Multiple glaciations and marine transgressions, western Kennedy Channel, Northwest Territories, Canada

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Along a 70 km section of western Kennedy Channel three prominent weathering zones are identified and serve to differentiate major events in the Quaternary landscape. The oldest zone (Zone 11b) is characterized by a deeply weathered, erratic-free terrain which extends from the mountain summits down to ca. 470 m above sea level. This zone shows no evidence of former glacierization. Zone 11a extends from ca. 470 to 370 m above sea level and is characterized by sparse granite, gneiss and quartzite erratics amongst weathered bedrock and extensive, oxidized colluvium. The Precambrian provenance and uppermost profile of these erratics reflect the maximum advance of the northwest Greenland Ice Sheet onto northeastern Ellesmere Island. These uppermost erratics along western Kennedy Channel decrease in elevation southward and suggest that the former Greenland ice was thickest in the direction of the major outlet of Petermann Fiord. No evidence of a former ice ridge in Nares Strait was observed. Zone II is marked by the moraines of the outermost Ellesmere Island ice advance which form a prominent morpho-stratigraphic boundary where they cross-cut the zone of Greenland erratics at ca. 250–350 m above sea level. These moraines show advanced surface weathering and ice recession from them is associated with a pre-Holocene shoreline at 162 m above sea level. Late Wisconsin/Würm glacial deposits, equivalent to Zone I, were not observed in the lower valleys bordering Kennedy Channel. The outermost Ellesmere Island ice advance (Zone II) is radiometrically bracketed by ^{14}C dates on *in situ* shells from subtill and supratill marine units which are $40{,}350 \pm 750$ and $>39{,}000$ B.P., respectively. Amino acid age estimates on the same shell samples and others from similar stratigraphic positions all suggest ages of $>35{,}000$ B.P. Stratigraphically and chronologically this ice advance is correlated with the outermost Ellesmere Island ice advance 20–40 km to the north which formed small ice shelves when the relative sea level was ca. 175 m above sea level. The Holocene marine transgression along western Kennedy Channel occurred in an ice-free corridor maintained between the separated margins of the northwest Greenland and northeast Ellesmere Island ice sheets during the last glaciation. Initial emergence may have begun ca. 12,300 B.P., however, sea level had dropped only 15 m by ca. 8000 B.P. after which glacio-isostatic unloading of the corridor was rapid. The implications of these data are discussed in the context of existing models on high latitude glaciation and paleoclimatic change.

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Field work on the Quaternary history of northeastern Ellesmere Island was continued during 1978 along western Kennedy Channel (Fig. 1). Previous investigations, 20–40 km to the northeast on Judge Daly Promontory, concentrated on the former interaction of the northeast Ellesmere Island and northwest Greenland ice sheets whose respective land masses today are separated only by the 30 km width of Kennedy Channel (England & Bradley 1978; England et al. 1978). These studies reported a maximum northwest Greenland Ice Sheet advance of great antiquity (tentatively $>80{,}000$ B.P.) that extended ca. 100 km beyond the present margin of the Petermann Glacier (Fig. 1). This ice advance onto northeastern Judge Daly Promontory is the oldest and most extensive glacial event presently reported in the area. However, several deeply weathered, erratic-free uplands project above this glaciated zone and are interpreted as older unglaciated surfaces.

Following an unknown interval the maximum northeast Ellesmere Island ice advance cross-cut the outermost zone of Greenland erratics and extended eastward to Kennedy Channel. These outermost Ellesmere Island glaciers were sufficiently thin to be strongly controlled by topography and both morphologic and stratigraphic evidence suggests that they were forced to float forming small ice shelves in several embayments along western Kennedy Channel (England et al. 1978). The relative sea level at this time of

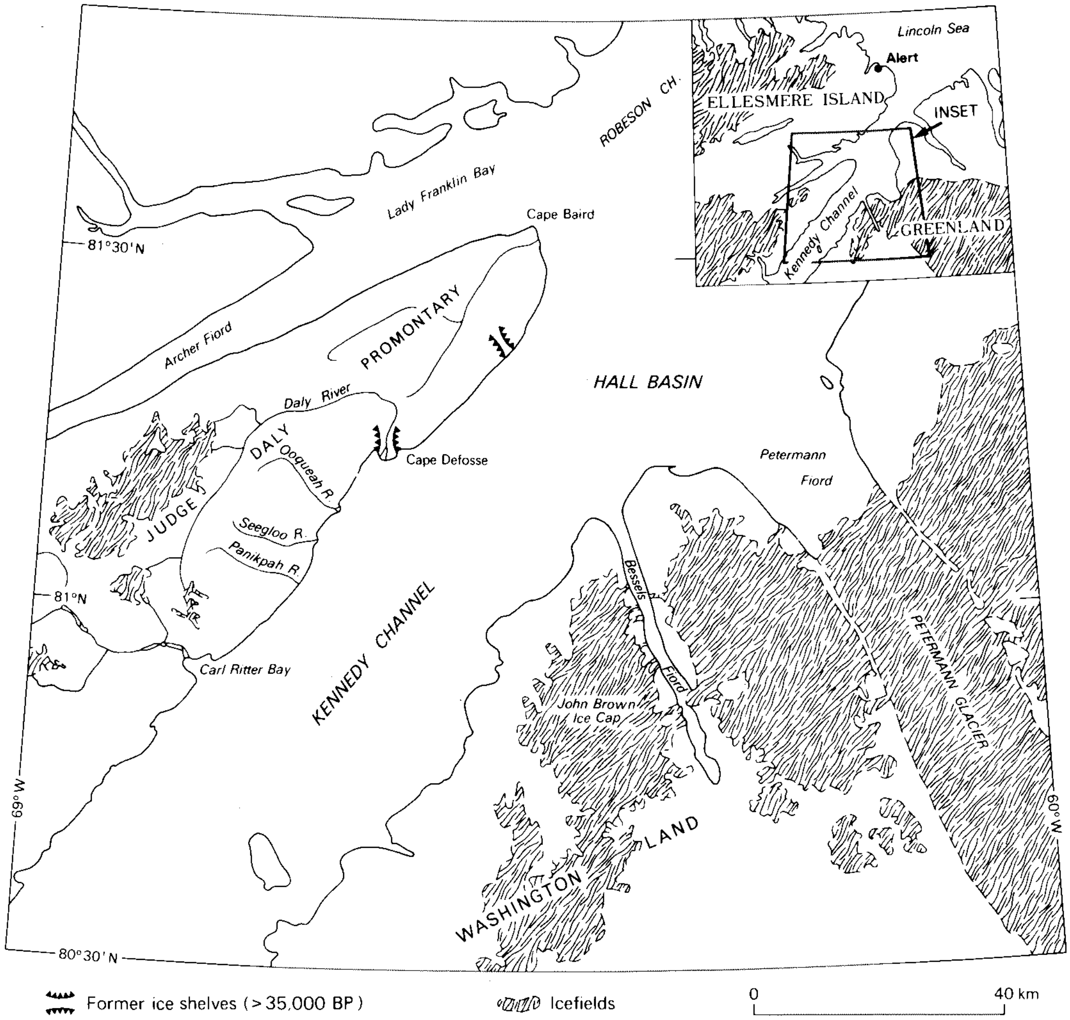

Fig. 1. Location map of northeast Ellesmere Island and northwest Greenland showing permanent icefields and specific field areas along western Kennedy Channel. Former ice shelf locations, based on previous field work, are also shown.

ice shelf formation is considered to have been ca. 175 m above sea level based, stratigraphically, on the height of a glacio-marine delta below prominent, horizontal (ice shelf) moraines and, theoretically, on the water depth required to float the estimated ice thicknesses in two different valleys. Both fossiliferous till and glacio-marine deltas associated with these ice shelves provided finite ^{14}C dates of 28,000–30,000 B.P.; however, these are considered to be minimum estimates due to the limitations of conventional ^{14}C dating in this time range. The degree of racemization of amino acids in the same shell samples all provided age estimates of >35,000 B.P. (England et al. 1978). No stratigraphic evidence was observed for late Wisconsin/Würm ice overriding these older glacial and marine deposits and hence it was concluded that the maximum Holocene shorelines in this area (at 90–110 m above sea level) had been formed in an ice-free corridor formerly depressed between the Ellesmere Island and Greenland ice sheets of the last glaciation (England 1978).

Field program

The 1978 field work was designed to test the stratigraphy and chronology based on these earlier findings. Specifically, observations were made to determine whether the major weathering zones described on northern Judge Daly Promonotory were comparable with those to the south. Investigations were also made to establish whether morphological evidence for additional, former ice shelves existed in other confined glacial valleys bordering Kennedy Channel. Lastly, due to its significance, the pre-Holocene shoreline at ca. 175 m above sea level required verification and hence efforts were made to obtain an independent check on the height and age of this former relative sea level associated with the most extensive Ellesmere Island glaciation. Additional observations were made in order to extend the profile of uppermost Greenland erratics previously mapped to the north (England & Bradley 1978) and to obtain dateable material from Holocene shorelines which would contribute new control points for the determination of the regional pattern of postglacial emergence (England 1976a).

Field description

Field work was conducted along western Kennedy Channel approximately midway between Cape Defosse and Karl Ritter Bay (Fig. 1). This area is noteworthy since it is located within 40 km of the present margin of the John Brown Ice Cap on northern Washington Land, Greenland (Fig. 1). At this point Kennedy Channel is only 30 km wide with maximum water depths of ca. 360 m (Canadian Hydrographic Service, Chart 430, 1973).

