Local events and regional correlation

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Local correlation and event stratigraphy

(M. Houmark-Nielsen)

The sequences at all three sites described above contain one or more coarsening upwards sequences, each beginning with glaciomarine mud and diamicton, overlain by sublittoral marine sand, and ending up with beach shingle. These prograding sequences represent a sedimentary evolution from a transgressive maximum through a regressive phase to periods of reworking and halts in deposition. Since facies associations in all sequences are the same, local correlation must be based not only on lithology and stratigraphic position, but also on radiometric age determinations (C-14- and TL-dating), amino acid analyses of marine shells, and faunal characteristics (see also discussion by Mode *et al.* 1983).

The localities include Saunders Ø, Narssârssuk and Qarmat. For comparison Holocene marine sediments in a section at Nunatarssûp nûa, immediately in front of the present glacier front in Wolstenholme Fjord (Fig. 1), are included in this discussion. The proposed correlation is shown in Fig. 23.

Local correlation

An important tool for correlation between the sites is the amino acid ratios in marine mollusc shells, both *in situ* and reworked in glacial sediments. Sejrup (above) distinguished two major marine episodes: the younger characterised by ratios in the total hydrolysate (Hyd) below 0.016, is C-14 dated to the Holocene. The older, the Thule aminozone, has ratios between 0.021 and 0.049, and is TL-dated to isotopic stage 5 (69–136 ka). This includes the major part of the sediments described above from Saunders Ø, Narssârssuk and Qarmat, and the ratios provide correlation between the unit-sequences S2-S5, N1-N5 and Q1-Q3, all with C-14 ages older than 35 ka.

Within the interval of the Thule aminozone, on the evidence of the TL dates, glaciomarine sediments (unit S2, samples 005, 007; Fig. 4) apparently were deposited between 136±10 ka and 119±ka, (units S4-S5, samples 006, 008, 009) and around 114±10 ka and 86–80±10 ka (units Q2-Q3 samples 143, 144, 147; Fig. 9). The youngest part of the sequence, unit S5a (sample 012), which is composed of beach shingle gave a TL age of 69±10 ka.

Correlation of till beds

The till bed on Saunders Ø (S1, Fig. 23) is overlain by the oldest deposits within the Thule aminozone. This glacial event is possibly represented by the lower till in section K at Narssârssuk. Redeposited shell fragments in the till and associated glaciomarine outwash of units N1-N2-N3 and Q1 have amino acid ratios between 0.030 and 0.037, suggesting a correlation between the till beds of Narssârssuk and the lower till at Qarmat.

The upper till at Qarmat (Q5), which is younger than a TL age of 61±10 ka (unit Q4, sample 185; Fig. 9) has no equivalents, except possibly the lower till bed at Nunatarssûp nûa, which has a gradational transition upwards into glaciomarine diamicton of early Holocene age.

Prograding marine sequences

Three successive transgression-regression cycles can be identified from lithological criteria. All three cycles are recognised in the Saunders Ø sequence, two at Narssârssuk, and one at Qarmat and Nunatarssûp nûa. The youngest is dated to the Early Holocene while the two older belong in isotopic stage 5.

A clue to the correlation of the two older events is again afforded by amino acid ratios, where Sejrup (above) with some hesitation distinguished a lower and an upper marine episode within the Thule aminozone. Lithologically the older episode is represented by units S2 and S3 (Fig. 23). TL dates suggest deposition and progradation in the interval between 136±15 ka and 119±10 ka. The younger marine sediments, overlying till at Narssârssuk and Qarmat, comprises units S4-S5, N4-N5 and Q2-Q3. TL dates indicate that glaciomarine deposition and subsequent progradation took place somewhere between 114±10 ka and 80±10 ka.

The third cycle comprises units S6-S7, N6-N7, and the coarsening-upward sequence overlying the till bed at Nunatarssûp nûa; this cycle has been C-14 dated to the Early Holocene, although a TL-date from Saunders Ø and amino acid ratios from Narssârssuk suggest that it could have begun earlier.

