Geomorphology and Sedimentary Record of Three Cuspate Forelands as Indicators of Late Holocene Relative Sea-level Changes, Disko, West Greenland.

Morten Rasch, Bjarne Holm Jakobsen & Niels Nielsen

Abstract

The coastal geomorphology of three cuspate forelands at Saqqarliit Ilorliit, western Disko, West Greenland is described, sediment core data from salt marshes and lagoons are presented, an emergence curve is constructed, and data are discussed in relation to late Holocene relative sea-level (RSL) changes. On western Disko, falling RSL in early-middle Holocene was followed by rising RSL in late Holocene. Emergence continued until c. 2.5 ka BP. The coastal geomorphology at Saqqarliit Ilorliit suggest transgression early in the interval 2.5 - 1.0 ka BP and between 0.7 ka BP and the present. The first transgression resulted in formation of an intertidal platform and coastal cliffs. Washover ridges and lagoons developed during the transgression after 0.7 ka BP. Based on the core data it is suggested that the transgression after 0.7 ka BP might have consisted of three transgression phases separated by periods with stable or slightly regressive conditions.

Keywords

West Greenland, relative sea-level, late Holocene, coastal geomorphology, lagoon sediments, cuspate forelands.

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In West Greenland information about late Holocene (Neoglacial, Local name: Vesterbygd glacial) relative sea-level (RSL) changes have been provided from scattered geological observations (Donner & Jungner 1975; Donner 1978; Foged 1979; Kelly 1979, 1980, 1985; Funder 1989), geomorphological observations (Binderup 1986; Bojsen & Frederiksen 1980; Rasch & Nielsen 1994, 1995; Rasch et al. 1996), archaeological observations (Mathiassen in Gabel-Jørgensen & Egedal 1940; Bøgvad 1940; Roussel 1941; Larsen & Meldgaard 1958; Weidick 1993; Kramer 1996) and early tidal observations (Gabel-Jørgensen & Egedal 1940; Saxov 1958). It is well established that falling RSL, caused by glacio-isostatic uplift after the Wisconsinan glaciation, approached present sea level c. 3 ka BP (Donner & Jungner 1975; Kelly 1980, 1985; Funder 1989; Frich & Ingolfsson 1990). It is also well established that RSL, at least in some parts of West Greenland during the last c. 3 ka, has been lower than at present (Mathiassen in Gabel-Jørgensen & Egedal 1940; Roussel 1941; Weidick 1976, 1993; Foged 1979; Rasch & Nielsen 1994, 1995; Rasch et al. 1996), and that a transgression maximum occurred in the middle of the present century (Gabel-Jørgensen & Egedal 1940; Saxov 1958). Based on the location of Thule Culture Eskimo ruins of different ages in relation to the present shoreline it has been suggested that RSL was relatively high before 0.4 ka BP, that it was relatively low between 0.4 and 0.2 ka BP, and that it has been rising since (Mathiassen in Gabel-Jørgensen & Egedal 1940; Weidick 1993).

The purpose of this investigation is to reconstruct the trend of the early-middle Holocene emergence of western Disko and to point out possible transgression phases during late Holocene. The geomorphology of three cuspate forelands at Saqqarliit Ilorliit (Fig. 1) is described, sediment core data from salt marshes and lagoons are presented, and a RSL curve for western Disko is constructed from published and new ^{14}C dates. Data are used to suggest and discuss a possible sequence of Holocene RSL changes.

Physical Settings

The study area, Saqqarliit Ilorliit, is located in the inner part of Akulliit, which is the middle of three large fiords on

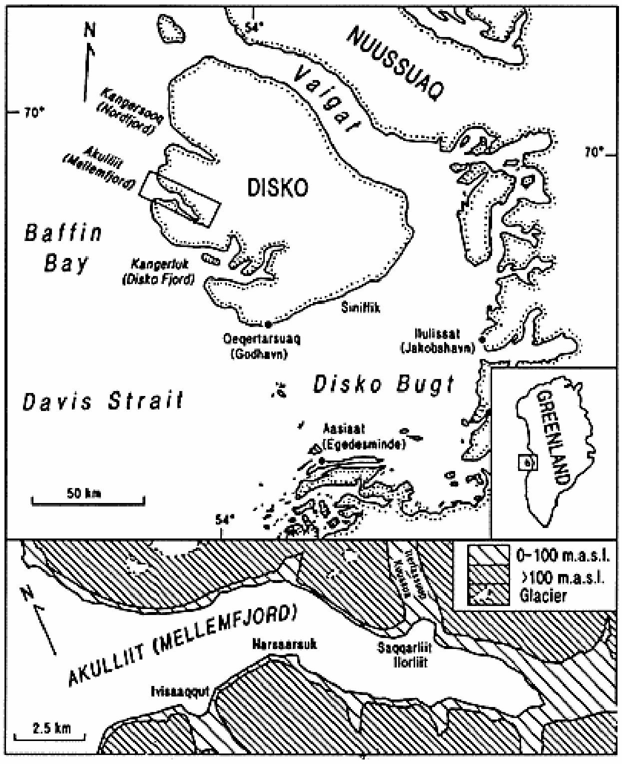


Figure 1: Location map showing the study area and the nearest towns. Old Danish names are given in brackets.

western Disko (Fig. 1). The fiord is c. 3 km wide and 25 km long with a maximum water-depth in the fjord of 160 m. The bedrock in the fiord consists of Tertiary basalts. Upwards, the fiord terminates at plateaus c. 1000 m.a.s.l.. Despite the steep fiord sides, depositional shorelines appear frequently along the fiord. Generally, littoral deposits consist of beach gravel. The Holocene marine limit is situated between 60 and 65 m.a.s.l. (Ingólfsson et al. 1990).

The wave climate on western Disko is characterized by wind generated waves and swell caused by cyclones in Davis Strait and Baffin Bay. Boulder beaches on the outer coasts indicate high energy conditions during storms. The intensity of waves decreases eastwards along Akulliit. The inner part of the fiord is a good natural harbour even during severe storms. Akulliit has semi-diurnal mixed tide with a spring tidal range of c. 2.9 m (unpubl. data). The sea in Akulliit is usually frozen from the middle of December to the beginning of June.

Methods

A geomorphological map of the coastal zone at Saqqarliit Ilorliit was prepared from field-checked air photo interpretation (Fig. 2). Altitudes of landforms were measured along profiles (Figs. 3 and 4) using electronic theodolite and echo-sounder. To allow comparison of altitudes between this and future investigations, a local datum (mean sea-level) was based on tidal observations over eight days. Absolute and relative errors on altitude measurements are considered to be respectively ± 0.5 m and less than ± 0.2 m.