Three prominent valleys were selected for study; these are occupied by the Ooqueah, Seegloo and Panikpah rivers (Figs. 1 and 2). This coastal portion of eastern Judge Daly Promontory is characterized by sharply dissected mountains extending to 1100 m above sea level. The mountains are composed of a conformable, northeast-trending sequence of lower and middle Paleozoic clastic and carbonate sedimentary rocks (Christie 1974). Some unconformable and poorly lithified Tertiary sandstones outcrop in the southern end of the field area. The mountains are cross-cut by deeply incised rivers which drain eastward and southeastward to Kennedy Channel from the central interior of Judge Daly Promontory. In the north-central interior of the Promontory, within 20 km of Kennedy Channel, there is a 300 km² ice cap whose outlet glaciers previously discharged eastward through the Ooqueah, Seegloo and Panikpah river valleys to sea level. Considerable evidence exists for substantial Ellesmere Island ice inundating the valleys from the interior of the Promontory. The most prominent evidence includes glacially abraded mountain summits together with moraines and numerous meltwater channels some of which breach interfluves up to ca. 610 m above sea level. In addition, numerous abandoned cirques occur in the coastal mountains indicating that considerable local ice was active in the past. The present day glaciation limit along this coastline is ca. 1100 m above sea level (Miller et al. 1975). Extensive glacial and raised marine deposits occur in all the major valleys.

Field results

The observations reported here include the major weathering zones together with the glacial and marine stratigraphy in the Ooqueah, Seegloo and Panikpah river valleys (Fig. 2). Several new ^{14}C dates and amino acid age estimates provide a time framework for this stratigraphy. Since the most complete stratigraphic record and many of the dating assessments come from the Seegloo river valley that area will be discussed first, followed by additional details from the Ooqueah and Panikpah river valleys (Fig. 2).

Seegloo River

Weathering zones and moraines

The lower Seegloo river valley is a deep glacial trough ca. 760 m in relief which abruptly opens out into a 5 km² foreland bordering Kennedy Channel (Fig. 2). Several weathering zones are present and they are numbered sequentially from their lowest elevations to the mountain summits. The oldest and uppermost weathering zone (Zone IIIb) is characterized by an erratic-free surface developed on lower Paleozoic carbonate bedrock and it extends from the mountain summits down to ca. 470 m above sea level (site A, Fig. 2). Where the bedrock outcrops it is highly frost shattered and jointed with tors 2–4 m in height. The tors exhibit a ubiquitous orange-brown oxidation and surface fretwork formed by solution weathering. In this zone a heavily oxide-stained colluvium mantles ca. 80% of the

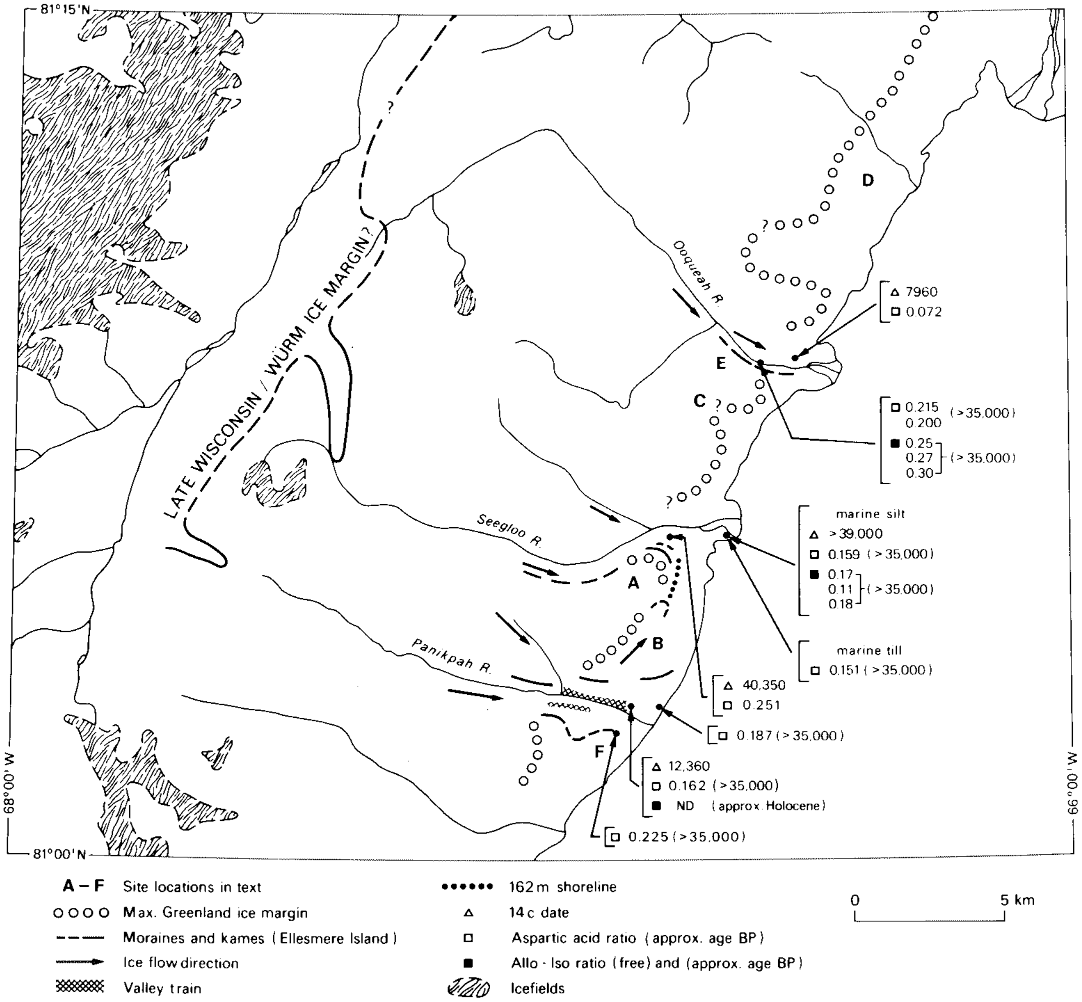

Fig. 2. Location map of western Kennedy Channel showing the Ooqueah, Seegloo and Panikpah river valleys. Also shown are site locations referred to in text; extent of Greenland erratics, prominent Ellesmere Island moraines, and available ^{14}C dates and amino acid age estimates. Note the proximity of the present day ice cap in the interior of Judge Daly Promontory and the possible late Wisconsin/Würm ice margin beyond it.

bedrock to a depth >0.5 m. No evidence of former glaciation was observed in this zone.

In the same area (site A, Fig. 2) one encounters the uppermost evidence of glaciation at ca. 470 m above sea level, where sparse granite, gneiss and quartzite erratics are embedded in oxidized colluvium (Zone IIIa). Tors are also present in Zone IIIa and there is no apparent weathering break with the unglaciated slopes above. The fact that many of these uppermost crystalline erratics have a Precambrian Shield provenance and decrease in elevation towards the interior of Ellesmere Island, clearly indicates a former advance of the northwest Greenland Ice Sheet onto this coastline (Christie 1967; England & Bradley 1978). Two kilometers to the south of the lower Seegloo River, crystalline erratics overtop the summit of a poorly lithified, Tertiary sandstone ridge (ca. 440 m above sea level) where deep meltwater channels have been dramatically incised on its western flank (site B, Fig. 2 and Fig. 3). The weathering of these Greenland erratics suggests considerable antiquity; most are characterized by either extensive

Fig. 3. View looking eastward at prominent meltwater channel on the western flank of the Tertiary ridge (site B, Fig. 2) south of the Seegloo River. Precambrian erratics in the channel date from the maximum Greenland ice advance that extended westward onto Ellesmere Island. Summit of the ridge in the background is >440 m above sea level.

frost shattering or a well developed, exfoliating desert varnish on the more resistant lithologies (Fig. 4).

In the lower Seegloo river valley this zone of sparse Greenland erratics extends from ca. 470 to 370 m above sea level, where it is cross-cut by the uppermost Ellesmere Island lateral moraine which marks the Zone II/IIIa boundary. This moraine is composed primarily of highly frost shattered and oxidized sedimentary clasts and increases in elevation to ca. 390 m above sea level within a few km inland. The moraine forms a prominent morpho-stratigraphic boundary against the weathered bedrock and crystalline erratics above (Fig. 5). Below this moraine, and probably representing ice recession from it, are abundant sedimentary and quartzite erratics that extend down to two kame terraces at 290 and 225 m above sea level (Fig. 5). These kame terraces occur at the outermost constriction of the valley immediately above the Seegloo foreland and hence occupy an area physiographically suited for ice stagnation. Both kame terraces exhibit advanced surface weathering which is similar to the uppermost moraine. In places they are covered only by an oxidized and travertine-coated lag gravel overlying a stoney sand regosol. Most sedimentary rock clasts (sandstones and carbonates) have been extremely frost shattered. Following the formation of the kame terraces there is no evidence for a subsequent period of glacial erosion or deposition in the lower valley.

Marine stratigraphy

Directly down slope from the uppermost moraine (site A, Fig. 2), along the south side of the Seegloo valley, the river has exposed a subtill marine unit at ca. 60 m above sea level (Fig. 6). The marine unit is composed of bedded silts and sands containing whole valves of *Hiatella arctica* and it underlies a 4 m thick complex of fossiliferous, indurated till intercalated with outwash and several sediment flows. The outwash is composed of lenses of cross-bedded pebbly sand together with finely laminated silts and sands that have been subsequently folded. These units grade upward into a massive silt with increasingly numerous dropstones. The silt in turn is overlain by an indurated lodgement

Fig. 4. Exfoliating desert varnish on granite erratic resting on the Tertiary ridge (>440 m above sea level) south of the Seegloo River. Advanced weathering of these erratics and the surrounding terrain suggests that this ice advance is of considerable antiquity.

till >5 m thick. The deposition of this sequence is considered to represent the initial advance of the outermost Ellesmere Island ice when the relative sea level had transgressed to at least 60 m above sea level and the uppermost moraines were being formed. Fig. 6 presents a composite diagram of the glacial and marine stratigraphy in the lower Seegloo river valley.