Event stratigraphy and age

The deposits at the three localities were thus laid down during at least three depositional cycles, each including glaciation with till deposition and glacitectonic activity,

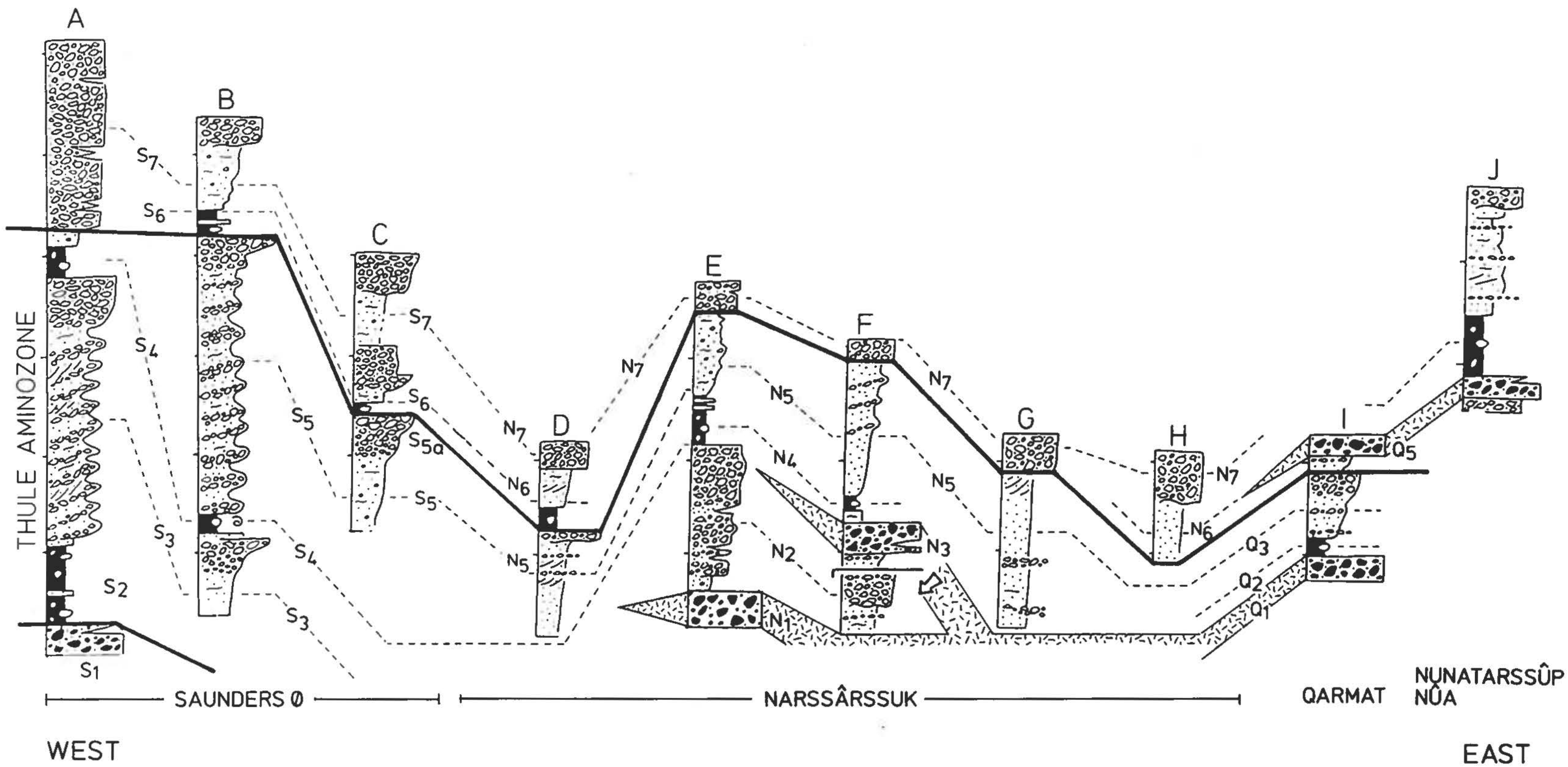

Fig. 23. Correlation between localities. Lithological sections compiled from Figs 4, 8 and 9.

