

## Article

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NORDQUA 86 participants

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# THE BAFFIN BAY REGION DURING THE LAST INTERGLACIATION: EVIDENCE FROM NORTHWEST GREENLAND

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**ABSTRACT** Coastal sections in the Thule area, northwest Greenland, provide a record of last interglacial glacial and oceanographic events on the northern perimeter of Baffin Bay. The record is dated by a combination of thermoluminescence and  $^{14}\text{C}$  dating; local and regional correlation is provided by amino acid analyses of mollusc shells, and periods of penetration by warm subarctic water have been identified by their foraminifera and mollusc faunas. Subarctic water reached the area on three occasions: during the Holocene, and in the Early and Late Sangamonian. Maximum, although restricted, ice coverage for the last interglacial/glacial cycle was attained during Middle Sangamonian times, and a smaller advance took place in the Late Wisconsinian. In between ice coverage was similar to the present, or smaller. The record provides a link between events in Arctic Canada and northern Greenland, and shows that in this large region there was a causal relationship between oceanographic change and glaciation.

**RÉSUMÉ** *La mer de Baffin au cours du dernier interglaciaire: reconstitution à partir de données du nord-ouest du Groenland.* Certaines coupes le long de la côte de la région de Thulé fournissent des données sur la glaciation et sur l'océanographie de la partie nord de la mer de Baffin au cours du dernier interglaciaire. Les événements ont été datés grâce à la combinaison des âges obtenus par thermoluminescence et par le  $^{14}\text{C}$ ; les corrélations locales et régionales ont été établies par l'analyse des acides aminés à partir des coquillages de mollusques; les périodes où les eaux chaudes subarctiques ont pénétré dans la région ont été identifiées grâce aux faunes des foraminifères et des mollusques. Les eaux subarctiques ont atteint la région en trois occasions: pendant l'Holocène, puis au début et à la fin du Sangamonien. Le recouvrement glaciaire maximal au cours du cycle interglaciaire-glaciaire, bien que limité, s'est produit au milieu du Sangamonien, et une avancée de moindre importance s'est produite au Wisconsinien supérieur. Entre les deux événements, la couverture glaciaire était semblable à celle d'aujourd'hui ou moindre. Ces données permettent d'établir des liens entre les événements qui se sont produits dans l'Arctique canadien et dans le nord du Groenland, et démontrent qu'il y a des relations de cause à effet entre les changements d'ordre océanographique et la glaciation.

**ZUSAMMENFASSUNG** *Das Gebiet der Baffin Bay während der letzten Interglazialzeit: Zeugnisse von Nordwest-Grönland.* Küstenschnitte im Thule-Gebiet, Nordwest-Grönland, geben Zeugnis von den glazialen und ozeanographischen Ereignissen im nördlichen Umkreis der Baffin Bay während der letzten Interglazialzeit. Diese Ereignisse konnten mit Hilfe der Kombination von Thermolumineszenz und  $^{14}\text{C}$  datiert werden: Mittels Aminosäureanalysen der Schalen von Mollusken konnte eine lokale und regionale Korrelation erreicht werden, und Perioden der Eindringung warmen subarktischen Wassers wurden mittels ihrer Foraminifera und Mollusken-Fauna identifiziert. Subarktisches Wasser erreichte das Gebiet bei drei Gelegenheiten: während des Holozän und im frühen und späten Sangamonium. Die maximale wenn auch begrenzte Eisbedeckung im letzten interglazialen/glazialen Zyklus wurde in den Zeiten des mittleren Sangamoniums erreicht, und ein geringerer Vorstoß fand im späten Wisconsinium statt. Dazwischen war die Eisbedeckung ähnlich wie in der Jetztzeit oder geringer. Diese Ergebnisse lassen eine Beziehung zwischen Ereignissen im arktischen Kanada und nördlichen Grönland erkennen und zeigen, dass es in diesem weiten Gebiet eine Kausalbeziehung zwischen ozeanographischer Veränderung und Vereisung gab.

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## INTRODUCTION

Evidence from coastal cliffs in the Thule area, northwest Greenland, show a detailed record of Sangamonian oceanography and glaciation at the northern extremity of Baffin Bay. The results provide the first correlation between Sangamonian events in North America and Greenland, and support and extend the contention, previously expressed by workers in Arctic Canada, that in this region there is a close relationship between oceanographic conditions and glaciation and that initial growth of the Laurentide Ice Sheet may have taken place during warm intervals in the Sangamonian (e.g. Andrews *et al.*, 1985; Andrews, 1988; and reviews by Vincent and Prest, 1987 and St-Onge, 1987).