The next youngest marine units occur down-valley on the outer Seegloo foreland where the river has exposed a 7 m section 1 km inland from Kennedy Channel. The basal unit in this section is an indurated and highly fossiliferous marine diamicton 2 m thick. The diamicton contains abundant, angular sedimentary rock clasts which are intermixed with equally abundant, complete bivalves of *Hiatella arctica* in a matrix of weakly bedded silts and sands. This unit is overlain by another 2 m of stratified silts and sands which are also indurated and highly fossiliferous (Fig. 6). This latter unit is conformable with the underlying marine diamicton and becomes progressively free of dropstones in its upper layers. These indurated marine deposits are in turn superimposed by a conformable sequence of loose, fossiliferous sands and gravels which form the outer portion of a Holocene terrace. Both of the indurated marine units are characterized by *in situ Hiatella arctica* which are very thick walled in comparison to the more fragile *Hiatella arctica* and *Portlandia (Yoldia) arctica* in the overlying Holocene deposits.

The marine diamicton discussed above is genetically interpreted as a till deposited into contemporaneous marine sediments beneath a floating glacier margin. This floating ice margin in turn is considered to coincide with the outermost Ellesmere Island ice advance whose outlet glacier was only ca. 320 m thick in the narrow confinement of the lower Seegloo river valley from which it spread out into the deep water of Kennedy Channel. The overlying, conformable sequence of marine silts and sands, which becomes free of dropstones, is considered to be synchronous with the removal of this local ice shelf and the formation of the uppermost

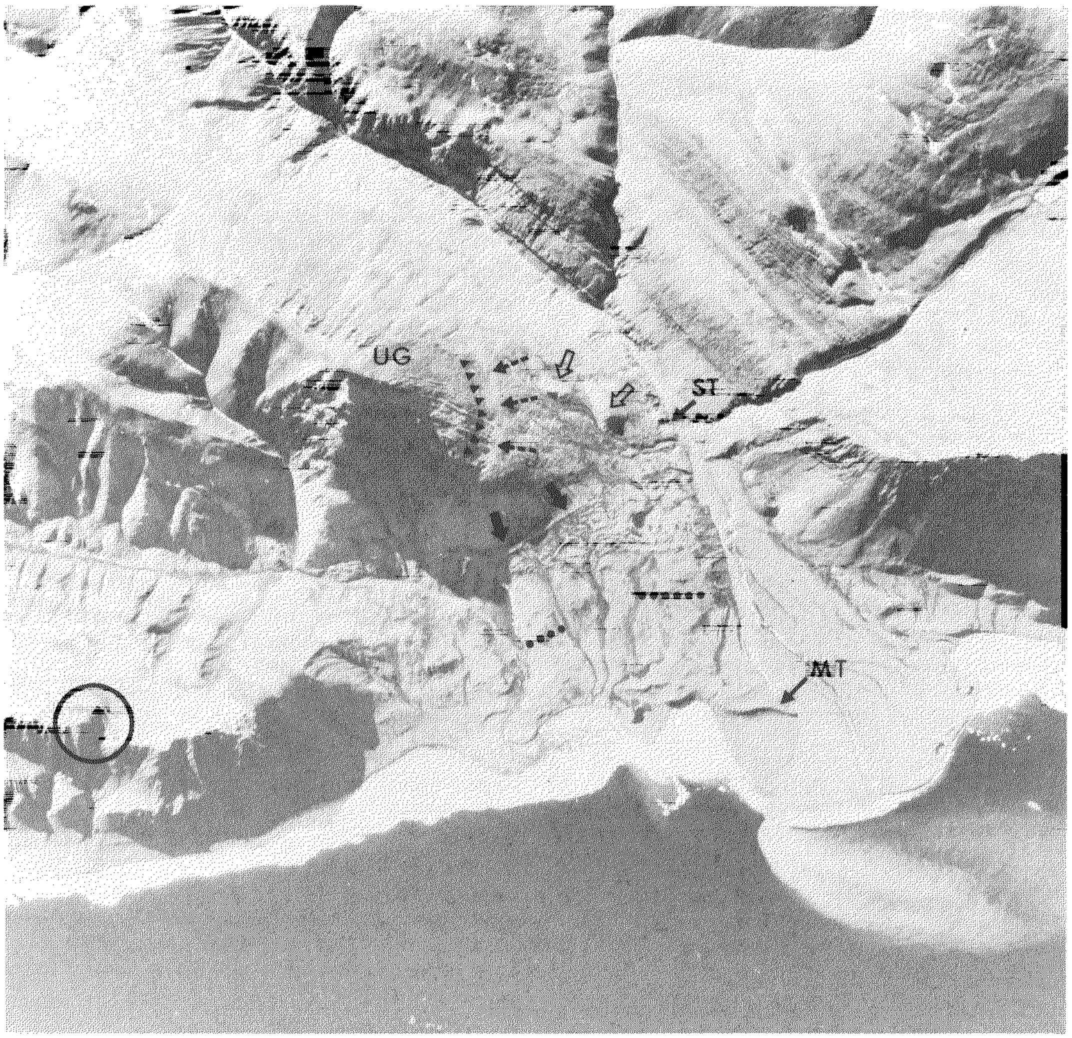

Fig. 5. Airphoto of the lower Seegloo River valley showing the uppermost, erratic free terrain (UG); the upper zone of Greenland erratics (black triangles); the highest Ellesmere Island moraines (dashed arrows) and subsequent kame terraces (open arrows). The prominent, pre-Holocene shoreline at 162 m above sea level is marked by solid black arrows. Dotted line shows the approximate upper limit of well-preserved Holocene beaches. Site of the indurated marine till (MT) and the subtill marine deposits (ST) are also shown. Circle encloses meltwater channel (Fig. 3) formed by the Greenland Ice Sheet. Airphoto A-16608-36, Department of Energy, Mines and Resources, Ottawa.

shoreline (discussed below) during the recession of the outermost Ellesmere Island ice advance. The overlying Holocene sands and gravels are considered to be the result of a much younger marine transgression (Fig. 6).

Immediately inland from this section, the highest marine transgression is marked by a prominent shoreline at 162 m above sea level which extends for 2 km along the uppermost edge of the Seegloo foreland (Figs. 5, 7 and 8). The sediment source for this 162 m shoreline is clearly associated with the recession of the outermost Ellesmere Island ice, whose kame terraces border it to the north and south at ca. 225 and 175 m above sea level, respectively. Numerous, regressive shorelines occur below this uppermost beach terrace, however, most have been dissected by prolonged fluvial and periglacial processes. In many places these lower terraces appear to have experienced the thermal

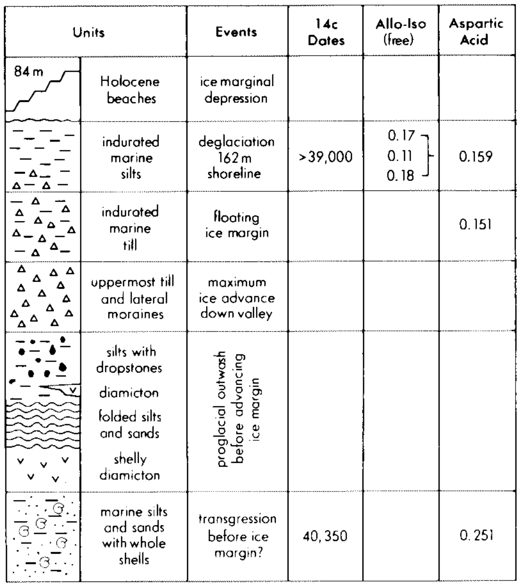

Fig. 6. Composite diagram of the glacial and marine stratigraphy observed in the lower Seegloo river valley. Corresponding ^{14}C dates and amino acid ratios are shown on the right (see also Table 1).

erosion of ice-wedge polygons forming baydjarakh-like landforms. At 84 m above sea level one abruptly encounters morphologically well-preserved raised beaches that extend to sea level. These beaches are interpreted as a Holocene transgression/regression cycle and they contrast sharply with the more weathered and periglacially disturbed marine deposits above. Due to the overriding of these beaches by extensive solifluction sheets it is concluded that they provide only a minimum estimate on the elevation of the upper Holocene shoreline.

Chronology

Table 1 lists the available ^{14}C dates and amino acid age estimates from the most recent field work along western Kennedy Channel. Whole valves of *Hiatella arctica* were collected *in situ* from the aforementioned subtill marine unit in the lower Seegloo river valley. This sample dated 40,350 ± 750 B.P. (SI-4028, Table 1 and Fig. 2) and it is considered to be a minimum estimate due to the limitations of ^{14}C dating in this time range. The degree of racemization of aspartic acid in the same sample (UA 649, Table 1) also suggests that this sample is >35,000 B.P. and possibly of mid Wisconsin/Würm age (N. W. Rutter pers. comm. 1979). Stratigraphically, this sample provides a maximum age estimate on the advance of the outermost northeast Ellesmere Island ice in this locality as demonstrated by its higher aspartic acid ratio in Fig. 6.

