Glacial History and Periglacial Landforms of the Zackenberg area, Northeast Greenland: Preliminary results

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The geomorphology of the Zackenberg area has been investigated with the purpose of establishing a geomorphological map of a 260 km² area around the planned research station. Production of a large digital three-dimensional elevation model, based on the use of a multi-model photogrammetric method, has been the basis for a GIS database and a topographical map (1:50,000) covering the investigation area.

Both glacial and periglacial landforms have been mapped and a preliminary Late Weichselian glacial history of the Zackenberg area reconstructed. A monitoring of 11 selected test field sites representing climatically sensitive land elements has been established, enabling the registration of even minor short-term variations in the geomorphic processes.

Keywords: *Zackenberg, Northeast Greenland, glacial and periglacial geomorphology, monitoring, dating, climatically sensitive land elements, climatic control.*

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Systematic geomorphological investigations in Northeast Greenland have not until now been carried out, and only limited information on the geomorphology exists from the region around Zackenberg (74.5°N, 20.5°W). Only Poser (1932) has described various periglacial terrain forms from the area between 73°N and 75°N in East Greenland, including some observations from the Zackenberg region. Therefore, the long-term research programme ZERO (Zackenberg Ecological Research Operations; Danish Polar Center, 1992), with the overall aim of monitoring the environmental impact caused by climatic changes, was initiated in the Zackenberg area. One of the first requirements was a detailed knowledge of the physical environment in the form of topographical and geomorphological maps.

The present paper briefly presents the preliminary results obtained during the field study in the area in July and August 1992.

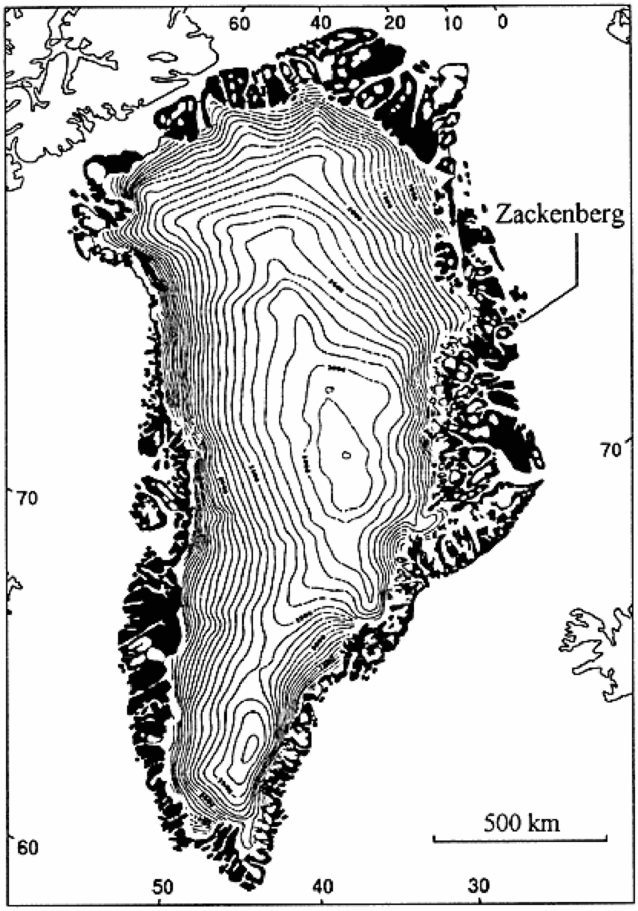

Fig. 1. Locational map of the Zackenberg research area.

THE STUDY AREA

The Zackenberg area is situated in the high-arctic region of Northeast Greenland, within the southern part of the National Park of North and East Greenland (Fig. 1) which is the largest national park in the world. The size of the investigated area is around 260 km² (Fig. 2). The topography is dominated by a major valley system surrounded by mountains rising to 1,450 m a s.l. and the study area is delimited towards the south by the fiord Young Sound (Fig. 2).

A major geological flexure and thrust zone is running nearly N-S through the central part of the area, separating Caledonian gneiss bedrock in the west from Cretaceous sandstone capped by Tertiary basalts in the eastern part (Koch & Haller, 1971).

