream' formerly flowed across the plateau of Pim Island from north to south, precisely at right angles to the present-day flow direction of Leffert Glacier (arrow), a major outlet glacier from the Prince of Wales Icefield. July 21, 1977. GSC-203241.

Fig. 4. View southward from the Cape Herschel plateau, with Cape Isabella in the distance (cf. Fig. 1). Note the striated and polished granite in the foreground created by the 'Smith Sound Ice Stream', and the veneer of till (shell-bearing) between the outcrops. August 15, 1987. GSC-205365.

Fig. 5. Telephoto view southeastward at Bowman Island from the plateau on the north side of Makinson Inlet. The top of the island is at ~570 m a.s.l.; the ice-capped mountains beyond, on the south side of the inlet, rise to over 1000 m. The southern shoulder of Bowman Island, where Figs. 7 and 8 were taken, is indicated by the arrow. July 9, 1977. GSC-203262-D.

Fig. 6. View eastward along the shoulder on the south side of Bowman Island, at ~250 m a.s.l. Note the smoothed and polished granite in the foreground, with R. J. H. Richardson for scale. July 14, 1977. GSC-203262-E.

Fig. 7. View southward at shaped and plucked granite on the southern shoulder of Bowman Island, at ~260 m a.s.l., with shell-bearing till (cf. Table 1) between the outcrops. The plateau (>600 m a.s.l.) in the distance is covered by a thin carapace of ice. July 14, 1977. GSC-203262-F.

Bowman Island (especially on the southern shoulder of the island at 250–260 m a.s.l.; cf. Figs. 5 to 7) and the development of incipient tors, or tor-like landforms, on the adjacent plateau to the north (Blake 1978). Twenty-five kilometres west of Bowman Island, on top of the headlands at the eastern end of Swinnerton Peninsula (Figs. 2 and 8), the dolomite on the plateau surface exhibits striae at elevations between 300 and 345 m. Still further west, atop the plateau north of innermost Pili-ravijuk Bay, striae are present at ~360 m a.s.l. (Fig. 9). However, Boulton (1979, p. 377) disagreed with my reasoning and stated:

Blake (1978) has noted in southeast Ellesmere Island that lower parts of the landscape show relatively fresh features of glacial scouring whilst higher areas show blockfields and tors. Blake suggests that the fresh sculpture gives the true age of the landscape which he considers to be of late Wisconsin age, and he invokes Sugden's (1977) suggestion that preglacial blockfields may have remained uneroded by ice in areas where the basal part of the ice sheet was below the melting point. Alternatively one could regard the blockfields and tors as indicators of the great antiquity of the last glaciation of those areas, and the areas of relatively fresh glacial sculpture as having been protected from weathering by relatively impermeable till which has recently been removed by high Holocene sea levels or fluvial erosion or mass wasting.
With regard to these comments it is important to note that: (1) the sculptured features on the southern shoulder of Bowman Island are, at 250–260 m, more than 100 m above the highest features related to Holocene emergence that I have found anywhere in the southern half of Ellesmere Island; (2) there are no significant streams flowing on Bowman Island; and (3) there is no field evidence that mass wasting has recently removed a till cover from the glacially polished and smoothed surfaces. On the contrary, because the outer edges of the ‘shoulders’ on Bowman Island are topographically higher than the inner parts, a protective cover of till could not have been removed by mass wasting to expose the features illustrated in Figs. 6 and 7. To me, Sugden’s (1977) suggestion still makes eminently good sense!

The till on Bowman Island (sand:silt:clay ratios of 50:31:10, 56:32:12 and 46:36:18) contains a significant amount of carbonate material derived from the Paleozoic terranes to the west. According to T. E. Bolton (pers. comm. 1977 and 1993), the well-preserved pygidium and incomplete thorax of a trilobite found in a limestone cobble in the till on the southern shoulder of Bowman Island is the Late Silurian species Encrinurus (Frammia) arcticus (Haughton). This species is a characteristic faunal element of the Read Bay Group [Douro Formation], earlier known as the Read Bay Formation (Bolton 1965). The locality nearest to Bowman Island where rocks of the Douro and Cape Storm Formations outcrop is close to the entrance to the north arm of Makinson Inlet, some 35 km to the northwest (Okulitch 1991).