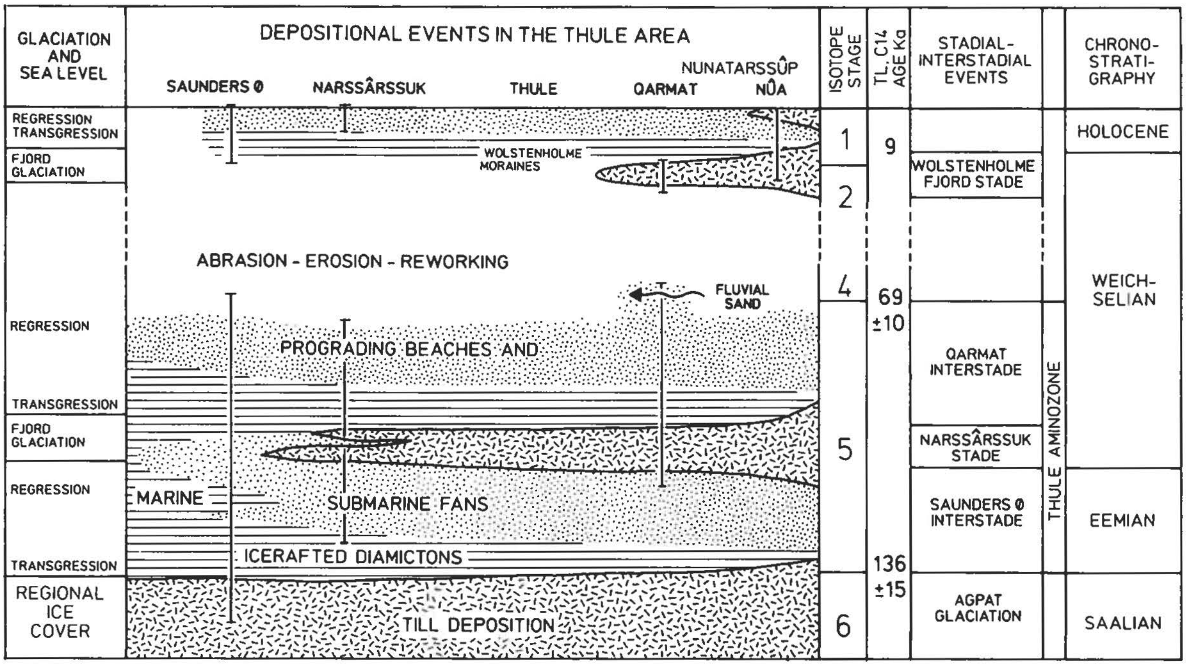

Fig. 24. Event-stratigraphic scheme for the Thule area in the period since isotope stage 6 (Saalian).

followed by marine transgression, glaciomarine sedimentation and subsequent progradation of coarse clastic sublittoral deposits and ending up with beach shingle (Fig. 24).

Based on this, a sequence of regional events can now be outlined, containing evidence from microfaunas (Fig. 11) and other fauna and flora (Tables 4, 5 and 6), and dated by TL-dating (Table 9), amino-acid analyses (Table 10), and radiocarbon dating (appendix). The distribution of ice cover during glacial events is shown on Fig. 10.

The main part of the sequence falls within isotopic stage 5 (74–130 ka, Martinson *et al.* 1987), but unfortunately neither TL-dating nor amino acid analysis have sufficient precision to refer our events to the 10 000 year substages within this interval. From oldest to youngest the following events are distinguished:

The Agpat glaciation. – This glaciation is represented by till (unit S1) on Saunders Ø, and possibly at Narssârssuk (unit a, section K). These till beds are provisionally correlated with the till cover found on upland plateaus, deposited by an ice sheet that covered the entire coastal region, extending into Baffin Bay. TL dates show that this event occurred prior to 136 ka, – and it is provisionally correlated with the Saalian (isotope stage 6).

The Saunders Ø interstade. – During the melting of the ice sheet a transgression caused deposition of ice-rafted diamicton and, later, glaciomarine mud on Saunders Ø (unit S2). During the subsequent regression progradation of a submarine delta fan ended up with deposition of beach shingle (unit S3). At Narssârssuk and Qarmat this period is known only from reworked marine fauna in younger glacial sediments. Sparse evidence from subarctic species suggest that the warm West Greenland current functioned as at present. TL dates indicate an age between 136 and 120 ka, and we provisionally correlate the event with a warm interval in early isotope stage 5, and with the Eemian chronozone (Bowen *et al.* 1986).