This study is a product of the "NORDQUA 86 Project", which included field studies by 33 Quaternary scientists and subsequent laboratory work, in the most concentrated Quaternary effort in a restricted area in Greenland.

Preliminary results were outlined in a series of papers read at the 18th Nordic Geologic Winter meeting (Feyling-Hanssen, 1988; Funder, 1988; Houmark-Nielsen, 1988; Mörner, 1988; Sejrup, 1988, and Sorby, 1988) while the present report draws on information from a collective monograph (Funder, *in press*). The authors responsible for different parts of the work are identified below by reference to this monograph.

Chronostratigraphic terminology here follows the Canadian recommendations by Fulton and Prest (1987), thus the Sangamonian is considered equivalent to marine isotopic stage 5. Ages of isotopic stages are from Martinson *et al.*, 1987.

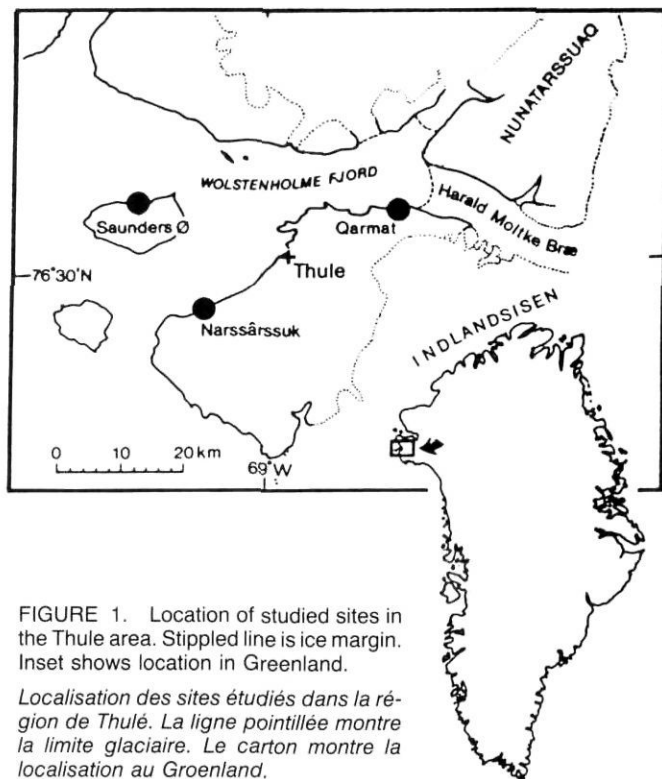


FIGURE 1. Location of studied sites in the Thule area. Stippled line is ice margin. Inset shows location in Greenland.

Localisation des sites étudiés dans la région de Thulé. La ligne pointillée montre la limite glaciaire. Le carton montre la localisation au Groenland.

## REGIONAL SETTING AND PREVIOUS STUDIES

Field work during the NORDQUA 86 Project was conducted along the 60 kilometre coastline of Wolstenholme Fjord (Fig. 1) — a wide and comparatively shallow (<500 m deep) fjord carved into Precambrian sedimentary rocks of the Thule Basin (Dawes *et al.*, 1982). The fjord is headed by calving outlet glaciers from the Inland Ice and from a local ice cap to the north. Ice free land occurs mostly to the south of the fjord, and is composed of gently undulating, largely till covered uplands that rarely exceed 500 m altitude.

Previous Quaternary studies in the area include work by Krinsley (1963) with Quaternary maps of areas to the south of the fjord, by Goldthwaite (1960), by Blake (1975), and scattered observations by Greenland geological Survey geologists passing through Thule (Weidick, 1977, 1978; Kelly, 1980).

Our attention was drawn to this area because earlier work, including infinite  $^{14}\text{C}$  dates from Saunders Ø (Krinsley, 1963; Blake, 1975, 1977, 1987) and Qarmat (Kelly, 1980), indicated a longer and more detailed record of pre-Holocene glacial and marine events than known elsewhere in West Greenland (e.g. Funder, 1984, 1989; Kelly, 1985, 1986).