In addition, the veneer of till overlaying striated bedrock on both the tip of the Swinnerton Peninsula and on Bowman Island contains fragments of marine pelecypods, dredged from the bottom of Makinson Inlet by the seaward-flowing trunk glacier. The first amino acid ra-

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**Fig. 8.** Telephoto view northward at the eastern tip of Swinnerton Peninsula and the north arm of Makinson Inlet. Two sites with striated dolomite at 300 and 345 m a.s.l. are indicated by arrows. At the northern locality shell fragments (cf. Table 1) were abundant in the overlying till. July 7, 1977. GSC-203262-B.

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**Fig. 9.** View northeastward out Piliravijuk Bay from the plateau west of base camp. Prince of Wales Icefield in the distance. The section studied (cf. Fig. 11) is indicated by the curved arrow. Raised beaches in the right foreground. Hammer and entrenching tool (arrows) are aligned parallel to striae preserved in dolomite bedrock under a thin veneer of till. August 3, 1977. GSC-1993-198.
Table 1. Amino acid ratios for pelecypod shells, Makinson Inlet, Ellesmere Island.

<table>
<thead>
<tr>
<th>Field sample no.</th>
<th>Site location and elevation</th>
<th>Species</th>
<th>Laboratory dating no.</th>
<th>14C age</th>
<th>Amino acid no.</th>
<th>Alle: Ile ratios in the total hydrolysate (HYD) and free fractions</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS-77-256</td>
<td>N coast Piliravijuk Bay, 40 m</td>
<td>Hiattella arctica</td>
<td>GSC-2519</td>
<td>8930 ± 100</td>
<td>AAL-522</td>
<td>HYD: 1st run 0.016, 2nd run 0.017, Free: N.D.</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>BS-77-52</td>
<td>NE corner Swinnerton Peninsula, 345 m</td>
<td>Hiattella arctica</td>
<td>AAL-520</td>
<td></td>
<td>AAL-886</td>
<td>HYD: 1st run 0.027, 2nd run 0.022, Free: 0.13, 0.21</td>
</tr>
<tr>
<td>BS-77-73</td>
<td>Bowman Island, 250–270 m</td>
<td>Hiattella arctica</td>
<td>AAL-521</td>
<td></td>
<td>AAL-885</td>
<td>HYD: 1st run 0.058, 2nd run 0.045, Free: 0.19, 0.26</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mya truncata</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

1 Radiocarbon age determination data as in Table 2, footnote d. δ13C = +1.4‰ for GSC-2519.
2 Standard procedure for determining isoleucine epimerization ratios (alle/Ile – formerly abbreviated allojiso) at the Amino Acid Laboratory (AAL), INSTAAR, University of Colorado, is to analyze three valves from each sample (Miller and Hare 1980). The samples listed here were treated under Preparation B (Miller 1985). ND = not detectable. All shells analyzed were determined to be aragonitic by powder x-ray diffraction (courtesy of A. C. Roberts, Mineralogy Section, Geological Survey of Canada).

Ratios, using *Hiattella arctica*, were reported in Blake (1980a). Since then additional determinations have been made, on *Mya truncata* from both localities. All available ratios for shells from Makinson Inlet are listed in Table 1. Although additional analyses would be desirable, it is of interest to note that two of the total Alle: Ile ratios on *Mya truncata* fragments in till are especially low. They compare favourably with equally low ratios from the uppermost pre-Holocene marine unit at Cape Storm (Blake 1980b), a unit from which numerous radiocarbon ages in the 35 000 to 45 000 year range have been obtained – on marine algae (*Laminaria* sp. and *Sphacelaria plumosa*), on a sternum from a dovekie, *Alle alle*, and on *Mya truncata* shells as well as on the siphon/periospicalum from this species (Blake 1992b). Also, numerous 14C determinations on terrestrial organic detritus from a site beside Glacier 7A-45, 5 km north of the north arm of Makinson Inlet (Fig. 2), have yielded ages in the 20 000 to 43 000 year range (Blake 1992b). For ice-free conditions to have prevailed there at that time, it is necessary for the whole of Makinson Inlet to have opened up. Thus marine fauna could invade the inlet, providing material to be dredged up during a subsequent Late Wisconsinan readvance.

Holocene emergence

**Cape Herschel**

The pattern of Holocene emergence at Cape Herschel has been discussed at length recently (Blake 1992a), and the curve is reproduced here (Fig. 10). The single age determination (TO-923; 7780 ± 70 years) on a fragment of *Mya truncata* from near the Holocene marine limit on the Greenland side (a site near Kap Inglefield, Blake et al. 1992) of Smith Sound has been added to Fig. 10, and it agrees closely with the data from Cape Herschel and environs (cf. Table 1 in Blake 1992a), some 45–55 km distant. Following the suggestion made by Mørner & Funder (1990) for the Wolstenholme Fjord area of Greenland, no additional correction for marine reservoir effects has been applied to TO-923. However, were the same 300-year correction made for this sample as for those from Ellesmere Island, it would still fit perfectly onto the emergence curve for Cape Herschel.