The Narssârssuk stade. – The regression was followed by renewed glaciation, this time of limited extent. At Narssârssuk and Qarmat till beds occur in the coastal sections (units N1-N3, Q1). The glacier did not reach Saunders Ø (Fig. 11), but high arctic foraminifera in lowermost unit S4 may represent a proglacial facies.

Moraines at Narssârssuk and Kap Abernathy on the north side of Wolstenholme Fjord mark the glacier margins during this advance. TL dates indicate an age of 114±10 ka, and we correlate this glaciation, the most extensive during the Weichselian, with one of the cold intervals in isotope stage 5.

The Qarmat interstade. – Again, this glacier advance was followed by isostatic depression resulting in deposition of ice-rafted diamicton at all three localities (units N5, Q2 and upper S4). Subsequent regression initiated beach-progradation (units S5, N5 and Q3). At Narssârssuk and Qarmat the sediments contain abundant subarctic organisms reflecting more extensive influx of subarctic water into northern Baffin Bay, and warmer summers, than known from the Holocene. By the end of the period sea-level dropped, and a final stage with sea-level 12 m above the present is recorded by subunit S5a on Saunders Ø. TL dates indicate an age between 114 ka and 69 ka, and we correlate this event with a warm interval in late isotope stage 5.

Hiatus. – The record, as outlined here, contains a gap of *c.* 60 000 years from which almost no information is available. The lack of glacial sediments shows that ice coverage was similar to the present, or – more likely – less extensive, while the lack of raised marine sediments shows, that relative sea-level was lower than the present; this assumption is indirectly supported by calculation of diagenetic temperatures from amino acid ratios.

The Wolstenholme Fjord stade. – The upper till bed at Qarmat (unit Q5) records a later glacier readvance, recorded also by lateral moraines along Wolstenholme Fjord, where the glacier front was only 10 km more advanced than at present (Fig. 11). The areas at Narssârssuk and Saunders Ø were not ice covered, and at these two localities glaciomarine diamicton with a high arctic foraminifer assemblage may represent the proglacial marine facies, deposited during isostatic submergence following the readvance (units N6, S6).

Radiocarbon dates on shells from sediments immediately over the diamicton on Saunders Ø, and from a locality on the north shore of Wolstenholme Fjord have given ages between 8.2 and 9.2 ka, providing a minimum age for the advance (samples K-4780 and 4781), and amino acid ratios from Narssârssuk indicate a slightly higher age (sample 104). A TL-dating from an underlying fluvial deposit at Qarmat (unit Q4) gives a maximum age of 61 ka, while another from Saunders Ø at 36±4 ka is considered erroneous since it seems incompatible with the local sea-level history. Hence, based on C-14 dates and the Holocene sea-level history we assume a Late Weichselian age for this advance, corresponding to isotope stage 2.

The Holocene. – After the ice advance, ice-rafted diamicton and glaciomarine mud was deposited in the interior Wolstenholme Fjord at Nunatarssûp nûa, and – during the subsequent Holocene regression – a prograding sequence topped by beach shingle at all localities (units S7 and N7).

Marine faunas with subarctic molluscs show that the West Greenland Current was operating as at present at least at 9.2 ka BP. Shell fragments in beach sediment 40 m above sea-level on Saunders Ø have a Holocene amino acid ratio, and C-14 age of 8.7 ka giving a maximum age for the onset of the Holocene regression (sample 013, Table 10 and appendix).

Thule and Baffin Bay

(S. Funder)

In this section the Thule record will be compared to that from other parts of the Baffin Bay region, as well as with results from deep sea cores.

Because of its importance for understanding the history of the Laurentide ice sheet over North America intensive Quaternary studies have been carried out in this region, and a large amount of information has accumulated from both Canada and Greenland. Much of this data has been presented in a volume concerning the Quaternary environments (Andrews 1985), and later reviewed by Andrews *et al.* (1986) and Kelly (1986). Fig. 25 shows sites with marine and/or glacial sediments that have been ascribed an age similar to that of the Thule record.

Regional amino acid stratigraphy

Amino acid analyses of mollusc shells have played an important role in correlation of these events; however ratios obtained prior to 1982 have been assayed by new standard preparation methods. Fig. 22B shows the distribution of post-1982 amino acid ratios in *Mya truncata* or *Hiatella arctica* shells from sediments on the Baffin Bay coasts assigned to isotopic stage 5.