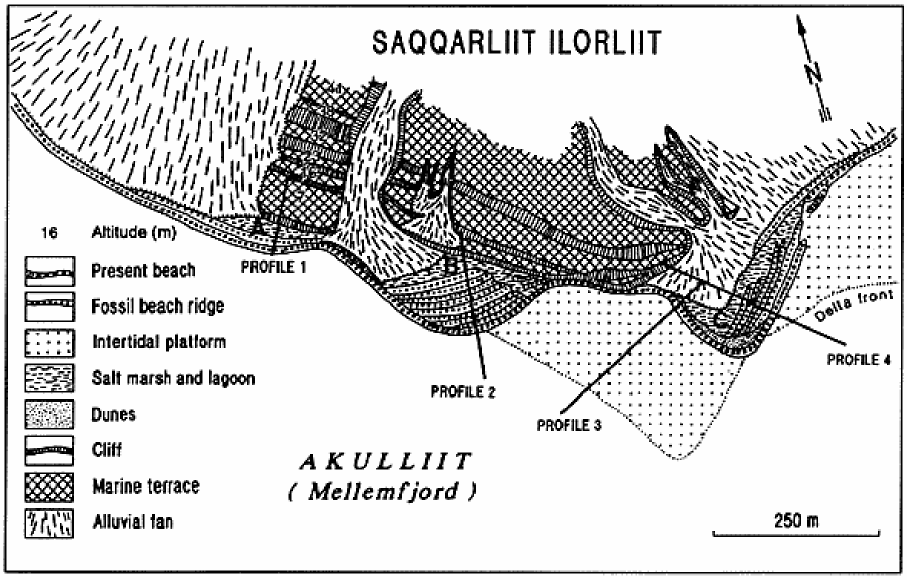


Figure 2: Geomorphologic sketch map of Saqqarliit Ilorliit. A, B and C indicate positions of cores (see Figure 10).

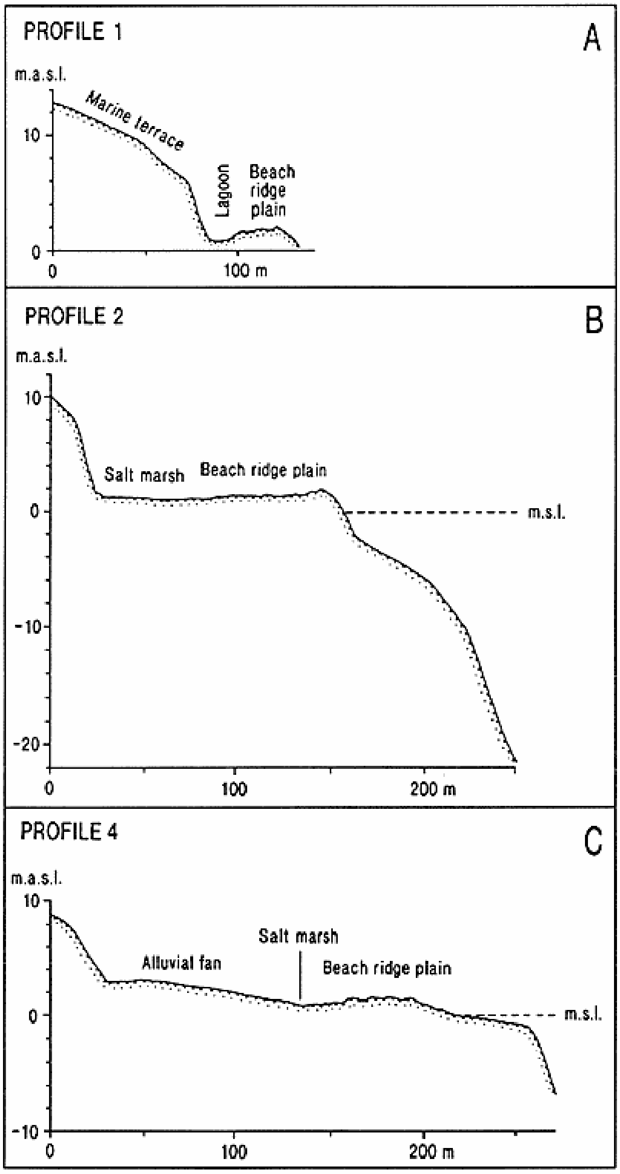


Figure 3: Topographic profiles of the western (A), the middle (B) and the eastern (C) cuspate forelands at Saqqarliit Ilorliit. Landward the profiles crosses a washover ridge (the present beach), a beach ridge plain (the cuspate foreland) and a coastal cliff. The positions of the profiles are shown in Figure 2.

Short sediment cores were collected from the deepest parts of lagoons within the three cuspate forelands by pressing plexiglass tubes into the sediment (Fig. 2). The sediment cores were described, and samples were collected for ^{14}C dating and for particle size and chemical analyses. Particle sizes were analysed by the sieve and pipette method. Total C and S were determined by combustion in a LECO induction furnace and extractable metals (Ca, Mg, Na, K, Fe and Mn) were analysed using atomic absorption spectrophotometry (AAS). For metal extraction a simplified successive treatment with concentrated nitric acid and hydrochloric acid, suggested by Bengtsson and Enell (1986), was used to determine the acid-soluble amounts of various elements. ^{14}C datings of organic carbon in seven lagoon sediment samples (AAR 1810-1816) were carried out on bulk samples using the AMS-technique at the University of Aarhus, Denmark (Heinemeier et al. 1992). Errors caused by pre-sampling contamination of bulk samples have been described in details by Mook and van de Plassche (1986).

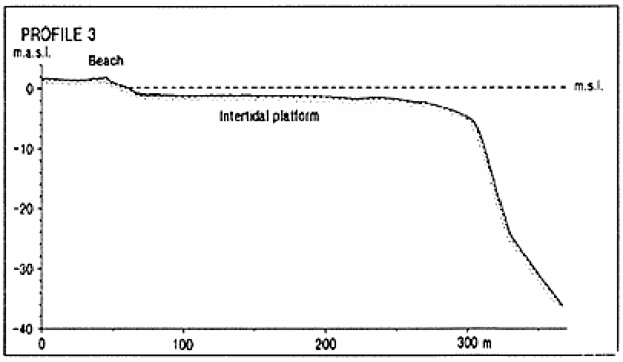


Figure 4: Topographic profile of the intertidal platform between the eastern and middle cuspate forelands at Saqqarliit Ilorliit. The position of the profile is shown in Figure 2.

Both new and published radiocarbon dates on marine and terrestrial/lacustrine material were used for the construction of a RSL curve (Table 1 and Fig. 11). The curve has been drawn on free hand. The criterias used for the construction of the curve are described in details in the figure text. Where possible, dates on marine material were corrected for isotopic fractionation by normalising to ^{13}C = 0.0 ‰ PDB. Dates on terrestial/lacustrine material (including the dates on the seven lagoon sediment samples) were corrected for isotopic fractionation by normalising to ^{13}C = -25.0 ‰ PDB. The marine reservoir effect in central West Greenland is expected to be 410 years (Rasmussen & Rahbek 1996).

