Journal of Coastal Research	16	2	306–315	Royal Palm Beach, Florida	Spring 2000

Holocene Relative Sea Level Changes in Disko Bugt, West Greenland

Morten Rasch

Institute of Geography
University of Copenhagen
Øster Voldgade 10
DK-1350 Copenhagen K
Denmark

ABSTRACT

RASCH, M. 2000. Holocene Relative Sea Level Changes in Disko Bugt, West Greenland. *Journal of Coastal Research,* 16(2), 306–315. Royal Palm Beach (Florida), ISSN 0749-0208.

An investigation of Holocene relative sea level (RSL) changes in Disko Bugt has been carried out with the purpose of reconstructing, with a good resolution in time and space, the Holocene RSL changes of a smaller part of Greenland, and thereby to allow testing of modern models for RSL changes in Greenland. This paper summarises the results of the investigation. The Holocene marine limit in Disko Bugt has been mapped, four RSL curves representing the Early-Middle Holocene emergence of different parts of Disko Bugt have been constructed, and attempts have been made to reconstruct the Late Holocene RSL changes within the region. Important conclusions are: 1. The rate of Early-Middle Holocene relative land rise increases towards the margin of the Greenland Ice Sheet. 2. RSL reached present sea level earlier in areas close to the Greenland Ice Sheet than in areas at greater distances from the Greenland Ice Sheet. 3. RSL fell below present sea level between 2 and 4 ka BP. 4. Submergence has occurred since ca. 1 ka BP.

ADDITIONAL INDEX WORDS: *Isostatic rebound, raised shore lines, coastal emergence, coastal submergence.*

INTRODUCTION

Since the first geophysical models for global relative sea level (RSL) changes were developed in the early 1970's a major aim in field studies of Holocene RSL changes has been to provide data to test and improve these models (e.g. QUINLAN and BEAUMONT, 1981; ANDREWS and PELTIER, 1989; LIVERMAN, 1994; LAMBECK, 1995; PELTIER, 1997). Despite the facts that the Greenland Ice Sheet at present is the second largest ice sheet in the world and that changes of its volume is of great importance to global sea-level, no attempts have been made so far to test the models of global RSL changes on field data from Greenland. This is probably due to our limited knowledge about the glacial history since Last Glacial Maximum (LGM) in Greenland and because most reconstructions of the Holocene RSL changes in Greenland have a limited resolution in time and space (FUNDER, 1989; FUNDER and HANSEN, 1996, WEIDICK 1996). In 1993, a research project was initiated with the purpose of reconstructing the Holocene RSL changes of a smaller part of Greenland (Disko Bugt) with good resolution in time and space and thereby to allow testing of geophysical models for RSL changes on data from Greenland. This paper, which presents the results from the first part of this study, focuses on reconstruction of RSL changes in Disko Bugt. In the years to come, the field observations presented here will be supplemented with more data on glacial history and Holocene RSL changes in the region, and the data material will be tested against model predictions of Holocene RSL changes in the region.

98123 received 13 April 1998; accepted in revision 20 May 1999.

Traditionally, the Holocene RSL changes in Disko Bugt have been reconstructed as one emergence curve representing the entire region (DONNER and JUNGNER, 1975; DONNER, 1978; FRICH and INGÓLFSSON, 1990; INGÓLFSSON *et al.,* 1990). As the number of datings has increased, it has, however, become possible to construct Holocene RSL curves for smaller parts of the region. Recently, four RSL curves representing the Early-Middle Holocene emergence of smaller parts of Disko Bugt have been published (RASCH and NIELSEN, 1995; RASCH *et al.,* 1997, RASCH and JENSEN 1997). Together with a new map of the Holocene marine limit in Disko Bugt and new and previously published material on Late Holocene RSL changes in the region, the RSL curves allow a discussion about variations of glacial rebound in time and space, as well as the possible mechanisms responsible for these variations.

This paper focusses on the RSL changes in Disko Bugt, West Greenland, from LGM to the present.

PHYSICAL SETTING

Disko Bugt is a large bay (area ca. 40000 km^2) situated in West Greenland between 68° and 71° N (Figures 1, 2 and 4). Bedrock mainly consists of Archaean gneisses and granites along the southern and the western part of the bay. The island Disko and the peninsula Nuussuaq are build up by Cretaceous sandstones and Tertiary basalts (ESCHER and PULVERTAFT, 1995). In southern and western Disko Bugt, the landscapes have developed by areal scouring during the Quaternary glaciations, whereas alpine landscapes and landscapes of selective linear erosion predominate on Disko and

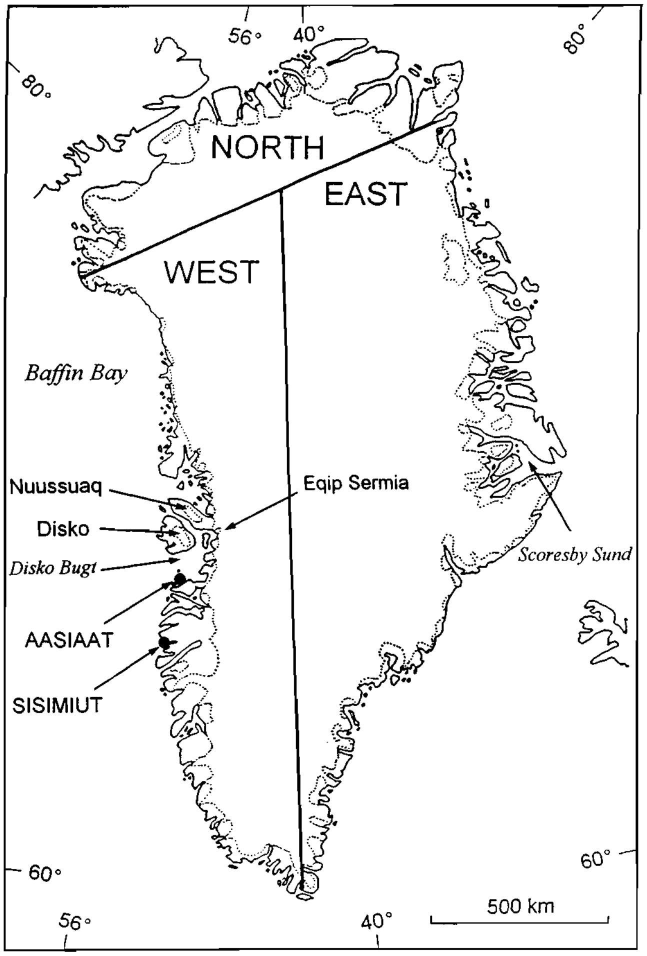

Figure 1. Location map. Location names in Disko Bugt are shown on the maps in Figures 2, 4 and 7.

Nuussuaq (SUGDEN, 1974). In southern and eastern Disko Bugt, the general altitude of the landscape decreases westwards from ca. 500 m a.s.l. near the Greenland Ice Sheet to ca. 100 m a.s.l. east of Aasiaat. Besides the Greenland Ice Sheet, no glaciers occur in this part of the region. On Disko and Nuussuaq, the highest peaks and plateaus are situated 1–2000 m a.s.l.. Most of the plateaus are covered with ice caps, and cirques and valley glaciers occur frequently at lower altitudes.