It was argued by Miller (1985) that although the region spans a considerable north-south climatic gradient, effective diagenetic temperatures (EDT) are most strongly controlled by summer warmth. Ratios from the 1500 km coastline of Baffin Island, where summer temperatures are very uniform, thus would have experienced the same thermal history and may be compared directly. Kelly (1986), on the other hand, found that in West Greenland separate epimerisation trends can be recognised in the north and south.

Our results (Sejrup, this volume) indicate that sea-level history may be more important than atmospheric temperatures, because it determines a shift between high and low EDT. However, for the sites shown in Fig. 1, i.e. West Greenland north of lat. 69° N and Baffin Island north of lat. 65° N, sea level history seems to have been the same, and it is therefore postulated that within this region thermal conditions have been suffiently uniform to allow correlation of mollusc faunas by their amino acid ratios.

A comparison of the data (Fig. 22) gives support to earlier age estimates, and indicates that marine events during isotope stage 5 are correlatable around Baffin Bay.

Correlation of events on land

The proposed correlation is shown in Fig. 26 which shows that the Olrik Fjord, Kaffehavn and Svartenhuk aminozones of West Greenland (Kelly 1986), as well as

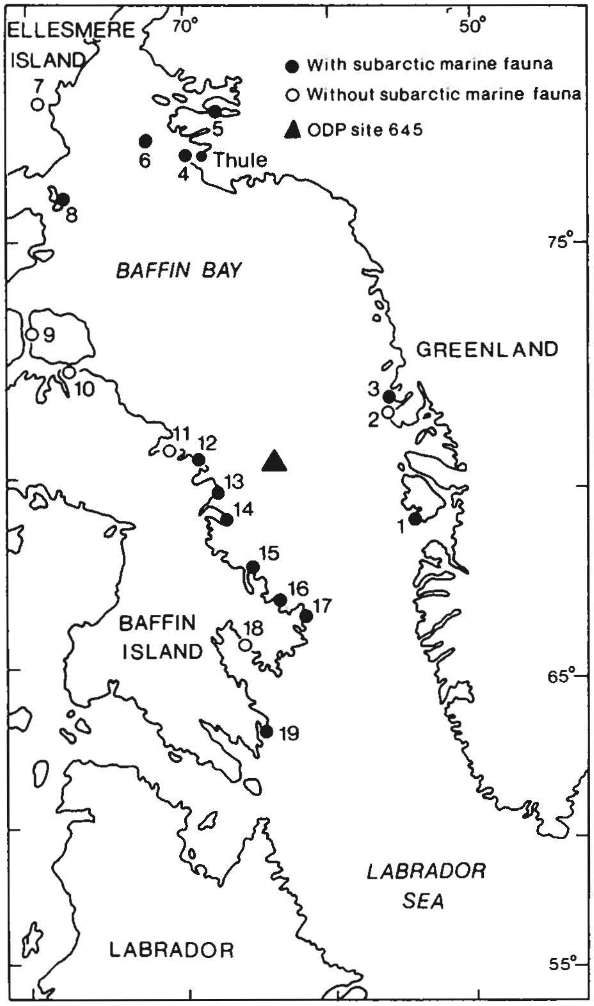

Fig. 25. Sites with marine and/or glacigene sediments ascribed to isotope stage 5 in the Baffin Bay region and site for ODP drilling.
Sites and sources: 1. Laksebugt (Funder & Símonarson 1984). 2. Søndre Upernavik and adjacent sites (Kelly 1986). 3. Kaffehavn (Kelly 1986). 4. Thule area (this work). 5. Olrik Fjord (Weidick 1978, Kelly 1986). 6. Isbjørneø (Blake 1977). 7. Makinson Inlet (Blake 1980). 8. Coburg Island (Blake 1973). 9. Bylot Island (Klassen 1985, 1987). 10. Pond Inlet (Klassen 1985). 11. Scott Inlet (Miller *et al.* 1977, Andrews *et al.* 1981). 12. Clyde Foreland (Miller *et al.* 1977, Andrews *et al.* 1981; Miller 1985). 13. Cape Henry Kater (Andrews *et al.* 1981, Miller 1985). 14. Qivitu Peninsula (Nelson 1981, Miller 1985). 15. Broughton Island (Brigham 1983b, Miller 1985). 16. Cape Dyer (Andrews *et al.* 1981, Miller 1985). 17. Cape Raper (Andrews *et al.* 1981, Miller 1985). 18. Pangnirtung (Miller 1985). 19. Allen Island (Osterman *et al.* 1985).

the Kogalu aminozone of Baffin Island (Miller 1985), may be correlated with the Thule aminozone, and thus dated within the interval 69–135 ka. For the southernmost locality (Laksebugt, site 1, Fig. 25) ratios are higher, and may reflect higher EDT in this area.

