Coastal morpho-stratigraphy and Holocene relative sea level changes at Tuapaat, southeastern Disko Island, central West Greenland

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The geomorphology of a coarse clastic coastal landscape at Tuapaat (69°24′N 52°36′W), southeastern Disko Island, central West Greenland, is described, and a coastal morpho-stratigraphy of the landscape is constructed. ^{14}C ages on marine shells, whale bones, peat and gyttja are used to construct relative sea level changes throughout the Holocene. The emergence of SE Disko Island occurred in the early part of the Holocene. The Holocene marine limit is situated ca. 80 m a.s.l. Between 4.7 and 1.0 ka BP, the relative sea level approached the present sea level and it has probably been below present sea level between 4.7 ka BP and the present. The morpho-stratigraphy in the lowest part of the coastal landscape at Tuapaat suggests a complex late Holocene relative sea level history which includes at least 3–4 transgressions during the last ca. 2.5 ka.

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Introduction

Present knowledge about late Holocene relative sea level (RSL) changes in West Greenland is very limited. The glacio-isostatic rebound following the Wisconsinan/Weichselian glaciation has been documented by several emergence curves representing local regions (Weidick 1972b; Kelly 1985; Funder 1989). From these curves it is well established that the RSL approached the present sea level between ca. 3 and 4 ka BP. Only scattered information is available today about the RSL changes that occurred in the period from 3–4 ka BP to the beginning of the present century, when tidal observations were initiated. However, it is well established that the RSL in some parts of West Greenland has been below the present sea level during the last ca. 3 ka, and that transgression(s) have occurred within the present millennia (Kelly 1980, 1985; Funder 1989; Weidick 1993; Rasch & Nielsen 1994; Rasch et al. in press).

The main objective of this study is to contribute to a greater understanding of late Holocene RSL changes in West Greenland. Special attention is given to RSL changes within the last millennia. Both traditional and new methods have been applied in the investigation. An age-altitude diagram based on Holocene dates from southeastern Disko Island has been constructed, and the chronological sequence of coastal landforms (the coastal morpho-stratigraphy) in a coarse clastic coastal landscape at Tuapaat (69°24′N 52°36′W) on the southern coast of Disko Island has been studied. In coarse clastic coastal landscapes, results of RSL changes are easily observed because regressions lead to repeated simple beach ridge (swash ridge) formations, while transgressions lead to the formation of either washover ridges (transgressive barriers) or coastal cliffs (Carter & Orford 1984; Tanner 1988; Rasch & Nielsen 1994). As a result, individual landforms in a coarse clastic coastal landscape show evidence of the course of the RSL at the time of their origin, and the entire landscape represents a chronologically arranged archive of former RSL changes.

Physical setting

Disko Island is situated in Disko Bugt, central West Greenland, between 69°15′N and 70°20′N and between 51°50′W and 55°00′W (Fig. 1). The climate is polar maritime. The mean annual temperature in the town, Qeqertarsuaq, southeastern Disko Island, is about −4°C and the mean annual precipitation varies between 100 and 500 mm (Danish Meteorological Institute 1962–1985). The island lies within the zone of continuous

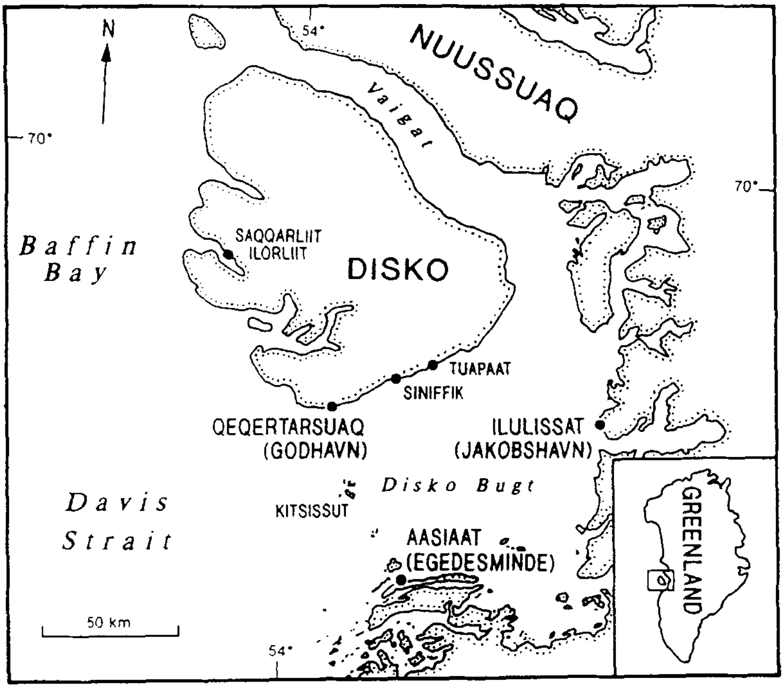

Fig. 1. Disko Island. Old Danish names of towns are given in brackets.

permafrost, and at present approximately 20% of Disko Island is glacierised (Humlum 1988).

The wave climate on southern Disko Island is characterised by wind waves from the east caused by katabatic winds blowing off the Inland Ice and by swell from the southwest and west caused by cyclones in Baffin Bay. The net littoral drift is dominated by swell impact and is directed towards the east. The sea surrounding Disko Island is ice-covered from mid-January to mid-April, and the shores of Disko Island are affected by ice-foot formation from December to the end of June (Nielsen 1979).