DEGLACIATION SINCE LAST GLACIAL MAXIMUM (LATE PLEISTOCENE—MIDDLE HOLOCENE)

It is well-established that Disko Bugt was covered by the Greenland Ice Sheet at LGM (KELLY, 1985; FUNDER, 1989; FUNDER and HANSEN, 1996), but very little is known about the deglaciation of the bay. It has been suggested that stillstands/readvances during the deglaciation occurred at ca. 10 ka BP (with the ice margin situated on a north-south oriented line from ca. 10 km west of Aasiaat to ca. 10 km west of Qeqertarsuaq) and at ca. 7 ka BP (10–20 km west of the present margin of the Greenland Ice Sheet), and that the Greenland Ice Sheet reached its present position at ca. 5 ka BP (WEIDICK, 1984; 1992a; 1993). The position of the 7 ka BP stillstand line is based on field observations (WEIDICK, 1968; DONNER and JUNGNER, 1978), while the 10 ka stillstand line has been extrapolated from better investigated areas south of Disko. Recently, FUNDER and HANSEN (1996) have hypothesized that the retreat of the Greenland Ice Sheet after the last glacial maximum occurred in two steps throughout Greenland. According to their hypothesis, the shelf and larger bays (like Disko Bugt) were deglaciated during the first step (in Disko Bugt before ca. 14 ka BP). This deglaciation was caused by calving as a result of rising RSL, and it did not cause significant glacio-isostatic uplift, because the retreating ice was replaced by sea water. During the second step (ca. 10–7 ka BP), the land based ice retreated from a position near the present shore line to the 7 ka BP position suggested by WEIDICK (1984). FUNDER and HANSEN (1996) have further hypothesized that the Holocene isostatic uplift of Greenland was a response to the unloading during the 10–7 ka BP retreat.

HOLOCENE MARINE LIMIT (LATE PLEISTOCENE—EARLY HOLOCENE)

Since 1976 maps of the Holocene marine limit (HML) in West Greenland have been updated at regular intervals as data improved (WEIDICK, 1976; 1992a; KELLY, 1985; FUNDER, 1989; FUNDER and HANSEN, 1996). All these maps show a pattern with elongated coast parallel domes with high uplift (> 80 m) over areas with relatively wide ice free zones (in West Greenland a high uplift dome occurs between Sisimiut and Aasiaat) separated by relatively low uplift (< 40 m) over more narrow ice free zones. On all previously published maps of HML, Disko Bugt is represented by a very low number of data points. Only the island Disko has been mapped with a satisfying density of data points (INGÓLFSSON *et al.*, 1990).

In this investigation HML have been measured on 36 localities in southern, eastern and northern Disko Bugt. In areas with Archean bedrock (*i.e.* southern and eastern Disko Bugt), the Holocene marine limit is generally sharp and easy to discern as the lowest occurrence of erratic boulders. In northern Disko Bugt, especially in Vaigat, it is much more difficult to determine the level of HML. The bedrock here consists of unconsolidated and easily eroded Cretaceous sandstones and Tertiary basalt breccias, and weathering has blurred/obliterated the HML on all except a few localities.

The new measurements of HML are plotted on the map in Figure 2 together with similar measurements from previous maps. On all except one locality, the altitudes of HML were measured with altimeter with an estimated error of ±5 m. The altitude of 108 m a.s.l. (marked with bold) southeast of Aasiaat has been measured with theodolite. On this locality, the altitude of HML was first measured twice with altimeter to respectively 110 and 105 m a.s.l.. These measurements differ surprisingly much from the altimeter measurements of 130 m a.s.l. from nearby localities (DONNER and JUNGNER,

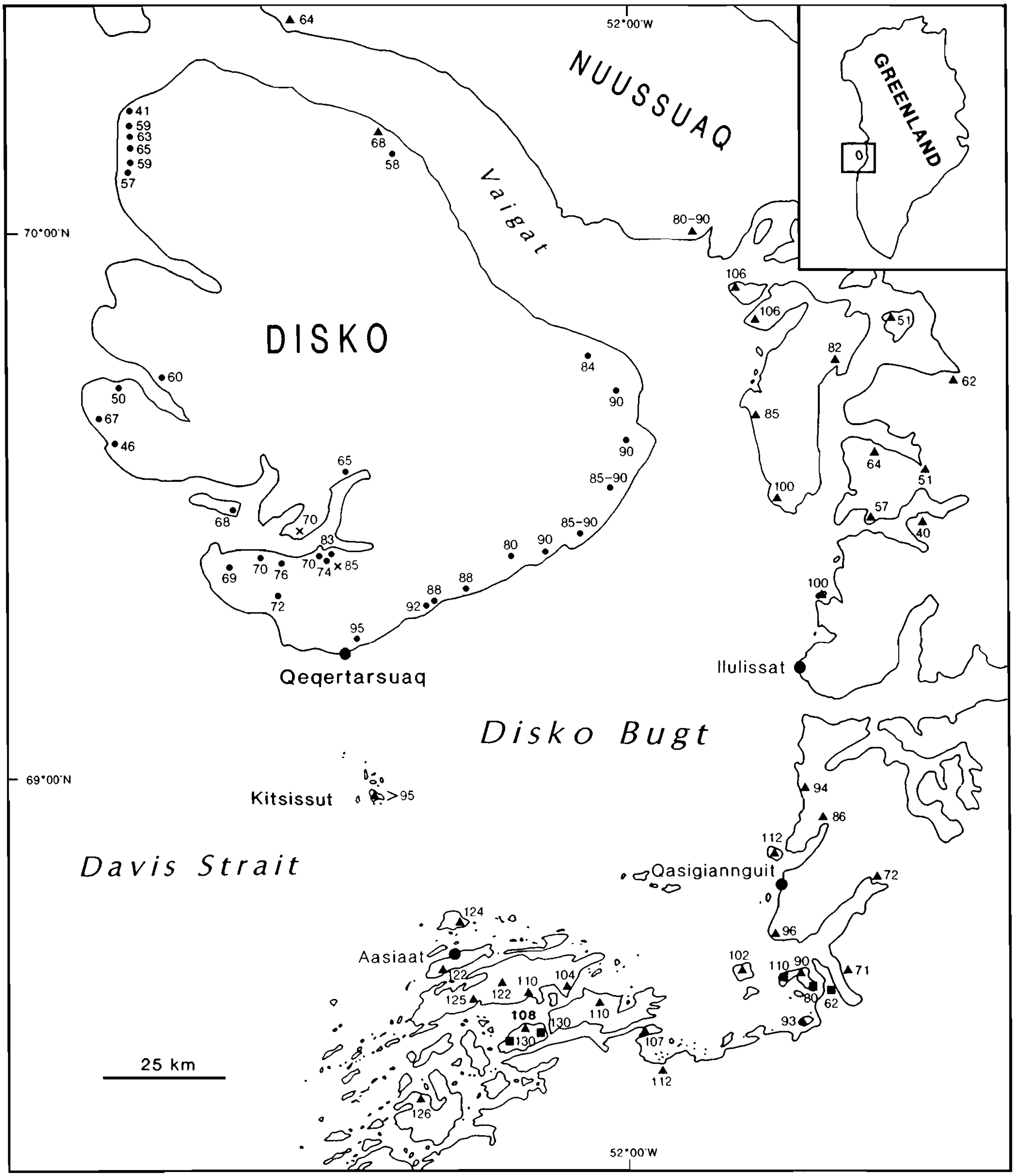

Figure 2. The Holocene marine limit in Disko Bugt. The altitude 108 m a.s.l. shown with bold (south of Aasiaat) was measured with theodolite with an estimated error of ±0.5 m. All other altitudes have been measured with altimeter with an estimated error of ±5 m. Sources for data: DONNER and JUNGNER, 1975 (■); Donner, 1978 (X); Ingólfsson *et al.*, 1990 (●); this work (▲).

1975). The new theodolite measurement (108 m) suggests that the HMLs of 130 m a.s.l. are too high.