## NATURE OF THE EVIDENCE AND METHODS

Coastal sections, up to 25 m high, in raised alluvial cones at three localities along Wolstenholme Fjord, represent a transect from the interior to the outer coast. Sedimentary facies change vertically and horizontally from shallow water beach shingle and sand to deep water glaciomarine mud and diamicton, and till beds reflect periods of glacier advance (Fig. 3).

Nine sections have been investigated in detail (Houmark-Nielsen *et al.*, *in press*), and lithological units are correlated by combining lithology with absolute and relative age estimates, and marine faunal composition (Houmark-Nielsen, *in press*).

The age-frame is provided by thermoluminescence dating of marine sediment (Kronborg and Mejdahl, *in press*), and the Holocene/Pleistocene boundary is defined by 27  $^{14}\text{C}$  dates (Mörner and Funder, *in press*). For correlation both between sites and with other sites in the northern Baffin Bay region marine bivalve shells have been analysed for their alloisoleucine: isoleucine ratios (Sejrup, *in press*). Finally, subarctic and cold water mass fluctuations have been identified by analyses of foraminifera and molluscs (Feyling-Hanssen and Funder, *in press*).

Some of these methods will be commented upon briefly.

## THERMOLUMINESCENCE AGES

Twelve samples of marine sediment from two localities have been dated at the Nordic Laboratory for Thermoluminescence Dating at Risø, Denmark. The results are described in detail by Kronborg and Mejdahl (*in press*). The dating was done on coarse grained alkali feldspars from marine sediments, using regeneration combined with plateau criteria. Bleaching time was adjusted to obtain maximum plateau length in a plot of paleodose vs. temperature (e.g. Mejdahl, 1985, 1986, 1988).

Ages are not corrected for changes in dose rate due to desiccation after emergence, which could reduce some ages by about 5%.

Because dating of sediment by thermoluminescence is still experimental, empirical control of the results is important. This has been achieved by dating sets of superimposed samples in each section, as well as samples from correlatable horizons. The results show that samples decrease in age upwards in sections, and that correlatable sediments have similar ages. Also, most ages are compatible with amino acid ratios on mollusc shells in the sediment. Finally, accepting the ages gives the best fit for other data as well. We therefore find that the TL-ages, within their limit of uncertainty, give reliable estimates of the age of the sediments.

The results are shown in Table I. Nine samples of pre-Holocene marine sediment cluster between ages of  $136 \pm 15$  (R-861001) and  $80 \pm 10$  ka (R-861011), while a beach ridge — probably formed during the final regression — is dated to  $69 \pm 10$  (R-861008). Considering the uncertainties we refer these sediments to the Sangamonian (73-125 ka).

#### AMINO ACID ANALYSES

Seventeen samples, each consisting of at least three valves of *Mya truncata*, have been analysed for their alloisoleucine: isoleucine ratios in the total hydrolysate and free fractions at the laboratory at Bergen University. The results are treated in detail by Sejrup (Fig. 4, and in press). The *in situ* samples show a clear distinction between Holocene and older material, the latter from samples that are  $^{14}\text{C}$  dated to more than 40,000 years, and grouped into the Thule aminozone with values between 0.021 and 0.049 in the total hydrolysate. With less confidence the aminozone can be divided into a younger (average  $0.023 \pm 0.002$ ), and an older (average  $0.039 \pm 0.006$ ) episode.

TABLE I

Thermoluminescence (TL) ages from the Thule area, and correlative events (for detailed description of ages and methods see Kronborg and Mejdahl, in press.)

Risø TL no.	Field no.	Event	TL Age (ka)
R-861001	005	Saunders Ø interstade	$136 \pm 15$
R-861003	007	Saunders Ø interstade	$119 \pm 10$
R-861002	006	Narssârssuk stade	$114 \pm 10$
R-861005	009	Qarmat interstade	$113 \pm 10$
R-861004	008	Qarmat interstade	$89 \pm 10$
R-861009	143	Qarmat interstade	$86 \pm 10$
R-861010	144	Qarmat interstade	$80 \pm 10$
R-861011	147	Qarmat interstade	$80 \pm 10$
R-861008	012	?Qarmat interstade	$69 \pm 10$
R-861012	185	Fluvial deposit, overlying Qarmat interstade	$61 \pm 6$
R-861007	011	Marine sediment, overlying Qarmat interstade	$36 \pm 4$
R-861006	010	Holocene/Late Wisconsinan	$14 \pm 2$

Using the TL-ages in the age/temperature relationship of amino acid kinetics implies that between 135 and 75 ka the sediments experienced high temperatures, close to  $0^\circ\text{C}$ , and probably were submerged. Later, however, temperatures in the sediments dropped to values similar to the present (mean annual temperature is  $-10^\circ\text{C}$ ), indicating that they were raised above sea level (Sejrup, in press).

