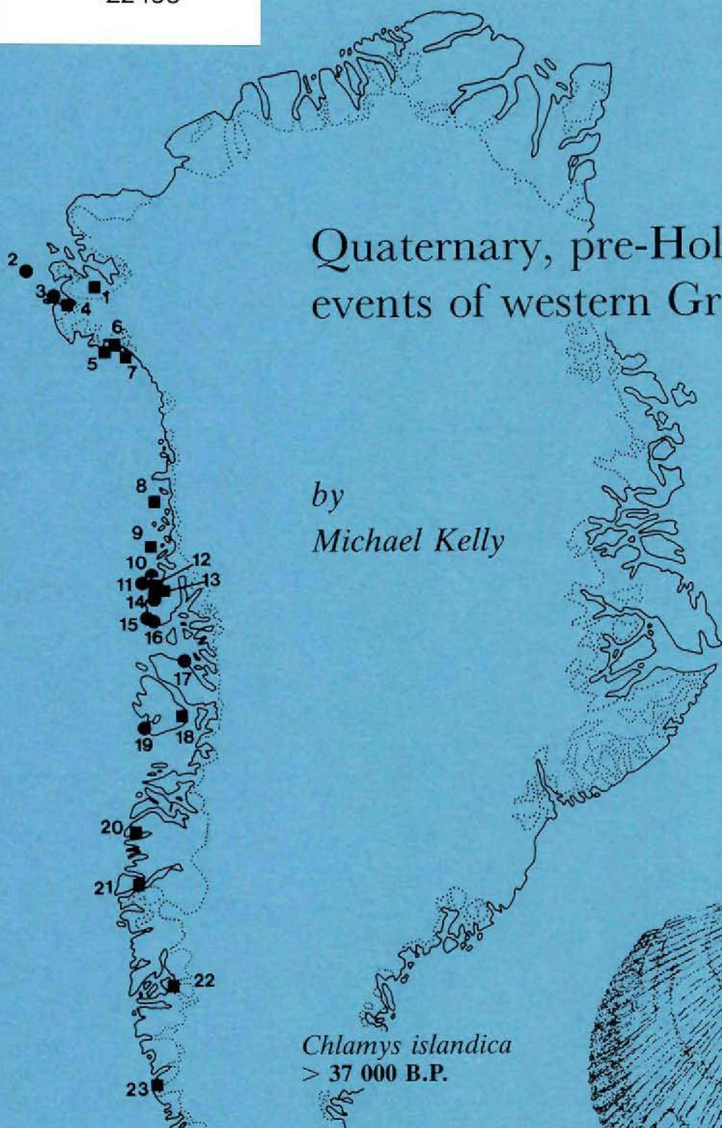
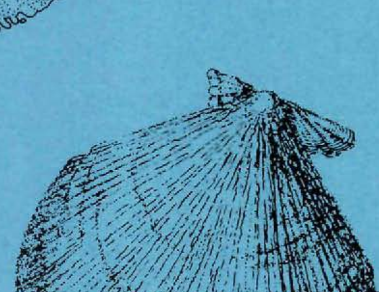
Quaternary, pre-Holocene, marine events of western Greenland

by
Michael Kelly





Chlamys islandica
> 37 000 B.P.

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Abstract

Lithological, faunal, radiocarbon and amino acid data are presented for ten new occurrences of *in situ* or redeposited pre-Holocene marine material in western Greenland, and further data on four previously described ones, bringing the total known occurrences to 22–23. The new and older data suggest that this material dates from a number of periods of marine inundation from the Early to Late Quaternary, the exact number being uncertain. A succession of marine events are designated for two regions of western Greenland. From the occurrence of the *Chlamys islandica – Mytilus edulis* faunal assemblage the sub-arctic West Greenland Current is considered to have existed during several of these marine events of different age.

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Introduction

Holocene marine deposits are widespread in western Greenland, laid down in the marine event which occurred during the phase of deglaciation and isostatic recovery at the end of the Sisimiut glacial event, an event which had glaciated virtually all of western Greenland in the late Weichselian/Wisconsinian (Kelly, 1985). In contrast, evidence of older marine events is sporadic and often indirect. Thus, although *in situ* marine deposits are known from several localities, at others the evidence takes the form of reworked marine sediment or fossils redeposited in younger glacial deposits.

Twenty-three possible occurrences of pre-Holocene marine material are currently known, including those described here for the first time (fig. 1, Table 1). A few of these have been known for a considerable time, e.g. Pátorfik (Rink, 1852) and Kugssineq (Steenstrup, 1883) (locs 17 & 16, fig. 1, Table 1), but it was the advent of radiocarbon dating which led to the increased recognition of pre-Holocene marine material, beginning with deposits on Saunders Ø (Krinsley *in* Davies *et al.*, 1963) (loc. 3). Since then amino acid analysis has been added to radiocarbon dating, and the geological criteria of litho- and biostratigraphy, as aids to their identification and interpretation.

Funder & Símonarson (1984) recently provided information about three key sites with pre-Holocene marine deposits (locs 17, 18 & 19) together with a review of the older records. In the present paper data are provided on a further 10 localities (5, 8–15, 20), together with new faunal and/or amino acid data on a further four previously described ones (1, 4, 6 & 7).

Lithostratigraphy

The stratigraphy of the deposits at localities for which new data are provided is described below. Sedimentological logs from the more important localities are shown in fig. 2.

Olrik Fjord (loc. 1). The brief description by Weidick (1978) indicates that unfragmented bivalve mollusc shells occurred in a shell-rich lens in a thick diamicton. It seems possible that this is a slice of reworked marine sediment in glacial deposits.

Wolstenholme Fjord (loc. 4). At this locality (Kelly, 1980) shell rich sands, with a few boulder sized clasts, occur in an isolated exposure at sea level on the south side of the fjord. Glacial deposits are widespread in the area and, although there are no exposures showing the relationships between the two, it is thought that the marine sediments are reworked slices.

Qungulertôq (loc. 5). Along the north coast of Melville Bugt, at this locality and at the nearby localities 6 & 7 (Kelly, 1980), are small exposures in low banks along the shore revealing shell bearing muds (5 & 6) or sands and gravels (7). At Qungulertôq they are overlain by unfossiliferous sands and gravels, but at the other two sites by diamictons (?tills). The