In southern Disko Bugt, HML falls towards east from ca. 130 m a.s.l. west of Aasiaat to ca. 70 m a.s.l. near the Greenland Ice Sheet. In this part of Disko Bugt, relatively large gradients of HML occur ca. 10 km east of Aasiaat (from 122 to 110 m a.s.l.) and east of Qasigiannguit (from ca. 110 to ca. 70 m a.s.l.). In northern Disko Bugt, HML reaches a maximum of ca. 100 m a.s.l. along the mainland coast. From there, HML decreases both westwards and eastwards to 40–60 m a.s.l. on western Disko and along the margin of the Greenland Ice Sheet. The islands Kitsissut (between Aasiaat and Qeqertarsuaq) in western Disko Bugt are all below HML. The highest point on these islands is 95 m a.s.l..

The general pattern of HML in Disko Bugt agrees reasonably well with the most recently published maps of HML in Greenland (WEIDICK, 1992a; FUNDER and HANSEN, 1996), though HML near the Greenland Ice Sheet is far too small (< 20 m a.s.l.) on the map of WEIDICK (1992a), and HML along the east coast of Disko Bugt is a little too small (20–80 m a.s.l.) on the map of FUNDER and HANSEN (1996).

It is suggested that the sudden fall of HML from 122 to 110 m a.s.l. ca. 10 km east of Aasiaat (Figure 2) marks the largest extent of the 10 ka readvance/stillstand of the Greenland Ice Sheet, and that at least a part of the large gradient of HML from ca. 110 m a.s.l. to ca. 70 m a.s.l. east of Qasigiannguit reflects the fall of RSL during the 7 ka BP readvance/stil-stand. Some of this gradient might also be due to glacio-isostatic depression during a Late Holocene readvance of the Greenland Ice Sheet (WEIDICK, 1993; OLSEN *et al.*, 1995). The theory above implies that transgression to HML occured before or at the same time as the deglaciation in southern Disko Bugt.

The proposed 10 ka BP stillstand line east of Aasiaat is not congruent with the 10 ka BP stillstand line suggested by WEIDICK (1984; 1992a). However, as noted above, the line of WEIDICK was based on extrapolation from better investigated areas south of Disko Bugt. The new position of the 10 ka BP stillstand line does not conflict with the hypothesis of FUNDER and HANSEN (1996) about the deglaciation since last glacial maximum. They hypothesize that Disko Bugt itself was deglaciated at ca. 14 ka BP, but that the land areas south of Disko Bugt remained ice-covered thereafter.

The relatively low HML on Disko and Nuussuaq compared to areas at the same longitude in southern Disko Bugt might reflect differences in glacio-isostatic response due to differences in bedrock geology (PELTIER, 1987; 1989), or it might simply be due to the fact that Disko and Nuussuaq lies on the northern flank of the high uplift dome between Sisimiut and Aasiaat (WEIDICK, 1992a; FUNDER and HANSEN, 1996). Alternatively, the differences might reflect a difference in the history of deglaciation in respectively northern and southern Disko Bugt. It is well known that the Greenland Ice Sheet did not cover Disko during the Wisconsinan glaciation (FRICH and INGÓLFSSON, 1990; INGÓLFSSON *et al.*, 1990). If it is correct, as hypothesized by FUNDER and HANSEN (1996), that the deglaciation of Disko Bugt itself was not supported by significant uplift, it would be expected that the uplift of Disko and Nuussuaq was a response to the local deglaciations. INGÓLFSSON *et al.* (1990) have showed that a readvance (The Disko stade) of the local ice caps on Disko occured at ca. 9 ka BP. This readvance was generally confined to glaciers facing east, and especially eastern Disko was extensively glaciated during the readvance. The relatively high HMLs on eastern Disko might correspond with an extensive ice cover during the Disko stade, while the relatively low HML's on western Disko might correspond with a Disko stade ice cover very similar to the present.

The relatively high HML (> 95 m) on the islands Kitsissut in western Disko Bugt does not agree well with the hypothesis of FUNDER and HANSEN (1990) about limited land rise in the parts of Greenland which, according to their hypothesis, were deglaciated before ca. 14 ka BP (like e.g. Disko Bugt). If it is correct that Disko Bugt was deglaciated before ca. 14 ka BP and that the deglaciation was not supported by relative land rise, it would be expected that the HML on Kitsissut was relatively low. The discrepancy either indicates that this part of Disko Bugt was not deglaciated before ca. 14 ka BP or that the deglaciation before ca. 14 ka BP was in fact followed by glacio-isostatic land rise. Planned datings of the deglaciation and the HML in southwestern Disko Bugt (based on lake cores at and above HML) will clarify this.

GLACIO-ISOSTATIC EMERGENCE (EARLY–MIDDLE HOLOCENE)

It has been known since the classical work of RINK (1852) about the geography in North Greenland that relative land rise has occurred in Disko Bugt. The indicators of Holocene emergence are very conspicuous in the landscape, when they first have been recognised (Figure 3). With the invention of the ^{14}C dating method it became possible to date marine material from different altitudes above present sea level and thereby to construct emergence curves. The early emergence curves for Disko Bugt represented the entire region (DONNER and JUNGNER, 1975; DONNER, 1978; FRICH and INGÓLFSSON, 1990; INGÓLFSSON *et al.*, 1990). Recently, Holocene RSL curves representing smaller parts of Disko Bugt have been constructed (RASCH and NIELSEN, 1995; RASCH *et al.*, 1996; RASCH and JENSEN, 1996). These curves are placed together in Figure 4. HML is fairly constant within each region represented by a curve. Readers are referred to the original publications for details about the construction and errors of the curves.

Figure 4 shows that the rate of Early-Middle Holocene relative land rise increases towards east (towards the margin of the Greenland Ice Sheet), and that RSL reached present sea level earlier in areas close to the Greenland Ice Sheet than in areas at greater distances from the Greenland Ice Sheet. The steepness of the RSL-curves just before they reach present sea level suggests that RSL continued to fall below present sea level, and, accordingly, that the RSL history of Disko Bugt was one of emergence in Early-Middle Holocene followed by submergence during Late Holocene.

Increasing rates of Early-Middle Holocene relative land rise towards the margin of the Greenland Ice Sheet have also been observed in the Scoresby Sund area in central East Greenland (FUNDER, 1978; FUNDER and HANSEN, 1996). In