Coastal geomorphology

Saqqarliit Ilorliit comprises three cuspate forelands at the mouth of a hanging valley (Figs. 1 and 2). The altitude of the cuspate forelands ranges from 0.9 to 1.5 m.a.s.l.

Table 1: Radiocarbon dates from Disko west of 54°W. Location numbers refer to the numbers in Figure 11.

Loc. no.	*Lab. no.*	*N lat.*	*W long.*	*Material*	*Elevation m.a.s.l.*	*Age, ^{14}C yrs BP*	*$\delta^{13}C$ 0/00 PDB*	*Reference*
8	AAR-1813	69°44'	54°30'	Mud	1.2	-190 +- 70	-25.0	This work
8	AAR-1814	69°44'	54°30'	Mud	1.2	300 +- 60	-24.4	This work
8	AAR-1815	69°44'	54°30'	Mud	0.8	360 +- 80	-25.5	This work
8	AAR-1810	69°44'	54°30'	Mud	0.9	420 +- 80	-24.8	This work
8	AAR-1816	69°44'	54°30'	Mud	0.6	620 +- 80	-26.0	This work
8	AAR-1811	69°44'	54°30'	Mud	0.8	700 +- 160	-24.8	This work
8	AAR-1812	69°44'	54°30'	Mud	0.7	710 +- 200	-25.0	This work
11	AAR-2198	69°44'	54°40'	Peat	0.6	840 +- 60	-21.6	This work
12	K-3161	69°44'	54°50'	Whale	2	2750 +- 80		Bojsen & Frederiksen 1980
5	K-3692	69°57'	54°21'	Shells	7 - 10	4750 +- 90	0.3	Ingólfsson *et al.* 1990
14	Hel-902	69°27'	54°14'	Shells	8.7	4780 +- 120	1.4	Ingólfsson *et al.* 1990
6	I-16358	69°57'	54°14'	Whale	4.5	5920 +- 120	-1.2	Bennike *et al.* 1994
7	RCD-24	69°52'	54°50'	Whale	22	6870 +- 80	0.0	Bennike *et al.* 1994
4	I-16357	70°04'	54°40'	Shells	3.8	6940 +- 120	-2.0	Bennike *et al.* 1994
6	I-16366	69°57'	54°49'	Shells	6.5	7190 +- 150	-21.6	Bennike *et al.* 1994
7	I-16356	69°52'	54°46'	Shells	22	7350 +- 120	-19.6	Bennike *et al.* 1994
7	K-5509	69°52'	54°46'	Shells	15 - 20	7810 +- 90	-0.8	Bennike *et al.* 1994
5	Hel-901	69°56'	54°17'	Shells	11.2	7980 +- 150	0.8	Donner 1978
14	K-3693	69°26'	54°21'	Shells	20	8050 +- 115	0.0	Ingólfsson *et al.* 1990
13	K-5969	69°37'	54°45'	Whale	36	8400 +- 90	-15.8	Bennike *et al.* 1994
10	AAR-2459	69°43'	54°38'	Shells	20	8730 +- 80	1.1	This work
9	Lu-3039	69°43'	54°25'	Shells	19	8770 +- 90	1.0	Ingólfsson *et al.* 1990
12	Lu-3041	69°44'	54°50'	Shells	35	9060 +- 90	0.5	Ingólfsson *et al.* 1990
2	I-16390	70°14'	54°47'	Shells	4	9200 +- 150	-1.9	Bennike *et al.* 1994
4	K-5510	70°03'	54°45'	Shells	38 - 44	9350 +- 100	-3.8	Bennike *et al.* 1994
3	Lu-3037	70°10'	54°50'	Shells	38	9360 +- 140	-0.8	Ingólfsson *et al.* 1990
1	I-16393	70°16'	54°37'	Shells	25	9920 +- 150	-3.7	Bennike *et al.* 1994

Marine terraces at 7, 16, 23, 32, 38 and 41 m.a.s.l. behind the forelands show that marine deposition has occurred on this site throughout the Holocene (Figs. 2 and 5). The terraces slope towards ESE, and they are separated by cliffs sloping less than 20°. The surfaces of the terraces consist of rounded to well-rounded pebbles covered by heath vegetation. No beach ridges could be discerned on the terraces in the field. However, on air photos a pattern of parallel light and dark bands can be seen on the terraces. These bands might represent remains of beach ridges that have been leveled out by solifluction, and the cliffs between the terraces might represent relict coastal cliffs formed by coastal erosion. Alternatively and more probably, the terraces represent fan deltas of the alluvial fan

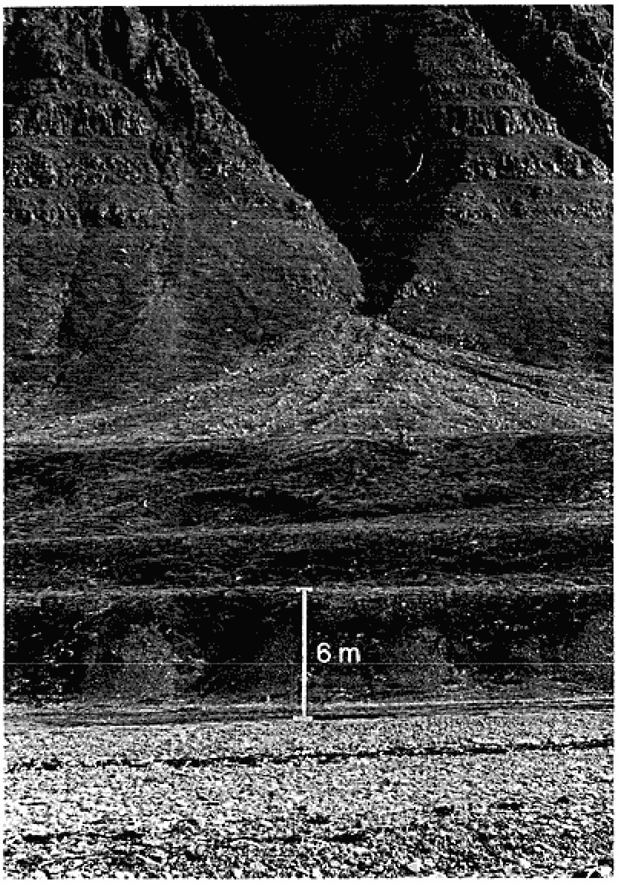


Figure 5: At Saqqarliit Ilorliit several marine terraces occur in the lowest c. 50 m of the terrain. The terraces indicate coastal deposition on the site throughout the Holocene. The unvegetated surface in the foreground of the picture is the beach ridge plain of the middle cuspate foreland.

now feeding the eastern cuspate foreland (Fig. 2), and the relatively gently sloping cliffs between them represent the original fronts of fan deltas formed by deposition.