#### FAUNA AND FLORA

The Thule area is located at the northern boundary of subarctic water mass penetration in Baffin Bay (Fig. 2), and a number of marine species have their northern limit in this general area because they are dependant on a supply of warm Atlantic water (e.g. Madsen, 1936, 1940; Vibe, 1954). These include the bivalves *Mytilus edulis* and *Chlamys islandica* and the barnacles *Balanus balanoides* and *B. crenatus*, which today are absent (*B. balanoides*) or sparse in the area

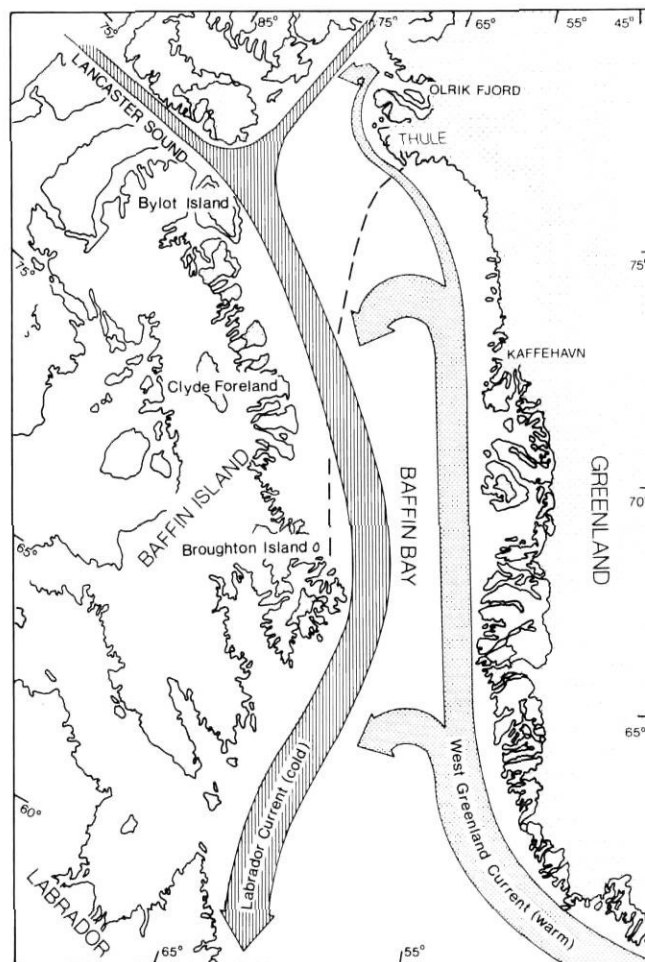


FIGURE 2. Summer surface currents in Baffin Bay (adapted from Jacobs et al., 1985). Hatched line shows northern boundary for subarctic zone (from Dunbar, 1968). Location of sites discussed in text is shown.

Courants de surface estivaux dans la mer de Baffin (adapté de Jacobs et al., 1985). Les tirets indiquent la limite nordique de la zone subarctique (de Dunbar, 1968). Localisation des sites commentés dans le texte.



(Feyling-Hanssen and Funder, in press). Their occurrence in the sediment, therefore, indicate periods with as much or greater influx of warm subarctic water into northern Baffin Bay as at present.

Fifty faunal samples have been analysed. The evidence from molluscs is corroborated by data from benthic foraminifers, showing that periods with the ameliorated *Nonionella auricula* assemblage are interrupted by periods with the less ameliorated *Islandiella helenae* assemblage and short intervals with the high arctic *Astrononion gallowayi* assemblage (Feyling-Hanssen and Funder, in press).

From these results, three periods of subarctic water dominance have been identified: the early Holocene, the Qarmat interstade (Late Sangamonian) and the Saunders Ø interstade (Early Sangamonian). The richest faunas, and the only occurrence of *Balanus balanoides*, is in the Qarmat interstade (Late Sangamonian).