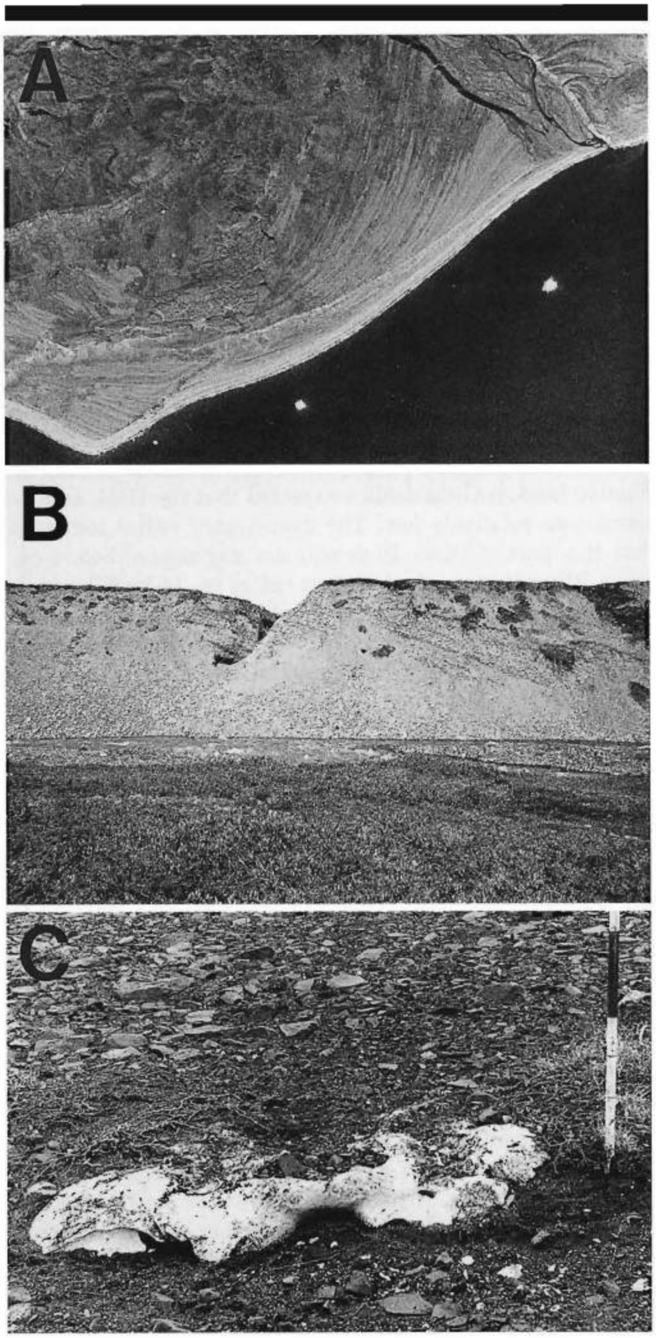

Figure 3. Marine terraces with beach ridges occur frequently below HML in Disko Bugt. The terraces have developed during the Early-Middle Holocene emergence. The air photo (A) shows the river mouth Siniffik on southern Disko (Figure 7). The large triangular terrace in the left side of the photo has developed as a wave dominated Gilbert delta during the Early-Middle Holocene emergence. The alternating light and dark bands are beach ridges. In cross-section (B) the terraces contain foreset beds dipping more than 20° (the cliff on the picture is ca. 15 m high). Occasionally marine fossils occur in the beach deposits. Photo (C) shows the cranium of a big whale in beach deposits ca. 7 m a.s.l. at Asuk in Vaigat, Northern Disko Bugt (Figure 7). The cranium has been dated to 4320 ± 100 a BP (K-6388). $\delta^{13}C$ is −14.9‰ PDB (RASCH, 1997). Determination of species has not been possible.

this part of Greenland, RSL also reached present sea level earlier near the Greenland Ice Sheet than at greater distances from the Greenland Ice Sheet (FUNDER and HANSEN, 1996).

WEIDICK (1992a) has suggested that relatively high rates of relative land rise near the Greenland Ice Sheet owe to the fact that the largest differences between Wisconsinan and present ice load occur in this region. Unfortunately, no work has been carried out to test this hypothesis on a geophysical basis.

Alternatively, the rising rates of Early-Middle Holocene emergence towards the Greenland Ice Sheet might be the result of differences in the rate of eustatic sea level rise at the time of deglaciation of the different parts of Disko Bugt. When western Disko Bugt was deglaciated at ca. 10 ka BP, the eustatic sea level rise was ca. 1.3 cm pr. year (FAIRBANKS, 1989). When eastern Disko Bugt was deglaciated at ca. 7 ka BP, the eustatic sea level was only rising ca. 0,7 cm pr. year (FAIRBANKS, 1989). Accordingly, the glacio-isostatic land rise had a lager relative effect on the Early-Middle Holocene RSL changes in eastern Disko Bugt than in western Disko Bugt, and with the same glacio-isostatic land rise in the two regions, the rate of relative land rise would be expected to be larger close to the Greenland Ice Sheet than at greater distance from the Greenland Ice Sheet.

Emergence curves only show the trend of RSL changes (WEIDICK, 1972a; SUTHERLAND, 1987; PIRAZZOLI, 1991). Consequently, short transgressions during the Early-Middle Holocene emergence (regression) would not be disclosed by the curves. However, a study of the coastal morpo-stratigraphy at Siniffik on southern Disko have revealed that the Early-Middle Holocene emergence probably occurred monotonously (RASCH and NIELSEN, 1994). Systematic morphostratigraphic investigations like the one at Siniffik has not been carried out elsewhere in Disko Bugt, but it is the authors impression from reconnaissances along the shores of Disko Bugt that the Siniffik results are representative for the entire bay.

SUBMERGENCE (LATE HOLOCENE)

Present knowledge about Late Holocene RSL changes in Disko Bugt originates from studies of Quaternary stratigraphy (KELLY, 1980; FUNDER, 1989; BENNIKE *et al.,* 1994; WEIDICK, 1996), studies of archaeology (MATHIASSEN, 1934; MATHIASSEN in GABEL-JØRGENSEN and EGEDAL, 1940; LARSEN and MELDGAARD, 1958; MØBJERG, 1986; JENSEN, 1995; RASCH and JENSEN, 1997), studies of coastal geomorphology (DONNER 1978; RASCH and NIELSEN 1994; 1995; RASCH, *et al.,* 1996; RASCH *et al.,* 1997), and from early tidal observations (PJETURRSON 1898; FRODA, 1924; EGEDAL, 1947; SAXOV, 1958). It is well known that RSL fell below present sea level between 4 and 2 ka BP (Figures 4 and 5), and that submergence has occurred in the nearest past (Figure 6).

Absolute datings of organic material from sediments which have been either deposited, superposed or eroded during the Late Holocene transgression are listed in Table 1. Where possible, dates on marine material have been corrected for isotopic fractionation by normalizing to $\delta^{13}C$ = 0.0‰ PDB, while