A cliff also separates the lowest marine terrace from the cuspate forelands (Figs. 2, 3 and 5). This cliff has been extensively modified by solifluction and gullying, but it is still much steeper (≈30°) than the cliffs above 7 m.a.s.l.. Between the middle and the eastern forelands the cliff is being eroded by the sea (Fig. 6). The sediment here consists of sand and gravel layers dipping 30° southwards. These layers probably resemble foreset layers of the fan-delta above the cliff. The layers are not parallel to the front of the cliff (Fig. 6), indicating that the cliff is not a relict delta front. It is suggested that the cliff was developed by coastal erosion.

The three cuspate forelands consist mainly of parallel gravel beach ridges (Fig. 2). The relict beach ridges are typically 10 m wide and 0.2 m high, they show no signs of overwash processes. These ridges probably developed as simple beach ridges, i.e. swash ridges (see Tanner 1988). The height of the beach ridges generally increases towards the shoreline. The patterns of the beach ridges indicate accretion by littoral drift from the west. The alluvial fans west of each foreland probably provided the sediment sources for the beaches (Fig. 2). Despite the local origin, the well-sorted sediment of the beaches originally consisted of subrounded to well-rounded basaltic pebbles (typical mean grain size: 20 mm). The sediment has been extensively weathered after deposition, and now the surfaces of the pebbles are notched with small cavities and many pebbles have broken apart (Fig. 7). The high degree of weathering suggests that the beaches are considerably older than the present beach in front of them. Salt marsh and lagoon deposits overlie the lowest parts of the beach ridges on the cuspate forelands. In the western and the middle forelands the tidal inlets have been sealed, and the former lagoon of the middle foreland has been completely overgrown by the salt-tolerant grass *Puccinellia sp.*. The lagoon in the eastern foreland is connected to the sea through a tidal inlet, and the central part is flooded at high tides. In the southern part, salt marsh occupies the swales between the beach ridges (Fig. 8).

The active beach ridge along the forelands is higher (≈0.5 m) and wider (≈25 m) than the relict beach ridges (Figs. 3 and 4), it has the whale-back shape characteristic for washover ridges (transgressive barriers), and it cross cuts the distal part of the relict beaches (Fig 2). On the tip of the eastern foreland dunes have formed on the beach crest. Partly buried wreckage and washover fans on the landward slope of the beach indicate that it occasionally has been washed over in modern time. It has not been possible to estimate the shore-line retreat at Saqqarliit Ilorliit, but along the proximal side of similar cuspate forelands at Saqqarliit Silarliit and Narsaarsuk in western Akulliit a shoreline retreat of at least 5 metres is indicated by the partly burial of Thule Culture (<0.5 ka BP) sod houses by similar washover ridges. The lichen coverage on the walls of these houses suggests an age of at least 100-200 years.

The shore faces of the forelands are generally steep (>10°). However, broad intertidal platforms occur east of the eastern foreland and between the eastern and the middle foreland. The platform east of the eastern foreland is part of the delta of the Iterlassuup Kuussua river (Fig. 1 and 2). The platform slopes less than 0.1 ° southwards, and sandy and muddy flats occur on the platform. The steep front (c. 10°) of the platform is situated c. 1.5 m below sea level. The platform between the middle and eastern forelands consists of a triangular plain c. 0.5 m below sea level. On air photos the edge of the platform appears as a white line attaching the present shoreline at the tip of the eastern foreland and at the eastern side of the middle foreland. The outline of the platform is almost identical to the outline of the eastern cuspate foreland, and the surface sediments of the platform mostly consist of subangular to

Figure 6: *Foreset layers exposed in an active coastal cliff between the middle and eastern cuspate forelands. The foreset layers generally dip 30 ° towards the south.*

Figure 7: *Typical sediment from the fossil beach ridges within the cuspate forelands at Saqqarliit Ilorliit. Notice the high degree of weathering and the low degree of lichen coverage.*

well-rounded granules and pebbles overlaid by a thin mud layer. At first sight this suggest that the platform originated as a cuspate foreland when RSL was lower than at present. However, no beach ridges occur on the platform, and its steep distal slope (>40°, Fig. 4) is difficult to explain as a former shore face developed by coastal deposition. Alternatively and more probably, the platform has formed as a fan delta before the development of the cuspate forelands. In arctic Canada similar platforms have been related to upward and outward growth of intertidal flats by material derived from erosion of beaches and raised marine sediments during a late Holocene transgression (Gilbert et al. 1987; Aitken & Gilbert 1989). At Saqqarliit Ilorliit, the sediments for the platforms probably originated from the nearby alluvial fans and from cliff erosion.

Lagoon sediment stratigraphy

The sediments in the lagoons of the cuspate forelands fall into two main groups (Fig. 9). Coarse layers (sand) separate mostly sandy-clayey silt. The sand plot in section A-IV represents the most vigorous hydrodynamic conditions. The fine grained sediments fall into the sections C-III and IV. Generally, older lagoon sediments fall into the most vigorous hydrodynamic class IV, whereas the younger sediments fall into class III, the latter representing more sheltered sedimentary conditions (Pejrup 1988), probably due to beach ridge formation and narrowing of tidal inlets. The chemical records (Fig. 10) indicate sediment sources and depositional conditions. The eastern lagoon (Fig. 10A), which is still open through a tidal inlet, is brackish, and the sodium content in its sediment is high. In the deepest part of the lagoon (0.94 m.a.s.l.) a 27 cm sediment core consists of several sandy, silty and clayey layers resting on coarse beach gravel. The oldest dated lagoon sediments (19-23 cm) have an age of 710 ± 200 a BP (AAR-1812). The sandy silt layer (13-23 cm) shows a slight upward decrease in the contents of the chemical elements Na and S mainly representing marine sources (Berner 1971) and a slight increase in the terrestrial element Fe. The bottom lagoon layer is covered by a 4 cm thick gravelly sand layer (9-13 cm) that fines upwards. This sand is covered by a 1 cm thick mud layer dated to 420 ± 80 a BP (AAR-1810), which is again covered by sand (5-8 cm). The uppermost sediment (0-5 cm) comprises clayey silt with a good sorting and a relatively high content of both C, S, Fe and Na.

The middle lagoon is isolated from the fiord and presently holds fresh water. In the deepest part of the lagoon (1.29 m.a.s.l.) sandy and silty sediments have a thickness of c. 13 cm and overlie sorted sand (Fig. 10B). The oldest mud layer (12-13 cm) was dated to 300 ± 60 a BP (AAR-1814) and six layers of mud and sand have been deposited since.