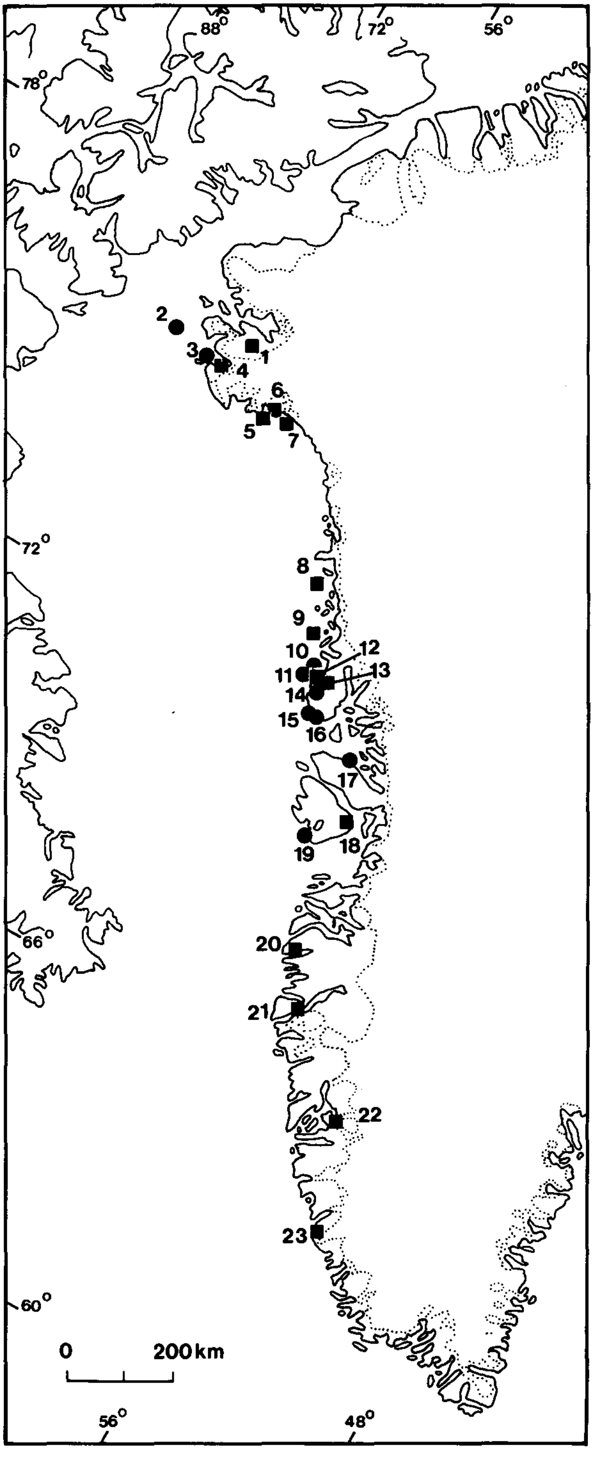


Fig. 1. Occurrence of pre-Holocene marine material. Circles: *in situ* deposits; squares: reworked or possibly reworked material. Locality numbers are those in Table 1.

Table 1. Location and mode of occurrence of pre-Holocene marine material

	LOCALITY		Mode	References (main)
1.	Olrik Fjord	77°12'N, 67°27'W	R?	Weidick, 1978
2.	Isbjørn Ø	76°44'N, 73°04'W	I	Blake, 1977
3.	Saunders Ø	76°36'N, 69°47'W	I & R?	Davies et al., 1963 Blake, 1975
4.	Wolstenholme Fjord	76°35'N, 68°11'W	R?	Kelly, 1980
5.	Qungulertôq	76°06'N, 63°57'W	I/R?	new locality
6.	Navdlortoq	76°08'N, 64°03'W	I/R?	Kelly, 1980
7.	Ivnârqigsorssuaq	76°13'N, 62°46'W	I/R?	" "
8.	Tugtorqortôq	73°39'N, 56°51'W	R	new locality
9.	Kingigtoq	72°40'N, 55°59'W	R	" "
10.	Kaffehavn	72°14'N, 55°40'W	I	" "
11.	Tukingassoq	72°08'N, 55°58'W	I	" "
12.	Søndre Upernavik	72°10'N, 55°30'W	R	" "
13.	Suvdlua	72°03'N, 54°39'W	R?	" "
14.	Nerutussoq	71°54'W, 54°57'W	I	" "
15.	Arfertuarssuk	71°30'N, 55°16'W	I	" "
16.	Kugssineq	71°27'N, 55°10'W	I	Laursen, 1944 Rosenkrantz, 1968
17.	Pátorfik	70°44'N, 52°40'W	I	Laursen, 1944 Simonarson, 1981 Funder & Símonarson, 1984
18.	Mudderbugten	69°39'N, 51°59'W	R	Funder & Símonarson, 1984
19.	Laksebugt	69°21'N, 53°54'W	I	" " "
20.	Eqalugsugssuit	67°20'N, 53°19'W	R?	new locality
21.	Naqerdloq kangigdleq	66°19'N, 52°47'W	R	Sugden & Miller, 1976
22.	? Kapisigdlit	∿64°26'N, 50°17'W	R	Bryan, 1954
23.	Frederikshåb Isblink	62°37'N, 50°08'W	R	Weidick, 1975

I - in situ   R - redeposited.

shells are fragmented and abraded, but are locally abundant. In the earlier preliminary report (Kelly, 1980) it was suggested that these were *in situ* marine deposits, but the evidence is equivocal and they may equally well be sorted glacigene sediments with redeposited shells.

Tugtorqortôq (loc. 8). In a bay on the western end of this island a complex sequence of interstratified diamictons and sands, capped by 0.4 m of gravel, are partially exposed in low cliffs along the shore. Shell fragments occur sparsely in a 20 cm zone in silty sand bands within a diamicton unit. The sediments are considered to be glacigene, belonging to an ice marginal facies, and the shells are obviously derived.

Kingigtoq (loc. 9). In the low coastal cliffs of this bay is exposed a till overlying coarse sands and boulder gravels. Small shell fragments occur very sparsely in a silty coarse sand below a 2 m till unit which forms a degraded moraine ridge. The host materials for the shells are considered to be fluvioglacial sediments deposited close to an ice margin.