Additional dates were obtained on whole valves of *Hiatella arctica* collected from the indurated marine silts which conformably overlie the indurated marine till in the outer Seegloo foreland. This sample is considered to correspond to the initial recession of the outermost Ellesmere Island ice advance and the transgression to 162 m above sea level. Four successive fractions of this shell sample were ^{14}C dated with the following results: the outermost 28.6%, normally removed in initial pretreatment, dated 22,940 ± 460 B.P. (SI-4030A), the next inner 25% dated 26,940 ± 840 B.P. (SI-4030B); the next inner 17.7% dated > 39,000 B.P. (SI-4030C), and the innermost 28.7% also dated >39,000 B.P. (SI-4030D, Table 1). The racemization of both D-alloisoleucine to L-isoleucine and aspartic acid in the same sample provided age estimates of >35,000 B.P. (AAL-981A and UA 681, respectively, Table 1). Finally, the racemization of aspartic acid from *in situ* shells in the indurated marine till gave ratios very similar to those from the overlying conformable marine silts (Table 1 and Fig. 6) suggesting that these two units are penecontemporaneous.

Ooqueah River

Weathering zones and moraines

The Ooqueah River is 7 km to the northeast of the Seegloo River (Fig. 2) and occupies a similar glacial trough extending from the interior of Judge Daly Promontory to Kennedy Channel. The weathering zones in this area were investigated on a bedrock ridge which separates the Ooqueah River from a prominent col at ca. 300 m above sea level 2 km to the south (site C, Fig. 2). No erratics were observed on the summit (ca. 585 m above sea level) and upper slopes of this ridge which are characterized by the same deeply oxidized and frost shattered colluvium that comprises the uppermost unglaciated zone (Zone IIIb) south of the Seegloo River. Below this, at the eastern end of the col, the uppermost quartzite erratic was observed at ca. 450 m above sea level, with numerous quartzite and

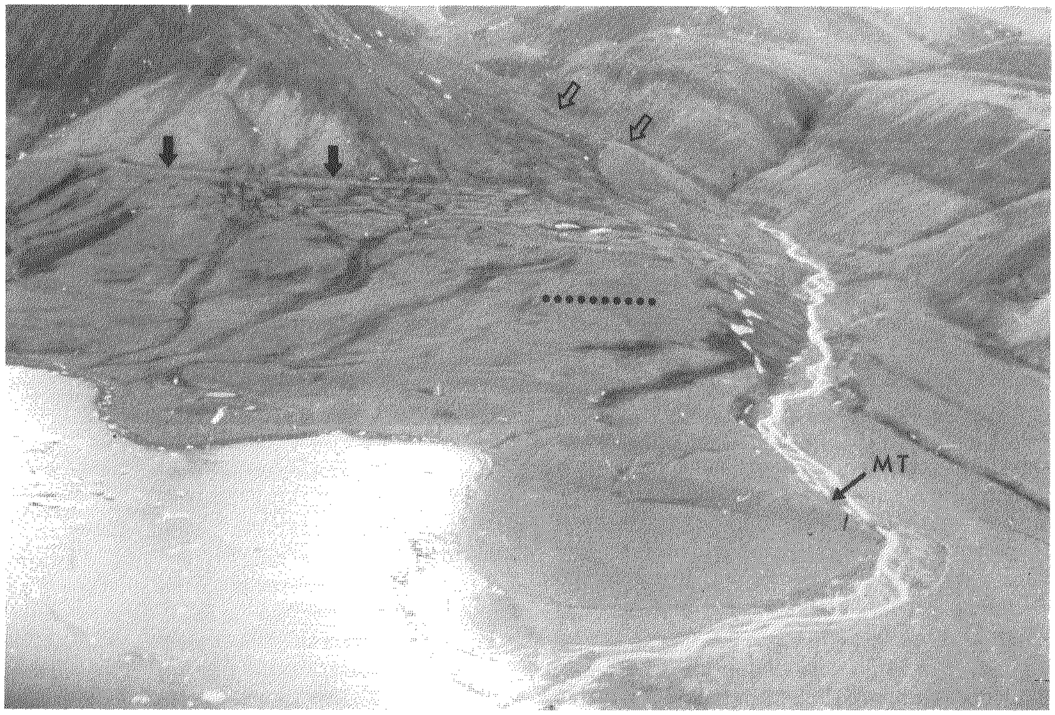

Fig. 7. Oblique view (looking westward) of the pre-Holocene shorelines, which rise to 162 m above sea level (solid black arrows) along the inland margin of the Seegloo foreland. Note the proximity of the recessional kame terraces (open arrows) on the south side of the valley where it begins to narrow. Uppermost Holocene beaches are marked with dotted line. Site of fossiliferous, indurated marine till and silt is also shown (MT).

sandstone erratics beginning to appear at ca. 410 m above sea level. This zone of abundant erratics extends eastward to small moraines at ca. 400 to 410 m above sea level whose highly weathered surfaces are covered only by oxidized grus and travertine-coated pebbles. In the same vicinity the uppermost granite erratic (Zone IIIa) was observed at ca. 390 m above sea level; however, this is considered a minimum estimate due to the limited number of observations made. By comparison, air photo interpretation suggests the presence of uppermost Greenland Ice Sheet moraines and meltwater channels at 460–610 m above sea level on a bedrock bench 6 km to the north of the Ooqueah river valley immediately above Kennedy Channel (site D, Fig. 2). It is of interest, however, that Greenland erratics were not observed farther west towards the interior of the col and hence it is possible that the bordering quartzite and sedimentary erratics (which increase in elevation inland) might reflect confluent Ellesmere Island ice in the uplands at this time. All the glacial deposits in the col overlie a terrain exhibiting similarly oxidized and comminuted surficial debris and hence are collectively included in Zone IIIa at this time.

Along the lower south side of the Ooqueah river valley the uppermost lateral moraines formed by Ellesmere Island ice occur at ca. 260 m above sea level (site E, Fig. 2). These moraines represent a former ice thickness of ca. 220 m at this point in the valley and above them one immediately encounters an extensive, oxidized scree slope. On the basis of their weathering and distinctive cross-cutting relationship with the terrain above, these moraines are considered to be stratigraphically equivalent to the uppermost (Zone II) Ellesmere Island moraines in the Seegloo river valley. These moraines occur immediately downvalley from a rock knoll at 240 m above sea level which is characterized by a patchy, weathered till overlying an oxidized and frost shattered carbonate bedrock. Where the till is being removed by mass wastage from

Fig. 8. The uniform surface of the 162 m shoreline with solifluction sheets overriding its surface from the adjacent hillslopes to the left (west).

the bedrock, striations are being exhumed indicating a former ice flow from the west, parallel with the axis of the valley.

Marine stratigraphy

Immediately down slope from the lateral moraines at site E, Fig. 2, the Ooqueah River has exposed a 50 m section of complexly interbedded silts, sands and gravels (Fig. 9). The basal units are characterized by beds of fossiliferous fine gravel intercalated with fine sands which are overlain in turn by involuted sands (load casts?). The central section is composed of interbedded sands and gravels with downvalley dips. The sediments coarsen upwards into outwash gravels extending to ca. 100 m above sea level. The upper surface of these gravels is highly irregular due to post depositional erosion. This outwash sequence is bordered immediately to the west by a massive fossiliferous till and whole, thick-walled valves of *Hiatella arctica* were collected along this contact. These outwash deposits are collectively interpreted as an aggrading, glacio-marine facies deposited along the margin of the outermost Ellesmere Island ice advance. They could also be the result of a minor readvance over the bedrock knoll during the overall recession. A minimum estimate on the relative sea level along this ice margin is ca. 100 m above sea level (the height of the glacio-marine outwash gravels), however it is possible that these units were subsequently abraded to their present height during sea level regression. A maximum estimate on the former sea level is ca. 152 m since a prominent glacio-fluvial outwash terrace slopes from this height towards sea level across the eastern flank of the bedrock knoll 1 km upvalley.

The youngest raised marine deposits observed were a sequence of Holocene fan deltas built out into Kennedy Channel ca. 2 km downvalley to the east. The uppermost Holocene shoreline observed occurs on the north side of the Ooqueah River, where a beach terrace rises to 85 m above sea level. A stream incision into this terrace has exposed foreset beds in which complete bivalves of *Hiatella arctica, Mya truncata* and *Portlandia (Yoldia) arctica* were collected at 66 m above sea level.

Location	Deposit	Dated Material	^{14}C Date	Lab. No.	Amino Acid Analyses Allo:Iso (Total)	Allo:Iso (Free)	Lab. No.	Aspartic Acid	Lab. No.	Age Est. BP
1. Beethoven Valley*	Proglacial delta 175 m a.s.l.	Fragmented Shells	29,670 ± 830/930	DIC-738	0.073 0.040	0.28 0.22		0.386	UA 646	>35,000
2. Daly River*	Proglacial delta 105 m a.s.l.	Fragmented Shells	27,950 ± 5400	St.4325	0.040 0.050} 0.054}	0.23 0.25		0.331	UA 647	>35,000
3. Ooqueah River	Outwash gravel/till contact	Whole Shells			0.026 0.031 0.046	0.25 0.27 0.30	AAL-981A B,C	0.215 0.200	UA 649 UA 678	>35,000 >35,000
	Foreset beds of 85 m shoreline	Whole Shells	7960 ± 150	GSC-2843				0.072	UA 676	Holocene
4. Seegloo River	Subtill marine deposit	Whole Shells	40,350 ± 750	SI-4028				0.251	UA 649	>35,000
	Indurated marine till	Whole Shells						0.151	UA 680	>35,000
	Supratill, indurated marine silts	Whole Shells	>39,000	SI-4030 C and D	0.020 0.020 0.019	0.17 0.11± 0.18	AAL-981A B,C	0.159	UA 681	>35,000
5. Panikpah River	Fossiliferous kames (~220 m a.s.l.)	Fragmented Shells						0.225	UA 679	>35,000
	Fossiliferous till on bedrock knoll, ~165 m a.s.l.	Fragmented Shells						0.187	UA 650	>35,000
	Outer surface of valley train 100 m a.s.l. beach	Fragmented Shells	12,360 ± 75	SI-4027	0.083 0.017 0.026} 0.032}	ND ND ND	AAL-982A B,C	0.162	UA 677	~Holocene (AAL-982) >35,000 (UA 677)

* For complete list of dates from northeastern Judge Daly Promontory see England *et al.* 1978.