The bedrock geology of southeastern Disko Island consists of unlithified Cretaceous sandstones overlaid by Tertiary basalt (Henderson et al. 1976), and the landscape is characterised by Tertiary plateaus that have been heavily dissected by glaciers during the Quaternary. The Tertiary plateaus are situated around 1000 m a.s.l., and today plateau surfaces are almost completely covered by ice caps. In the lowermost part of the terrain, in the unlithified sandstones, gullies have blurred the glacial origin of the landscape. The border between Cretaceous sandstones and Tertiary basalts is situated ca. 400 m a.s.l. at Tuapaat.

During the Wisconsinan/Weichselian glaciation, only a small part of Disko Island was covered by Inland Ice (Frich & Ingólfsson 1990; Ingólfsson et al. 1990). The margin of Inland Ice probably lay a few kilometres north of the present shoreline on southern Disko Island, and an extensive ice-shelf possibly occurred west of Disko Island (Bennike 1994). The Wisconsinan/Weichselian extent of the local glaciers on the island is almost unknown. It is, however, known that large valley glaciers occurred in the fiords on the western coast of the island (Donner 1978; Ingólfsson et al. 1990). The occurrence of glaciers in the fiords on western Disko Island and the altitude of the Holocene marine limit on the island (60–90 m a.s.l.) suggest extensive local glaciation.

During the retreat of the Inland Ice ca. 10 ka BP, the RSL rose to the Holocene marine limit. Generally, the Holocene marine limit on Disko Island increases towards the southeast from ca. 60 m a.s.l. on northwestern Disko Island to ca. 90 m a.s.l. on southeastern Disko Island (Ingólfsson et al. 1990). At Tuapaat, the Holocene marine limit is situated at 80 m a.s.l.

Between 10 ka BP and 3 ka BP, the RSL fell continuously from the Holocene marine limit to the present sea level (Donner & Jungner 1975; Frich & Ingólfsson 1990; Ingólfsson et al. 1990; Bennike et al. 1994). During this period coarse clastic beach ridge plains developed along the shores of Disko Island (Rasch & Nielsen 1994).

During the last 3–4 ka, the RSL in Disko Bugt has been very close to or below the present sea level (Donner & Jungner 1975; Frich & Ingólfsson 1990; Ingólfsson et al. 1990). As a result, subaerial deposits containing information about marine events in this period are sparse and confined to the terrain immediately above sea level. The scarcity of information concerning marine events, including RSL changes, during the last 3–4 ka is illustrated by the very low number of radiocarbon dates on marine fossils from this period (Fig. 2).

Study area – geomorphology

The research site for the field investigation is a small cuspate foreland near the mouth of the Tuapaat River on the southern coast of Disko Island about 40 kilometres east of the town Qeqertarsuaq/Godhavn (Fig. 1). The interior of the foreland is mainly built up of simple beach ridges (swash ridges) consisting of rounded to well-rounded pebbles and cobbles (Tuapaat means well-rounded stones in Inuit-language). The pattern of the beach ridges indicate that they have been formed during littoral drift from the west (Figs. 3, 4 and 5). The mean elevation of the foreland is about 3 m a.s.l. A washover ridge (transgressive barrier) separates the interior of the foreland from the sea. The washover ridge is significantly higher and wider than the simple beach ridges in the interior part of the foreland (Fig. 6).

Towards the west, the interior simple beach ridges of the cuspate foreland are superimposed by an alluvial fan (Figs. 5 and 7). Landward, the foreland is bounded by a fossil coastal cliff which leads to marine terraces at higher elevations. The front of the cliff is dissected by two larger and several smaller gullies. These gullies have produced the yellow sandy sediment for the alluvial fan that covers the coastal landscape in the western part of the foreland.

The landscape immediately above the cuspate foreland consists of gently sloping and vegetated marine terraces with scattered exposures of coarse clastic beach sediment. The landscape has been extensively adjusted by solifluction, and it is therefore difficult to discern the detailed geomorphology of individual beach ridges even in the exposures in the vegetation. The marine terraces continue to the Holocene marine limit at 80 m a.s.l.

Methods

An age-altitude diagram based on 33 Holocene dates on terrestrial and marine material from the southeastern part of Disko Island and the islands of Kitsissut (south of Disko Island) has been constructed (Fig. 7). The Holocene marine limit is consistently situated ca. 80–90 m a.s.l. in the area represented by the diagram (Funder 1989;

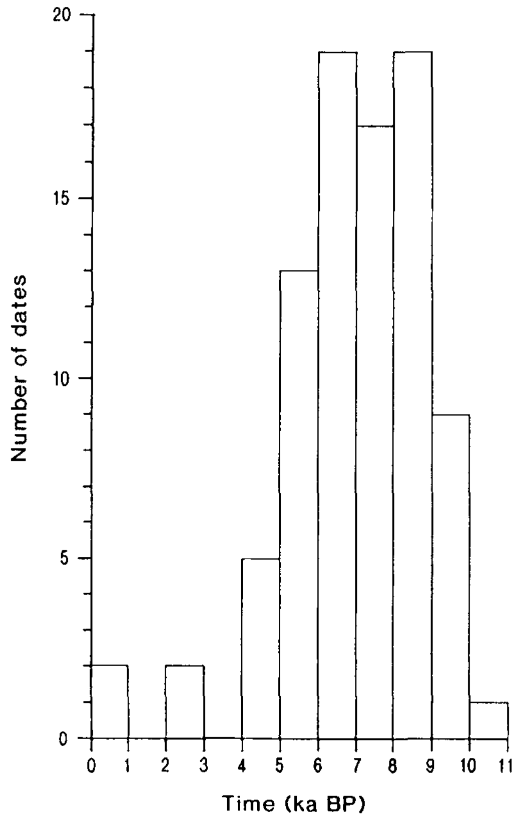

Fig. 2. Frequency distribution of radiocarbon dated shells and whale bones from Disko Bugt. The total number of ^{14}C dates is 87. Only four dates exist from the period after 4 ka BP Sources for dates: Weidick (1968, 1972a, 1972b, 1973, 1974), Donner & Jungner (1975), Donner (1978), Bojsen & Frederiksen (1980), Ingólfsson et al. (1990), Frich & Ingólfsson (1990), Bennike et al. (1994), and the present work.