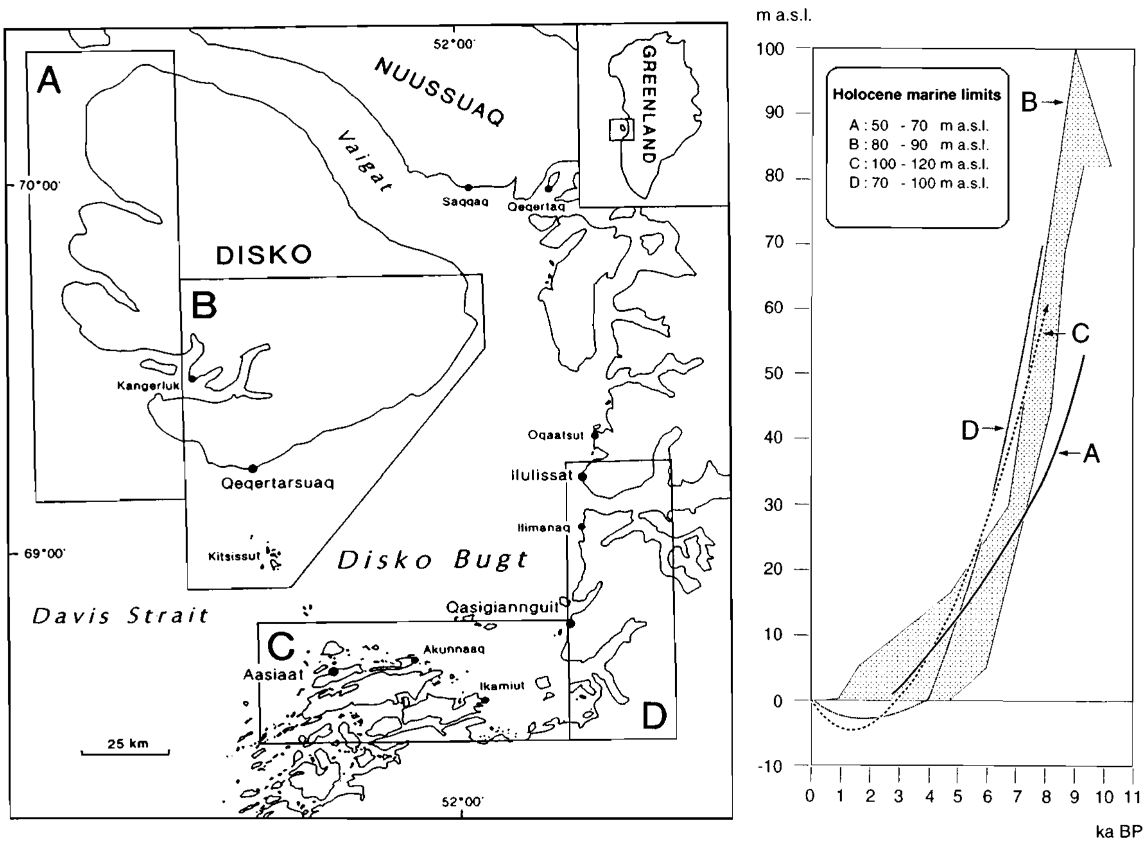

Figure 4. Holocene RSL-curves from Disko Bugt. Sources: RASCH *et al.*, 1997 (curve A); RASCH and NIELSEN, 1995 (curve B), RASCH and JENSEN, 1997 (curve C and D). The shaded area (curve B) marks the zone in which the RSL curve of region B must lie. Readers are refered to the original publications for details about the construction of the individual curves and for plots including data points.

dates on terrestrial material have been corrected by normalizing to $\delta^{13}C = -25.0‰$ PDB. The marine reservoir effect in West Greenland is expected to be ca. 400 years (RASMUSSEN and RAHBEK, 1996). The samples for the datings I-16414 and K-6181 originate from present beaches on respectively southern Nuussuaq and southern Disko (BENNIKE *et al.*, 1994; RASCH and NIELSEN, 1995), while the samples for the datings AAR-1812, AAR-1816, AAR-2198 and AAR-2199 originate from the bottom layer of lagoon sediments from cores taken at different localities on Disko (RASCH, 1997; RASCH *et al.*, 1997). These datings all give minimum ages for the transgression. The dating Hel-945 was carried out on material from a peat layer (0.3 m a.s.l.) from western Disko (DONNER, 1978). The peat is now under erosion by the sea. The datings AAR-2351 and AAR-2554 were carried out on samples of peat which underlie the foreshore sediments of transgressive beaches at former Eskimo dwelling sites in southeastern Disko Bugt (RASCH and JENSEN, 1997). These datings all give maximum ages for the initiation of the transgression. At the first glance, the datings in Table 1 seem to limit the possible time span in Disko Bugt for minimum RSL to the period between 970 ± 110 a BP and 840 ± 60 a BP. However, as with the Early-Middle Holocene emergence (Figure 4), the time of minimum RSL is also expected to vary from place to place, and accordingly, more datings are needed to locate minimum RSL more precisely in both space and time.

Based on the stratigraphy in three lagoons on western Disko it has been suggested that the transgression after 1 ka BP consisted of three transgression phases culminating at 0.7 ka BP, 0.4 ka BP and in middle of the present century (RASCH *et al.*, 1997). A transgression maximum at ca. 0.4 ka BP has also been suggested by WEIDICK (1993). The suggestion of WEIDICK was based on earlier published material about the distance relation between Thule Culture (after ca. 600 BP) Eskimo ruins of different ages and the present shore line (MATHIASSEN in GABEL-JØRGENSEN and EGEDAL, 1940). The transgression maximum in the middle of the present century has been measured directly (SAXOV, 1958).

Topographic profiles of present beaches have been surveyed on different localities on Disko. Representative profiles are shown in Figure 7. It is common to all the profiles that washover ridges (*i.e.* transgressive coastal barriers) constitute the present beaches. At some of the localities (A, B, C and D) the present beaches are followed landward by sequences (beach ridge plains) of simple beach ridges (*i.e.* swash ridges) again followed by relict coastal cliffs leading to marine terraces at higher elevations. At other localities (E and F),

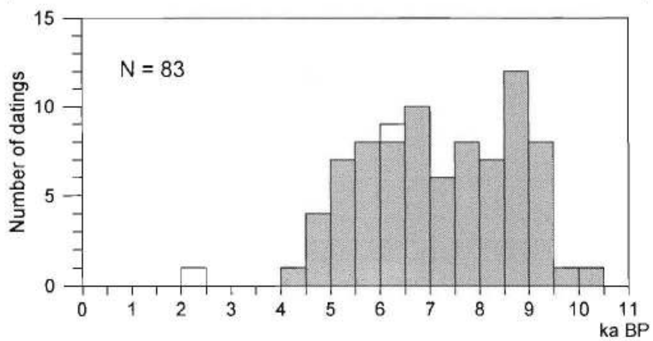

Figure 5. Age distribution of datings on marine shells from Disko Bugt. The two datings marked with white boxes have been carried out on material from the same unit of glacio-marine till (0.8–2.3 m a.s.l.) at Eqip Sermia (69°46′N, 50°13′W) in northeastern Disko Bugt. The unit was first dated to 2190 ± 75 BP by conventional ^{14}C dating (i.e. on a large sample) (K-3662, INGÓLFSSON *et al.*, 1990). This dating has been considered as evidence of relatively high RSL at ca. 2 ka BP (WEIDICK, 1993). Recently, the age of the unit has been checked by conventional ^{14}C dating new material from the unit. The new dating (K-6373) gives an age of 6420 ± 110 BP ($\delta^{13}C$ = 1.4‰ PDB). Sources for datings: WEIDICK, 1968; 1972a; 1972b; 1973; 1974; DONNER and JUNGNER, 1975; DONNER, 1978; FRICH and INGÓLFSSON, 1990; INGÓLFSSON *et al.*, 1990; BENNIKE *et al.*, 1994; RASCH *et al.*, 1997; RASCH and JENSEN, 1997; RASCH, 1997; this work.

lagoons occur immediately behind the present beaches. The washover ridges and the lagoons probably originated during the transgression after ca. 1 ka BP (RASCH and NIELSEN, 1995; RASCH *et al.*, 1997). It has been suggested that the relict coastal cliffs originated during a transgression between 2.5 and 1 ka BP, and that this transgression was followed by a regression leading to the development of the simple beach ridges behind the present beaches (RASCH and NIELSEN, 1995; RASCH *et al.*, 1997). A transgression between 2.5 and 1 ka BP has also been suggested by OLSEN *et al.* (1995).

It has been argued that the Late Holocene submergence in West Greenland was a response to the well documented "Neoglacial" readvance of the Greenland Ice Sheet starting at ca. 5 ka BP and culminating during the Little Ice Age (KELLY, 1980; FUNDER, 1989; WEIDICK, 1993; 1996; OLSEN *et al.*, 1995). In southeastern Disko Bugt, the Greenland Ice Sheet has advanced 10–20 km since ca. 5 ka BP (WEIDICK *et al.*, 1990; WEIDICK, 1992b). Based on a geophysical model, KELLY (1980) has demonstrated that the Late Holocene readvance of the Greenland Ice Sheet might have caused subsidence even at the outer coast of Greenland. Glacio-isostatic depression due to Late Holocene glacier readvance might also have been the mechanism responsible for the submergence of Disko and Nuussuaq, where the local ice caps also expanded during the Late Holocene (WEIDICK, 1968; HUMLUM, 1987).