Chronology

The racemization of amino acids was used to provide an age estimate on the whole valves of *Hiatella arctica* collected along the contact between the fossiliferous till and the outwash deposits (Fig. 9). This shell sample (AAL-981, Table 1) provided a higher, and hence older, ratio of D-alloisoleucine to L-isoleucine (allo:iso ratio) in both the free and total fractions than did the Seegloo River shell sample, which also gave innermost ^{14}C dates of >39,000 B.P. (AAL-980 and SI-4030 C & D, respectively, Table 1). The racemization of aspartic acid for the same sample also suggests ages >35,000 B.P. (UA 648 and 678, Table 1). It should be pointed out here that both the allo-iso and aspartic acid ratios provide age estimates only on a relative scale and that the respective values are not age equivalent between the two systems due to their different rates of racemization, even under similar diagenetic histories (Rutter et al. 1979).

A sample of *Mya truncata* from the foreset beds of the 85 m Holocene terrace dated 7960 ± 150 B.P. (GSC-2843). Hence this date corresponds to the emergence of the 85 m shoreline in this locality. It is of interest that the uppermost, morphologically prominent raised beaches in the Seegloo and Panikpah river valleys occur at very similar elevations. This date on the 85 m shoreline in the lower Ooqueah river valley compares closely with a previous date of 8200 ± 260 B.P. (DIC-549) on a 90 m delta along the lower Daly River 13 km to the northeast (England & Bradley 1978).

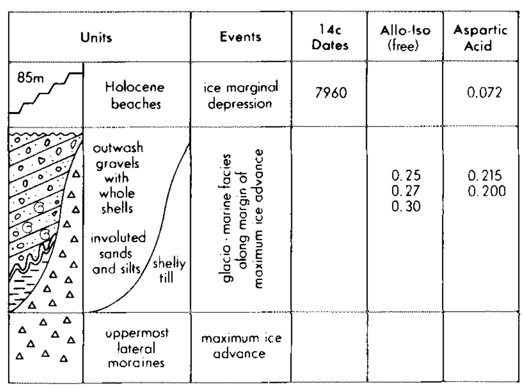

Fig. 9. Composite diagram of the glacial and marine stratigraphy in the lower Ooqueah river valley. Corresponding ^{14}C dates and amino acid ratios are shown on the right (see also the above Table).

Panikpah River

Weathering zones and moraines

The former advance of the Greenland Ice Sheet across the summit of the Tertiary ridge (ca. 440 m above sea level), three kilometers to the north of the lower Panikpah River (site B, Fig. 2), has already been discussed. Similar meltwater channels with crystalline erratics also occur on the western flank of the Tertiary ridge to the south of the Panikpah River suggesting a former extent of the Greenland Ice Sheet to >440 m above sea level in this locality as well (site F, Fig. 2). Bordering the north side of the same ridge, ca. 1 km inland from Kennedy Channel, are fossiliferous kame terrace remnants composed of sedimentary clasts which extend to ca. 220 m above sea level. These kame terraces are considered to represent the uppermost Ellesmere Island ice advance (Zone II) above which one encounters weathered bedrock and colluvium. They mark a former ice thickness of ca. 180 m in the lower valley. The somewhat anomalous occurrence of shell fragments in the uppermost kame terraces suggests either erosion and redeposition of marine sediments by the advancing ice or the upward transferal of contemporaneous marine sediments by basal accretion beneath a floating ice margin.

Downvalley, similar glacial erratics and a discontinuous fossiliferous till extend across the summit of an isolated bedrock knoll at 165 m above sea level immediately above Kennedy Channel. The knoll is composed of thick-bedded, competent Ordovician limestones (Christie 1974) which are oxidized and pitted by solution weathering, and resistant quartzite erratics have orange-brown oxidation rinds. Roche moutonnées and grooves indicate a former ice flow direction from SSW to NNE as the ice spread out radially into Kennedy Channel. Where the adjacent fossiliferous till is being eroded from the bedrock, striations are being exhumed which are otherwise absent on exposed bedrock surfaces. This suggests that caution should be taken in interpreting apparently fresh striations as clear evidence of late Wisconsin/Würm ice coverage. In the lower Panikpah river valley samples of fragmented shells were collected for amino acid analyses from both the uppermost kame terraces and the till on the bedrock knoll.

During the maximum ice advance down the Panikpah river valley moraines were formed around the base of the northernmost Tertiary ridge (site B, Fig. 2) where they cross-cut the zone of Greenland erratics. A prominent moraine skirts the southeastern flank of this ridge at an estimated height of 200 m above sea level below which are kame deltas at ca. 130 and 115 m above sea level overlooking Kennedy Channel. Whether these kame deltas formed in a marine environment is not known. Other moraines occur at ca. 235 m above sea level on the west side of the ridge representing diffluent ice flowing northward through a deep fault which leads to the Seegloo foreland. Recession from this latter ice margin formed kame terraces at ca. 175 m above sea level which border the southern end of the 162 m shoreline. The youngest glacial deposition apparent in the lower Panikpah river valley is represented by a prominent valley train which abruptly rises and terminates against what must have been a former ice margin ca. 4 km inland from Kennedy Channel (Fig. 2).

Marine stratigraphy

No estimate can presently be made on the former relative sea level during the recession of the maximum Ellesmere Island ice from the lower Panikpah river valley. Extensive surficial deposits occur, however, most of these are highly dissected and non-fossiliferous, and insufficient time was available for differentiating the complex facies changes present. In the col west of the southernmost Tertiary ridge (site F, Fig. 2), prominent dead-ice topography occurs immediately above the aforementioned valley train whose outwash surface has aggraded over non-fossiliferous silts and sands to ca. 115 to 120 m above sea level. Downvalley, on both sides of the Panikpah River, are complex sections exposing a basal till overlain by aggradational sequences of involuted sands, bedded silts and outwash gravels which are in turn capped with thin diamictons overlain with more silts and gravels (Fig. 10). No apparent weathering breaks were observed in these sections and they are presently interpreted as representing the initial advance of the maximum Ellesmere Island ice (basal till) overlain by a proglacial outwash sequence which appears to be interrupted by a readvance or at least local sediment flows in the upper section. A similar section appears to extend beneath the valley train on the north side of the Panikpah River. Fig. 10 is a provisional composite diagram of the stratigraphy in the lower Panikpah river valley.

The aforementioned valley train on the north side of the Panikpah River (Fig. 2) forms a highly abraded, rolling terrace which descends over 3 km to ca. 102 m above sea level at its seaward edge. Discontinuous beach ridges are superimposed over its outer edge up to ca. 100 m above sea level and fragmented shells in this locality were collected at the surface where active cryoturbation favors their exposure. A prominent sequence of raised beaches begins immediately below this point at 86 m above sea level and these are considered equivalent to the uppermost well-preserved beaches in the Seegloo and Ooqueah river valleys which occur at similar elevations (±2 m). In other localities additional fossiliferous units, apparently of Holocene age, have been superimposed over the flanks of the valley train up to at least 86 m above sea level.

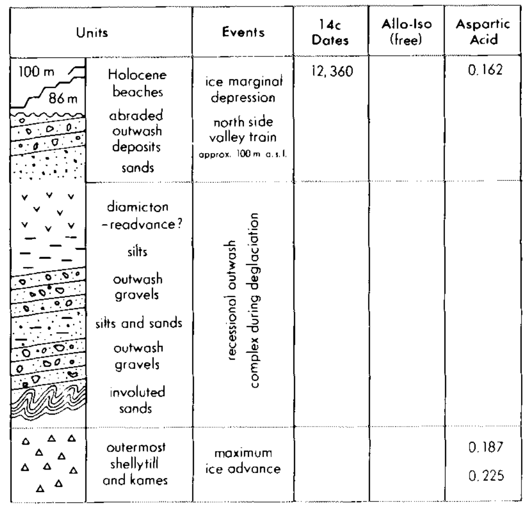

Fig. 10. Composite diagram of the glacial and marine stratigraphy in the lower Panikpah river valley. Corresponding ^{14}C dates and amino acid ratios are shown on the right.

Chronology

A provisional composite diagram of the stratigraphy of the lower Panikpah river valley together with its available age assessments is presented in Fig. 10. Fragmented shells collected from the uppermost kames (220 m above sea level) along the south side of the valley provided an aspartic acid ratio indicating an age of >35,000 B.P. The aspartic acid ratio for this sample is in fact very similar to those obtained on the whole shells collected from the ice-contact outwash in the lower Ooqueah river valley (samples UA 679 and UA 649/678, respectively, Table 1). Downvalley from these kames additional shell fragments collected from the fossiliferous till on the 165 m bedrock knoll provided a somewhat younger aspartic acid ratio but nonetheless an age estimate of >35,000 B.P. (UA 650, Table 1).