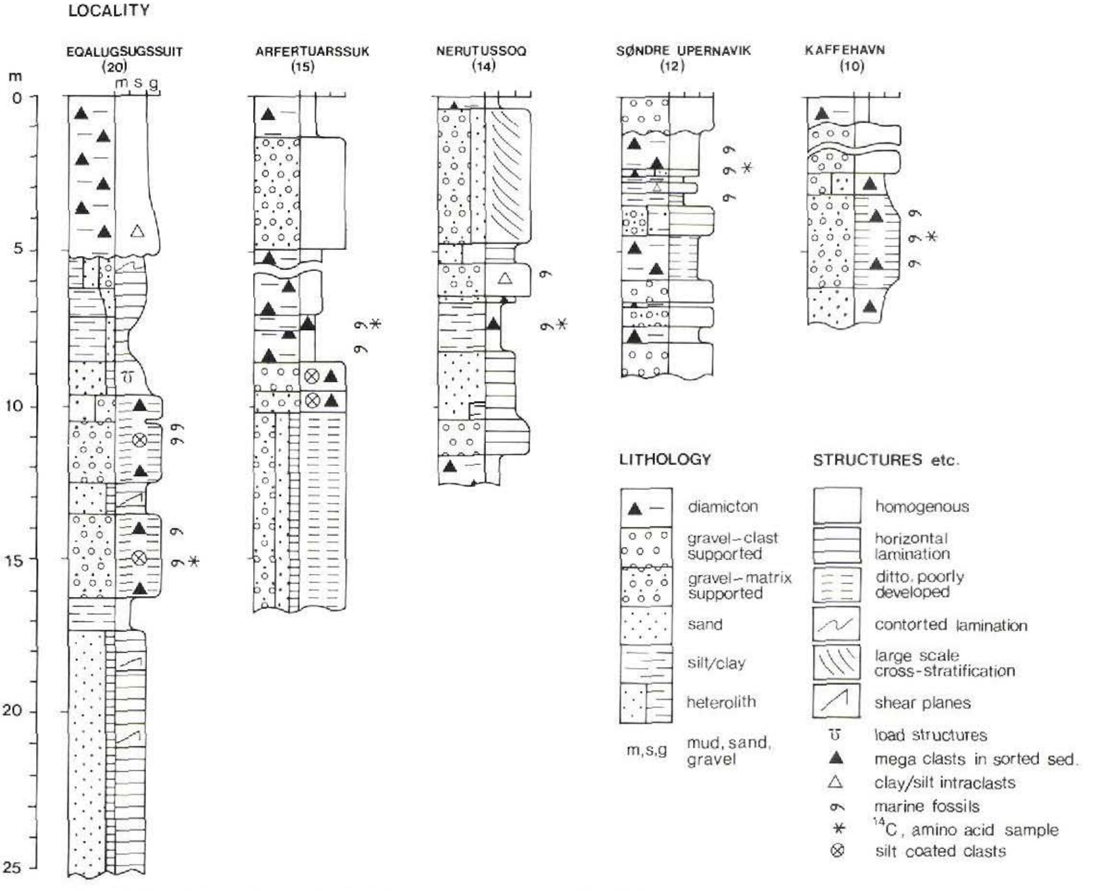


Fig. 2. Graphic sedimentological logs from some new localities.

Kaffehavn (loc. 10) (fig. 2). The exposures occur in low cliffs on the promontory on the west side of this bay on the north of the island of Qeqertaq. Here *c.* 3 m of clast supported fine gravels, containing coarser clasts and abundant shells, are interbedded with unfossiliferous gravels. A boulder rich diamicton is locally present, apparently unconformably overlying the gravels. The shells are largely fragmented *Mytilus edulis* but whole valves also occur. The gravels are interpreted as being an *in situ* littoral marine facies with a content of ice rafted clasts. Subsequently these were overridden by ice which laid down a till.

Tukingassoq (loc. 11). On the south side of this island are steep, high cliffs in basalts. Locally sediments are preserved in infilled hollows on the face of the cliff. They have not been properly examined because of difficult access, but they appear to consist of stratified, coarse clast supported boulder gravels, which locally contain whole, complete bivalve mollusc shells. They are interpreted as *in situ* coarse littoral marine deposits and talus.

Søndre Upernavik (loc. 12) (fig. 2). In the bay on the south side of the island Qeqertaq, near the settlement of Søndre Upernavik, are 10 m cliffs in unconsolidated sediments. These are a complex sequence of mainly interbedded gravels and diamictons. Repeated thin diamictons, 0.2–0.4 m thick, in the lower part of the exposed sequence, are interpreted as subaqueous debris flow deposits or flow tills, whilst the *c.* 2.5 m thick diamicton in the upper part is probably a true till. The deposits as a whole are considered to belong to a proximal glaciomarine facies passing up into glacial facies. Shells occur in the till and, in particular, in silts immediately below this. In the latter, whole paired valves of *Hiatella arctica* occur in an intraformational 'conglomerate' of silt pebbles in a sandy silt matrix. Despite their fresh appearance it seems likely that these shells, like those in the till, have been redeposited following glacial erosion of nearby marine sediments.

Suvdlua (loc. 13). On the north-west side of the inner part of this fjord, exposures in a stream bank reveal 6 m of diamicton below sands and gravels. The diamicton, which may be a till or proximal glaciomarine sediment, contains sparse whole and fragmented shells.

Nerutussoq (loc. 14) (fig. 2). On the south-east side of Umiarfik fjord, further seawards than locality 13, are extensive exposures of unconsolidated sediments in the steep face of a broad terrace. These mainly consist of a thick (>9 m) sequence of cross-stratified basaltic sands and gravels with a west to north-west dip. Above these lies a thin (0.4 m) diamicton with predominantly basaltic clasts. Metamorphic clasts occur also in the diamicton and the gravels below. At the south-west corner of the exposures the gravels are thinner and beneath them appear *c.* 7 m of sorted sediments of various lithologies from silts to gravels. At the base is a second diamicton with locally derived basalt clasts only. Bivalve mollusc shells occur principally in a 1.6 m poorly consolidated clayey silt unit containing clasts up to 3 cm. The shells are mainly disarticulated whole valves or fragments, except for small genera such as *Portlandia* which are complete. Fragmented shells, together with silt clasts, occur also in a gravel further up the sequence. The main fossiliferous unit is considered to be an *in situ* marine/glaciomarine deposit laid down in an interval between two periods of glacial deposition. The youngest of these was preceded by the formation of a delta of coarse clastic sediments. No unconformities have been proved yet within this sequence.

Arfertuarssuq (loc. 15) (fig. 2). In this fjord, at the south-west corner of Svartenhuk Halvø, thick unconsolidated sediments are exposed in cliffs at its head. These are mainly a sequence of diamictons and gravels, but an 0.5 m thick poorly consolidated clayey silt also is present, containing abundant whole and articulated bivalve mollusc shells, together with occasional clasts. Less frequent shells occur also in clast rich diamictons beneath the silt. At the base of the succession are thick (>6 m) poorly sorted sands and gravels. Above the fossiliferous units are further diamictons and gravels. Throughout, the main clast lithology is basalt but in all units erratic metamorphic rocks are present also. The shell bearing sediments are undoubtedly *in situ* marine deposits whilst the diamictons are probably partly glaciomarine and partly glacial deposits, their exact interpretation being uncertain.

Eqalugsugssuit (loc. 20) (fig. 2). On the south side of this inlet off Nordre Isortoq 26 m of sediments are exposed in a steep gully. They consist essentially of a coarsening upwards sequence beginning with thick (>8 m) well sorted sands and culminating in a 5 m thick till. Shells occur at several horizons in poorly sorted, silt coated, coarse sands and gravels with occasional boulder sized clasts. The shells are notably well preserved, in particular including large articulated shells of *Chlamys islandicus,* together with *Balanus* compartments. The provenance of these shells is problematic. Two aspects of the host sediment lithology suggest that they are not an *in situ* death assemblage – the silt coatings, indicating deposition in silt laden water – and the poor sorting, suggestive of a proximal turbidite facies. If this interpretation is correct then the shells must have been reworked from older marine deposits in such a way that their abrasion was minimised. That this can happen can be seen at localities such as Cornell Gletscher (Ryder Isfjord, 74°N) where meltwater streams today are redepositing articulated bivalve shells, reworked from slices of Holocene marine sediments which have been incorporated in Neoglacial moraines. In general, therefore, the Eqalugsugssuit deposits are interpreted as deltaic, glaciolacustrine and glacial facies laid down at the beginning of a glacial episode.

As the brief descriptions above indicate, there can be doubt in some cases about the identity of the fossiliferous sediments, e.g. whether they are *in situ* marine sediments, or redeposited fossils in glacigene sediments. The inferred modes of occurrence given in Table 1 should be regarded therefore as provisional.