**Makinson Inlet**

Raised beaches are better developed in inner Makinson Inlet than on the outer east coast at Cape Herschel. This
is primarily because the presence of slabby sedimentary rocks has provided a source for shingle from which beaches could be constructed. The presence of raised beaches in Piliravijuk Bay was noted first by Bentham (1941) on a sledding journey in 1937, and the first collection of shells for 14C dating was made by R. L. Christie in 1960 on the west side of the southernmost arm of Makinson Inlet (Fig. 2). His collection, at an elevation of \( \sim 73 \) m, gave \( 8200 \pm 220 \) years (GSC-146; Dyck & Fyles 1964), and he noted that the marine limit, based on the presence of both shell fragments and rounded cobbles, was at \( \sim 103 \) m (pers. commun. from R. L. Christie, 1993).

In 1961, J. G. Fyles worked on Swinnerton Peninsula, and of particular interest is a sample of marine pelecypods that he collected at \( \sim 85 \) to 91 m. The whole shells and fragments of *Hiattella arctica*, *Mya truncata* and *Astarte* sp. were from a sandy ground surface, at approximately the upper limit of raised beaches, and Fyles' interpretation was that they were from a beach (pers. commun. from J. G. Fyles, 1993). Two determinations were made. In the standard preparation, the outer 10% of shell material was removed by HCl leach. The 10–100% leach fraction gave \( 29430 \pm 680 \) years (GSC-134). In the second preparation, nearly two-thirds of the shell material was removed, and the 63–100% leach fraction gave \( 29800 \pm 220 \) years (also GSC-134). As Fyles pointed out (in Dyck & Fyles 1964), the close correspondence of the two age values on different fractions suggests the absence of major contamination and hence the results may approximate the true age of the sample. However, as the elevation of the sample is below the limit of Holocene submergence at two nearby localities, the dated shells may well have been washed out of the shell-bearing till.

Finally, D. A. Hodgson visited the western part of Makinson Inlet, including Piliravijuk Bay, in 1972, 1973 and 1974. He made the first collection of driftwood from the raised beaches at the head of the bay (cf. Table 2), and he mapped the surficial deposits (Hodgson 1979). In addition, he determined the elevation of several features which he designated as kame deltae along the west side of the north arm, all of whose apices lie between 85 and 100 m a.s.l. (Hodgson 1985).

Nearly all the data from Piliravijuk Bay were gathered during a single field season, and the work was aided by the fortunate situing of our 1977 field camp close to both raised beaches and a stream-cut section (Fig. 11). In the brief time available no clearly defined limit of Holocene marine submergence was found. The highest beach observed was at approximately 100 m a.s.l., close to the value measured by Christie some 20 km to the southeast. However, as Fig. 12 shows, the Holocene marine limit may be as high as 120 m, assuming that the emergence curve has the correct inclination in its upper half. A value of 120 m would be close to the 130 m recorded for Cape Storm (Blake 1975a), 175 km to the southwest of Piliravijuk Bay, and the 135 m estimated for Cape Herschel (Blake 1992a), 225 km to the northeast.

The flights of raised beaches west of the base camp contain a fair number of far-traveled coniferous driftwood logs, and these allow precise dating of the passage of the shoreline over the past 6000 radiocarbon years. This is in marked contrast to two pieces of locally derived Arctic willow (*Salix* sp.) extracted from a nearby stream section (Fig. 11). Both Holocene wood and Pleistocene wood (cf. Table 2) were collected at an elevation of approximately 43 m in a massive stony silt unit (sand: silt: clay ratios of 8:76:16, 8:77:15 and 10:73:17), several meters below the present-day surface of the stream terrace. Reworked wood samples such as these have been reported from the head of Vendom Fiord by Hodgson (1973), and there are abundant occurrences of 'old' wood in terrace deposits to the north (cf. Fyles 1989). Although the Arctic willow dated at \( 7920 \pm 110 \) BP (GSC-2712) is of no use in defining the position of the shoreline, as it sank into relatively deep water, the result tells us that woody plants lived in the area at this time and it confirms the validity of the age determination on in situ *Mya truncata* shells in the same 1.7 m thick silt unit (Blake 1979; cf. Table 2 in the present paper).