Fig. 3. Aerial photo of the study area at Tuapaat (Aerial photo: 268K-123, Copyright: Kort og Matrikelstyrelsen, Denmark).

Ingólfsson et al. 1990). The shaded area in the diagram represents the band in which the RSL curve must lie (higher than dated marine material and lower than dated terrestrial/lacustrine material). The diagram differs from previously published emergence curves from Disko Bugt (Donner & Jungner 1975; Frich & Ingólfsson 1990; Ingólfsson et al. 1990) by only including dates from a restricted area with a uniform altitude of the Holocene marine limit. In addition, no interpretations concerning depth range of occurrence of dated fossils were applied in the construction of the diagram. Most of the animals normally found as fossils in marine deposits in West Greenland live in a wide zone (from the shoreline to water depths of tens of metres), and interpretations concerning depth range of occurrence will therefore be very uncertain unless good information about stratigraphy and sedimentology of the adjoining sediments is available (Donner & Jungner 1975; Andrews 1986; Sutherland 1987; Pirazolli 1991).

A geomorphological sketch map of the coastal landscape at Tuapaat (Fig. 4) was prepared using

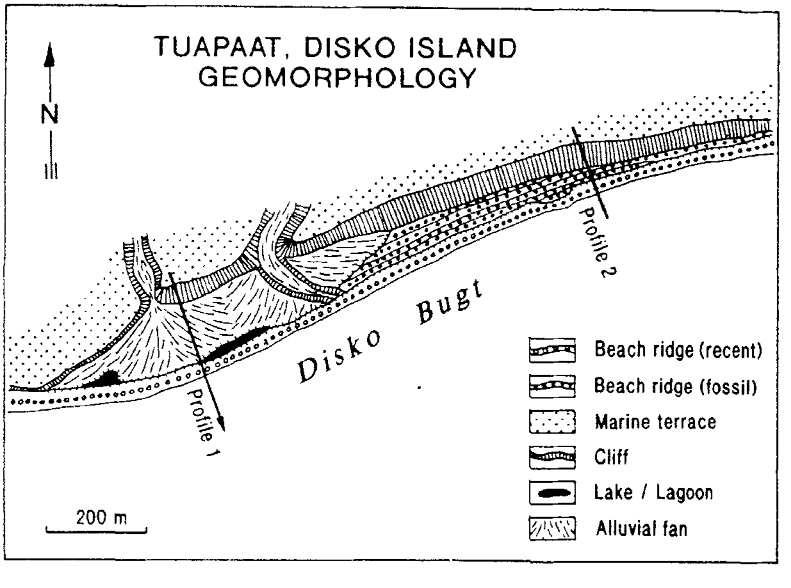

Fig. 4. Geomorphological sketch map of the study area at Tuapaat.

Fig. 5. The study area at Tuapaat. The interior of the cuspate foreland consists of coarse clastic simple beach ridges. In the background, towards the west, an alluvial fan covers the simple beach ridges (Fig. 6). The cliff on the right side of the photo is approximately 7 m high.

aerial photograph interpretation and field data. Levels of coastal landforms were measured in terrain profiles using electronic theodolite and echo-sounder (Figs. 8 and 9). Local datum was based on tidal observations on the location. Absolute and relative errors on altitude measurements are considered approximately ± 0.5 m and less than ± 0.2 m, respectively.

A coastal morpho-stratigraphy of the cuspate foreland was interpreted from the geomorphological sketch map and from the terrain profiles (Figs. 8 and 9). The term morpho-stratigraphy denotes a system for relative dating of landscape elements. A morpho-stratigraphic unit is a stratigraphic unit primarily identified by the surface form it displays. The applied principles of coastal

Fig. 6. An alluvial fan superimposes the coastal deposits in the westernmost part of the study area. The alluvial fan is built up by sediments eroded from the marine terraces at higher elevations. In the spring and early summer, the interior, eastern part of the foreland is flooded (notice the lake in left side of the photo). The lake is dammed by an ice core within the present beach ridge. The lake drains when the ice core melts in the early autumn.