The fragmented shells collected amongst the 100 m raised beaches on the outer edge of the valley train provided a ^{14}C date of 12,360 ± 175 B.P. (SI-4027, Table 1). The racemization of D-alloisoleucine to L-isoleucine (free ratio) for the same sample (AAL-982, Table 1) also suggested a slightly pre-Holocene age and clearly distinguished it from the ratios of the >35,000 B.P. samples (G. H. Miller, pers. comm. 1979). On the other hand, the allo:iso (total) ratios for sample AAL-982 are in fact quite similar to those values listed for the other 'old' dates in Table 1. Finally, the aspartic acid ratio for this sample (UA 677, Table 1) suggests that it is also much older than ca. 12,000 B.P. since its ratio is even greater than that obtained on shells ^{14}C dated at >39,000 B.P. (SI-4030 C & D, and UA 681, Table 1) and it is substantially higher than the ratio obtained on *in situ* Holocene shells dated 7960 ± 150 B.P. (GSC-2843 and UA 676, Table 1). Consequently, the conflicting amino acid results suggest that the ^{14}C date of 12,360 ± 175 B.P. may represent a mixture of Holocene and 'old' shells and verification of this date is clearly required. In addition, the stratigraphic relationship between this surface shell sample and the valley train is not yet certain. It is possible that the establishment of the valley train is >35,000 B.P. and that it was simply abraded to its present height (ca. 102 m above sea level) by streams grading into the ca. 100 m shoreline which was superimposed on its outer edge at 12,000 B.P. (assuming that the 12,000 B.P. date is correct).

In comparison to the 12,360 B.P. date the remaining six ^{14}C dates on initial Holocene emergence along western Kennedy Channel all date between 7910 ± 145 and 8380 ± 150 B.P. (DIC-545 and 737, respectively, England & Bradley 1978). If the 12,360 B.P. date is correct it is of interest that only ca. 15 m of emergence occurred between this time and 7960 ± 150 B.P. (GSC-2843, 85 m sea level, Ooqueah river valley). This brings into question the glacio-isostatic significance of such a small initial ice load change in the Panikpah river valley, particularly given the sizeable instantaneous sea level changes which are involved in the geophysical modelling of initial ice recession (Clark 1976; Clark et al. 1978). This estimate on the initial rate of emergence (15 m in ca. 4400 radiocarbon years) requires the comparison of the two finite dates from the Ooqueah and Panikpah river valleys, however, this is considered reasonable since previously constructed isobases for this area parallel the coastline (England 1976a). This orientation of the isobases is reinforced by a subsequent date of 8200 ± 260 B.P. (DIC-549, England & Bradley 1978) from a 90 m delta in the lower Daly river valley (Fig. 1), which compares closely with the Ooqueah river valley emergence (this paper). If one extends a line southwestwards through these points (the Daly and Ooqueah river mouths) it passes through the lower Seegloo and Panikpah river mouths. Such an isobase pattern also appears consistent with the uniform upper elevations of the prominent Holocene beaches in the Ooqueah, Seegloo and Panikpah river valleys (previously discussed) at ca. 85 m above sea level.

Summary

Observations on the mountains surrounding the Ooqueah, Seegloo and Panikpah river valleys confirm the presence of the prominent weathering zones previously described on northeastern Judge Daly Promontory (England & Bradley 1978). The oldest and uppermost zone (herein referred to as Zone IIIb) is characterized by a deeply weathered, erratic-free surface which shows no evidence of former glaciation. The upper margin of Zone IIIa cross-cuts the unglaciated summits at ca. 470 m above sea level (minimum estimate) and it is characterized by sparse granite, gneiss and quartzite boulders previously deposited by the northwest Greenland Ice Sheet. These erratics occur amongst deeply weathered bedrock and extensive colluvium, which suggests that their deposition is of great antiquity. The upper surface of Zone IIIa in this locality (ca. 470 m above sea level) is considerably lower than its uppermost surface on northern Judge Daly Promontory where Greenland erratics extend to >870 m above sea level 70 km to the northeast (England & Bradley 1978). This suggests that the maximum northwest Greenland ice advance was thickest in the direction of the major ice source of Petermann Fiord (Fig. 1).

The upper margin of Zone II is marked by lateral moraines formed by the maximum Ellesmere Island ice advance which cross-cuts the zone of sparse Greenland erratics. These moraines form a prominent morpho-stratigraphic boundary at ca. 220–350 m above sea level in the lower Ooqueah, Seegloo and Panikpah river valleys. It is likely that these moraines are the product of the same glaciation which formed the ice shelf moraines to the north, since these different moraine systems all occur at similar elevations and exhibit similar rock weathering and prominent cross-cutting relationships at the Zone II/IIIa boundary. Chronological evidence, discussed below, also indicates that these moraines are of similar age. Finally, Zone I is reserved for the area formerly covered by late Wisconsin/Würm ice and its subsequent postglacial marine transgression. With the possible exception of the ice margin which bordered the valley train along the Panikpah River, no Zone I glacial deposits were observed in these lower valleys.

Fig. 11 is a provisional, composite diagram of the glacial and marine stratigraphy in the Ooqueah, Seegloo and Panikpah river valleys. This reconstruction, together with its associated ^{14}C dates and amino acid ratios, can be compared with Fig. 12, which is a composite diagram based on our previous field work to the north (England & Bradley 1978; England et al. 1978). In the lower Seegloo river valley the maximum Ellesmere Island ice advance is stratigraphically bracketed by subtill and supratill, *in situ* marine deposits ^{14}C dated at $40,350 \pm 750$ B.P. (SI-4028) and >39,000 B.P. (SI-4030 C & D, respectively). The racemization of both D-alloisoleucine to L-isoleucine and aspartic acid in the same samples confirm these radiometrically 'old' dates with ratios indicating ages >35,000 B.P. In the lower Ooqueah river valley whole shells collected along the contact between the till and outwash gravels of the equivalent ice advance provide amino acid ratios (allo:iso free) which are the same as those from the ice shelf moraines and outwash terraces on northeastern Judge Daly Promontory and which also have minimum ^{14}C dates in the 28,000–30,000 B.P. range (Figs. 11 and 12, and England et al. 1978). However, whereas the allo:iso ratios associated with the outermost ice advance in the Ooqueah river valley and northeastern Judge Daly Promontory

Units		Events	14c Dates	Allo-Iso (free)	Aspartic Acid
85m	Prominent Holocene beaches to approx. 85m max. 100m	ice marginal depression	7,960 12,360?	N.D.	0.072 0.162
	indurated marine silts with shells	deglaciation from maximum ice advance and formation 162m shoreline	>39,000	0.17 0.11 ± 0.18	0.159
	indurated marine till with shells	max. ice float-ing in Kennedy Channel			0.151
	outwash sands and gravels with shells till	glacio-marine outwash along maximum ice margin		0.25 0.27 0.30	0.215 0.200
	fossiliferous till (160m) and kames (220m a.s.l.)	maximum ice advance to Kennedy Channel			0.187 0.225
	subtill bedded silts and sands	marine transgression overridden by maximum ice advance	40,350		0.251

Fig. 11. Composite diagram of the glacial and marine stratigraphy for the Ooqueah, Seegloo and Panikpah river valleys. Corresponding ^{14}C dates and amino acid ratios are shown on the right.

are very similar this is not the case for the aspartic acid ratios which are higher (older) in the latter area. Given the proximity of these two areas it is unlikely that differing diagenetic histories can explain this discrepancy hence it is possible that the northeastern Judge Daly Promontory ice retreated earlier. Since both areas have similar weathering zones and pre-Holocene shorelines it is presently concluded that they were both affected by the same glacial episode.

In addition to these old dates on *in situ* shells it is apparent that the recession of the maximum Ellesmere Island ice margin from the Seegloo river valley is associated with a distinct, pre-Holocene shoreline at 162 m above sea level. This shoreline closely approximates the previous estimate of a relative sea level at ca. 175 m above sea level associated with the former ice shelves on northeastern Judge Daly Promontory. Stratigraphic evidence for shorelines at similar elevations in the Ooqueah and Panikpah river valleys has not yet been found; however, aggradational outwash sequences extend to >100 m above sea level. No further evidence of former ice shelf moraines was found in the confined lower parts of these valleys, since the ratio of

Units		Events	14c Dates	Allo-Iso (free)	Aspartic Acid
90 m	Holocene beaches	ice marginal depression	8200 7910		
105m 175m	marine deltas	deglaciation from maximum ice advance	27,950 29,670	0.23 0.25 0.18 0.20 0.28 0.22	0.331 0.386
	shelly tills	ice shelf moraine approx. 200 m	28,610 23,110	0.28	
	subtill bedded sands	preglacial sands with Dryas octopetala	>25,000		

Fig. 12. Composite diagram of the glacial and marine stratigraphy based on previous field work (England et al. 1978) along the lower Daly River and Beethoven Valley, 20–40 km to the northeast on Judge Daly Promontory. Corresponding ^{14}C dates and amino acid ratios are shown on the right.

maximum ice thickness (ca. 220–350 m) to sea level depth (ca. 160 m) was apparently too great to allow flotation of these ice margins. Beyond these confined valleys, however, it is most likely that these outlet glaciers were forced to float as they spread out and thinned in the deep water of Kennedy Channel. The distinctive fossiliferous marine till in the lower Seegloo foreland supports this contention.

In all three valleys there is no evidence of late Wisconsin/Würm ice of either Greenland or Ellesmere Island origin overriding these older glacial and marine deposits. The one possible exception is that late Wisconsin/Würm ice constructed the prominent valley train in the Panikpah river valley; however, this requires stratigraphic and radiometric clarification. A prominent moraine system, evident on air photographs, extends along the entrances to the Ooqueah, Seegloo and Panikpah river valleys ca. 15 km inland (Fig. 2) and this may represent the late Wisconsin/Würm ice margin formed by the Judge Daly Promontory ice cap. Beyond this former ice margin one immediately encounters a more weathered terrain which is co-extensive with, and similar in appearance to, the Zone II surfaces in the lower valleys.