**Dating results and discussion**

All the new 14C age determinations from the north side of innermost Piliravijuk Bay are listed in Table 2. A calibrated age BC (cal BC) also has been produced for each determination (except TO-113) by R. P. Beukens of IsoTrace Laboratory, University of Toronto (pers. comm. 1991 and 1993), and the cal BC ages have been converted to cal BP ages by following Stuiver & Pearson (1986), where cal BP = 1949 + cal BC.

The oldest marine shells (three *Portlandia arctica* valves), from \( \sim 40 \) m a.s.l. in the 15 m high section studied on the north side of Piliravijuk Bay, are 9150 ± 60 radiocarbon years old (TO-224). The shells are from 0.5 to 0.8 above the base of a unit interpreted as being glaciomarine silt. This reddish appearing clayey-silt (Munsell colour brown – 7.5YR 5/2; sand:silt:clay ratios of 4:70:26 and 5:58:37) is underlain directly by a 1+ m thick non-fossiliferous unit with many more stones (40% > 2 mm), with numerous striated cobbles and with a sand:silt:clay ratio of 44:42:14. This stony unit, olive-gray (5Y 5/2) at the base and grayish-brown (10YR 5/2) at the top, is interpreted as a till.

The age of the *Portlandia arctica* shells at Piliravijuk Bay is similar to a date of 9270 ± 110 years (GSC-3180) on shells of the same species from 65 m a.s.l. on the east side of the north arm of Makinson Inlet, near Hook Glacier (Fig. 2; see also Fig. 3, Blake 1981). At that site the shells occur in a 3 cm thick band in silt, 2 m below the present surface of a terrace.

Opposite Glacier 7A-45, north of the extreme northern end of the north arm (of Makinson Inlet) (Fig. 2) and
about 36 km north of the shell site beside Hook Glacier, *Hiatella arctica* shells were collected by S. B. McCann in a silt/clay unit at ~36 m a.s.l. These shells, the northernmost found in the Makinson Inlet drainage basin, gave an age of 7330 ± 80 BP (GSC-1972), and the collection also contained *Portlandia arctica* and *Mya truncata*. The only other sample related to past positions of sea level at the head of the northern arm of Makinson Inlet is a deeply imbedded large driftwood log (*Larix* sp.) collected between Glacier 7A-45 and ice-dammed Split Lake, at ~47 m a.s.l. (Fig. 2). This log is 6260 ± 60 years old (GSC-3688; Blake 1983), and this sample plots close to, but slightly above, the emergence curve for Pirilavijuk Bay (Fig. 12). The presence of this dated log shows that when the 7330-year-old pelecypods were alive, relative sea level had to have been at an elevation higher than that at which the wood was found. Comparison with the emergence curve suggests that the shells relate to a sea level at 60 m or above, yet the surface elevation at the apex of the delta is given as 87 m by Hodgson (1985; and pers. comm. 1993).

If we assume that these shells relate to the initial marine incursion, coinciding with the progression of a calving bay northward up this arm of Makinson Inlet, then it took approximately 2000 radiocarbon years for the ice to retreat the 36 km from Hook Glacier to this