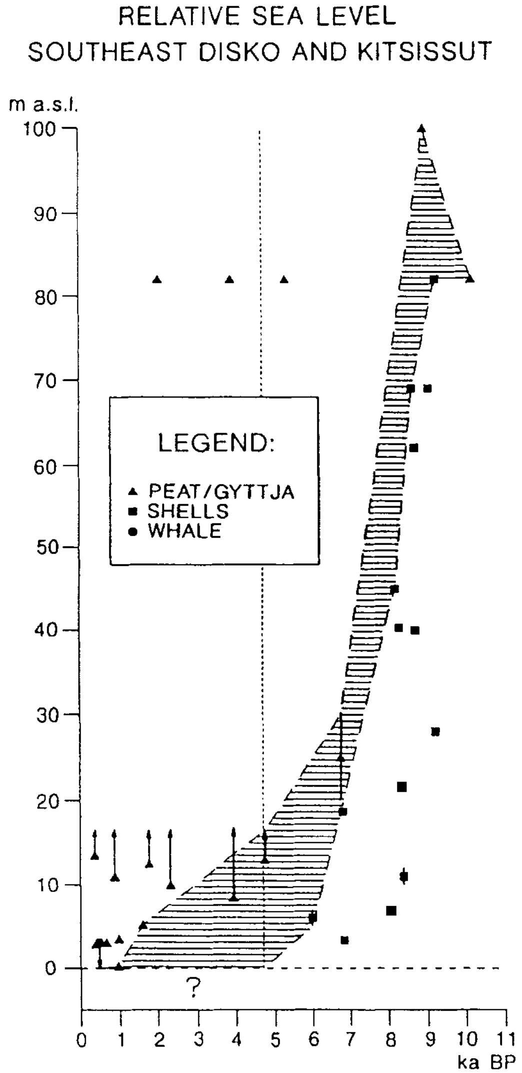

Fig. 7. Age-altitude diagram of ^{14}C dates from southern Disko Island and Kitsissut. The shaded area marks the zone in which the RSL curve must lie. Upward directed arrows point to the threshold altitude of lakes in which dated gyttja samples have been collected. The downward directed arrow in the lower left corner of the diagram points to the expected RSL (0 m a.s.l.) at the time when the whalebone in Profile 2 (K-6181) was deposited. The dotted vertical line represents dating I-6239 (see Table 2). The exact field altitude of this sample is unknown. It is however known that the sample was collected above sea level. Sources for the dates: See Table 2.

morpho-stratigraphy have been described in detail by Rasch and Nielsen (1994). Five different morpho-stratigraphic unit types were identified at Tuapaat (Table 1, Figs. 8 and 9).

Three pits were dug within Profile 1 in the alluvial fan deposits in the western part of the study area (Figs. 4 and 8). The northernmost and the southernmost pits both reached the surface of the beach deposits underneath the alluvial deposits. Because of permafrost, it was not possible to excavate to the coastal basement in the middle pit. In the northernmost pit, three layers of peat were discovered just above the coastal deposits. The stratigraphy of this pit was logged (Fig. 10), samples of the different layers were analysed for grain size, and plant species within the peat layers was determined by Bent Fredskild, Museum of Botany, University of Copenhagen. Three different facies types were identified from the log.

A whale bone was found embodied in the sediments on the landward side of the present beach in Profile 2 in the eastern part of the foreland (Fig. 9). The whale bone and the peat layers from the northernmost pit in Profile 1 were radiocarbon dated (Table 2). The samples K-6179, K-6180 and K-6181 were dated at the Carbon-14 Dating Laboratory at the National Museum of Denmark, Copenhagen, while sample AAR-1422 was dated at the AMS ^{14}C Laboratory at the University of Aarhus, Denmark. The date of K-6181 was corrected for isotopic fractionation by normalising to $\delta^{13}C = 0.0‰$ PDB. K-6179, K-6180 and AAR-1422 have been corrected by normalising to $\delta^{13}C = -25.0‰$ PDB.

Results

Age-altitude diagram

The age-altitude diagram in Fig. 7 illustrates well the emergence of southeastern Disko Island in the early part of the Holocene. Between 9 and 7 ka BP, the RSL fell continuously with a rate of about 3 cm/yr from ca. 80 m a.s.l. to ca. 30 m a.s.l. The width of the shaded area in the lower part of the diagram illustrates that present knowledge about the exact course of the emergence of southeastern Disko Island after ca. 7 ka BP is very limited. However, the lower part of the diagram indicates that the RSL reached present sea level in the period between 4.7 and 1.0 ka BP, and that it has probably been below present sea level for at least part of the period between 4.7 ka BP and the present.

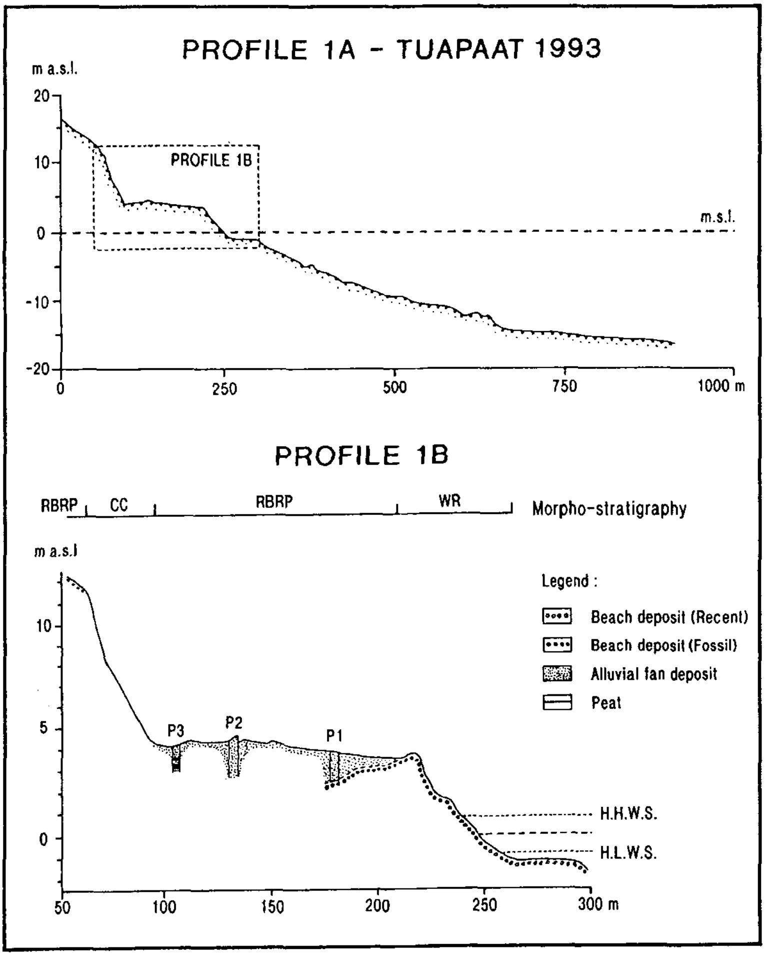

Fig. 8. Topographic profile from the western part of the cuspate foreland. The position of Profile 1 is shown in Fig. 4. (Profile 1). The morpho-stratigraphy of the profile has been logged above Profile 1B. The abbreviations used in the morpho-stratigraphic log are defined in Table 1. A detailed log of the stratigraphy in the northernmost pit (P3) is given in Fig. 10.