In sediments from the Qarmat interstade, remains of detritus from land contain a seed from the plant *Menyanthes trifoliata*, identified by O. Bennike (personal communication, 1987). This species presently has its northern limit 800 km to the south. Also at this time, the beetle *Amara alpina* lived in the area (Böcher, 1989). This beetle does not live in Greenland now, and apparently has not been able to immigrate during the Holocene. *Amara alpina* was found in peat from nearby Ellesmere Island, but its proposed age at this locality is younger (Blake, 1982).

Therefore, surprisingly, there is evidence that conditions during the Late Sangamonian both in the sea and on land were warmer than during the Holocene.

**RESULTS**

The alluvial cones contain three distinct coarsening upward sequences, reflecting transgression-regression cycles (Houmark-Nielsen, in press). Each cycle begins with deposition of glaciomarine mud or till, representing a glacier advance, and ends with shallow water sand or beach shingle deposited during the isostatic rebound following glacier retreat (Fig. 3).

The oldest event recorded is the *Agpat glaciation*, represented by a till bed exposed at sea level in the cliff on Saunders Ø. TL-dates from overlying sediment shows that it is older than  $136 \pm 15$  ka (R-861001), and it is provisionally correlated with the erratic boulders and till found on mountain plateaus in all parts of the area, reflecting a period when the whole area was inundated by an ice sheet.

This glaciation was followed by ice margin retreat and regression during the *Saunders Ø interglaciation*. Sediments from this period were often reworked during later glacier overriding, and *in situ* marine sediment is present only on Saunders Ø. TL-dates suggest an age between  $136 \pm 15$  (R-861001) and  $119 \pm 10$  ka (R-861003), and amino acid values are characteristic of the older Thule aminozone. *Chlamys islandica*, *Balanus crenatus* and possibly *Mytilus edulis*, as

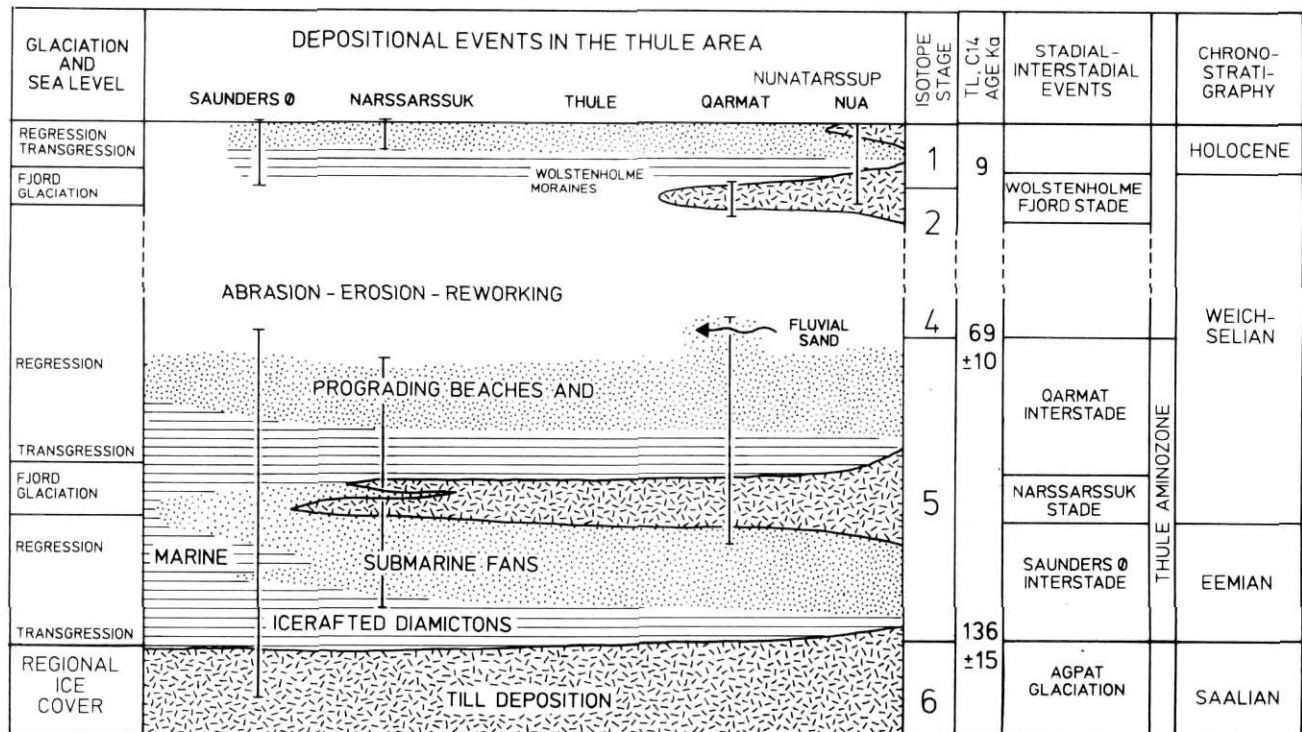


FIGURE 3. Event stratigraphy and sedimentary facies associations in the Wolsteholme Fjord region. Vertical bars in centre-diagram show the exposed sequence at each locality (from Houmark-Nielsen, in press).