### Table 2. Radiocarbon age determinations, Pirilavijuk Bay, Makinson Inlet, Ellesmere Island.

<table>
<thead>
<tr>
<th>Sample elevation m a.s.l.</th>
<th>Dated material</th>
<th>Field sample no</th>
<th>Laboratory dating no.</th>
<th>Corrected age (conventional 14C years before 1950)</th>
<th>Calibrated range</th>
<th>Sample weight (g)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>~36* Hiatella arctica</td>
<td>BS-77-277</td>
<td>GSC-2692</td>
<td>+1.4</td>
<td>8090 ± 70</td>
<td>9138–8980</td>
<td>46.4</td>
<td>Highest level Holocene shells found in the area. Shells are aragonitic. Other species: <em>Mya truncata</em>, <em>Macoma calcarea</em>, <em>Clinocardium clitium</em>.</td>
</tr>
<tr>
<td>~42* Mya truncata</td>
<td>BS-77-235B</td>
<td>GSC-2701</td>
<td>+1.8</td>
<td>8040 ± 110</td>
<td>9142–8947</td>
<td>59.2</td>
<td>Outer fraction (11–55%). Outermost 10% removed by HCI leach. Inner fraction (56–100%).</td>
</tr>
<tr>
<td>~42* Salix sp.</td>
<td>BS-77-252</td>
<td>TO-113</td>
<td>1.0</td>
<td>41 260 ± 400</td>
<td>7920 ± 110</td>
<td>7.3</td>
<td>Single willow, largest stem is 25 cm long. Sample mixed with dead gas for counting.</td>
</tr>
<tr>
<td>~42* Salix sp.</td>
<td>BS-77-249</td>
<td>GSC-2712</td>
<td>-28.3</td>
<td></td>
<td>8995–8560</td>
<td></td>
<td>Considerable Fe-staining.</td>
</tr>
<tr>
<td>~40* Hiatella arctica</td>
<td>BS-77-256</td>
<td>GSC-2519</td>
<td>+1.4</td>
<td>8930 ± 100</td>
<td>9824–9489</td>
<td>46.0</td>
<td>Other species: <em>Mya truncata</em>, <em>Macoma calcarea</em></td>
</tr>
<tr>
<td>~40* Portlandia arctica</td>
<td>BS-77-256</td>
<td>TO-224</td>
<td>1.0</td>
<td>9150 ± 60</td>
<td>9964–9854</td>
<td>0.349</td>
<td>Sample is three large leaf valves (1.7–1.8 cm long, 1.1 cm high). 50% preleach with HCI.</td>
</tr>
<tr>
<td>32.0 Picea sp.</td>
<td>BS-77-386</td>
<td>GSC-2713</td>
<td>-24.5</td>
<td>5930 ± 60</td>
<td>6851–6728</td>
<td>11.6</td>
<td>Large log (near stump) – exposed part is 60 cm long, 27 cm diam.</td>
</tr>
<tr>
<td>30.5 Picea sp.</td>
<td>BS-77-385</td>
<td>GSC-3703</td>
<td>-23.4</td>
<td>5630 ± 70</td>
<td>6486–6400</td>
<td>11.4</td>
<td>Large log, 20 cm exposed; 49 cm total length, 5 cm max. diam.</td>
</tr>
<tr>
<td>23.0 Larix sp.</td>
<td>BS-77-364</td>
<td>GSC-2705</td>
<td>-25.3</td>
<td>4900 ± 60</td>
<td>5661–5588</td>
<td>11.7</td>
<td>Small log, 30 cm exposed; 49 cm total length, 5 cm max. diam.</td>
</tr>
<tr>
<td>21.0 Picea sp.</td>
<td>BS-77-362</td>
<td>GSC-2651</td>
<td>-25.6</td>
<td>4600 ± 60</td>
<td>5326–5287</td>
<td>11.8</td>
<td>Small log, 35 cm exposed; 92 cm total length, 16 cm diam. (above fork).</td>
</tr>
<tr>
<td>21.0 Picea sp.</td>
<td>BS-77-361</td>
<td>GSC-3411</td>
<td>-24.3</td>
<td>4590 ± 90</td>
<td>5329–5255</td>
<td>12.5</td>
<td>Small log 1.35 m long, 18 cm in diam. 15 cm buried under shingle.</td>
</tr>
<tr>
<td>19.5 Picea sp.</td>
<td>BS-77-359</td>
<td>GSC-3456</td>
<td>-23.8</td>
<td>4480 ± 60</td>
<td>5288–5029</td>
<td>11.3</td>
<td>Log 3.7 m long, 10 cm diam., lying in its own depression in beach shingle.</td>
</tr>
<tr>
<td>4.6 Picea sp.</td>
<td>BS-77-357</td>
<td>GSC-9305</td>
<td>-24.5</td>
<td>2880 ± 60</td>
<td>3086–2941</td>
<td>12.2</td>
<td>Small log, 45 cm exposed; 70 cm total length, 9 cm max. diam.</td>
</tr>
<tr>
<td>3.0 Picea sp.</td>
<td>HCA-72-26-7-8B</td>
<td>GSC-1836</td>
<td>-24.4</td>
<td>2060 ± 50</td>
<td>2071–1958</td>
<td>13.2</td>
<td>Log 1.2 m long, 10–15 cm in diam., exposed 50 cm below surface in coastal section.</td>
</tr>
</tbody>
</table>

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* Elevations marked by asterisks determined by surveying altimeter. Leveled elevations (Wild NK-10) have been rounded off to the nearest half-metre.

* Marine molluscs and cirripeds identified by W. Blake, Jr.; most wood samples identified L. D. Farley-Gill, plus two by H. Jette and one by R. J. Mott.