The Zackenberg area is located in the zone of continuous permafrost with an active layer 20 to 70 cm thick (late August 1992). The mean annual air temperature is -10.3°C and the mean annual amount of precipitation 214 mm water equivalent at Daneborg, 30 km SE of the Zack-

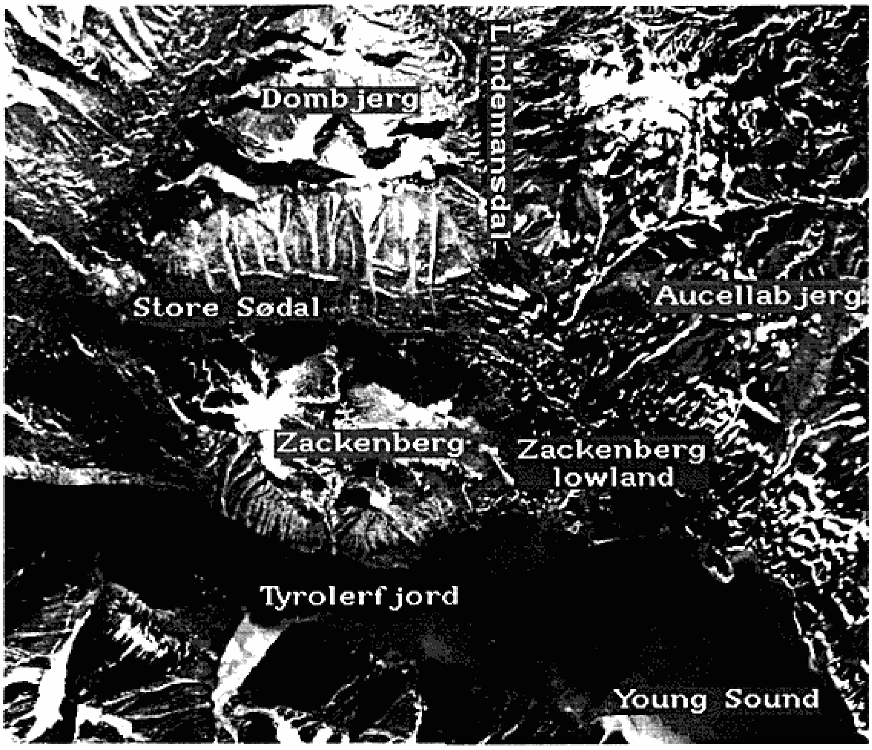

Fig. 2. Aerial photo showing the 260 km^2 study area at Zackenberg (approximate scale 1:150,000). North is towards the top. Young Sound is seen in the southeastern part of the photo. 05.08.1987.

enberg area (Danish Meteorological Institute, 1967, 1968 & 1978, mean values 1951-70). As much as 87% of the annual precipitation falls as snow. Rain has only been reported in the period May-October, which is generally a period with few occurrences of precipitation (Fig. 3). The prevailing wind direction is from the N and NNE (Fig. 4). From data on occurrences of precipitation and wind, it appears that heavy snowdrifting from the N and NNE is frequent during the winter.

TOPOGRAPHICAL MAPPING

Official topographical 1:250,000 maps exist of the area (Geodetic Institute, Copenhagen), at contour intervals of 100 m. These maps, although of remarkable quality for such a remote area, were not sufficient for carrying out detailed geomorphological mapping, therefore, a digital topographical 1:50,000 model of the Zackenberg area was established by means of multi-model photogrammetry (Humlum, 1992) using aerial photographs from 1985 (scale 1:150,000). Vertical contours on this map are at 20 m intervals. This topographic 8.5 Mbyte database will be used as a database for GIS-analyses of the study area.

GLACIAL GEOMORPHOLOGY OF THE ZACKENBERG AREA

At present, the investigation area is situated about 30 km east of the Greenland Ice Sheet margin, and only few local glaciers are found within the area. The area was, however, almost completely covered by the Greenland Ice Sheet and local glaciers during the Late Weichselian. A short outline of the preliminary results on the Late Weichselian deglaciation history will be given in the following sections and in the figures 5, 6 and 8. The palaeoglaciological history outlined below is based on observations of; moraine ridges, old medial moraines, striae, glaciofluvial deposits, old shorelines and different datings.