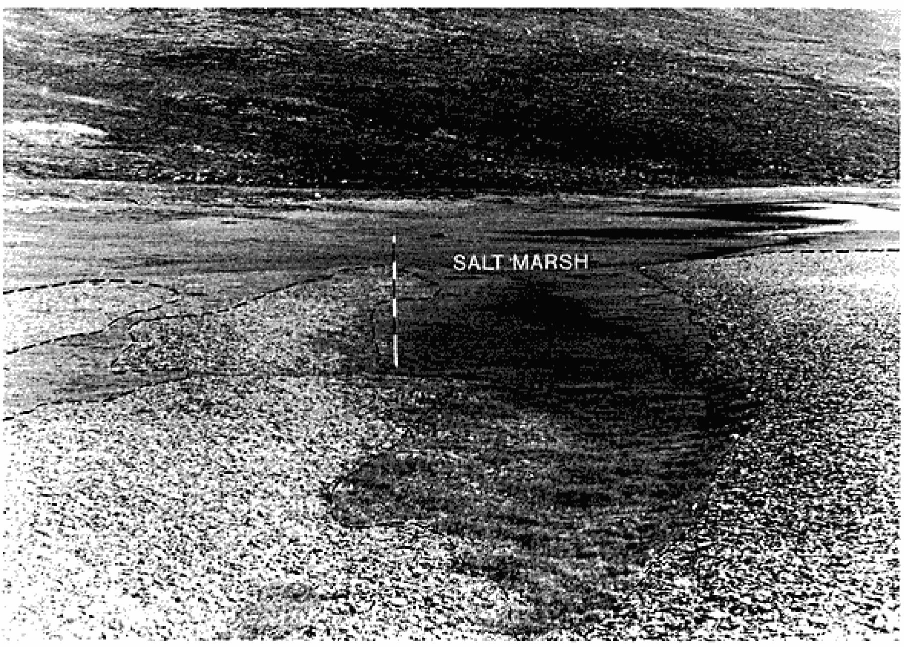


Figure 8: Development of salt marsh on top of fossil beach ridges on the eastern cuspate foreland indicate RSL rise since the origin of the beach ridges. The survey stick in the centre of the picture is 1.4 m high.

The mud layer from 9-11 cm shows a relatively low content of Na and S and a high content of Fe. A sandy layer (4-5 cm) dated post AD 1955 (AAR-1813) represents a marked change in the lagoon environment. The sediment changes from a weakly organic, stratified sediment generally high in Na and S to a generally low organic, silty sediment (0-4 cm) showing a low content of Na and S and a strongly increasing amount of Fe.

The western lagoon now holds fresh water as well. Sediments in the deepest part of the lagoon (0.89 m.a.s.l.) are dominated by silt which is 27 cm thick and covers beach gravel (Fig. 10C). The oldest sandy silt (25-27 cm) is dated to 620 ± 80 a BP (AAR-1816) which dates lagoon formation at this site. A gravelly band at a depth of 17 cm and a somewhat finer sandy silt layer (12-17 cm) represents a transition zone to a sediment of clayey silt (2-12 cm) relatively high in both S, Na and Fe. The sandy silt at 15-17 cm have an age of 360 ± 80 a BP (AAR-1815). In the clayey silt the sand content increases in the upper few centimetres and a sand layer from 0.5-3 cm represents a change in sedimentary conditions followed by the most recent sedimentation of a silty material relatively low in Na.

Discussion and Conclusions

Movements of the shoreline (recession/progradation) at a given site might result from changes of RSL, changes of wave climate and changes of littoral sediment sources (e.g. Forbes et al. 1995; Orford et al. 1996). Besides, short dramatic events like extreme storms, tsunamis or calving of icebergs might cause movements of the shoreline. When synchronous and similarly directed shoreline movements are observed at sites with different exposure and sediment source it is, however, most probable that the shoreline movements resulted from changes of the RSL, climatically controlled changes in the littoral sediment budget or from tsunamis. Morphological sequences like that at Saqqarliit Ilorliit have been observed at several locations on Disko (Rasch & Nielsen 1994, 1995; Rasch et al. 1996). Therefore, it is considered probable that the morphological sequences result from changing RSL or climate. Topographic profiles of the cuspate forelands are shown in Fig. 3. Proceeding landwards, all profiles cross the active beach (a washover ridge), the simple beach ridges of the cuspate forelands (superposed in places by younger deposits) and a relict coastal cliff leading to higher marine terraces. The coastal cliff and the contact between the washover ridge and the simple beach ridges represent unconformities. The morphological sequences indicate shoreline progradation (formation of the lowermost marine terrace) followed by shoreline recession (formation of the coastal cliff and the intertidal platform), again followed by shoreline progradation (formation of the cuspate forelands) and shoreline recession (formation of the washover ridge and the lagoons).

RSL in Akulliit was well above the present sea-level until c. 2.5 ka BP (Fig. 11). The oldest lagoon sediments resting on the beach ridges of the cuspate forelands are at least 0.7 ka old. This shows that the cuspate forelands, and probably also the relict coastal cliff and the shore platform between the eastern and middle forelands developed after 2.5 ka BP and before 0.7 ka BP. At Tuapaat on the south coast of Disko a similar cuspate foreland has been superposed by an alluvial fan (Rasch & Nielsen 1995). The bottom of the alluvial fan was dated to 980 ± 60 a BP (AAR-1422); indicating that this foreland developed before 1 ka BP, and suggesting that the forelands at Saqqarliit Ilorliit also developed before 1 ka BP.