* Laboratory designations: GSC – Geological Survey of Canada; TO – IsoTrace Laboratory, University of Toronto.

* All age determinations from the Radiocarbon Dating Laboratory, Geological Survey of Canada, are based on a 14C half-life of 5568 ± 30 years and 0.95 of the activity of the NBS oxalic acid standard. Ages are quoted in conventional radiocarbon years before present (BP) where 'present' is taken to be 1950. All finite age determinations from this laboratory are based on the 2σ criterion; i.e., there is a 95% probability that the correct age in conventional radiocarbon years lies within the stated limits of error. 13C / 12C ratios were determined at the Department of Earth Sciences, University of Waterloo, under the direction of P. Fritz, R. J. Drimmie and M. E. Patton. Relative to the PDB standard, it is GSC practice to normalize 13C values on terrestrial organic materials and bones of all types to ~25.0‰, whereas marine shells are normalized to 0.0‰ (Lowdon and Blake 1970). The IsoTrace results are the average of two machine-ready targets (normal precision), measured on different occasions. TO-113 has been corrected for natural and sputtering fractionation to a base of 13C = -25‰, and the result has also been corrected for a total system background of 0.077 ± 0.005 pMC. TO-224 has been corrected for natural and sputtering fractionation to a base of 13C = 0‰, equivalent to a reservoir correction of 410 years. The TO-ages quoted are based on a 14C half-life of 5568 ± 30 years and the Libby 14C meanlife of 8033 years. The errors represent 68.3% confidence limits. Preparation of the machine-ready sample causes the fractionation of the sample material to vary systematically from the top to the bottom of the target. The computer analysis program uses the 13C / 12C ratio obtained during the measurement, which is the product of this fractionation and the natural fractionation of the sample, to correct the 13C / 12C ratio, at no time during the measurement. While this procedure yields a highly reliable result for the 13C / 12C ratio, at no time during the measurement is a value of the natural fractionation alone obtained (see IsoTrace Laboratory, 1984 Annual Report, 84.12.31, Chapter II.2, p. 31–64, Radiocarbon Analysis, by R. P. Beukens).

* The procedure for obtaining calibrated ages is described in the text.

* Log 77-361 (at 20.8 m) is slightly below 77-362 (at 21.2 m).
site, a rate in the range of 1.8 to 2.1 km/century. On the other hand, if there are older Holocene marine deposits now buried below the alluvium in the valley below Glacier 7A-45, then the rate of retreat was even more rapid. However, it is worth noting that the date of 7330 ± 80 years (GSC-1992) is only slightly older than two ages on marine shells east of the head of Vendom Fiord (Fig. 2): 7010 ± 80 years (GSC-1858) and 6980 ± 90 years (GSC-1957; both in Hodgson 1985). *Hiatella arctica* was used for these age determinations, and in both cases the relevant sea level was >53 m. Still further north, *Hiatella arctica* shells collected on the crest of an end moraine at 56 m a.s.l. at the head of Strathcona Fiord (Fig. 1) are 6780 ± 80 years old (GSC-3765; Hodgson 1985), and ~7 km southeast of the head of this fiord *Mya truncata* shells collected by the writer and R. J. H. Richardson in silt at ~22 m a.s.l. are 6570 ± 80 years old (TO-2209). Thus the 7330-year-old shells north of Makinson Inlet fit well into the regional picture of a northward- and eastward-retreating ice front, the youngest age being one of 5730 ± 70 BP (TO-530) on algae in a lake at ~830 m, 23 km southeast of the head of Strathcona Fiord (Blake 1989).

The highest sample of Holocene shells found near Piliravijuk Bay, at approximately 82 m a.s.l., is only 8090 ± 70 years old (GSC-2692), and it is this sample which defines the upper half of the emergence curve (Fig. 12). Some 1000 radiocarbon years earlier, when *Portlandia arctica* was the dominant species, relative sea level was probably close to 120 m. An estimated 80 m of emergence, approximately two-thirds of the total amount, occurred in the span of 2500 years between, roughly, 8800 and 6300 BP. *P. arctica*, an Arctic species which thrives in silt-laden waters near river mouths and glaciers and which can live at depths from 3 to 400 m (e.g., see Odhner 1915; Ockelmann 1958; Beklemishev et al. 1977; Funder 1978; Spjeldnæs 1978; Lubinsky 1980; Bennike 1987), is not present in the 8000-year-old sample.