Early Weichselian

In the northeastern part of the Zackenberg lowland a small kame terrace was found. The feature was techtonized and covered by a till. A luminescence dating on glaciolacustrine sediments within the terrace gave a preliminary age beyond 84,000 BP and below 120,000 BP. This kame terrace may thus have been deposited during an early Weichselian deglaciation period.

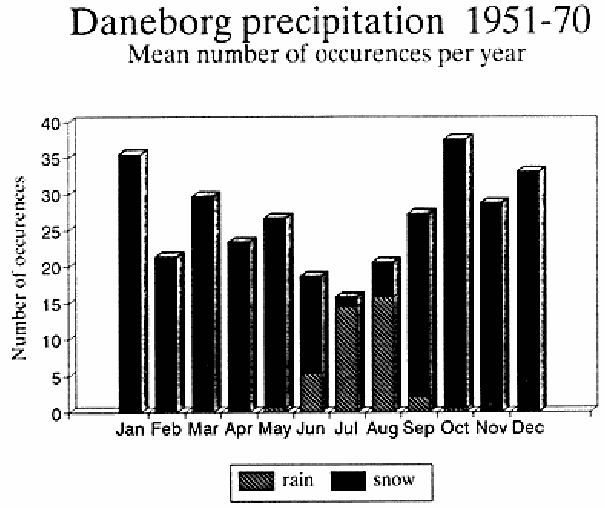

Fig. 3. Diagram showing the precipitation type and mean monthly frequency at Daneborg, during the period 1951-70. Data from the Danish Meteorological Institute (DMI), 1967, 1968 and 1978.

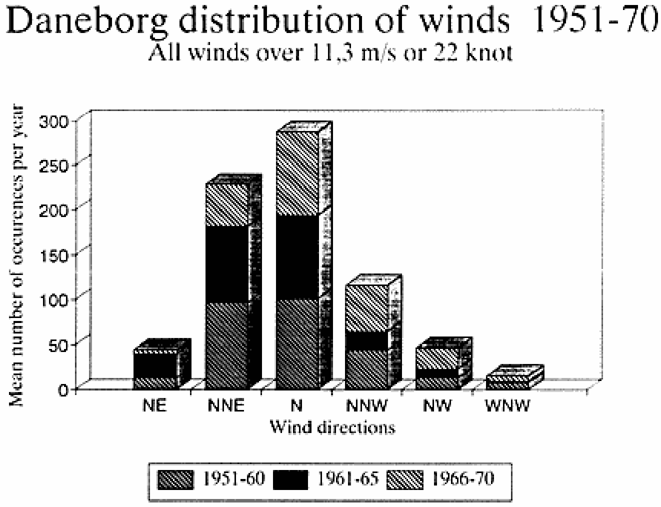

Fig. 4. Diagram showing the distribution of wind directions for winds over 11.3 m/s at Daneborg during the periods 1951-60, 1961-65 and 1966-70. No other winds (southerly) were that strong. Data from the Danish Meteorological Institute (DMI), 1967, 1968 and 1978.

Young Sound stage

During the Late Weichselian, the Zackenberg area is assumed to have been glaciated by large outlet valley glaciers from the Greenland Ice Sheet until approximately 10,000-9,500 BP, when the Nanok stadial terminated, according to the regional chronology for northern East Greenland (Hjort, 1981). An attempted reconstruction of the ice cover during the Late Weichselian glaciation maximum around 10,000 BP (Hjort, 1979) would judge the maximum position of the glacier front in the Young Sound area to be situated about 30 km SE of Zackenberg at the entrance of the fiord, probably simultaneously building the present Sandøen Island, near Daneborg, as a terminal moraine.

Striae and moraines show that during this period two large outlet glaciers from the Greenland Ice Sheet almost covered the Zackenberg area (Fig. 5). The northernmost of these large valley glaciers is preliminary designated as the Zackenberg glacier, while the other is called the Tyrolerfjord glacier after the present Tyrolerfjord. This palaeoglaciological situation we designate as the Young Sound stage, as the two ice streams then merged and together partly covered the present Young Sound area (Fig. 5).