Table 1. Characteristics of the five morpho-stratigraphic unit types identified within the cuspate foreland at Tuapaat (compiled from Rasch & Nielsen 1994).

Morpho-stratigraphic unit type	Characteristics	Indication of	Code
Simple beach ridge	Narrow sharp-crested beach ridge with internal beds generally dipping 5°–10° towards the sea.	Coastal progradation	SBR
Washover ridge	Beach ridge with rounded crest and with internal beds following the surface of the ridge. Washover ridges are usually higher and wider than simple beach ridges. Typical internal bed slopes are less than 5°.	Coastal recession	WR
Regressive beach ridge plain	Gently sloping marine terrace with several more or less parallel simple beach ridges on the top.	Coastal progradation	RBRP
Coastal cliff	Coastal cliffs are usually more or less straight, coast parallel cliffs. Coastal deposits will always occur at the foot of a coastal cliff.	Coastal recession	CC
Morphologic unconformity	Limit between morpho-stratigraphic units of very different age.	Coastal recession	MU

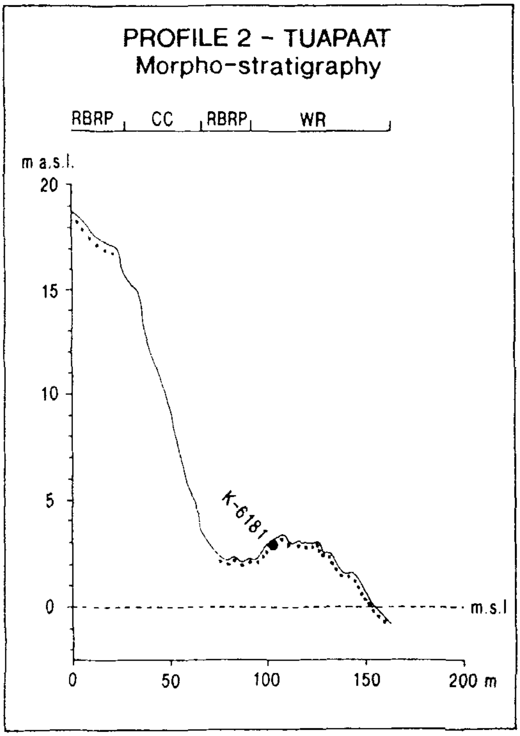

Fig. 9. Topographic profile from the eastern part of the cuspate foreland. The position of the profile is shown in Fig. 4 (Profile 2). Symbols are the same as in Fig. 8. The morpho-stratigraphy of the profile has been logged above the profile. The abbreviations used in the morpho-stratigraphic log are defined in Table 1. K-6181 marks the position of a whalebone that was found within the sediments of the beach ridge. The bone has been radiocarbon dated to 480 ± 75 BP.

Morpho-stratigraphy

The morpho-stratigraphy of the cuspate foreland at Tuapaat (Figs. 8 and 9) indicates four phases of shoreline movement. The marine terraces above ca. 10 m a.s.l. indicate coastal progradation (RBRP). This was followed by coastal recession (CC) and resulted in the formation of the fossil coastal cliff at the northern edge of the foreland. Phase three was another period of shoreline progradation (RBRP) which formed the simple beach ridge plain within the cuspate foreland. The final phase involved coastal recession (WR) and the development of the washover ridge at the shoreline of the foreland.

The washover ridge at the present shoreline consists of two separated ridges (Fig. 11). In Profile 1, it is not possible to distinguish between the two ridges, probably because the inner ridge has been superimposed by alluvial fan deposits (Fig. 8). However, in Profile 2 a sharp boundary occurs between the outer and the inner ridges of the washover ridge (Figs. 9 and 11). On the outer ridge the beach sediments are washed clean by waves and washovers, while lichens, comprised mostly of *Rhizocarpon jemtlandicum* with typical diameters of 2 cm, grow on top of the sediments of the inner ridge. Both the inner and outer ridges contain large volumes of sediment (Fig. 11) and

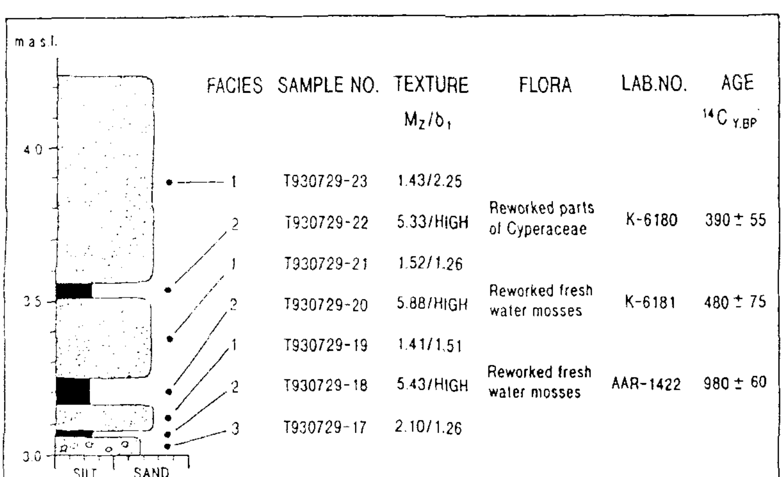

Fig. 10. Log of the stratigraphy in the northernmost pit (P3) in Profile 1 (Fig. 8). Grain size (M_z) and sorting (d_1) are given in F-values. Facies 1 consists of thin lenticular layers of sand and silt. Root horizons occur scattered within the facies. The facies type has been interpreted as alluvial fan deposits. Facies 2 consists of a poorly sorted, silty sediment with reworked parts of plants and mosses. The facies type has been interpreted as lake sediments originating from small pools in depressions in the alluvial fan. Facies 3 consists of sand with scattered occurrences of rounded–well rounded pebbles and cobbles. This facies type has been interpreted as beach sediments.