The stratigraphy and regional geological setting at most sites indicates the pre-Holocene age of the marine material, in that it underlies or is included in the deposits of ice advances which are considered to be older than the Holocene (Kelly, 1985). The most important exception to this is at Isbjørn Ø (loc. 2) (Blake, 1977) where tills are apparently absent between the Holocene and pre-Holocene marine deposits. Other exceptions are at Tukingassoq (11) where the stratigraphy is poorly known, and at Frederikshåb Isblink (23) and Kapisigdlit where redeposited material occurs in late and early Holocene moraines respectively.

Kapisigdlit may not qualify as a pre-Holocene marine site at all, as the evidence there consists of silt concretions containing pollen of species which may derive either from a local interglacial flora, or be long distance transported and hence of any age, including Holocene (Bryan, 1954).

Biostratigraphy

The composition of the marine faunas, from the new or incompletely described localities, is shown in Table 2, together with published faunal lists from other sites, except Pátorfik, for comparison.

Several faunas contain species which have limited distributions in Greenland today. Most notable of these are species with distributions related to the extent of the warm, sub-arctic West Greenland Current which flows northwards along the coast – *Chlamys islandica*, *Mytilus edulis* and *Balanus hameri* (Funder & Símonarson, 1984). Three new localities contain *Chlamys* and one *Mytilus*, the latter, at Kaffehavn (10) being close to the northern limit of continuous distribution for this species (Madsen, 1940). The occurrence of *Balanus hameri* at Eqalugsugssuit (20) is also close to its northern limit (Stephensen, 1914).

Another distinctive category of faunas occurs in the *in situ* marine deposits from Svartenhuk Halvø or nearby (locs 13, 14 & 15), typified by the presence of *Portlandia intermedia* (identified by L. Símonarson), but with several other species which appear to be uncommon in the other known pre-Holocene deposits, with the exception of the much older deposit at Pátorfik (see below), e.g. *Modiolaria nigra*, *Palliolum groenlandicum*, *Thyasira flexuosa*, *Tridonta borealis* and *T. montagui*. All are species with panarctic or panarctic-boreal distributions today which include western Greenland (Ockelmann, 1958). In contrast the species

Table 2. Compositions of pre-Holocene faunas (excepting Pátorfik)

Species	LOCALITIES																				
	New data													Published data (see Table 1 for refs.)							
	4. Wolstenholme Fjord	5. Qungulertôq	6. Navdlortoq	7. Ivnârqigsorssuaq	8. Tugtorqortôq	9. Kingigtoq	10. Kaffehavn	11. Tukingassoq	12. Søndre Upernavik	13. Suvdlua	14. Nerutussoq	15. Arfertuarssuk	20. Eqalugsugssuit	1. Olrik Fjord	2. Isbjørn Ø	3. Saunders Ø	16. Kugssineq	18. Mudderbugten	19. Laksebugt	21. Naqerdloq kangigdleq	23. Frederikshåb Isblink
Bivalvia																					
Nucula tenuis (Montagu)											r	r							c		
Portlandia arctica (Gray)																	+		a		
Portlandia intermedia (Sars)										r	r	r									
Mytilus edulis Linnaeus							a									+			r		
Modiolaria nigra (Gray)											c	r									
Chlamys islandica (Müller)	r	c	c										c	+	+	+		a			+
Palliolum groenlandicum (Sowerby)										r	r										
Tridonta borealis (Chemnitz)												a									
Tridonta montagui (Dillwyn)			r								c	a					+				
Tridonta elliptica (Brown)																	+				
Thyasira flexuosa (Montagu)											r										
Serripes groenlandicus (Chemnitz)	r												r						r		
Clinocardium ciliatum (Fabricius)	r		r																r		
Macoma calcarea (Chemnitz)	a		r				r				a	c					+	r	c		
Macoma moësta (Deshayes)																			a		
Hiatella arctica (Linnaeus)	c	a	a	a	r	r	c	a	a		a	c		+		+	+	a	a	+	
Mya truncata Linnaeus	a	a	a	a					c	c	c	a	c			+	+	a	a		+
Gastropoda																					
Puncturella noachina (Linnaeus)							r														
Acmaea testudinalis (Müll)							c														
Margarites sp.							r														
Cingula arenaria (Mighel & Adams)							r														
Lora sp.							r														
Cirripedia																					
Balanus balanus (Linnaeus)	c	r	c	r		r	r		c	c	c		r		+			+			
Balanus hammeri (Ascanius)													a								
Echinodermata																					
Strongylocentrotus droebachiensis		c	r				c				c	r	c								

a – abundant, c – common, r – rare, + – present.

characteristic of subarctic water masses, mentioned above, are absent. Much of the character of this fauna may be due to its association with a particular sediment facies, since the species are all either restricted to or are common on muddy bottoms, especially those with ice rafted coarser material (Ockelmann, 1958). Despite this, the fauna is not incompatible with a marine climate harsher than today, although there is no definite indication of such a condition.

The remaining three faunas (locs 8, 9 & 10) contain only ubiquitous arctic species which are not of any diagnostic value.

Considering the previously published faunas, the one described by Laursen (1944) from Kugssineq (16) on Svartenhuk Halvø correlates with the other Svartenhuk Halvø faunas, since it has certain faunal similarities, has provided an infinite radiocarbon date (Rosenkrantz, 1968), and lies only a few kilometres from Arfertuarssuq (15). Funder & Símonarson (1984) have summarised and discussed the previous records of occurrence of the subarctic species *Chlamys islandica* and *Mytilus edulis* (locs 1, 2, 3, 4, 17, 18 & 19), which notably include a cluster of sites around the present northern limits of the species. At one locality (Laksebugt, 19) the subarctic *Mytilus* occurs in the same fauna as the high arctic *Portlandia arctica* and *Macoma moesta*, which is considered to indicate the existence of fluctuating water mass conditions (Funder & Símonarson, 1984). The fauna from Pátorfik (17), which is the most diverse fauna known, has been shown to be distinct from all the other pre-Holocene faunas in its association of subarctic Greenland and boreo-arctic non-Greenland species together with more commonly occurring arctic species (Laursen, 1944; Símonarson, 1981; Funder & Símonarson, 1984).

The main conclusions to be drawn from the faunal evidence are that several different fossil assemblages occur amongst pre-Holocene material, and that one of these, the *Chlamys–Mytilus* fauna, is indicative of an oceanic circulation in western Greenland similar to the present.

Radiocarbon and amino acid evidence

Radiocarbon dates for bivalve molluscs from the new localities are given in Table 3. They are either infinite, or if finite (9 & 13) are considered to be minimum ages, giving overall ages greater than 35–40 ka. Most of the previously described occurrences have been radiocarbon dated (see references in Table 1) and mostly they give minimum ages in the same range as above. One of the two exceptions is Olrik Fjord which produced a radiocarbon date of 18.9 ka, which Weidick (1978) considered was due to contamination of the sample by Holocene shells, since dates of >33 and >37 ka were obtained also. The other young date, 21.7 ka (Weidick, 1975) comes from redeposited shells in the late Holocene moraines at Frederikshåb Isblink, and it is possible that this is also due to the admixture of Holocene and much older shells, the former being common in the moraines of this age in the area.