As is seen on figure 5, the coherent tongue of the Zackenberg and the Tyrolerfjord glacier flowed towards the east as the large Young Sound glacier, creating a distinct medial moraine across the central Zackenberg lowland, crossing all the way from the eastern slope of the Zackenberg mountain from about 450 m a.s.l. towards southeast across the lowland to the present coast line. This former medial moraine is marked by a linear concentration of large boulders extending towards the SE from the Zackenberg mountain and probably represents the former dividing ice flow line between the Tyrolerfjord and the Zackenberg glaciers. Nearly all the way round the Zackenberg mountain, lateral moraines can be identified up to about 500 m a.s.l., revealing that the altitude of the surface of the glaciers during the Young Sound stage must have been up to 500 m above the present sea level. Furthermore, the occurrence of moraines shows that the equilibrium line altitude (ELA) at that time must have been more than 430-450 m above the contemporary sea level, which at that time probably was about 50-70 m above the present (Fig. 5).

The Zackenberg glacier itself had a medial moraine too, showing that it consisted of two ice streams, the Store Sødal glacier and the Lindeman glacier, flowing respectively from the west and the north (Fig. 5). Remnants of this medial moraine in the form of a linear accumulation of large boulders are still present in the area where the Lindeman and Store Sødal valleys merge, and can be traced across the terrain for about 2 km.

Zackenberg I stage

The deglaciation after the Nanok stadial started at around 9,500 to 9,300 BP in the areas north of the Zackenberg area according to Hjort (1981) and preliminarily, we assume the same to have been the case in the Zackenberg area.

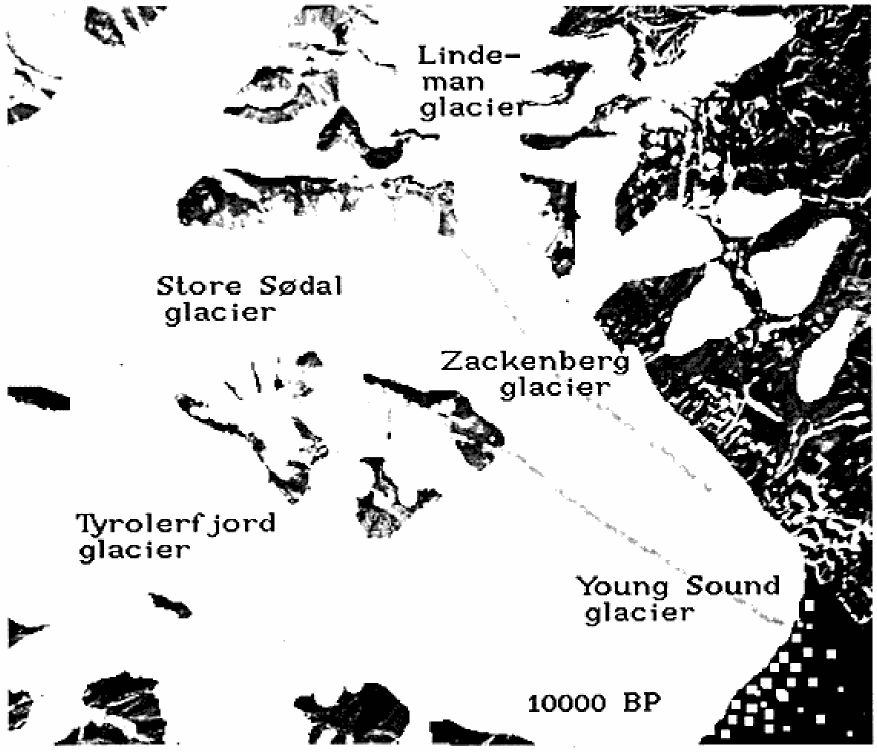

Fig. 5. Reconstruction of the ice cover in the Zackenberg area about 10,000 BP. This palaeoglaciological situation is designated as the Young Sound stage. Approximate scale 1:150,000. North is towards the top.

The oldest evidence of a frontal retreat position of the glaciers during the deglaciation period is some 10-20 m high terminal moraine ridges across the Zackenberg lowland, reflecting the position of the Zackenberg glacier at approximately 9,000 BP (tentative age), see Fig. 6. This stage we designate as Zackenberg I, after the first formation of terminal-moraines within the Zackenberg lowland area.