Table 2. Radiocarbon dates from the southeastern part of Disko Island and Kitsissut. Where possible, dates on marine material have been corrected for isotopic fractionation by normalising to $\delta^{13}C = 0.0‰$ PDB, while dates on terrestrial material have been corrected for isotopic fractionation by normalizing to $\delta^{13}C = -25.0‰$ PDB.

Loc. no.	Lab. no.	N lat.	W long.	Material	Elevation m a.s.l.	Age, ^{14}C yrs BP	$\delta^{13}C$ ‰ PDB	Reference
3	K-5774	69°27′	53°40′	Gyttja	13.5[2]	370 ± 55	−20.1	Bennike 1994
10	K-6180	69°24′	52°37′	Peat	2.9	390 ± 55	−27.7	This work
10	K-6181	69°24′	52°36′	Whale	3.1	480 ± 75	−14.5	This work
10	K-6179	69°24′	52°37′	Peat	3.2	670 ± 75	−27.7	This work
5	K-5777	69°16′	53°50′	Gyttja	11[2]	890 ± 65	−24.3	Bennike 1994
2	Hel-945	69°29′	53°38′	Peat	0.3	970 ± 110		Donner 1978
10	AAR-1422	69°24′	52°37′	Peat	3.5	980 ± 60	−28.2	This work
7	UA-1787	69°04′	53°32′	Peat	5.2	1610 ± 100		Bennike et al. 1994
3	K-5775	69°27′	53°40′	Gyttja	12.5[2]	1780 ± 55	−20.6	Bennike 1994
6	K-3908	69°17′	53°28′	Gyttja	82	2050 ± 80	−24.2	Ingólfsson et al. 1990
5	K-5778	69°16′	53°50′	Gyttja	10[2]	2330 ± 75	−22.3	Bennike 1994
6	K-3909	69°17′	53°28′	Gyttja	82	3900 ± 90	−24.5	Ingólfsson et al. 1990
5	K-5779	69°16′	53°50′	Gyttja	8.5[2]	3930 ± 85	−24.1	Bennike 1994
5	I-6239	69°16′	53°50′	Shells	?[3]	4685 ± 120		Weidick 1973
3	K-5776	69°27′	53°40′	Gyttja	13[2]	4730 ± 115	−23.5	Bennike et al. 1990
6	K-3666	69°17′	53°28′	Gyttja	82	5310 ± 95	−24.7	Ingólfsson et al. 1990
6	K-3691	69°15′	53°35′	Shells	5–7	5990 ± 95	−1.0	Ingólfsson et al. 1990
1	K-3505	69°32′	53°41′	Gyttja	20–30	6750 ± 105	−22.8	Foged 1989
3	Hel-904	69°27′	53°40′	Shells	18.7	6800 ± 150[1]	2.1	Donner 1978
2	Hel-905	69°29′	53°38′	Shells	3.3	6840 ± 140	1.5	Donner 1978
3	Hel-903	69°26′	53°42′	Shells	6.8	8050 ± 170[1]	1.8	Donner 1978
3	Lu-3040	69°26′	53°35′	Shells	45	8170 ± 80	1.1	Ingólfsson et al. 1990
2	Hel-906	69°29′	53°38′	Shells	40.3	8280 ± 170[1]	2.0	Donner 1978
2	Hel-907	69°29′	53°38′	Shells	21.6	8340 ± 170[1]	4.5	Donner 1978
4	Lu-3038	69°26′	53°27′	Shells	10–12	8390 ± 80	0.9	Ingólfsson et al. 1990
9	K-4568	69°18′	53°15′	Shells	69	8620 ± 120	0.8	Frich & Ingólfsson 1990
8	RCD-21	68°59′	53°19′	Shells	62	8690 ± 90	1.0	Bennike et al. 1994
11	K-3660	69°40′	52°00′	Shells	40	8700 ± 120	0.3	Ingólfsson et al. 1990
11	K-3667	69°40′	52°01′	Gyttja	100	8950 ± 125	−12.9	Ingólfsson et al. 1990
9	Hel-2210	69°18′	53°15′	Shells	69	9060 ± 120[1]	1.7	Frich & Ingólfsson 1990
9	K-4567	69°18′	53°15′	Shells	28	9220 ± 130	0.6	Frich & Ingólfsson 1990
6	AAR-5	69°17′	53°28′	Shells	82	9240 ± 250		Ingólfsson et al. 1990
6	K-3665	69°17′	53°28′	Gyttja	82	10180 ± 155	−23.7	Ingólfsson et al. 1990

[1] Date was not corrected for isotopic fractionation by authors of first publication. Date has been corrected to $\delta^{13}C = 0.0‰$ PDB.
[2] Threshold of lake situated at 16.5 m a.s.l.
[3] A field altitude of 19 m a.s.l. was quoted by Weidick (1973). According to Frich & Ingólfsson (1990) this altitude is incorrect.

have small dunes developing on the surface. It is unlikely that the ridges are ephemeral coastal landforms resulting from single larger storms. The ridges more probably represent permanent features developed at different times as a result of coastal recession.