Since there is no evidence that late Wisconsin/Würm ice inundated these lower valleys it is concluded that the establishment and subsequent emergence of their Holocene shorelines was the product of glacio-isostatic adjustments beyond both the northeast Ellesmere Island and northwest Greenland ice sheet margins at this time. Hence these recent observations reinforce similar arguments for the existence of an ice-free corridor extending along western Kennedy Channel during late Wisconsin/Würm time (England 1976a 1978; England & Bradley 1978). The earliest recorded emergence associated with the last glaciation in this area may relate to the 100 m shoreline presently dated 12,360 ± 75 B.P. (SI-4027). However, this initial emergence requires radiometric verification and, in addition, it represents only a very minor glacio-isostatic adjustment since the relative sea level along this coastline was still 86 m above sea level at 7960 ± 150 B.P. (GSC-2843). This latter elevation also coincides with the uppermost limit of prominent raised beaches in the Ooqueah, Seegloo and Panikpah river valleys. Presumably the rapid period of postglacial emergence, equivalent to widespread glacio-isostatic unloading, began ca. 8000 B.P. with an earlier, questionable phase of minor emergence in the ice-free corridor beginning ca. 12,400 B.P. The one exception to this on northeastern Ellesmere Island comes from Alert (Fig. 1), 180 km to the north of the Panikpah River, where shells associated with a 120 m shoreline dated 10,100 ± 210 B.P. (GSC-1815, England 1976a, 1978).

In addition, Weidick (1978) has reported shell dates as old as 9180 ± 150 B.P. (GGU-226441) from central Hall Land, northwest Greenland. This sample, collected at 85 m above sea level, is presently considered to represent a sea level regression from the local marine limit (110 m above sea level), which in turn is estimated to date ca. 9500 to 10,000 B.P. (Weidick 1978). Alternatively this sample could be the product of a transgression to a younger marine limit, assuming that such sites remained ice-free during the last glaciation. At present the majority of dates on initial postglacial emergence along northeastern Ellesmere Island range from ca. 8100 to 8400 B.P. (England & Bradley 1978) and hence this interval is presently considered to represent the initial period of glacio-isostatic unloading as well.

Conclusion

Over twenty-five ^{14}C dates and amino acid age estimates are now available on the glacial and marine stratigraphy covering a 70 km section of western Kennedy Channel. These dates, including those on *in situ* subtill and supratill marine deposits, consistently demonstrate that the maximum northeastern Ellesmere Island ice advance, and its subsequent recession, occurred >35,000 B.P. This ice margin is clearly associated with former relative sea levels at 162 and ca. 175 m above sea level, which are >50 m above the uppermost Holocene shorelines observed on Judge Daly Promontory. There is no evidence in this area to support the previous speculations that the northeast Ellesmere Island and northwest Greenland ice sheets were confluent during the late Wisconsin/Würm glaciation (Blake 1970; Dansgaard et al. 1973; Hughes et al. 1977). To the contrary, this most recent data reinforces the conclusions of previous researchers in the region who have presented stratigraphic and chronologic evidence for limited ice extent during the last glaciation (Koch 1928; Davies et al. 1963; Tedrow 1970; England 1974, 1976b, 1978; Weidick 1976; England & Bradley 1978). In addition, not only were there extensive ice-free areas along northeastern Ellesmere Island during late Wisconsin/Würm time, but the preservation of several pre-Holocene glaciated surfaces (Zones II and IIIa) and an uppermost unglaciated one (Zone IIIb) in this area also strengthens the arguments for refugia formerly based on entomological and botanical evidence from northern Ellesmere Island (Leech 1966 and Brassard 1970, respectively).

Collectively, these various field observations corroborate with paleoclimate theories which argue for increased aridity, and hence reduced ice extent, in high latitudes during the last glaciation (Tanner 1965; Lamb & Woodroffe 1970; Williams et al. 1974; Boulton 1979). Similar evidence of high arctic aridity has been suggested from isotopic studies of the Camp Century and Devon Island ice core records where increased cold (greater continentality) begins after ca. 60,000 B.P. (Dansgaard et al. 1970; Patterson et al. 1977). This aridity in the high arctic likely resulted from the buildup of the late Wisconsin/Würm Laurentide Ice Sheet to the south (Lamb & Woodroffe 1970) coupled with corresponding changes in the atmosphere/ocean circulation in the North Atlantic/Baffin Bay region (Johnson & McClure 1976).

At present we find no evidence that a major ice ridge ever existed over Kennedy Channel joining the northwest Greenland and northeast Ellesmere Island ice sheets. In fact, the uppermost profile of Greenland erratics along eastern Judge

Daly Promontory, which marks the oldest glacial event in this area (Zone IIIa), declines sharply to the south away from the important present day outlet of the Petermann Glacier. This profile of uppermost erratics suggests that the maximum extent of the northwest Greenland Ice Sheet may have been more irregular and directly related to major outlet sources than was previously recognized. As a result, our research does not support the conclusion of Raynaud & Lebel (1979) that the northwest Greenland Ice Sheet was ca. 800 m thicker than today during late Wisconsin/Würm time.

The occurrence of Holocene raised marine deposits (up to 85–100 m above sea level), immediately downvalley from higher shorelines (162–175 m above sea level) and moraines both dated >35,000 B.P., clearly demonstrates the presence of an ice marginal depression (Walcott 1970) along western Kennedy Channel during the late Wisconsin/Würm glaciation. Due to the limited size of the Judge Daly Promontory ice cap at this time it is apparent that much of this postglacial emergence resulted from the recession of the bordering northwest Greenland Ice Sheet, which presumably terminated in Kennedy Channel during the last glaciation (Weidick 1972; Patterson 1977). Hence this postglacial emergence along western Kennedy Channel represents unrestrained rebound in an ice-free corridor and it is likely that its initiation also chronologically reflects the initial recession of the northwest Greenland Ice Sheet (England 1976a; England & Bradley 1978). Continuing research on the late Quaternary stratigraphy and glacio-isostasy in this region will help clarify the past activity of the Greenland and Ellesmere Island ice sheets. And with improved chronologies, better models of high latitude ice sheet dynamics and their related paleoclimatic controls can be developed.

Postscript in response to comments made by referees

This paper has concentrated on new data from western Kennedy Channel which points to reduced late Wisconsin/Würm ice extent in high latitudes; however, it should be noted that this perspective is sharply contrasted by observations on east-central Ellesmere Island and the Carey Islands. In these localities fresh glacial sculpture and erratics up to >500 m above sea level have been interpreted as evidence for expansive, non-local ice of late Wisconsin/Würm age flowing southward from Kane Basin through Smith Sound (Blake 1977a and b). This ice advance presumably involved both the Humboldt Glacier (northwest Greenland) and the numerous valley glaciers issuing from east-central Ellesmere Island. Although the certainty of the late Wisconsin/Würm age attributed to this glacial sculpture has been previously debated (Boulton 1979) there are additional considerations which are not yet fully accommodated by this model. Most noteable is the preservation of several deeply weathered till zones, representing multiple glaciations on outermost Inglefield Land, northwest Greenland, which have remained undisturbed despite their present day proximity to the Humboldt Glacier to the north and the main Greenland Ice Sheet to the east (Tedrow 1970). The question remains how this low plateau (ca. 200 to 450 m above sea level) escaped erosion by the Greenland Ice Sheet while the latter ice severely sculptured far more distant and higher portions of east-central Ellesmere Island involving an ice thickness of at least 1200 m at the entrance to Smith Sound (Blake 1977b)?

An additional problem facing this model of expansive late Wisconsin/Würm ice is presented by 'old' radiometric dates on marine deposits along the Greenland coast adjacent to northern Baffin Bay. In Orlik Fiord, northwest Greenland, Weidick (1976, 1978) reports interglacial marine deposits containing shells of *Chlamys islandicus* dated >33,000 and >37,000 B.P. (GSC-2426 and 2497, respectively) which are superimposed by Holocene marine units which extend to 45 ± 5 m above sea level. These interglacial marine deposits do not appear to have been overriden by glacier ice although they occur in the likely path of any ice advance which would extend out to the Carey Islands. Additionally, on the Carey Islands and Saunders Island 'old' radiometric dates have also been obtained on both *in situ* raised marine deposits and marine tills which are superimposed by Holocene marine transgressions (Davies et al. 1963; Blake 1977a). However, Blake (1975, 1976) does describe non-fossiliferous diamictons (0.5 to 1.5 m thick) which are till-like in appearance separating the 'old' marine units from the upper Holocene deposits on the Carey Islands and Saunders Island. Although striations are present on the summits of the Carey Islands many of these rock surfaces exhibit considerable, subsequent alteration by frost shattering (Fig. 90.4 in Blake 1977a). Also it is not known to what extent these striations have been exhumed from terrain older than the last glaciation, as occurs along western Kennedy Channel (this paper). These considerations, taken together with the 'old' radiometric dates, suggest that the earlier conclusions asserting deglaciation of the Carey Islands and Saunders Island >32,000 B.P. (Davies et al. 1963; Bendix-Almgreen et al. 1967) provide a reasonable alternative to the hypothesis of more recent, non-local ice coverage of these sites. As well, expansive late Wisconsin/Würm ice flowing southward from Kane Basin and Smith Sound is problematic in terms of the limited Holocene emergence presently reported from the Carey Islands (minimum estimate of 25–30 m above sea level, Blake 1977a); Saunders Island (25 m above sea level, Davies et al. 1963); Orlik Fiord (45±5 m above sea level, Weidick 1978); and Inglefield Land (70 to ca. 80 m above sea level, Nichols 1969). However, it should be noted that beaches of unknown age do extend to 80 m above sea level on the Carey Islands (Bendix-Almgreen et al. 1967; Blake 1975, 1977a) and to ca. 40 m above sea level on Saunders Island (Davies et al. 1963).