Behind the outermost terminal moraine ridge several other moraine ridges are found. On the highest of these, an old coastline is discernible as a cliff with an associated horizontal terrace at about 70 m a.s.l. (measured by multimodel photogrammetry; Humlum, 1992). This represents the highest Late Weichselian sea level found within the Zackenberg area. Beyond the outermost terminal moraines, this maximum sea level has cut into older lateral moraine deposits (Fig. 7), from the preceeding Young Sound stage. The coast line was probably formed shortly after the glacier front had retreated from the above-mentioned Zackenberg I terminal moraines, but before the following Zackenberg stage II (see below).

The coastal cliffs and adjoining terraces (Fig. 7) are especially well developed along slopes facing southwest, which represents a rather protected position in relation to e.g. swells from the ocean to the southeast. One explanation for the development of these cliffs may be frequent and strong catabatic winds from the then larger Greenland Ice Sheet in the west. These catabatic events must have occurred during the summer period, where the sea was ice-free, allowing erosion of the cliffs and terraces. Another explanation could be erosion by waves caused by calving along the terminus of the backwasting Tyrolerfjord glacier in the southwest (Fig. 6). If the assumed dating of the Young Sound glacier retreat and the subsequent division into two separate glaciers are real, then this explanation reveals that the backwasting was relatively fast, strongly indicating that the Tyrolerfjord glacier at that time was floating. The exact frontal position of the assumed floating Tyrolerfjord glacier is not known, but it was most likely south of the central part of the Zackenberg mountain where the Young Sound becomes narrower, as is indicated in Figure 6. This position would have made it

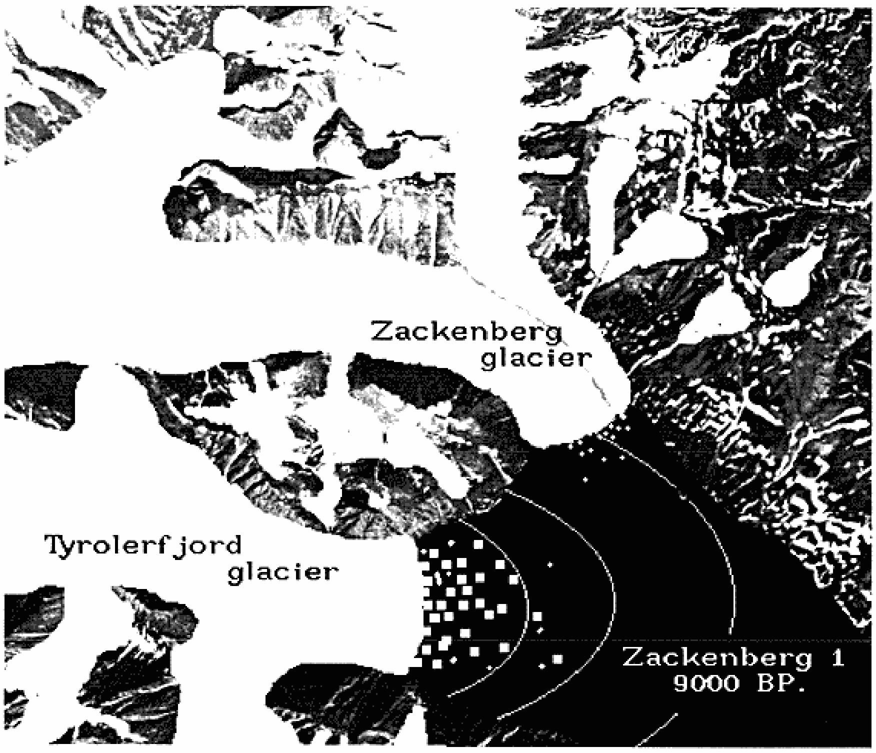

Fig. 6. Reconstruction of the ice cover in the Zackenberg area about 9,000 BP. This palaeoglaciological situation is designated as the Zackenberg I stage. Sea level was about 70 m above present sea level. Approximate scale 1:150,000. North is towards the top.

possible for calving waves to affect both the terminal moraines of the Zackenberg glacier as well as the former coastal area to the southeast (Fig. 6). Future echo-soundings of the bottom of the Young Sound and the Tyrolerfjord will probably yield further information on this question. Hjort (1981) also assumed the presence of floating glaciers during the Nanok stadial in the area north of Zackenberg.