The basal peat (Fig. 10, 3.06–3.08 m a.s.l.) in the northernmost pit (P3) in Profile 1 was dated to 980 ± 60 BP (AAR-1422). The date implies that the fossil coastal cliff behind the cuspate foreland, and at least the inner part of the simple beach ridge plain of the cuspate foreland, developed before 980 ± 60 BP The RSL did not reach the present sea level before 4.7 ka. Accordingly, the fossil coastal cliff developed during the period between 4.7 and 1 ka BP The whale bone that was found in the inner beach ridge of the washover ridge was dated to 480 ± 75 BP (K-6181). This result implies that the inner beach ridge of the washover ridge was active in the 15th century, that the simple beach ridge plain of the cuspate foreland was developed before the 15th century, and that the outer beach ridge of the washover ridge was formed after the 15th century.

Fig. 11. The washover ridge that encompasses the cuspate foreland at Tuapaat consists of two separated ridges. The inner ridge is covered by the lichen, *Rhizocarpon jemtlandicum*, with typical diameters of 2 cm. No lichens occur on the outer ridge. Notice the small dunes on top of the ridges.

Discussion

There has been some confusion about the shape of Holocene RSL curves of Disko Bugt. Donner and Jungner (1975) used a best fitting second degree polynomia for their construction of a RSL curve representing the entire Disko Bugt. The curve shows emergence in the period between deglaciation and about 1.5 ka BP followed by submergence in the period between 1.5 ka BP and the present. According to their curve, the RSL was below present sea level between ca. 3 ka BP and the present. In later attempts to construct RSL curves for the entire Disko Bugt, it has been presumed that the RSL fell continuously with a decreasing rate throughout the Holocene, and that the RSL did not fall below present sea level (Frich & Ingólfsson 1990; Ingólfsson et al. 1990). The present study supports Donner and Jungner's idea of a RSL history characterised by emergence in the early part of the Holocene followed by submergence in the late Holocene.

In the Nuuk area in the southern part of West Greenland, Norse ruins that now occur below sea level demonstrate that the RSL in that area has been lower than at present (Weidick 1976). No such unequivocal indication of lower than present relative sea level has been observed on southeastern Disko Island. However, in Disko Bugt, frequent occurrence of Eskimo ruins that have been partly destroyed by coastal erosion convincingly suggest that one or more transgressions have occurred since habitation of the ruins (Mathiassen 1934). The theory is strongly supported by the fact that washover ridges and coastal cliffs occur frequently along the present shores of southern Disko Island (Rasch & Nielsen 1994). In addition, a Dorset-Culture (600–0 BC) midden that was found below the mean high water level in the southeastern part of Disko Bugt is difficult to explain without presuming that the RSL has been below present sea level (J. F. Jensen, Museum of Qasigiannguit pers. comm.).

The proposed late Holocene submergence in Disko Bugt may have resulted from isostatic adjustment to late Holocene (Neoglacial) glacier advances (Kelly 1980; Funder 1989). Alternatively, the proposed Holocene RSL changes on southeastern Disko Island (emergence in the early part of the Holocene followed by late Holocene submergence) might have resulted from the migration of a collapsing fore-bulge. RSL-curves showing emergence followed by submergence occur frequently in the literature concerning RSL changes in the outer part of formerly glaciated areas (e.g. Forman 1990; Quinlan & Beaumont 1981), and convincing accordance between such RSL-curves and theoretical RSL-curves has been achieved in geophysical models that include the migration of a collapsing forebulge on a viscoelastic earth (Clark et al. 1978; Quinlan &

Beaumont 1981; Andrews & Peltier 1989; Liverman 1994).

Only trends of the RSL history can be interpreted from age-altitude diagrams. The investigation of the morpho-stratigraphy in the lowermost part of the coastal landscape at Tuapaat does, however, allow a discussion of possible smaller fluctuations of the RSL in the latest part of the Holocene. Changes in the shoreline position (recession/progradation) at a given location must result from either changes of the RSL, shifting of the wave climate or changes of littoral sediment sources. Changes in shoreline position caused by shifting wave climate or changes of the littoral sediment sources will be expected to have only local significance, while changes in shoreline positions caused by RSL changes will be expected to have significance over larger areas and to occur on coasts with different exposure and sediment sources. Therefore, when indications of synchronous and similarly directed shoreline movements are observed at locations with different exposure and sediment sources, it is most probable that the shoreline movements have resulted from changing RSL.

Coastal landscapes with a morpho-stratigraphy very similar to the morpho-stratigraphy of the cuspate foreland at Tuapaat are common on Disko Island (Fig. 12). Therefore, it is suggested that the morpho-stratigraphy at Tuapaat, and at the other Disko Island study sites, reflects shoreline displacements caused by RSL changes. This suggestion implies that the proposed coastal recessions at Tuapaat in the period between 4.7 and 1.0 ka BP, before and after the 15th century, all resulted from transgressions caused by rising RSL. Unfortunately, the Tuapaat field observations do not allow for an exact determination of the relative sea level at the transgression maxima.

Weidick (1993) has suggested that transgression maxima occurred in the coastal part of West Greenland in the 14–15th century and in the middle of the present century. This interpretation is based on archaeological observations of the