Stratigraphie des événements et associations des faciès sédimentaires dans la région du fjord de Wolsteholme. Les lignes verticales au centre du diagramme identifient la séquence à découvert à chacun des sites (de Houmark-Nielsen, sous presse).

well as the *Nonionella auricula* foraminifer assemblage show that subarctic water reached at least as far north as at present.

The next cycle began with the *Narssârssuk stade*, an advance of the fjord glacier which overrode the localities at Narssârssuk and Qarmat, forming conspicuous moraines on the former site. Saunders Ø was not overridden and here marine sediment with the high Arctic *Astrononion gallowayi* assemblage was deposited. A TL-date here indicates an age of  $114 \pm 10$  ka for the advance.

Following ice margin retreat, marine regression took place, and the sediments of the *Qarmat interstade* were laid down with rich faunas containing *Mytilus edulis*, *Chlamys islandicus*, *Balanus balanoides*, and *B. crenatus*, showing that conditions were warmer than those known from the Holocene. TL-dates suggest an age between  $114 \pm 10$  (R-861002) and  $80 \pm 10$  ka (R-861010; R-861011), while a beach ridge incised into the sequence gave an age of  $69 \pm 10$  ka (R-861008), and may date from the final regression phase. Amino acid ratios correspond to the younger Thule aminozone.

After this, there is a long lasting hiatus. The absence of both marine sediment and signs of glacier activity suggest that sea level was at or below present, and glacier margins were at their present locations or farther back.

The next event recorded is renewed glacier advance, the *Wolstenholme Fjord stade*, during which the fjord glacier pushed up to 10-15 km in front of its present terminus. Glaciomarine sediment from this time is overlain by a new regressive sequence with subarctic molluscs that date back to 9.2 ka. The glacier recession therefore began shortly before this time.

## REGIONAL CORRELATION

During the past fifteen years intensive Quaternary studies have been carried out in areas bordering on the northern Baffin Bay, both on Baffin Island (see summaries by Miller, 1985, and Andrews *et al.*, 1985), and in West Greenland (Kelly, 1985, 1986).

Correlations between sites were based on amino acid analyses of mollusc shells. The rate of amino acid epimerization depends as much on the temperatures experienced by the shells, the effective diagenetic temperature (EDT), as it does on time; and it was argued by Miller (1985) that because Baffin Bay coasts presently have similar EDT, mollusc faunas from this region may be correlated by their amino acid ratios. As noted above, our results indicate that sea level history may be a more important factor than atmospheric temperatures in the diagenesis, since it determines a shift between periods with high and low EDT (Sejrup, in press). However, since the lithology of the deposits implies that they have experienced the same sea level history, we postulate that the ratios may be used for correlation. (See also discussion by Mode *et al.*, 1983). Figure 4 shows that the Olrik Fjord, Kaffehavn and Svartenhuk aminozones of northern West Greenland, as well as the Kogalu aminozone of Baffin Island have similar alloisoleucine: isoleucine ratios and thus are correlated with the Thule aminozone.