Zackenberg II stage

From around 9,000 to 8,000 BP the sea level appears to have been falling rapidly to about 20-30 m above the present sea level, and the coastline moved southwards as indicated by the presence of at least one conspicuous marine terrace at 40 m a.s.l., cut into the terminal moraines belonging to Zackenberg I and by smaller sets of discontinuous beach ridges in the area between the terminal moraines and the present coastline. The reason why no other significant marine levels are preserved in the Zackenberg lowland area is probably due partly to the the rapid isostatic rise of the land area, and partly to a significant contemporary glaciofluvial sedimentation by the large meltwater river from the deglaciating Zackenberg glacier, thus covering most coastal terrain features created during the regression.

Around 8,000 BP a delta about 20 m thick was built out into the Young Sound in the southern part of the present Zackenberg lowland, after the sea level had dropped to about 15-20 m above the present sea level. As the delta is not secondarily affected by either marine erosion or deposition, it postdates the former higher sea levels. Fossil glaciofluvial valleys north of the delta indicate that much of the glaciofluvial sediments in the delta were derived during a readvance and following standstill of the otherwise backwasting Zackenberg glacier. This readvance position is clearly marked by conspicuous moraine ridges about 1.5 km north of the outermost terminal moraine ridges of Zackenberg I stage. We have designated this younger frontal position as the Zackenberg II stage (Fig. 8).

Salix herbacea leaves collected from the upper part of fluvial foresets in the delta are ^{14}C-dated to 7,920 ± 140

Fig. 7. Coastal erosional cliffs and terraces cut into deposits belonging to the Young Sound stage. Uppermost cliff at about 70 m a.s.l. Eastern part of the Zackenberg lowland, beyond the Zackenberg I terminal moraines. Seen towards northeast. July 1992.

BP (AAR-1217), while Mya truncata shelves found in marine bottomsets further to the south are ^{14}C-dated to 6,900 ± 175 BP (K-6032). Both datings have been corrected using the calibration programme Calib ver. 3.03. These datings indicate that the delta sedimentation lasted for at least 1000 years.

The beginning of the Zackenberg II stage itself may, however, be somewhat older, as moraines from this stage are apparently marine abraded up to about 28-30 m a.s.l. The topsets of the Zackenberg delta are only about 15-20 m a.s.l. Based upon ^{14}C-dating of marine shelves of Mya truncata collected about 10 km ESE of the delta locality at 31 m a.s.l., in the mouth of a valley called Permdal, giving an age of 8,835 ± 130 BP (Weidick, 1977; lab.no. 203318:I-9133), a period from about 9,000 to at least 6,900 BP for the Zackenberg II stage may be realistic (Fig. 8).

The deglaciation following the Zackenberg II stage appears to have been rather quick. The Store Sødal glacier receeded at least 10 km upvalley in about 500 years. This is indicated by a luminescence dating of 6,481 ± 650 BP on aeolian sand in the upper part of the Store Sødal valley, deposited after the glacier has receeded from the area. This will be discussed further in the section on wind activity below.

PERIGLACIAL GEOMORPHOLOGY OF THE ZACKENBERG AREA

After about 6,900 BP, the outlet valley glaciers from the Greenland Ice Sheet receded from the central Zackenberg lowland area and glaciers are presently only found on mountains higher than 1,000 m a.s.l.

Since the area was deglaciated, periglacial processes have been active in the area and to some degree they have converted the glacial landforms. Particularly in the eastern sedimentary part of the area, the relatively unconsolidated sandstones have been affected by different periglacial processes, especially on sloping terrain.

In the following sections some of the dominant periglacial landforms within the study area will be briefly presented.

Icewedges and debris islands

In most of the central lowland, large-scale polygon patterns occur. The diameter of the polygons is about 5 to 10 m. Normally the wedges are revealed on the terrain surface by furrows, as much as 1 m wide, flanked by two small ridges on each side of the furrow. The thickness of the active layer covering icewedges was found to be about 70 cm in August 1992.