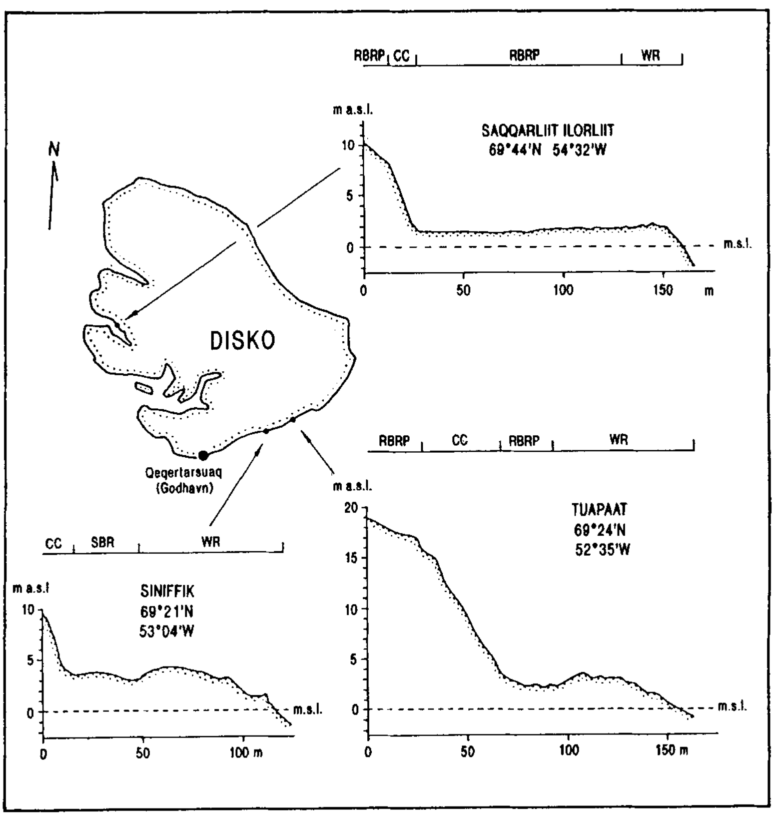

Fig. 12. Topographic profiles of the lowermost part of the coastal landscape at different sites on Disko Island (compiled from Rasch et al. in press). All profiles have been measured perpendicular to the shoreline. The morpho-stratigraphy of the profiles has been logged above the profiles. The abbreviations used in the morpho-stratigraphic log have been defined in Table 1.

spatial relation between the present shoreline and Thule-culture Eskimo ruins of different ages (Mathiassen in Gabel-Jørgensen & Egedal 1940) and on early tidal observations (Saxov 1958). Recently, supporting evidence for this theory have been found in a study of morpho-stratigraphy and chemical stratigraphy within a coastal/lagoonal landscape system at Saqqarliit Ilorliit on western Disko Island (unpubl. data) (Fig. 1). At Saqqarliit Ilorliit, high sodium and sulphur content and relatively coarse grain sizes in lagoon sediments from the 14th century and the middle of the present century might suggest transgression maxima in these periods. Based on the Saqqarliit Ilorliit data it might further be suggested that transgressions have occurred early in the period between 2.5 and 0.7 ka BP and in the 16–17th century. The morpho-stratigraphy at Saqqarliit Ilorliit is illustrated in Fig. 12. The transgression early in the period between 2.5 and 0.7 ka BP led to the formation of the coastal cliff, while the transgressions in the present millennia led to the development of the washover ridge immediately landward of the shoreline and to marine influenced sedimentation in lagoons behind the washover ridge.

Considering the errors on radiocarbon dates, the Tuapaat results agrees well with the preliminary results from Saqqarliit Ilorliit. The coastal cliff at Tuapaat may have formed during the transgression that was dated to the period between 2.5 and 0.7 ka BP at Saqqarliit Ilorliit. The date of 980 ± 60 BP on the peat sample from the northernmost pit (P3) in front of the fossil coastal cliff at Tuapaat only implies that the cliff was formed before ca. 1.0 ka BP Consequently, the dating reduces the possible time interval for the transgression to the period between 2.5 and 1.0 ka BP.

The inner beach ridge of the washover ridge at Tuapaat was probably active during the 14–15th century transgression maximum, and the outer beach ridge of the washover ridge might have formed during the 16–17th century transgression and/or during the transgression culminating in the present century. An age of at least 500 years on the washover ridges constituting the present beaches in Disko Bugt also agree well with the implications of a date of 380 ± 80 BP (I-16414) on a whale bone that was found in the present beach ridge on the western part of Nuussuaq peninsula, northwestern Disko Bugt (Bennike et al. 1994; O. Bennike; Geological Survey of Denmark pers. comm.). This whalebone was probably also deposited during or after the transgression culminating in the 14–15th century.

A morpho-stratigraphic sequence similar to that at Tuapaat has also been described from Siniffik ca. 20 km west of Tuapaat (Fig. 12) (Rasch & Nielsen 1994). Based on the sizes of lichens, *Rhizocarpon jemtlandicum*, on the beach ridges at Siniffik and on the oldest buildings in the town of Qeqertarsuaq, it was suggested that the relict coastal cliff (Fig. 12, CC) at Siniffik developed during a transgression in the middle of the 15th century. As the morpho-stratigraphic sequences at Siniffik and Tuapaat are almost identical, it is probable that the individual morpho-stratigraphic units at the two sites developed synchronously. This implies that the fossil coastal cliff at Siniffik was formed before 0.7 ka BP.

Conclusions

Between 9 and 7 ka BP the RSL on southern Disko Island fell continuously with a rate of about 3 cm/yr from ca. 80 m a.s.l. (the Holocene marine limit) to ca. 30 m a.s.l. The RSL reached present sea level between 4.7 and 1.0 ka BP Present knowledge of the course of the RSL curve on southern Disko Island between 7 and 1 ka BP is very limited due to the scarcity of dates on marine material from this period. It is suggested, however, that the RSL history of southern Disko Island was one of emergence in the early part of the Holocene followed by submergence in the late Holocene. The suggestion implies that the RSL has been below present sea level during the period between 4.7 ka BP and the present.

Indications of at least three late Holocene transgressions were found at Tuapaat. The exact timing of the transgressions is unknown, though several data suggest that the first transgression occurred early in the period between 2.5 and 1.0 ka BP, that the second transgression culminated in the 14–15th century, and that the third transgression culminated in the middle of the 20th century. In addition, one transgression may have occurred in the 16–17th century.

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