Formation of the cuspate forelands marks a change from

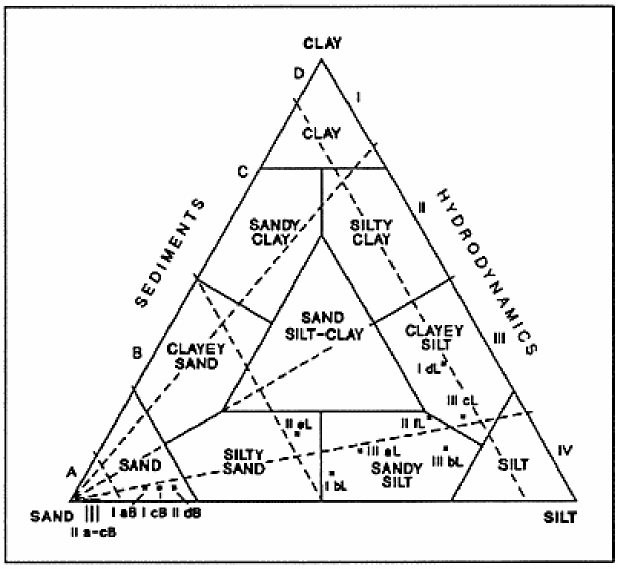
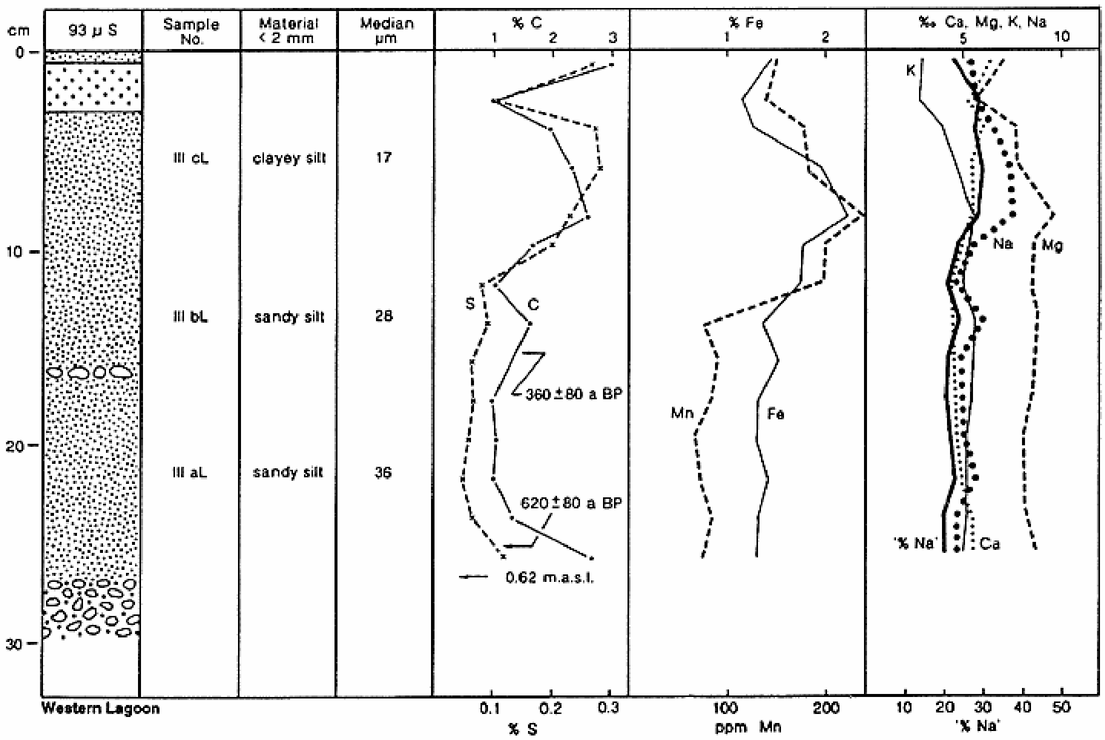


Figure 9: Triangular diagram for the characterisation and grouping of lagoon and beach sediments at Saqqarliit Ilorliit. The dotted lines are superimposed on the sediment classification by Shephard (1954) and divide the triangle in facies of constant sand content and constant textural composition of the mud fraction which is supposed to be associated with the hydrodynamic conditions during sedimentation. Sample numbers (e.g. I aB) are the same as the sample numbers in the logs in Figure 10.

A


cm
93 μ S
Sample No.
Material < 2 mm
Median μm
% C
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‰ Ca, Mg, K, Na
III cL
clayey silt
17
III bL
sandy silt
28
III aL
sandy silt
36
S
C
360±80 a BP
620±80 a BP
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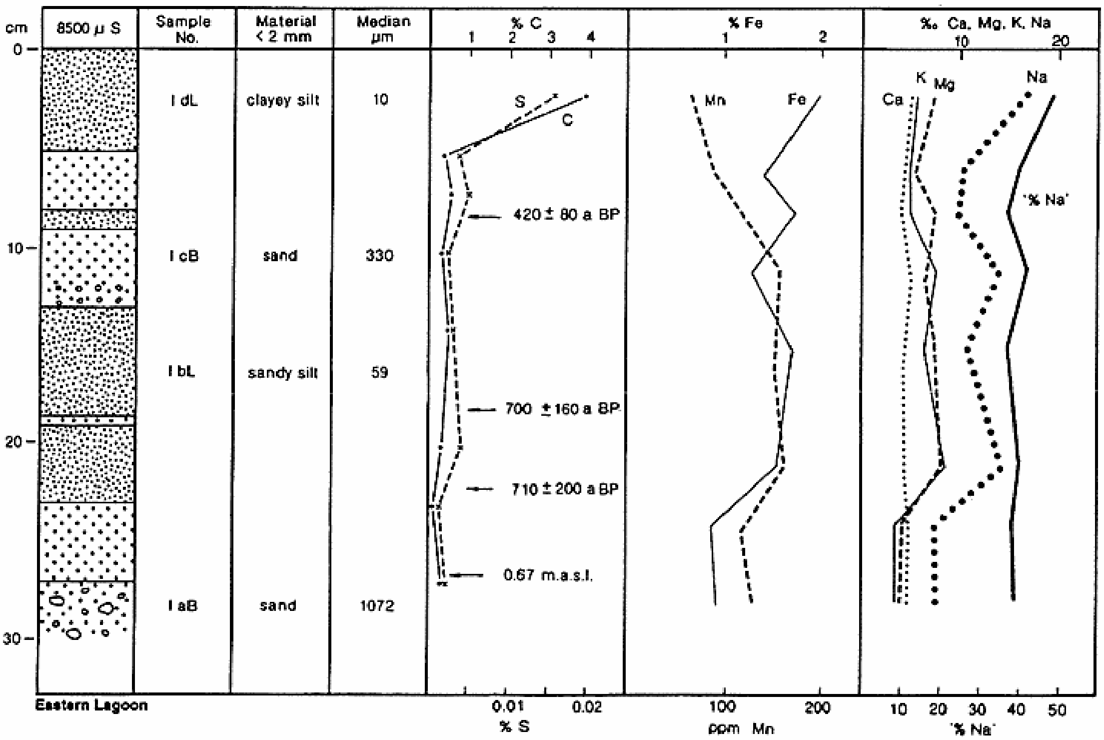
B