Amino acid data are available for many of the pre-Holocene occurrences, in the form of total and free D-alloisoleucine/ L-isoleucine ratios (aIle:Ile) obtained for bivalve mollusc shells. Tables 4 and 5 list all the analyses that have been carried out for the Geological Survey of Greenland by G. Miller, Geochronology Laboratory, University of Colorado, and fig. 3 shows the data diagrammatically. The earlier analyses of western Greenland material performed by the same laboratory, some of which have been published (Kelly, 1980), have

Table 3. Radiocarbon data from shells from western Greenland

Locality	GGU No.	Lab. No.	Date B.P.	Species dated
9. Kingigtoq	194451	HAR-2953	37 430	?
10. Kaffehavn	261738	HAR-4887	>40 000	M. edulis, M. truncata H. arctica
12. Søndre Upernavik	261750	HAR-4883	>42 000	H. arctica
14. Nerutussoq	262007	HAR-4885	39 600±1800	M. calcarea, H. arctica M. truncata
15. Arfertuarssuk	261797	HAR-4884	>40 000	T. borealis
20. Eqalugsugssuit	110406	K-1555	>35 000	C. islandica

proved to be subject to laboratory fractionation and other errors (Miller *et al.*, 1982). These old series data (Table 5) have been corrected using the factors shown in Table 4, which were established by re-analysing a single representative of each of the earlier batches of samples. In general these correction factors are consistent with those obtained by the re-analysis of a large number of arctic samples (Miller, 1985). Other new series amino acid data have been given by Funder & Símonarson (1984) for Pátorfik, Mudderbugten and Laksebugt (17, 18, 19). The data from the last two localities are included in fig. 3. Sugden & Miller (1976) report an old series total aIle:Ile value for redeposited shell fragments in till at Naqerdloq kangigdleq (21). For comparison with the older data, two sets of aIle:Ile ratios for samples with finite radiocarbon ages are shown in Table 6.

As has been widely discussed (e.g. Miller & Hare, 1980) aIle:Ile ratios in shells can be used for correlation purposes and the establishment of local stratigraphies within areas which have experienced similar diagenetic temperature histories. Interpretation of the Greenland data is problematical because their large geographical spread implies a spatial as well as temporal variation in diagenetic temperature regimes. The present mean annual temperatures vary across the region by about 8°C (−2.7°C at Holsteinsborg (66° 57′N) to −10.5°C at Dundas (76° 34′N) (Lysgaard, 1969)). Although Andrews & Miller (in press) consider that summer temperatures are more representative of effective diagenetic temperatures, there is still a present day difference of 3.1°C in the maximum monthly mean temperatures, together with a variation in the duration of positive temperatures, by a factor of *c.* 2 (Lysgaard, 1969). Consequently long distance correlation remains uncertain. However, it is usually assumed that within a restricted geographical area any differences in amino acid ratios are primarily due to age differences unless secondary factors have operated, such as local differences in ground temperatures. These can arise by several means, which may affect variously *in situ* or reworked shells, e.g. burial by glacier ice of different thermal regimes, different histories of marine submergence, subaerial exposure during reworking by past or present erosional processes. The effects of the last have been minimised by using shells excavated from sections for analysis (except Nerutussoq (14) AAL-2521). Other im-

Table 4. Amino acid data (new and re-analysed) from shells from western Greenland

Locality, Lab. No., sample No. & species analysed	aIle : Ile ratios				
	New series		Old series		
	Total	Free		Total	Free
1. Olrik Fjord	0.0285	0.30			
AA-2849/GGU 226427	0.031	0.28			
M. truncata	0.034	0.25			
x̄	0.031	0.28			
5. Qungulertôq	0.056	0.31	AA-2158	0.059	0.37
AA-3519/GGU 194467	0.053	0.27	GGU 194467	0.084	0.34
M. truncata	0.049	0.28	M. truncata	0.092	0.34
	0.053	0.29		0.078	0.35
Correction factor (total) = 0.673					
7. Ivnârqigsorssuaq	0.075	0.43	AA-1118	0.056	0.50
AA-3520/GGU 194478	0.093	0.42	GGU 194472	0.055	0.55
M. truncata	0.096	0.395	M. truncata	0.055	0.61
	0.088	0.415		0.055	0.55
Correction factor (total) = 1.60					
10. Kaffehavn	0.031	0.21	AA-2519	0.043	0.21
AA-3517/GGU 261734	0.032	0.23	GGU 261736	0.049	0.22
M. truncata	0.030	0.18	M. truncata	0.046	0.20
	0.031	0.21		0.046	0.21
Correction factor (total) = 0.674					
13. Suvdlua	0.0215	0.15			
AA-2934/GGU 261798	0.022	-			
H. arctica	0.022	0.23			
	0.022	0.19			
14. Nerutussoq	0.021	0.18			
AA-2935/GGU 262001	0.022	0.16			
M. truncata	0.021	0.17			
	0.021	0.17			
20. Eqalugssugssuit	0.125	0.501	AA-430	0.155	0.34
AA-3518/GGU 213563	0.160	0.570	GGU 110406	0.17	0.34
M. truncata	0.124	0.532	M. truncata		
	0.136	0.534		0.163	0.34
Correction factor (total) = 0.837					

Table 5. Amino acid data, old series analyses corrected using factors from Table 4

Locality and correction factor	aIle : Ile ratios			
	Corrected Total	Lab. & sample No. & species analysed	Old Series Total	Old Series Free
4. Wolstenholme Fjord	0.064	AAL-1119	0.040	0.44
x 1.6	0.082	GGU 194484	0.051	0.42
	0.059	*H. arctica*	0.037	0.46
	0.068		0.043	0.44
6. Navdlortoq A	0.119	AAL-1117	0.075	0.38
x 1.6	0.096	GGU 194471	0.060	0.31
	0.059	*H. arctica*	0.037	0.39
	0.091		0.057	0.36
6. Navdlortoq B	0.059	AAL-2156	0.087	0.36
x 0.673	0.057	GGU 194466	0.084	0.33
	0.052	*M. truncata*	0.077	0.30
	0.056		0.083	0.33
	0.061	AAL-2158	0.090	0.40
	0.061	GGU 194466	0.091	0.38
	0.030	*H. arctica*	0.045	0.20
	0.050		0.075	0.33
8. Tugtorqortôq	0.081	AAL-2159	0.12	0.34
x 0.673	0.084	GGU 194419	0.125	0.33
	0.081	*H. arctica*	0.12	0.31
	0.082		0.122	0.33
9. Kingigtoq	0.158	AAL-1116	0.099	0.45
x 1.6	0.139	GGU 194451	0.087	0.38
	0.149	*M. truncata*	0.093	0.415
11. Tukingassoq	0.021	AAL-2522	0.031	0.19
x 0.674	0.024	GGU 261756	0.035	0.20
	0.024	*H. arctica*	0.036	0.19
	0.023		0.034	0.193
12. Søndre Upernavik	0.024	AAL-2523	0.036	0.18
x 0.674	0.029	GGU 261750	0.043	0.21
	0.017	*H. arctica*	0.025	0.18
	0.023		0.035	0.19
14. Nerutussoq	0.029	AAL-2521	0.043	0.17
x 0.674	0.024	GGU 262007	0.036	0.20
	0.022	*H. arctica*	0.033	0.23
	0.025		0.037	0.20
15. Arfertuarssuk	0.022	AAL-2518	0.033	0.13
x 0.674	0.019	GGU 261797	0.028	0.17
	0.018	*M. truncata*	0.027	0.15
	0.020		0.029	0.15