Because of the presence of early Holocene shells at elevations above 100 m at several sites along the south coast of Ellesmere Island (as well as whale bones at 118 m near Cape Storm; Blake 1975a) and shells at 107.5 m near Cape Herschel to the northeast (Blake 1992a; cf. Fig. 10 in the present paper), it seems reasonable to relate the pelecypod shells at ~40 m at Piliravijuk Bay to an equally high relative sea level. The alternative, that these 9000-year-old shells define a position of relative sea level only slightly above the elevation at which the fossils now occur, and that sea level then rose to a point above the 8000-year-old shells now at ~82 m, is not indicated by the nature of the enclosing sediments, which directly overlie till; the coarsening-upward sequence at the site records only a gradual shallowing. Furthermore, shells at 50–52 m at Clarence Head, on the outer east coast of Ellesmere Island (Fig. 2) are 9220 ± 90 years old (GSC-2531, *Mya truncata*) and 9330 ± 110 years old (GSC-3183, *Hiatella arctica*; both results in Lowdon & Blake 1981). These shells were collected on a loose talus slope, where they almost certainly have been subjected to downward creep. Thus sea level when the pelecypods lived was an unknown amount above 52 m, perhaps at ~80 m, where there is a morphological break in the slope. Finally, as noted earlier, *Portlandia arctica* shells at 65 m a.s.l. at Hook Glacier, only 27 km northeast of Piliravijuk Bay, are 9270 ± 110 years old (GSC-3180).
Holocene emergence along the Ellesmere Island coasts

Fig. 12. Time-elevation diagram for inner Piliravijuk Bay, Makinson Inlet, showing the pattern of Holocene emergence. Elevations of samples, all collected within 2 km of base camp (Fig. 2), are uncorrected for the eustatic rise of sea level. One other driftwood sample, from ~47 m near Split Lake, 55 km to the north, is included in the diagram for comparative purposes.
The 'apparent age' of marine shells or 'reservoir effect' — that is, the time necessary for atmospheric CO₂ to mix with the surface water of the sea — has been widely discussed in the literature (cf. Mangerud & Gulliksen 1975). Because the dissolved bicarbonate derived from atmospheric CO₂ is used by molluscs and other marine organisms to construct their shells, a correction must be applied to the resultant ¹⁴C ages. The correction necessary for both Cape Herschel and Piliravijuk Bay is approximately 300 years, based on the analysis of several turn-of-the-century collections of marine pelycypods and cirripeds from Ellesmere Island and North-West Greenland waters (Blake 1987, 1992a). This value is close to the 325 ± 45 years figure given by Stuiver et al. (1986; cf. also Stuiver & Braziunas 1993) for southeastern Ellesmere Island. The 300 years is in addition to the built-in 410-year correction to ¹⁴C age determinations on marine shells (normalized to 0% on the PDB scale) at the Geological Survey of Canada (GSC) and, at the time that sample TO-224 was processed, at the IsoTrace Laboratory, University of Toronto. The additional 300-year correction means that the 9150 of TO-224 becomes 8850, the 8930 of GSC-2511 becomes 8630, etc., as indicated in Fig. 12. The effect of this correction is to make the upper part of the Makinson Inlet curve slightly steeper than it would be otherwise, but there is no effect on the lower part of the curve, which is based entirely on age determinations on far-traveled coniferous driftwood.

Another feature of the Makinson Inlet curve is that a slight lessening in the rate of emergence is suggested at approximately 5000 BP in order to accommodate the ¹⁴C ages on driftwood (question mark in Fig. 12). A decrease in the rate of emergence at this time would agree with the data from both Cape Storm and Cape Herschel (cf. Blake, 1970, 1975a, b, 1992a). Data from those two sites indicate that a slight transgression or period of balance occurred just at the time that a pumice drift reached Jones Sound and Makinson Inlet, and hence the pumice became concentrated over a narrow vertical interval on the beaches. Pumice was not abundant on the beaches in Piliravijuk Bay, and the two pieces found were between 20.5 and 22.5 m a.s.l. Driftwood at 23.0 m is 4900 ± 60 years old, whereas at Cape Storm the abundant pumice at 22.0–22.5 m is bracketed by radiocarbon-dated logs at 22.0 m (5040 ± 60 BP, GSC-1410) and 22.5 m (5100 ± 50 BP, GSC-826; Blake 1970, 1975a). In outer South Cape Fiord (Fig. 1), where the pumice is concentrated at 17.5 m and is just below a pronounced notch in the raised beaches, driftwood logs at 17.0 m and 21.0 m are 4710 ± 60 BP (GSC-1047) and 5220 ± 80 BP (GSC-1912), respectively (Blake 1975a). The ages of the driftwood are close enough to show that a single pumice drift is involved, providing a useful time line for correlating beaches throughout the region.