cm
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‰ Ca, Mg, K, Na
I dL
clayey silt
10
I cB
sand
330
I bL
sandy silt
59
I aB
sand
1072
S
C
420± 80 a BP
700 ±160 a BP
710±200 a BP
0.67 m.a.s.l.
Mn
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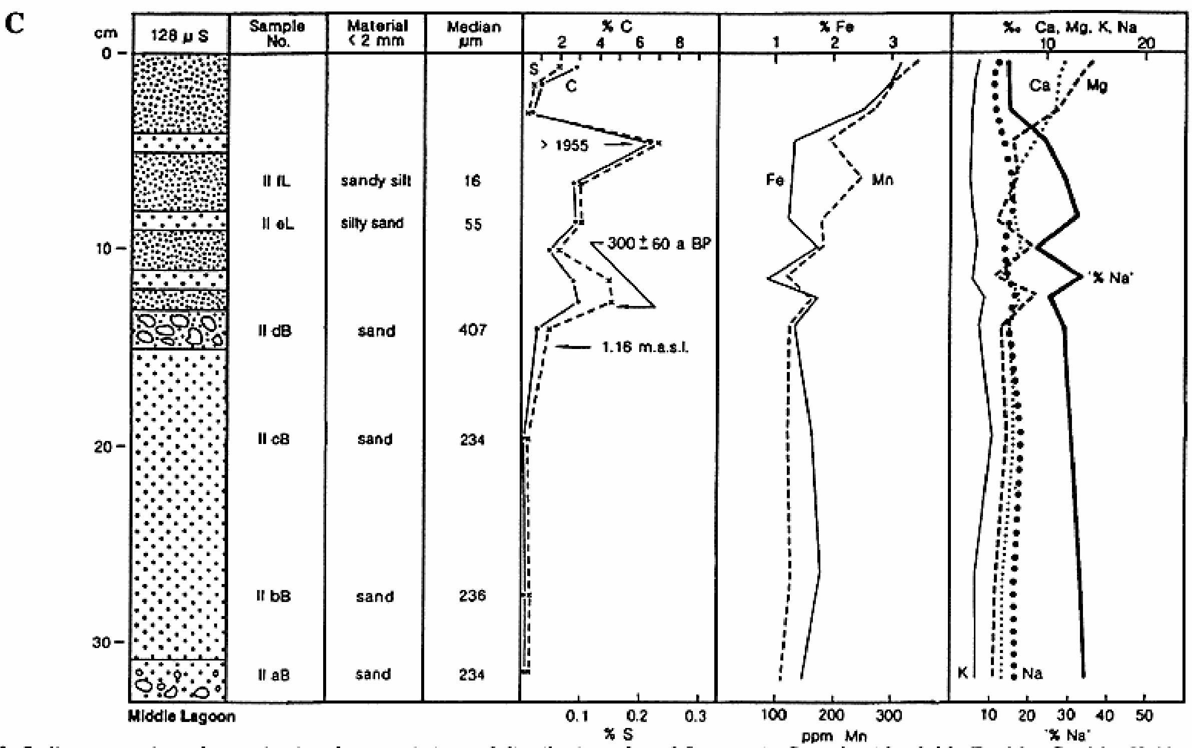

Figure 10: Sediment stratigraphy, grain size characteristics and distribution of total S, organic C, and acid soluble Fe, Mn, Ca, Mg, K, Na. Sandy materials are shown by open dot signature and silty materials are shown by a dense dot signature. Gravelly layers are shown by indicating coarse fragments. Grain size characteristics and sample numbers -L and -B refer to the two groupings: 'lagoon silt' (L) and 'beach sand' (B) shown in the triangular diagram in Figure 9. '%Na' gives the weight percentage Na of total Ca+Mg+K+Na. Present EC values of the lagoon water are given on top of the stratigraphic columns and ^{14}C datings are indicated.

erosional to depositional conditions. This change might have resulted from increased sediment supply to the littoral zone during stable RSL; for example as a result of increased sediment discharge from the alluvial fans during a relatively warm period with increased precipitation. However, formation of simple beach ridges are normaly considered indicative of regression (e.g. Tanner 1988), while both stable and rising RSL will lead to development of washover ridges (transgressive barriers) on gravel beaches (e.g. Carter & Orford 1984).

Based on the geomorphology at Saqqarliit Ilorliit it is suggested that: **1.** The terraces above c. 7 m.a.s.l. developed as fan deltas before 2.5 ka BP during the early-middle Holocene glacio-isostatic emergence. **2.** The fossil coastal cliff immediately below the marine terraces and the intertidal platform between the eastern and the middle forelands developed during a transgression after 2.5 ka BP. **3.** The cuspate forelands originated during a regression or a period with stable RSL between 2.5 and 1 ka BP. **4.** The present beach and the lagoons formed during a transgression after 0.7 ka BP.

Surprisingly, RSL on western Disko did not reach present sea-level before c. 2.5 ka BP (Fig. 11). This is much later than in the eastern part of Disko Bugt. Here undisturbed Saqqaq Culture (4.3 - 2.7 ka BP) middens occur immediately above present sea-level. The occurences of these middens prove that RSL was close to or below present sea-level at c. 4 ka BP (Møbjerg 1986; Grønnow 1990, 1994; Böcher & Fredskild 1993). Well established geophysical models describe RSL changes resulting from the migration of a collapsing forebulge during and after the retreat of an ice sheet (Clark et al. 1978; Quinlan & Beaumont 1981; Peltier 1987). According to these models RSL is expected to reach its minimum earlier in areas situated far from the ice sheet than in closer areas; opposite to what is observed in Disko Bugt. However, the late approach to present sea-level of the RSL on western Disko is confirmed by archaeological observations in Kangerluk (Møbjerg 1986). Here paleo-Eskimo (4.3 - 1.9 ka BP) settlements occur significantly above neo-Eskimo (<1.0 ka

BP) settlements; probably because of continued uplift after 4.3 ka BP. The unexpected late uplift of western Disko might have resulted from isostatic effects of local ice caps or from tectonics

Sedimentology and chemical stratigraphy of lagoon sediments obviously are archives of changes in the sedimentary environment. However, one should be careful to infer specific changes in RSL from changes in lagoon environments. There are many sediment sources in lagoon and lake environments (e.g. Engstrom & Wright 1984, Sly 1978, Jones & Bowser 1978). The organic components mostly include biotic production in the lagoon with normally low but varying additions of detritus from terrestrial sources. The inorganic components mainly include mineral particles and dissolved ions imported through the tidal inlet, over the barrier (during washovers) or from the drainage basin.

Obviously, stratified lagoon sediments records could easily reflect quite stable climatic and RSL conditions and merely show the intrinsic variability in a lagoonal development. Alternatively, changes in climate, erosion and transport processes in the drainage basin, or changes or cut off of the tidal inlet due to RSL changes would influence the sediment record found.

Bearing the complexity of lagoon formation processes in mind, and combining coastal morphological observations and sediment records from the three lagoons, suggestions are presented of the RSL changes in Akulliit during the last millenia. Conclusions concerning RSL changes drawn from the sedimentary records are strengthened by the apparent parallellity of changes in sedimentary dynamics and lagoon development in all three lagoons and by the good accordance with geomorphological observations and previous investigations.