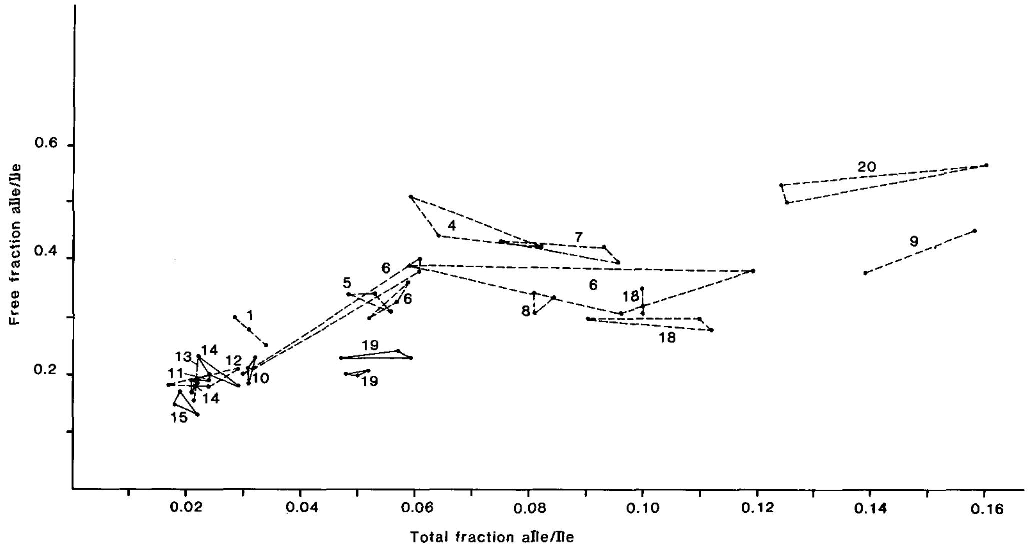


Fig. 3. AIle:Ile ratios in the free and total fractions in shells from western Greenland, excepting Pátorfik (17) and Naqerdloq kangigdleq (21). Solid lines: envelopes of values from *in situ* shells; dashed lines: from reworked material.

Table 6. Holocene and late pre-Holocene amino acid data from western Greenland

Locality & Sample No.	^{14}C date Lab. No.	aIle : Ile data			Ref.
		total		free	
		corrected value	old series		
a. Sanerâta timâ (63° 30.8'N) GGU 157315	13380±175* I-7624	∿ 0.021	0.027†	≤0.09	Weidick, 1975; Miller & Hare, 1980
b. Kangiussap imâ (71° 45.5'N) GGU 261711	9400±110‡ HAR-4881	0.014	0.021*	ND	new locality
		0.011	0.016	"	
		0.011	0.017	"	
		x̄ 0.012	0.018 (AAL-2520)		

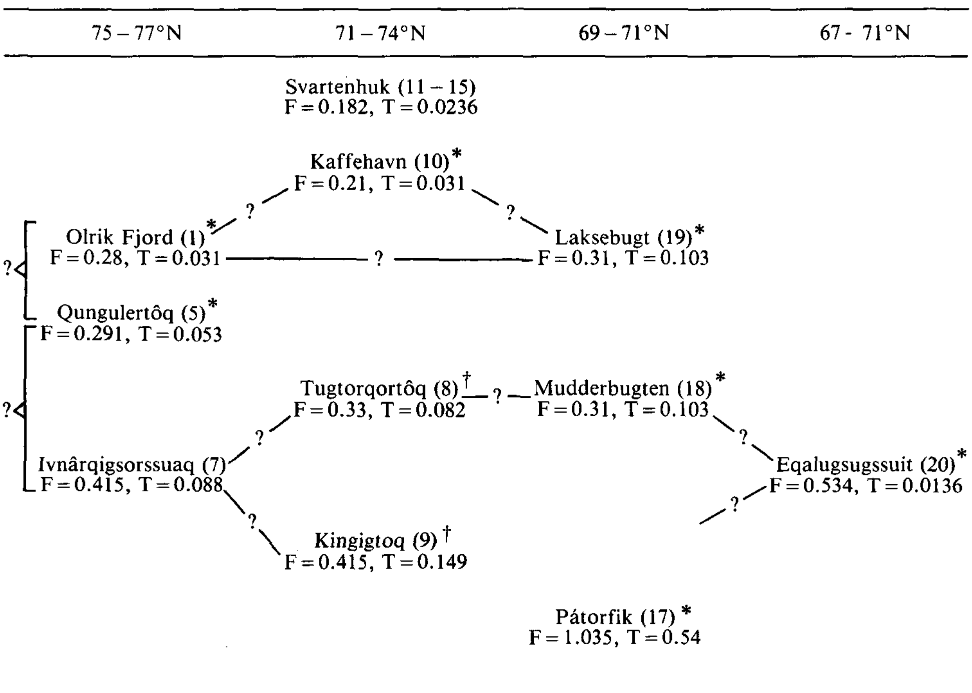
*Mya truncata, †Hiatella arctica, ‡Portlandia arctica.

portant secondary factors are the mixing of shells of different ages by reworking, and the loss of, or contamination by, amino acids during diagenesis.

The increase in within site variation with apparent age shown by fig. 3 is likely to be due to these secondary factors. The extreme variation in the data from Navdlortoq (6) is probably due to the mixing of shell faunas by reworking. Other localities at which the shells may be redeposited, however, show little variation, e.g. Qungulertôq (5).

Since correlation over short distances is most secure, a series of local aminozones, in the sense of Nelson (1982), have been proposed for different latitudinal bands in western Greenland (fig. 4) (Funder & Símonarson, 1984; Kelly, 1985). However, several alternative schemes for their correlation over longer distances are possible. In addition the zones are heterogenous, in that some are based on *in situ* shells and others on reworked shells, which may obscure age relationships between aminozones.

Whilst the clustering of the data in fig. 3, bringing data from northern and southern localities together, suggests that regional aminozones could be defined, they would only correlate material of similar age if there had been uniform diagenetic thermal regimes over the whole 10° spread of latitude in western Greenland. Miller (1985), in fact, suggests that this was the situation along the length of the eastern Canadian arctic. However, except for localities 9 & 20, separate trends can be recognised in fig. 3 for northern and southern localities, suggesting the possible existence of several thermal regimes.