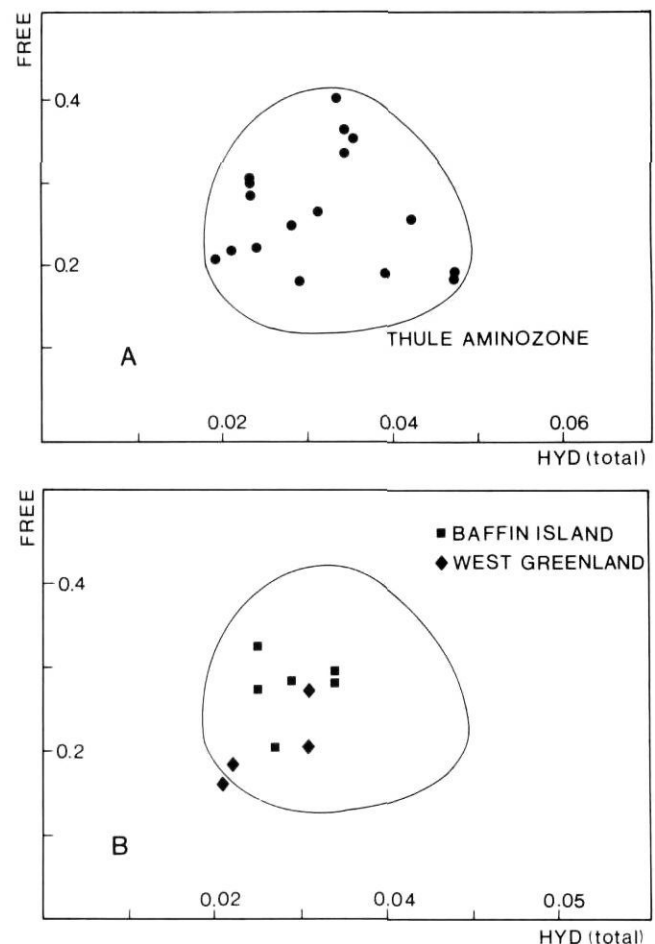


FIGURE 4. Comparison of alle:lle ratios from: A) the Thule aminozone, and B) Kogalu aminozone, Baffin Island (squares) and Svartenhuk, Olrik Fjord and Kaffehavn aminozones, West Greenland (diamonds). Data from Sejrup (in press), Miller (1985) and Kelly (1986).

Comparaisons des rapports alle:lle de: A) l'aminozone de Thulé et B) l'aminozone de Kogalu, dans l'île de Baffin (carrés), et les aminozones de Svartenhuk, du fjord d'Olrik et de Kaffehavn, dans l'ouest du Groenland (losanges). Les données sont de Sejrup (sous presse), de Miller (1985) et de Kelly (1986).

From the published literature (e.g. Miller and Andrews, 1977; Andrews *et al.*, 1981; Brigham, 1983; Miller, 1985; Klassen, 1985; Kelly, 1985, 1986) these occurrences also have similarities in lithology, fauna and setting. The proposed correlation is shown in Figure 5. Common features in the implied succession of events are: isostatic subsidence and occurrence of subarctic molluscs, especially in the Late Sangamonian (Qarmat interstade, late Kogalu aminozone), and evidence for glacier advance in Middle Sangamonian times (Ayr Lake stade, Narssârssuk stade), whereas in all areas, the period preceding the glacier advance (equal to the Saunders Ø interstade) is less well known.

As noted above, the Thule aminozone is TL-dated to the interval 136-80 ( $-69$ ) ka (R-861001; R-861011; R-861008), and the Narssârssuk stade to  $114 \pm 10$  ka (R-861002). On Baffin Island the previous age estimate for the duration of