Although pumice was not discovered on the raised beaches at Cape Herschel, we can deduce from the emergence curve that the shoreline of 5000 radiocarbon years ago falls somewhere between 22.5 and 25.0 m a.s.l. (Blake 1992a). If 22.5 m is the correct value, then this shoreline is at a similar elevation to the pumice at Piliravijuk Bay and Cape Storm, and the isobase for the 5000-year-old shoreline is oriented roughly northeast–southwest. As I have discussed previously (Blake 1992a), all the available data indicate the 5000-year-old shoreline is higher to the northwest and lower toward the southeast.

Conclusions

A study of raised marine features on the north shore of Piliravijuk Bay in south-central Ellesmere Island leads to similar conclusions to those arrived at earlier from investigations at Cape Storm and South Cape Fiord, both on the south coast of the island, and at Cape Herschel, on the east-central coast facing Smith Sound and Greenland.

1. The highest marine pelycypods of Holocene age were collected at an elevation of ~82 m. An age determination on Hiatella arctica shells from this collection gave 8090 ± 70 years BP (GSC-2692).

2. The oldest pelycypods (Portlandia arctica), representing a deeper water deposit at ~40 m a.s.l., were 9150 ± 60 years old (TO-224). As this species can live at considerable depths, and because the shells are ~1000 years older than the collection at 82 m, this age determination probably provides a close approximation for the age of the Holocene marine limit, estimated to be somewhere in the range of 100 to 120 m. At Cape Herschel, where the curve is better controlled, the highest Holocene shells relate to a sea level above 108 m.

3. The age determinations on marine pelycypod shells, together with a series of eight ¹⁴C ages on far-traveled driftwood of Picea and Larix, have allowed construction of an emergence curve. At Piliravijuk Bay approximately two-thirds of the emergence took place in the first 2500 radiocarbon years, i.e., between ~8800 and 6300 BP, at a mean rate of approximately 3.2 m/century.

4. No field evidence was found around Piliravijuk Bay or elsewhere in inner Makinson Inlet for a generation of older marine features topographically above the limit of Holocene marine submergence. To the east of the study area, the collection site for the 28 000 to 30 000-year-old shells, interpreted as a beach at the time the collection was made in 1961, is lower in elevation than the highest Holocene marine features recorded by both the writer and R. L. Christie.
5. One sample of locally derived Salix sp., in a deep-water silt deposit at ~42 m a.s.l., shows that Arctic willow was growing at the site by ~8000 BP. The other age for Salix sp., 41 260 ± 400 BP (TO-113), together with the two earlier dates on shells of 28 000 to 30 000 years and a few low amino acid ratios on shells in till, supports the concept of the mid-Wisconsinan Cape Storm Nonglacial Interval proposed for the region, based on extensive data from Cape Storm on the south coast of Ellesmere Island, from the east coast near Cape Herschel, and from the north arm of Makinson Inlet (Blake 1992b). The growing body of evidence for an ice-free interval (or intervals) in mid-Wisconsinan time is well documented in Spitsbergen (Mangerud & Svendsen 1992), and a whole series of major δ18O fluctuations are recorded in the ice cores from Greenland between 25 000 and 40 000 calendar years BP (Johnsen et al. 1992).

6. The sum of available observations and data – the Holocene emergence at Pilarivujik Bay, the presence of single thin veneer of shell-bearing till in which some marine pelecypod shells have low amino acid ratios, the freshness of the glacier sculpture on Bowman Island, and the difference in ages of in situ shells between Pilarivujik Bay and the head of the north arm of Makinson Inlet – provides strong evidence that a major trunk glacier filled Makinson Inlet and flowed eastward to Baffin Bay in Late Wisconsinan time. The same conclusion has been reached in a previous study (Blake 1992a) for the Smith Sound area, where coalescing ice from Greenland and Ellesmere Island flowed southward into northernmost Baffin Bay.


Oke and E. 1988: A summary of the marine fauna of the Canadian Arctic Archipelago and North Greenland. Figure 2 in Trettin, H. P. (ed.): Innuitian Orogen and Arctic Platform, Canada and Greenland. *Geological Survey of Canada, Geology of Canada no. 3, scale 1:200,000.*