* Contains *Chlamys islandica* and/or *Mytilus edulis*. † Based on corrected value

Fig. 4. Local aminozones with mean free (F) and total (T) aIle:Ile ratios (locality numbers in brackets) (based on Kelly, 1985).

Fig. 5 illustrates another approach to the problem of regional correlation, if assumptions can be made about the diagenetic temperatures. In this hypothetical case it is assumed that there was a latitudinal gradient in diagenetic temperatures as large as that for present mean annual temperatures. The Arrhenius equation (Miller, 1985), describing the rate of epimerisation of aIle to Ile in the total fraction has been used to calculate isochrons for an assumed range of diagenetic temperatures. The analytical data have been located on this diagram by assuming that the relevant effective diagenetic temperature is the same as the present mean annual temperature, as indicated approximately by the latitude of the locality.

The diagram can be used to determine the range of possibilities that exist for correlating, and dating, the marine material according to whatever hypothetical diagenetic temperature model is proposed. The alternatives are constrained closely only by the minimum radiocarbon ages for the youngest shells.

Chronostratigraphy of marine events

In western Greenland, in the Middle and Late Quaternary at least, the duration of marine sedimentation, and its spatial extent, will be controlled mainly by the behaviour of the Greenland Ice Sheet and its glacioisostatic effects, and the eustatic responses to global ice sheet changes. In the sense used here a marine event could include both the transgressive and regressive phases associated with a major retreat of an ice margin and its subsequent advance. Typically, therefore, the deposits of distinct marine events would be separated by glacial deposits, except in the area beyond the maximum ice margin position. Also, depending on their relative elevation, the deposits of a single marine event could be interrupted by terrestrial non-glacial deposits. However unless the scale of the associated ice margin fluctuation is defined, the term 'marine event' has a relative meaning only. These criteria are difficult to apply because of the lack of stratigraphic continuity in the deposits, and in practice the marine events have been separated here on the basis of apparent age differences.

Since it is mainly the amino acid data which indicate that there have been a number of marine events in the area, the more securely based aminozones are used to define the marine events. For the area north of 71°N, from which most of the new data come, the Svartenhuk and Kaffehavn marine events are based on the aminozones of those names. It is not known how many more marine events are represented by the aminozones based on reworked faunas (Qungulertôq, Ivnârqigsorssuaq, Kingigtoq), because of the uncertain effects of reworking. Provisionally, one only has been proposed – the Meteorbugt marine event (Kelly, 1985).

The Svartenhuk marine event, to which the deposits at localities 11–15 belong, and probably also that at the nearby site at Kugssineq (16) (Laursen, 1944), is clearly the youngest pre-Holocene event. Although their radiocarbon age is >40 ka, the amino acid values suggest a very young age, with the mean total aIle/Ile ratio indicating a mean age of >55 ka for an effective diagenetic temperature of −7°C. The lithostratigraphic evidence suggests that the marine event was closely linked in time to a glacial advance which brought the ice margin to the outer coast, overriding the marine deposits. The till below the marine horizon at Nerutussoq (14) may be from an oscillation of the same advance, or indicate the existence of a distinct older glacial advance. The faunas of arctic bivalves in these deposits are compatible with the marine event being closely related to a glacial advance.

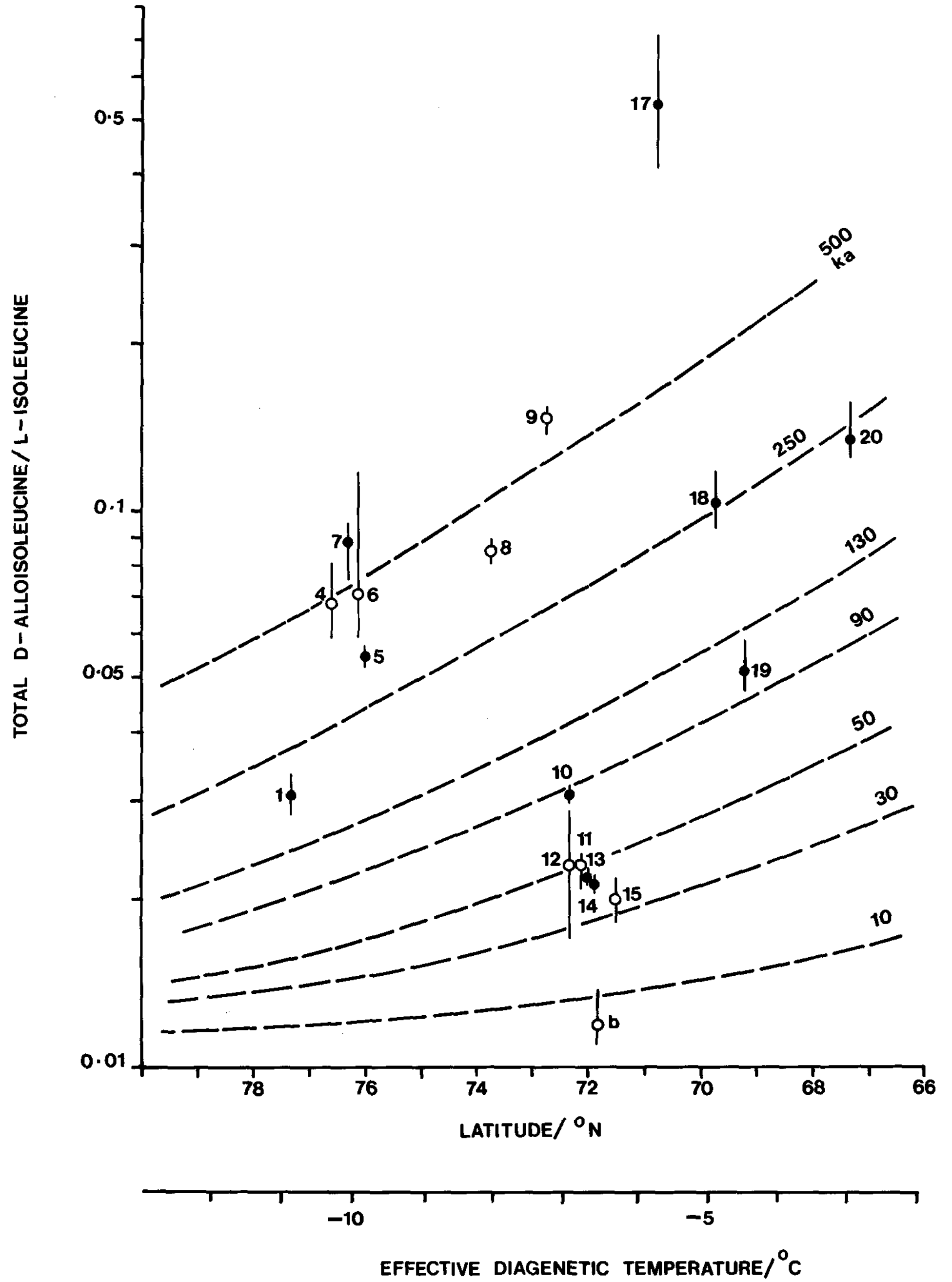


Fig. 5. Latitudinal distribution of total fraction aIle:Ile ratios (means and ranges, solid circles: new series values; open circles: corrected old series values), and AIle:Ile isochrons for a hypothetical diagenetic temperature model. Locality numbers refer to Table 1 and letter to Table 6 (based on Kelly, 1985).