Alternatively, it is hypothesized that the Late Holocene submergence might have resulted from migration of a collapsing forebulge originally developed in front of either the Greenland Ice Sheet or the Laurentian Ice Sheet. In Canada Late Holocene submergence has been related to the migration of a collapsing forebulge (QUINLAN and BEAUMONT, 1981; ANDREWS and PELTIER, 1989; LIVERMAN 1994). In Greenland, however, more work need to be done to test this

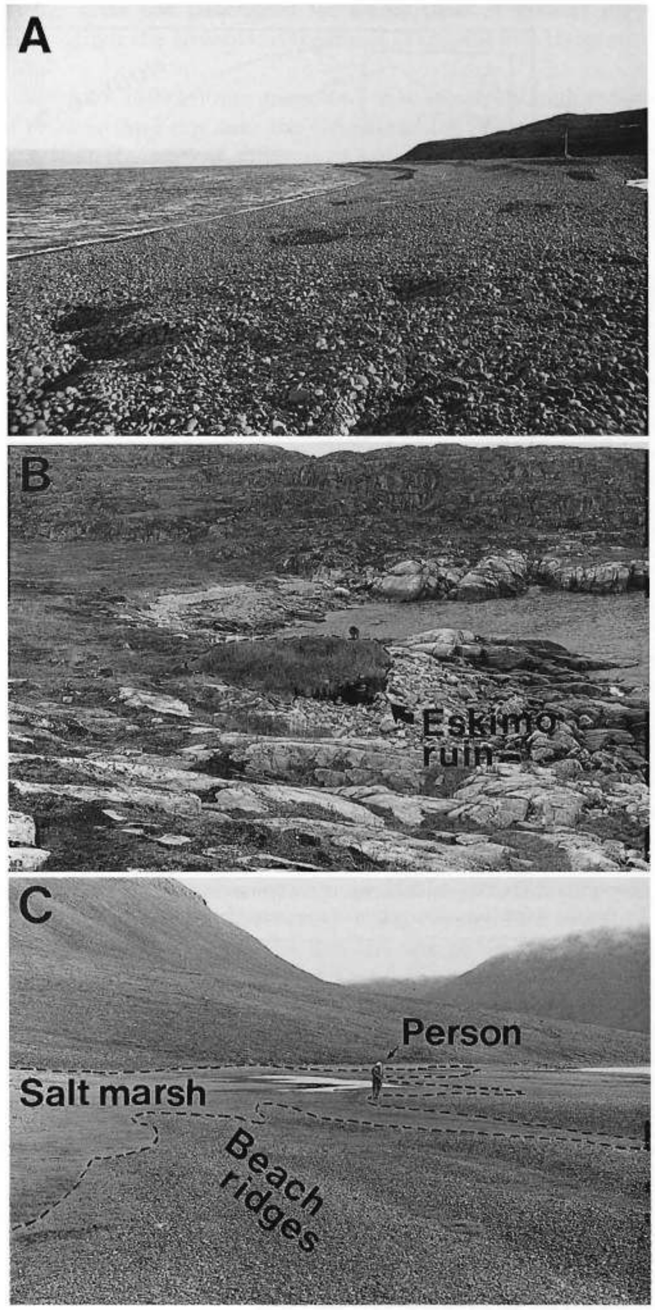

Figure 6. The frequent occurrences along the shores of Disko Bugt of washover ridges (A), partly submerged Thule Culture Eskimo ruins (B) and salt marsh formation on top of relict beach ridges (C) all indicate Late Holocene transgression.

hypothesis. Especially, a better mapping of ice margin positions at the LGM (before ca. 14 ka BP), at the still-stands/readvances during the recession of the Greenland Ice Sheet (Early-Middle Holocene), and at the minimum extent of the Greenland Ice Sheet (Middle-Late Holocene) is needed to allow geophysical modelling of local Holocene RSL changes within Disko Bugt (and in Greenland as a whole) and to disclose the different mechanisms involved in those changes.

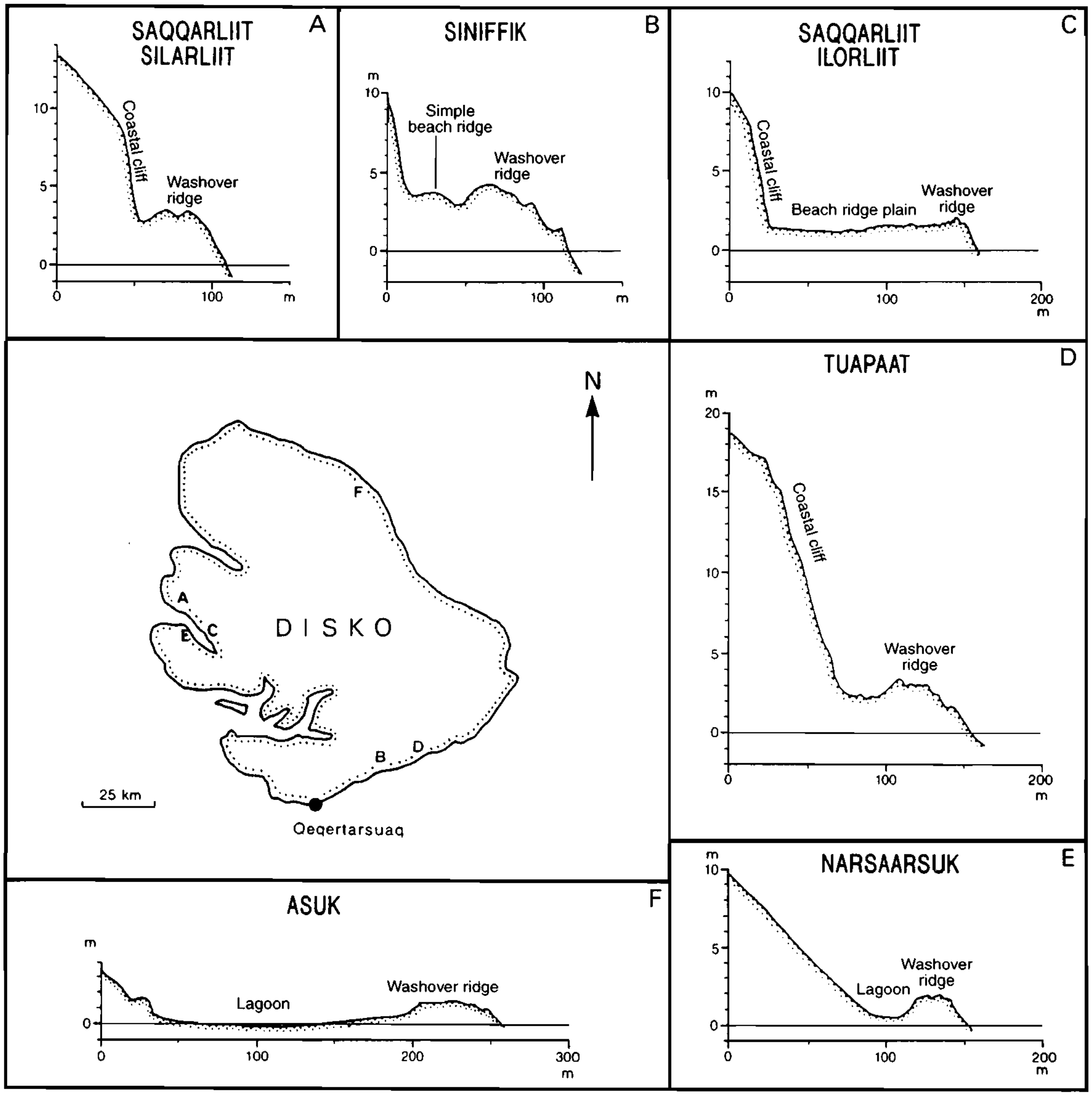

Figure 7. Topographic profiles of the active beaches at different localities on Disko. Washover ridges (transgressive barriers) constitute the active beaches on all the localities. The washover ridges probably started to develop during a transgression after ca. 1 ka BP. A relict coastal cliff occur behind the active beaches on all localities except Asuk and Narsaarsuk. The cliffs might have developed during a transgression in the period between ca. 2.5 and ca. 1 ka BP. Sources: RASCH and NIELSEN, 1994 (profile B); RASCH and NIELSEN, 1995 (profile D); RASCH *et al.*, 1997 (profile C); this work (profiles A, E and F).