A characteristic feature of the marine sediments at almost all sites is their association with evidence for glacier advance. On Bylot Island, off northern Baffin Island (site 9, Fig. 25), this evidence is referred to the Eclipse glaciation (Klassen 1985, Klassen & Fisher 1988), and to the south on Clyde Forland (site 12, Fig. 25) to the Ayr Lake stade (Miller *et al.* 1977, Miller 1985), which from their setting and amino acid characteristics can be correlated to our Narssârssuk stade, with a TL age of 114±10 ka.

Although this glacier advance in both areas marks the maximum of Weichselian glaciation, it was more dramatic on the Canadian side; thus whereas the glacier in Wolstenholme Fjord was only 40 km more advanced than now, the straits between the Canadian arctic islands were closed by glaciers (Klassen & Fisher 1988, Osterman *et al.* 1985), and on parts of Baffin Island fjord glaciers reached the outer coast and spread out as large lobes (Dyke *et al.* 1982).

In both areas the glacier advance was accompanied by isostatic subsidence and deposition of marine sediments with subarctic faunas during the Qarmat interstade of Thule, and the late Kogalu aminozone of Baffin Island. At Thule the presence of *Menyanthes trifoliata* and *Balanus balanoides* indicate warmer summers and more abundant subarctic water than known from the Holocene (see p.32), and the subarctic water continued around the northern perimeter of Baffin Bay, flowing south along the coast of Baffin Island. This is shown by the frequent occurrence of the subarctic *Chlamys islandica* in areas that are now dominated by cold polar water, as well as the gastropod *Colus spitsbergensis* on Clyde Foreland. However *Mytilus* – common in the sediments at Thule – has not been reported from sites along the Baffin Island coast (Andrews *et al.* 1981).

The marine episode preceding the glacier advance, the Saunders Ø interstade, is less well known. This is undoubtedly due to the facts that sea-level was close to its present level, and that sediments at most sites were later eroded by glaciers. As noted above, *Chlamys islandica*, *Balanus crenatus* and possibly also *Mytilus* lived at Thule, showing that the warm West Greenland current was functioning as at present. From its setting it may be suggested that the horizon with well preserved *Mytilus* on Coburg Island (site 8, Fig. 25) should be referred to this episode, indicating that also during this period subarctic water penetrated deeper into northeastern Baffin Bay than during the Holocene (Blake 1973).

From Baffin Island only a few deposits are referred to the pre-Ayr Lake stade episode (e.g. Miller *et al.* 1977), and we have not been able to find records of subarctic marine fauna. However, on Broughton Island (site 15, Fig. 25) a higher than Holocene abundance of *Betula* pollen in a horizon immediately below glaciomarine sediments of the Ayr lake stade is "...considered to be indicative of interglacial, terrestrial climatic conditions ... when relative sea-level stood at < 5 m asl." (Brigham 1983a: 589). On Bylot Island (site 9, Fig. 25) well devel-