On the western and eastern cuspate forelands the oldest lagoon deposits occur 0.6-0.7 m.a.s.l. and date back to 0.6 -0.7 ka BP. The lagoon development on top of relict beach ridges probably was the result of a transgression starting before 0.7 ka BP and leading to formation of the washover ridge now constituting the present beach. Datings of basal peat from similar lagoons at Narsaarsuk in Akulliit (840 ± 60 a BP, AAR-2198) and at Asuk (755 ± 60 a BP, AAR-2199) on northern Disko support this theory (Rasch 1997). The transgression might have been followed by 1-200 years of stable or slightly regressive conditions causing a decreasing Na content and an increasing Fe content in the lagoons. This change might however also reflect increased

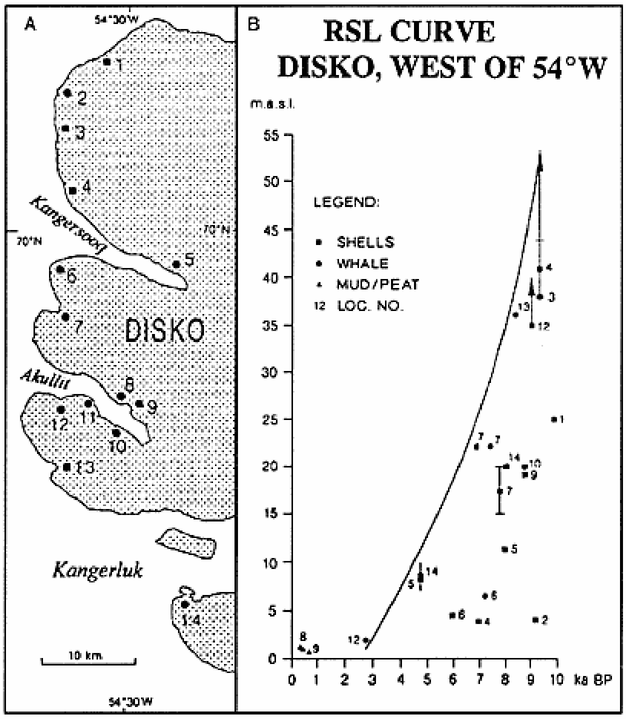

Figure 11: Emergence curve representing Disko west of 54 °W. Applied dates are listed in Table 1. The numbers next to the data points for the emergence curve (B) refer to the location numbers on the map (A). Upward directed arrows point to the top of fossil deltas in which dated shell samples have been collected (Ingólfsson et al. 1990). Error bars mark the error on altitude determination when possible. The whale bone from location 12 was found embedded in a relict beach ridge 2 m.a.s.l. (Bojsen & Frederiksen 1980). The dating of the whale bone (K-3161, see Table 1) implies that RSL was close to present sea-level at 2750 ± 80 a BP.

terrestrial influence in the lagoon due to, e.g. increased precipitation. The simultaneous increase in Fe:Mn and C:S ratios is in good accordance with a strong freshwater input. The lagoon at the middle foreland was established at c. 0.4 ka BP. The bottom of this lagoon is situated slightly higher (1.1 - 1.2 m.a.s.l.) than the bottom of the other lagoons, and the lagoonal development probably reflects a RSL rise. In the other lagoons the event resulted in deposition of coarse gravelly sand. Following the RSL rise which resulted in formation of the middle lagoon, sediment accumulation in the other lagoons changed to more fine grained materials. This change might mark the beginning of a stabilisation or regression of RSL leading to less vigorous hydrodynamic conditions in the lagoons and allowing relative sulphide rich authigenic mineral precipitation (e.g. Berner 1971; Jakobsen 1987, 1988). The low organic

carbon content in the lagoon sediments presumably have been rate limiting for sulphide formation, and the shallow water lagoon sediments therefore show quite low C:S and Fe:Mn ratios as compared to organic rich marine and brackish sulphide rich sediments (Berner & Raiswell 1984). The somewhat low Fe:Mn ratios additionally could indicate a reduced terrestrial iron source.

A transgression starting before the present century and followed by a regression after 1950 has been measured in the town of Qeqertarsuaq (Saxov 1958) and in other towns in both West and East Greenland (Gabel-Jørgensen & Egedal 1940; Saxov 1958, 1961). The transgression might explain a thin sandy layer immediately below the muddy surface sediment in all three lagoons. In the middle lagoon the layer was dated to post 1955 AD. The layers might also have resulted from a short but dramatic event like a washover caused by a storm, calving of a large iceberg or a tsunami. The layers do, however, mark a significant change in the sedimentary environments of the western and middle lagoons (the freshening of the lagoons), which could not result from a short but dramatic event. It has not been possible to date the onset of the suggested transgression, but the burial (by a washover ridge) of relatively old sod houses in western Akulliit and the character of the wreckage on the landward slope of the active beach at Saqqarliit Ilorliit (see above) suggest that the transgression started at least 1-200 years ago. After deposition of the sandy layers, the tidal inlets were sealed at the western and the middle forelands, and the lagoons freshened. The freshening of the two lagoons might have resulted from the regression after 1950 (Saxov 1958).

At Sandness in southern Greenland a Norse church from c. 0.8 ka BP has been submerged by 6 m (Roussel 1941); indicating transgression after 0.8 ka BP. The RSL rise on Disko during the same period has definitely been much smaller, and though it has not been possible to measure the RSL rise on Disko, a rise of c. 1 m since 0.8 ka BP seems more realistic. Weidick (1993) has related the submergence of the Norse church to the late Holocene advance of the Inland Ice. The difference in relative uplift between Sandness and Disko might reflect differences in distance to the Inland Ice and/or regional differences in late Holocene glacial history.

The proposed 0.4 ka BP transgression at Saqqarliit Ilorliit accords well with the observations from entire West Greenland of Thule Culture Eskimo ruins from 0.2 - 0.4 ka BP affected by RSL rise (Mathiassen 1930, 1931, 1934, 1936; Mathiassen in Gabel-Jørgensen & Egedal 1940) and with implications of two datings on whale bones embedded in the landward slope of the active beaches (washover ridges) at Tuapaat on southern Disko (480 ± 75, K-6181) and on eastern Nuussuuaq (380 ± 60, I-16414) (Rasch & Nielsen 1995; Bennike et al 1994; O. Bennike, Geological Survey of Denmark pers.comm.). The datings imply that the washover ridges at the two sites were active in the period 0.5 - 0.4 ka BP.

The following conclusions are drawn from the core data: **1.** A RSL rise has occurred on Disko since 0.7 ka BP. **2.** The RSL rise might have occurred as three transgressions (c. 0.7 ka BP, c. 0.4 ka BP and the present century) separated by periods with stable or slightly regressive conditions.

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