Table 1. *Datings of the beginning of the last major transgression in Disko Bugt.*

Lab. No.	Place Name	N Lat.	W Long.	Material	Elevation m a.s.l.	Age ^{14}C a BP	δ^{13}C ‰ PDB	Reference
I-16414	Kangeq	70°43′	54°36′	Whale	5	380 ± 80	−18.1	Bennike *et al.*, 1994
K-6181	Tuapaat	69°24′	52°36′	Whale	3.1	480 ± 75	−14.5	Rasch and Nielsen, 1995
AAR-1816	Saqqarliit Ilorliit	69°44′	54°30′	Gyttja	0.6	620 ± 80	−26.0	Rasch *et al.*, 1997
AAR-1812	Saqqarliit Ilorliit	69°44′	54°30′	Mud	0.7	710 ± 200	−25.0	Rasch *et al.*, 1997
AAR-2199	Asuk	70°12′	53°19′	Basal peat	1	755 ± 60	−27.1	Rasch, 1997
AAR-2198	Narsaarssuk	69°44′	54°40′	Basal peat	1	840 ± 60	−21.6	Rasch, 1997
Hel-945	Ikeneq	69°29′	53°38′	Peat	0.3	970 ± 110		Donner, 1978
AAR-2554	Orpissooq	68°37′	50°52′	Peat	0.4	1025 ± 55	−27.7	Rasch and Jensen, 1997
AAR-2343	Annertusuaqqap Nuua	68°35′	51°52′	Charcoal	−0.1	2530 ± 75	−23.4	Rasch and Jensen, 1997

SUMMARY AND CONCLUSIONS

A mapping of the HML in Disko Bugt has been carried out. The map shows regions of relatively high uplift in southwestern Disko Bugt and on eastern Disko, and regions of relatively low uplift in northern Disko Bugt and near the Greenland Ice Sheet. Large gradients of HML occur ca. 10 km east of Aasiaat and on a north-south oriented line east of Qasigiannguit. It is suggested that the large gradient east of Aasiaat marks the largest extension of the 10 ka BP readvance/stillstand of the Greenland Ice Sheet, and that at least a part of the large gradient east of Qasigiannguit is due to the 7 ka BP readvance/still-stand of the Greenland Ice Sheet.

Based on four Holocene RSL curves from different regions within Disko Bugt it is concluded that the Holocene RSL history of Disko Bugt was one of Early-Middle Holocene emergence followed by Late Holocene submergence. The curves also show an increase in the rate of Early-Middle Holocene land rise towards the margin of the Greenland Ice Sheet, and that RSL reached present sea level earlier in areas close to the Greenland Ice Sheet than in areas at greater distances from the Greenland Ice Sheet.

Submergence in Late Holocene is indicated by frequent occurrences of transgressive beaches and partly submerged Eskimo ruins along the shores of Disko Bugt. The Late Holocene transgression probably started at ca. 1 ka BP, and it might have consisted of three transgression phases culminating at ca. 0.7 ka BP, at ca. 0.4 ka BP and in the middle of the present century. Besides, the transgression after 1 ka BP, it has also been suggested that a transgression occurred in the period between 2.5 and 1 ka BP.

ACKNOWLEDGEMENT

This paper is based on observations collected in the period between 1993 and 1996. Thanks are extended to A. Mikkelsen, M. Oddershede, P. Unger, K. Kjær, T. OLSEN and P. OLSEN for assistance in the field, to A. Long, O. HUMLUM, B. Elberling and N. NIELSEN for helpful comments on the manuscript and to J. Jønsson and O. B. Berthelsen for technical help with figures and tables. The Danish Science Research Council made funds available for instruments and field work. Transport to field localities were provided by the Arctic Station (University of Copenhagen) in Qeqertarsuaq, Greenland.

LITTERATURE CITED

ANDREWS, J.T., and PELTIER, W.R., 1989. Quaternary geodynamics in Canada. *In:* FULFTON, R. J. (ed.), *Quaternary geology of Canada and Greenland*. Geological Survey of Canada, Canada, pp. 543–572.

BENNIKE, O.; HANSEN, K.B.; KNUDSEN, K.L.; PENNEY, D.N., and RASMUSSEN, K.L., 1994. Quaternary marine stratigraphy and geochronology in cenral West Greenland. *Boreas*, 23, 194–215.

DONNER, J., 1978. Holocene history of the west coast of Disko, central West Greenland. *Geografiska Annaler*, 60A, 63–72.

DONNER, J. and JUNGNER, H., 1975. Radiocarbon dating of shells from marine Holocene deposits in the Disko Bugt area, West Greenland. *Boreas*, 4, 25–45.

EGEDAL, J., 1947: The sinking of Greenland. A continuation of F. FRODA's measurements. *Meddelelser om Grønland*, 134(7), 6 p.

ESCHER, J.C. and PULVERTAFT, T.C.R., 1995. *Geological map of Greenland, 1:2.500.000*. Geological Survey of Greenland, Copenhagen.

FRICH, P. and INGÓLFSSON, O., 1990. Det holocæne sedimentationsmiljø ved Igpik samt en model for den relative landhævning i Disko Bugt, Vestgrønland. *Dansk geologisk Forening. Årsskrift for 1987–89*, 1–10.

FAIRBANKS, R.G., 1989. A 17,000-year glacio-eustatic sea-level record: influence of glacial melting rates on the Younger Dryas event and deep-ocean circulation. *Nature*, 342, 637–642.

FRODA, F., 1924. Some observations made in Greenland in North-Greenland 1923. *Meddelelser om Grønland*, 59, 39–54.

FUNDER, S., 1978. Holocene stratigraphy and vegetation history in the Scoresby Sund area, East Greenland. *Grønlands geologiske Undersøgelse Bulletin*, 129, 66 p.

FUNDER, S. 1989: Quaternary geology of the ice-free areas and the adjacent shelves of Greenland. *In:* FULFTON, R. J. (ed.), *Quaternary geology of Canada and Greenland*. Geological Survey of Canada, Canada, pp. 743–792.

FUNDER, S. and HANSEN, L., 1996. The Greenland ice sheet—a model for its culmination and decay during and after the last glacial maximum. *Bulletin of the Geological Society of Denmark*, 42, 137–152.

GABEL-JØRGENSEN, C.C.A. and EGEDAL, J., 1940. Tidal observations made at Nanortalik and Julianehaab in 1932–1934. *Meddelelser om Grønland*, 107(2), 1–47.

HUMLUM, O., 1987. Glacier behaviour and the influence of upper-air conditions during the Little Ice Age in Disko, central West Greenland. *Geografisk Tidsskrift*, 87, 1–12.

HUYBRECHTS, P., 1994. The present evolution of the Greenland ice sheet: an assessment by modelling. *Global Planetary Change*, 9, 39–51.

INGÓLFSSON, O.; FRICH, P.; FUNDER, S., and HUMLUM, O., 1990. Paleoclimatic implications of an early Holocene glacier advance on Disko Island, West Greenland. *Boreas*, 19, 297–311.

JENSEN, J.F., 1995. Annertusuaqqap Nuua—en Dorset-boplads i Sydostbugten, Vestgrønland. *Tidsskriftet Grønland*, 5(1995), 225–240.

KELLY, M., 1980. The status of the Neoglacial in western Greenland. *Grønlands geologiske Undersøgelse Rapport*, 96, 24 p.