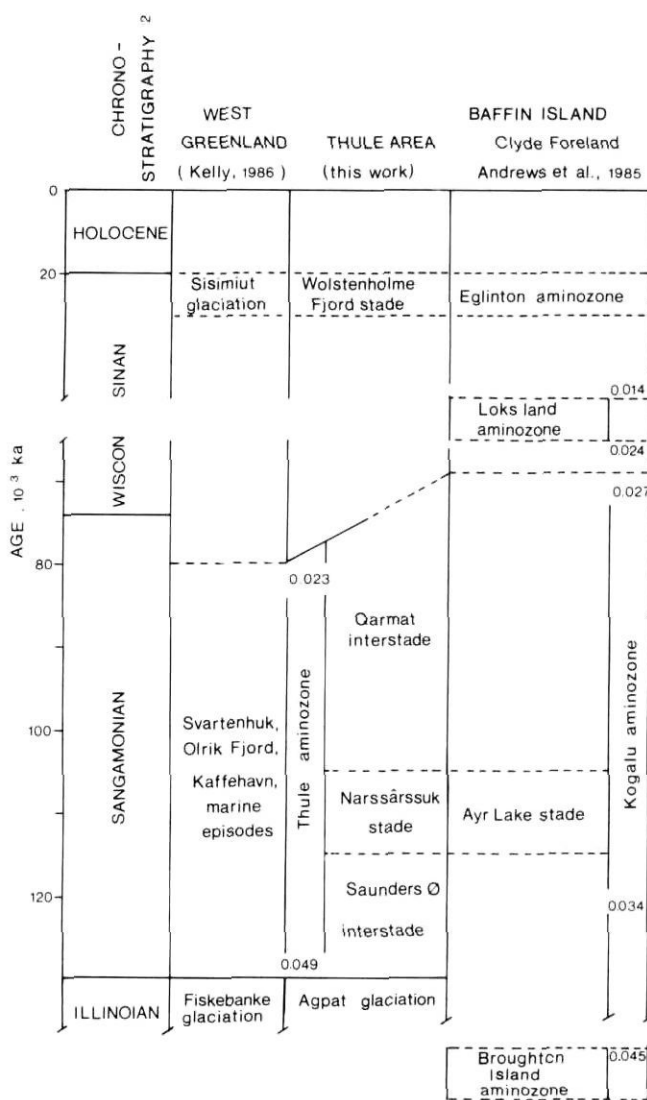


FIGURE 5. Proposed correlation between Sangamonian deposits in the Baffin Bay region.

*Corrélation proposée entre les dépôts sangamoniens de la région de la mer de Baffin.*

the correlative Kogalu aminozone was 69-125 ka, calculated from amino acid ratios and partly supported by limiting  $^{14}\text{C}$  and U-series dates, and an age of 110 ka was suggested for the Ayr Lake stade (Szabo *et al.*, 1981; Miller, 1985). When comparing these ages it should be kept in mind that no allowance for high EDT during periods of marine submergence has been made for the Baffin Island amino acid ratios. Using the "Thule model" on these ratios would render young ages older and old ages younger (see above).

## DISCUSSION

The results from Thule provide, for the first time, a correlation between glacial events in North America and Greenland, and show that during the Sangamonian they were in phase over an extensive region, comprising West Greenland north of lat.  $70^{\circ}\text{N}$  and eastern Baffin Island north of lat.  $65^{\circ}\text{N}$ . Unfortunately

the deep-sea stratigraphy is not clear because varying amounts of melt water mask the global oxygen isotope signal in this confined basin (De Vernal *et al.*, 1987). However, recent results from ODP site 645 in northern Baffin Bay indicate that during isotope stage 5 subarctic dinocysts occurred together with pre-Quaternary palynomorphs, indicating influx of warm water contemporaneously with severe glacial erosion on land (Hillaire-Marcel *et al.*, in press).

This is in agreement with the fact that both in the eastern Canadian Arctic and northwest Greenland ice cover apparently reached its Sangamonian/Wisconsinan maximum during the Ayr Lake/Narssârssuk stades, dated to ca. 114 ka in the Thule record. In both areas this advance was associated with influx of subarctic water. Also the Late Wisconsinan Wolstenholme Fjord/Eglinton stades apparently were associated with appearance of subarctic water along adjacent coasts. However, on both occasions the change in ice cover was more dramatic in Canada than it was in Greenland, as seen from outlines of glaciation on eastern Baffin Island by Dyke *et al.* (1982) and Klassen (1985).

Therefore there is now, both from land and deep sea, a considerable amount of evidence in favour of the hypothesis often expressed by workers in Canada, that there is a causal relationship between influx of warm water into Baffin Bay and onset of glaciation, and that the Laurentide Ice Sheet may have originated during the Sangamonian (e.g. Andrews *et al.*, 1985; Andrews, 1988, and discussion by St-Onge, 1987).

## CONCLUSIONS

The NORDQUA 86 work in the Thule area has shown that:

- Raised alluvial fans in this area contain a detailed record of Sangamonian and Holocene glacial and oceanographic events.
- There were at least three distinct transgression-regression cycles, each reflecting isostatic rebound following glacier retreat.
- The regression phases are dated to the Holocene, and Late and Early Sangamonian, and during all subarctic water penetrated at least as far into Baffin Bay, as it does now.
- The richest faunas belong in the Late Sangamonian, and contain some species, that do not live in the area at present.
- The record can be correlated with previous results from northern West Greenland and eastern Baffin Island, and it is especially interesting that in all parts of the area maximum ice cover during the last interglacial/glacial cycle was attained during Middle Sangamonian times.
- The results therefore support the earlier hypothesis that there is a relationship between ice growth in this region and influx of warm subarctic water, and the Laurentide Ice Sheet may have begun its growth during the Sangamonian.

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