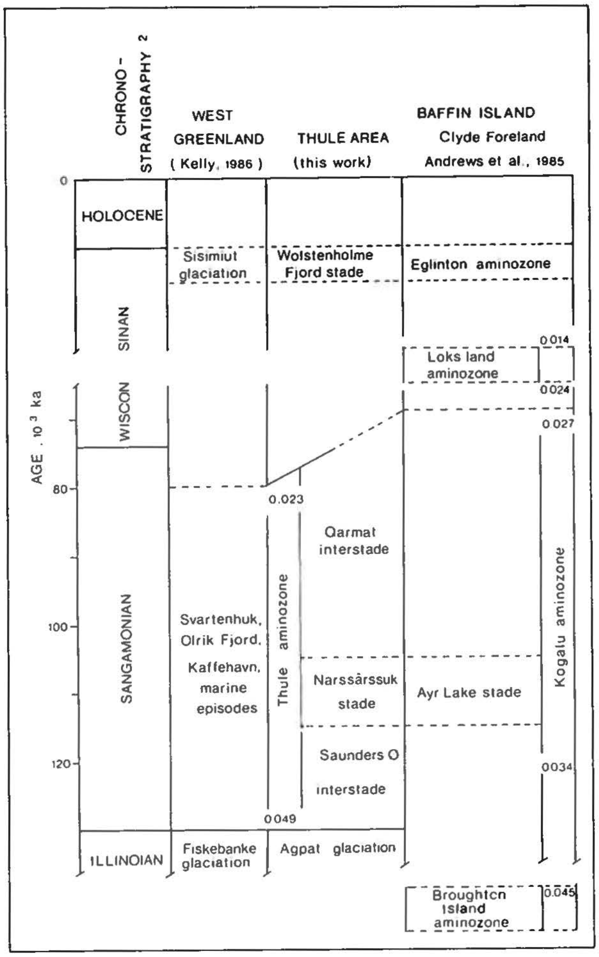

Fig. 26. Proposed correlation of glacial and marine events in Greenland and on Baffin Island.

oped buried soils occur in a similar stratigraphic position (Klassen 1987).

Sparse as it is, this evidence indicates more substantial influx of subarctic water, and a warmer climate, than during the Holocene also for the time interval represented by the Saunders Ø interstade.

Before this period, extensive glaciation occurred on both sides of Baffin Bay during the Baffin glaciation of northern Baffin Island (Klassen 1987), and the Agpat glaciation in the Thule area. Although there is no dating of these events, the similarities in stratigraphical setting and nature of the evidence suggests a correlation.

A salient feature in the Thule record is the hiatus from *c.* 70 to *c.* 10 ka. From Baffin Island a slightly different timing of events was suggested by Andrews *et al.* (1986). Here the warm Kogalu aminozone extended into isotopic stage 4, and marine transgression occured later, at *c.* 44 ka, during the Loks Land aminozone. However, the dating of these events relies on age calculations from amino acid ratios which are similar to those obtained for the Thule aminozone, suggesting the possibility that both the Loks Land and the older Broughton Island aminozones should be correlated with the Thule aminozone, and referred to isotope stage 5 (Fig. 26).

Finally, in both areas there was a limited resurgence of glaciers in the Late Weichselian or Early Holocene, the Cape Hatt glaciation of Bylot Island (Klassen 1987), the Eglinton aminozone of Clyde Foreland (Miller 1985), and the Wolstenholme Fjord stade in Thule. This advance was accompanied by renewed transgression with influx of warm subarctic water, beginning before 9.2 ka at Thule, before 8.3 ka on northern Baffin Island, and at 9.7 ka on southern Baffin Island (p. 28).

Deep sea results

The results from deep sea boring and piston coring in Baffin Bay have recently been discussed by De Vernal *et al.* (1987), De Vernal & Hillaire-Marcel (1988), and Hillaire-Marcel *et al.* (in press), who showed that peaks of melt water influx have disturbed the oxygen isotope signal, making correlation with the global oxygen isotope stratigraphy difficult. However, the results from deep sea drilling at ODP sites 645 and 646 indicate that during isotope substage 5e the Labrador Sea and Baffin Bay had warmer than present surface water, while high erosion rates and abundant reworked pre-Quaternary palynomorphs reflect intense glacial activity around Baffin Bay during the later part of isotopic stage 5 (De Vernal & Hillaire-Marcel, 1988), which may be correlative with the Ayr Lake stade/Eclipse glaciation/Narssârssuk stade on land. However, the deep sea record contains no evidence for late stage 5 influx of subarctic water to northern Baffin Bay, as shown by the faunas of the Qarmat interstade and late Kogalu aminozone on land.

Discussion

The evidence shows that oceanographic and glacial events in northern and eastern Baffin Bay at the onset of the last ice age were in phase, and support the contention by Andrews *et al.* (1986) that glaciation in this region may be controlled by presence of warm water along the coasts, bringing moisture into regions which today have a cold and dry climate unfavourable for formation of ice on land.

A major unresolved problem remains: why did the northern Baffin Bay region apparently have conditions warmer than today during the Early Weichselian, at a time when our hemisphere seems to have experienced the temperature decline heralding the coming of the ice age?