KELLY, M., 1985. A review of the Quaternary geology of western Greenland. *In:* ANDREWS, J. T. (ed.), *Quaternary environments, Eastern Canadian Arctic, Baffin Bay and Western Greenland*. Allen and Unwin, Boston, pp. 461–501

LAMBECK, K., 1995. Constraints on the Late Weichselian ice sheet over the Barents Sea from observations of raised shorelines. *Quaternary Science Reviews*, 14, 1–16.

LARSEN, H. and MELDGAARD, J., 1958. Paleo-Eskimo cultures in Disco Bay, West Greenland. *Meddelelser om Grønland*, 161(2), 1–75.

LIVERMAN, D.G.E., 1994. Relative sea-level history and isostatic rebound in New Foundland, Canada. *Boreas*, 23, 217–230.

MATHIASSEN, Th., 1934. Contributions to the archaeology of Disko Bay. *Meddelelser om Grønland*, 93(2), 1–192.

MØBJERG, T., 1986. A contribution to paleoeskimo archaeology in Greenland. *Arctic Anthropology*, 23, 19–56.

OLSEN, O.B.; WEIDICK, A.; REEH, N.; THOMSEN; H.H.; BRAITHWAITE, R.J., and BØGGILD, C.E., 1995. Environmental impact on Greenland glaciers. *Grønlands geologiske Undersøgelse Rapport*, 165, 79–87.

PELTIER, W.R., 1987. Mechanisms of Relative Sea-level Change and the Geophysical Responses to Ice-water Loading. *In:* DEVOY, R.J.N. (ed.), *Sea surface studies: a global view*. Croom Helm, New York, pp. 57–94

PELTIER, W.R., 1989. Models of glacial isostasy. *In:* FULTON, R.J. (ed.). *Quaternary geology of Canada and Greenland*. Geological Survey of Canada, Canada, pp. 562–572

PELTIER, W.R. 1997. Postglacial variations in the level of the sea: Implications for climate dynamics and solid-earth geophysics. *Reviews of Geophysics*, 36, 603–689.

PIRAZZOLI, P.A., 1991. *World atlas of Holocene sea-level changes*. Elsevier Publishers, Amsterdam, 300 p.

PJETURRSON, H., 1898. Opmaalingsexpeditionen til Egedesminde-

Distrikt. Geologiske Optegnelser. *Meddelelser om Grønland*, 14, 288–347.

QUINLAN, G. and BEAUMONT, C., 1981. A comparison of observed and theoretical postglacial relative sea level in Atlantic Canada. *Canadian Journal of Earth Sciences*, 18, 1146–1163.

RASCH, M., 1997. A compilation of radiocarbon dates from Disko Bugt, central West Greenland. *Danish Journal of Geography*, 97, 143–151.

RASCH, M. and NIELSEN, N., 1994. Holocene relative sea-level changes indicated by morphostratigraphic sequences; Sinigfik, Disko Island, West Greenland. *Geografisk Tidsskrift*, 94, 37–45.

RASCH, M. and NIELSEN, N., 1995. Coastal morpho-stratigraphy and Holocene relative sea level changes at Tuapaat, southeastern Disko Island, central West Greenland. *Polar Research*, 14(3), 277–289.

RASCH, M. and JENSEN, J.F. 1997: Ancient Eskimo dwelling sites and Holocene relative sea-level changes in southern Disko Bugt, central West Greenland. *Polar Research*, 16(2), 101–115.

RASCH, M.; CHRISTIANSEN, H.H.; HANSEN, B.U.; HASHOLT, B.; HUMLUM, O., JAKOBSEN, B.H., and NIELSEN, N., 1996. Greenland landscape elements as indicators of rapid environmental change. *In:* BERGER, A.R. and IAMS, W.J. (eds.), *Geoindicators: Assessing Rapid Environmental Changes in Earth Systems*. A.A. Balkema, Rotherdam, pp. 55–78.

RASCH, M.; JAKOBSEN, B. H., and NIELSEN, N., 1997. Geomorphology and sedimentary record of three cuspate forelands as indicators of Late Holocene relative sea-level changes, Disko, West Greenland. *Danish Journal of Geography*, 97, 33–46

RASMUSSEN, K.L. and RAHBEK, U., 1996. The ^{14}C reservoir effect in Greenland. *In:* GRØNNOW, B. (ed.), *Paleo-Eskimo Cultures of Greenland*. Danish Polar Center, Copenhagen, pp. 237–242.

RINK, H., 1852. Om den geographiske Beskaffenhed af de danske Handelsdistrikter i Nordgrönland og Udsigt over Nordgrönlands Geognosi. *Kongelige danske Videnskabernes Selskabs Skrifter Række 5, Naturvidenskabelig og mathematisk Afdeling*, 3, 37–98.

SAXOV, S., 1958. The uplift of Western Greenland. *Meddelelser fra Dansk Geologisk Forening*, 13, 518–523.

SUGDEN, D.E. 1974. Landscapes of glacial erosion in Greenland and their relationship to ice, topographic and bedrock conditions. *Institute of British Geographers, Special publication*, 7, 177–195.

SUTHERLANDnm, D.G. 1987: Dating and Associated Methodological Problems in the Study of Quaternary Sea-level Changes. *In:* DEVOY, R.J.N. (ed.), *Sea surface studies: a global view*. Croom Helm, New York, pp. 165–197.

WEIDICK, A., 1968: Observations on some Holocene glacier fluctuations in West Greenland. *Meddelelser om Grønland*, 165(6), 1–202.

WEIDICK, A., 1972a. Holocene shore-lines and glacial stages in Greenland—an attempt at correlation. *Grønlands geologiske Undersøgelse Rapport*, 41, 1–39.

WEIDICK, A., 1972b. C^{14} dating of survey material performed in 1971. *Grønlands geologiske Undersøgelse Rapport*, 45, 58–67.

WEIDICK, A., 1973. C^{14} dating of survey material performed in 1972. *Grønlands geologiske Undersøgelse Rapport*, 55, 66–75.

WEIDICK, A., 1974. C^{14} dating of survey material performed in 1973. *Grønlands geologiske Undersøgelse Rapport*, 66, 42–44.

WEIDICK, A., 1976. Glaciation and the Quaternary. *In*: ESCHER, A. and WATT, S. (eds.), *Geology of Greenland*. Geological Survey of Greenland, Denmark, pp. 431–458

WEIDICK, A., 1984. Studies of glacier behaviour and glacier mass balance in Greenland—a review. *Geografiska annaler*, 66A, 183–195.

WEIDICK, A., 1992a: Landhævning og landsænkning i Grønland siden sidste istid. *Naturens Verden*, 1992(3), 81–96.

WEIDICK, A., 1992b. Jakobshavn Isbræ area during the climatic optimum. *Grønlands geologiske Undersøgelse Rapport*, 155, 67–72.

WEIDICK, A., 1993. Neoglacial change of icecover and the related response of the Earth's crust i West Greenland. *Grønlands geologiske Undersøgelse Rapport*, 159, 121–126.

WEIDICK, A., 1996: Neoglacial changes of ice cover and sea level in Greenland—a classical engima. *In:* GRØNNOW, B. (ed.), *The Paleo-Eskimo cultures of Greenland*. Danish Polar Center, Copenhagen, pp. 257–270.

WEIDICK, A.; OERTER, H.; REEH, N.; THOMSEN, H.H., and THORNING, L., 1990. The recession of the Inland Ice margin duriong the Holocene climatic optimum in the Jakobshavn Isfjord area of West Greenland. *Palaeogeography, Palaeoclimatology, Palaeoecology (Global and Planetary Change Section)*, 82, 389–399.