Finally, it is not certain whether the fresh glacial sculpture observed along the east-central coast of Ellesmere Island is the product of an expansive Greenland Ice Sheet or simply local ice. This area today is characterized by tidewater glaciers along ca. 30% of its coastline (Koerner 1979) and the local ice caps support one of the lowest equilibrium line altitudes in the Canadian arctic (300 m above sea level, Miller et al. 1975). This favorable glacio-climatic regime clearly reflects the presence of increased cyclogenesis and orographic precipitation occasioned by the 'North Water', a major polynya in northern Baffin Bay (Koerner 1979). The contemporary influence of the 'North Water' on the glaciers of northern Baffin Bay has been previously demonstrated by Koerner (1966) and Mock (1968), who show substantial increases in snow accumulation on southeastern Devon Island and the Thule Peninsula, respectively. More recently this glacio-climatic influence of Baffin Bay has been demonstrated to extend back into the early Holocene as shown by the asymmetric profiles on the ice caps of central Ellesmere and Devon islands which have disproportionately thickened in their eastern sectors (Koerner 1977). Consequently, it seems plausible that northern Baffin Bay could have generated such increased accumulation during previous glacial regimes in this area and this might explain the glacially sculptured terrain described by Blake (1977b). Collectively these previous considerations by no means imply that a single solution is necessary for the glacial histories of northeastern and east-central Ellesmere Island. Assuming that these two models are not mutually exclusive then these considerations can be accommodated. On the basis of the existing evidence it is possible that these two areas have experienced such dissimilarities in the past as suggested by their differing glacio-climatic regimes today. However, it seems unlikely that the radial outflow from the more massive Greenland Ice Sheet during the late Wisconsin/Würm glaciation could produce such a differential response to the north and south as these two models from Ellesmere Island presently suggest.

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References

Bendix-Almgreen, S. E., Fristrup, B. & Nichols, R. H. 1967: Notes on the geology and geomorphology of the Carey Øer, North-West Greenland. *Medd. Grønland 164,* 1–18.

Blake, W., Jr. 1970: Studies of glacial history in Arctic Canada. I. Pumice, radiocarbon dates and differential postglacial uplift in the eastern Queen Elizabeth Islands. *Can. J. Earth Sci. 7,* 634–664.

Blake, W., Jr. 1975: Glacial geological investigations in northwestern Greenland. *Geol. Surv. Can., Pap. 75–1A,* 435–439.

Blake, W., Jr. 1976: Glacier ice cores, climate, and chronology around northern Baffin Bay. *Am. Quat. Assoc. Abstr.* (4th Biennial mtg.), 20–21. Arizona State University, Tempe.

Blake, W., Jr. 1977a: Radiocarbon age determinations from the Carey Islands, northwest Greenland. *Geol. Surv. Can., Pap. 77–1A,* 445–454.

Blake, W., Jr. 1977b: Glacial sculpture along the east-central coast of Ellesmere Island, arctic archipelago. *Geol. Surv. Can., Pap. 77–1C,* 107–115.

Boulton, G. S. 1979: A model of Weichselian glacier variation in the North Atlantic region. *Boreas 8,* 373–395.

Brassard, G. R. 1971: The mosses of northern Ellesmere

Island, Arctic Canada. Ecology and phytogeography, with an analysis for the Queen Elizabeth Islands. *Bryologist 74,* 234–281.

Canadian Hydrographic Service, 1973: Chart No. 430, Kane Basin to Lincoln Sea. *Marine Science Directorate,* Dept. of Environment, Ottawa.

Christie, R. L. 1967: Reconnaissance of the surficial geology of northeastern Ellesmere Island, Arctic Archipelago. *Geol. Surv. Can., Bull. 138.* 50 pp.

Christie, R. L. 1974: Northeastern Ellesmere Island: Lake Hazen region and Judge Daly Promontory. *Geol. Surv. Can., Pap. 74–1A,* 297–299.

Clark, J. A. 1976: Greenland's rapid postglacial emergence: a result of ice-water gravitational attraction. *Geology 4,* 310–312.

Clark, J. A., Farrell, W. A. & Peltier, W. R. 1978: Global changes in postglacial sea level: a numerical calculation. *Quat. Res. 9,* 265–287.

Dansgaard, W., Johnsen, S. J., Clausen, H. B. & Langway, C. C., Jr. 1970: Ice cores and paleoclimatology. *In* Olsson, I. U. (ed.): *Radiocarbon Variations and Absolute Chronology,* 337–348. John Wiley & Sons Inc., New York.

Dansgaard, W., Johnsen, S. J., Clausen, H. B. & Gundestrup, N. 1973: Stable isotope glaciology. *Medd. Grønland 197:2.*

Davies, W. E., Krinsley, D. B. & Nicol, A. H. 1963: Geology of the North Star Bugt area, northwest Greenland. *Medd. Grønland 162,* 1–68.

England, J. 1974: Advance of the Greenland Ice Sheet onto northeastern Ellesmere Island. *Nature 252,* 373–375.

England, J. 1976a: Postglacial isobases and uplift curves from the Canadian and Greenland High Arctic. *Arctic and Alpine Res. 8,* 61–78.

England, J. 1976b: Late Quaternary glaciation of the eastern Queen Elizabeth Islands, N.W.T., Canada: alternative models. *Quat. Res. 6,* 185–202.

England, J. 1978: The glacial geology of northeastern Ellesmere Island, N.W.T., Canada. *Can. J. Earth Sci. 15,* 603–617.

England, J. & Bradley, R. S. 1978: Past glacial activity in the Canadian High Arctic. *Science 200,* 265–270.

England, J., Bradley, R. S. & Miller, G. H. 1978: Former ice shelves in the Canadian High Arctic. *J. Glaciol. 20,* 393–404.

Hughes, T., Denton, G. & Grosswald, M. G. 1977: Was there a late-Würm Arctic Ice Sheet? *Nature 266,* 596–602.

Johnson, R. G. & McClure, B. T. 1976: A model for Northern Hemisphere continental ice sheet variation. *Quat. Res. 6,* 325–353.

Koch, L. 1928: Contributions to the glaciology of north Greenland. *Medd. Grønland 15.*

Koerner, R. M. 1966: Accumulation on the Devon Island ice cap, Northwest Territories, Canada. *J. Glaciol. 6,* 383-392.

Koerner, R. M. 1977: Ice thickness measurements and their implications with respect to past and present ice volumes in the Canadian High Arctic ice caps. *Can. J. Earth Sci. 14,* 2697–2705.

Koerner, R. M. 1979: Accumulation, ablation, and oxygen isotope variations on the Queen Elizabeth Islands ice caps, Canada. *J. Glaciol. 22,* 25–44.

Lamb, H. H. & Woodroffe, A. 1970: Atmospheric circulation during the last Ice Age. *Quat. Res. 1,* 29–58.

Leech, R. E. 1966: The spiders (Areneida) of Hazen Camp, 81°49'N, 71°18'W. *Quaest. Entomol. 2,* 153–212.

Miller, G. H., Bradley, R. S. & Andrews, J. T. 1975: The glaciation level and lowest equilibrium line altitude in the High Canadian Arctic: maps and climatic interpretation. *Arctic and Alpine Res. 7,* 155–168.

Mock, S. J. 1968: Snow accumulation studies on the Thule Peninsula, Greenland. *J. Glaciol. 7,* 59–76.

Nichols, R. L. 1969: Geomorphology of Inglefield Land, North Greenland. *Medd. Grønland 188.* 109 pp.

Patterson, W. S. B. 1977: Extent of the late-Wisconsin glaciation in northwest Greenland and northern Ellesmere Island: a review of the glaciological and geological evidence. *Quat. Res. 8,* 180–190.

Patterson, W. S. B., Koerner, R. M., Fisher, D., Johnsen, S. J., Dansgaard, W., Bucher, P. & Oescheger, H. 1977: An oxygen-isotope climatic record from the Devon Island ice cap, arctic Canada. *Nature 266,* 508–511.

Raynaud, D. & Lebel, B. 1979: Total gas content and surface elevation of polar ice sheets. *Nature 281,* 289–291.

Rutter, N. W., Crawford, R. J. & Hamilton, R. D., 1979: Dating methods of Pleistocene deposits and their problems: IV Amino Acid racemization dating. *Geoscience Canada 6,* 122–128.

Tanner, W. F. 1965: Cause and development of an ice age. *J. Glaciol. 73,* 413–430.

Tedrow, J. C. F. 1970: Soil investigations in Inglefield Land, Greenland. *Medd. Grønland 188.* 93 pp.

Walcott, R. I. 1970: Flexural rigidity, thickness and viscosity of the lithosphere. *J. Geophys. Res. 75,* 3941–3954.

Weidick, A. 1972: Holocene shore-lines and glacial stages in Greenland – an attempt at correlation. *Rapp. Grønlands Geol. Unders. 41.* 39 pp.

Weidick, A. 1976: Glaciations of northern Greenland – new evidence. *Polarforschung 46,* 26–33.

Weidick, A. 1978: Comments on radiocarbon dates from Northern Greenland made during 1977. *Rapp. Grønlands Geol. Unders. 90,* 124–128.

Williams, J., Barry, R. G. & Washington, W. M. 1974: Simulation of the atmospheric circulation using the NCAR global circulation model with Ice Age boundary conditions. *J. Appl. Meteorol. 13,* 305–317.