A provisional estimate of the age of the older Kaffehavn marine event from the amino acid data is >90 ka. Notably the type deposit has a fauna containing subarctic bivalves. The overlying till appears to belong to the post-Svartenhuk advance and it may be that the Kaffehavn and Svartenhuk events are both part of one long marine event. The Olrik Fjord aminozone may date also from this interval, or from an older marine event. The (probably) reworked fauna at this site includes subarctic species indicating that subarctic water masses extended up to 77°N.

Faunas with subarctic species also occur in deposits of the apparently older Meteorbugt marine event (*sensu lato*) which appear to date broadly from the Middle Quaternary, though more than one event may prove to be represented by these deposits. Again the faunas indicate the extension of subarctic water masses up to their present northern limit. The previously known northern sites with subarctic faunas, Saunders Ø and Isbjørn Ø, for which there is no amino acid data available, may therefore be correlated with either the Olrik Fjord or Qungulertôq deposits, which apparently belong to different marine events of possibly very different age.

For the region south of 71°N a similar approach may be made, in that the three aminozones of Funder & Símonarson (1984) may be used to define marine events – Laksebugt, Mudderbugten and Pátorfik, named after the relevant aminozones. The Eqalugsugssuit marine material described earlier can be assigned to the Mudderbugten event from the amino acid data, if some allowance is made for a difference in diagenetic temperature. The reworked shells at Naqerdloq kangigdleq (21) (Sugden & Miller, 1976) may also belong here. Funder & Símonarson considered the age of the Laksebugt aminozone to be *c*. 130 ka, of the Pátorfik to be Early or Middle Quaternary, and of the Mudderbugten to be between these two. The mixed polar and subarctic fauna at Laksebugt, together with the large isostatic depression implied by the elevation of the deposit, was taken as evidence of the deposit dating from a glacial/interglacial transition, inferred to correspond with the oceanic isotope stage 5/6 transition (Funder & Símonarson, 1984).

The faunas present in all four deposits in this southern region, from possibly three different marine events, contain subarctic molluscs. The boreal-subarctic-arctic fauna of Pátorfik, as well as its amino acid values, shows the uniqueness of this deposit amongst the others known from western Greenland.

Discussion

The features of the pre-Holocene marine material of the area which show the most variation, are the composition of the bivalve mollusc faunas and the amino acid ratios derived from these. The amino acid data appear to be the most sensitive for stratigraphical purposes but unfortunately their use is greatly limited by the uncertainty about the differences in diagenetic temperatures to be expected over such a wide latitudinal distance as occurs in western Greenland. In addition the impact on the data of local variation in diagenetic temperatures, to which the redeposited faunas may be particularly susceptible, is difficult to assess. However one interpretation of the data suggests that a minimum of four pre-Holocene marine events are represented by the twenty-three known deposits, with a possibility that this may be six or more.

The chief diagnostic biostratigraphic feature, of a subarctic faunal component, is shown by the amino acid data to have been a recurring characteristic, being found in deposits of at least three and maybe five marine events, the number depending on the aminozone correlation. It appears, therefore, that a fully developed subarctic West Greenland Current, extending to *c.* 77°N, occurred during at least two of the pre-Holocene marine events.

The lithostratigraphic data are least useful for correlative purposes since the sequences of deposits produced in each glacial and marine cycle are potentially the same, and also because the duration of time gaps is not evident. The latter means that the glacial deposits overlying or incorporating reworked marine material may date from any time from immediately succeeding the marine event up to the time of the last major glaciation to cover western Greenland – the Sisimiut glacial event (>13 ka) (Kelly, 1985).

Fig. 6 gives a provisional interpretation of the stratigraphy of marine and glacial events in western Greenland. Similar complex sequences of marine events/episodes have been described from adjacent arctic areas, also reflecting glacioisostatic and eustatic events accompanied by changes in marine circulation patterns, i.e. East Greenland (e.g. Funder, 1984; Hjort & Björck, 1984) and East Canadian Arctic Islands (e.g. Miller, 1985). Funder

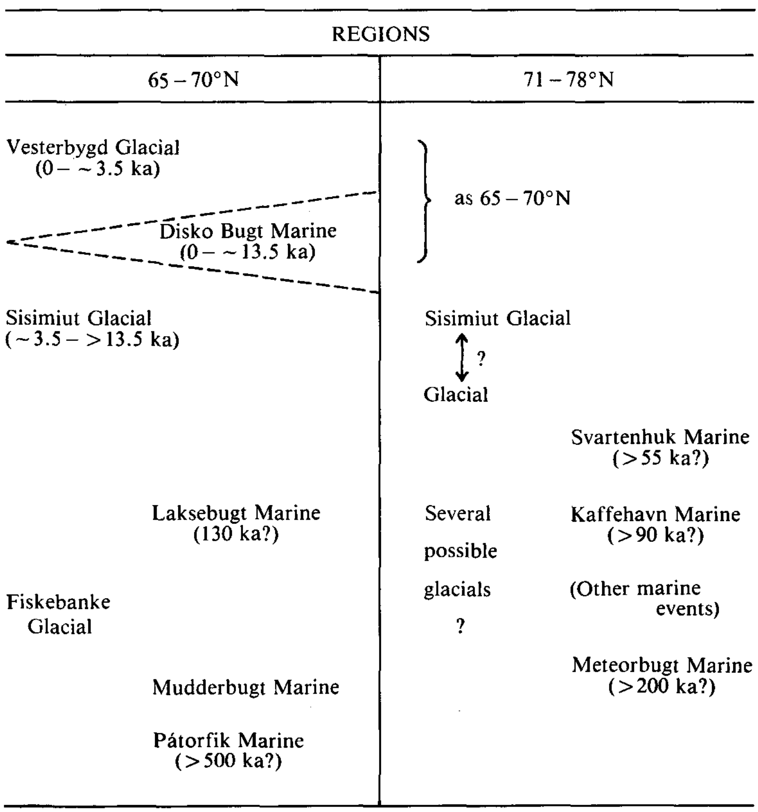


Fig. 6. Stratigraphy of marine and glacial events in two regions of western Greenland and their provisional ages.

(1984) has attempted recently to correlate the West and East Greenland successions with the offshore marine records of the North Atlantic and Baffin Bay. Putting the western Greenland sequence in its regional context in this part of the Arctic depends on the matching of glacial events, the age indications of amino acid data and the faunal evidence of water mass characteristics, all forms of evidence which have their limitations. For example, there probably have been major differences in amplitude of glacial advances in the region, e.g. between East and West Greenland (Funder, 1984). The uncertainties associated with the amino acid data have been referred to already. In addition it is not yet clear whether the subarctic West Greenland Current, with its characteristic fauna, existed only during periods with hemispheric interglacial climates such as the present, as Funder has suggested, or whether it persisted into glacial episodes, as the offshore marine evidence suggests, according to Aksu (1985).

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