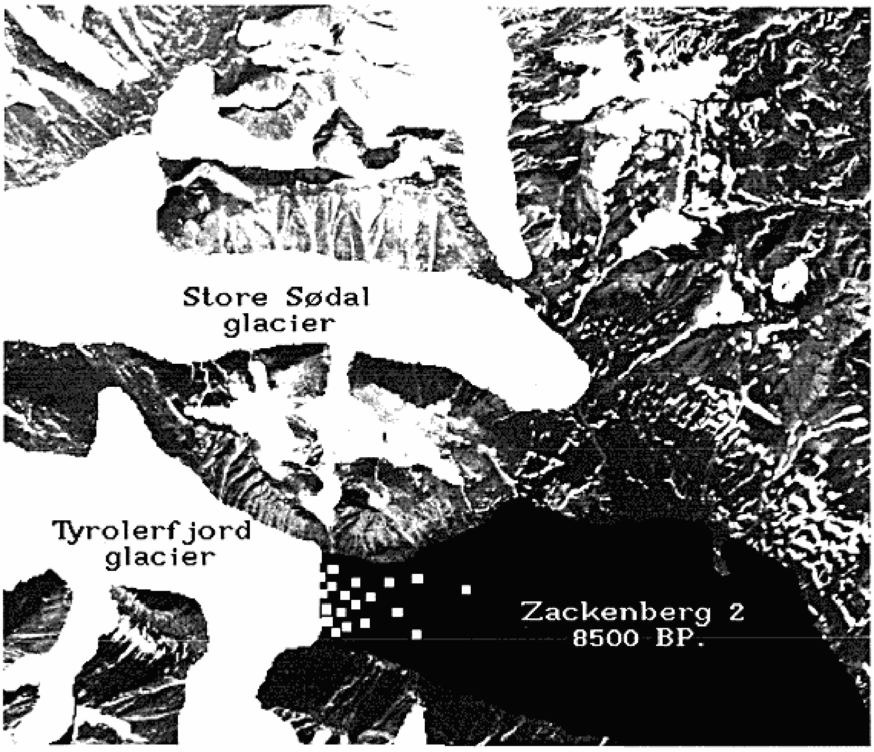

Fig. 8. Reconstruction of the ice cover in the Zackenberg area about 8,500 BP. This palaeoglaciological situation is designated as the Zackenberg II stage. Sea level was about 20 m above present sea level. Approximate scale 1:150,000. North is towards the top.

Digging showed that the width of one of the wedges varied from 1.5 to 1.9 m beneath the active layer (Fig. 9). The wedge consisted of about 90% (by volume) ice with a clear vertical stratification with layers 1-5 mm thick.

In the coastal cliff of the Zackenberg delta another icewedge was investigated, extending about 2 m down from the surface, revealing a beautiful vertical vein structure that ended almost like a root, with the veins at different depths (Fig. 10). This icewedge was 20 to 30 cm wide and there were about 50 individual veins, each with a thickness from 0.1 to 1 cm. The surrounding layers were forced upwards at the flanks of the icewedge as is normal for wedges primarily filled with ice (Washburn, 1979).

Numerous areas with active debris islands were found both in the lowlands (Fig. 11) and higher up in the mountains. The dimensions of the individual debris islands were usually around 2 to 5 m and they were of a sorted type.

Wind activity

The above-mentioned prevalence of winds from the north during winter is clearly reflected in the landscape, especially regarding the accumulation of snow in topographic lee positions. Most snow accumulations are thus facing south, that is, towards the sun.

The pronounced wind activity is also revealed by the presence of a large number of wind-polished stones and boulders. Particularly south of the Lindemans valley, north of the Zackenberg lowland, a deflation area with numerous heavily wind-polished stones exists. Also at many other sites windpolished stones were found indicating northerly and north-westerly wind directions, partly reflecting local winds controlled by topography, but primarily caused by the prevailing regional wind from the north.

A sand-dune landscape is found in the valley bottom at the northwestern corner of the Zackenberg mountain, south of the distal part of a recent delta flat 2 km^2 in size extending out in the western end of the Store Sødal lake (Fig. 12). The delta surface is free of vegetation allowing the northerly winds to transport sediment from the delta surface and onto the area just south of the delta, creating

Fig. 9. Trench dug across icewedge, exposing the active layer late in August 1992. The upper surface of the icewedge, which is about 2 m wide, is seen in the bottom of the trench. August 1992.

the dune area. The dune area extends about 100 m south of the delta and is active only in the easternmost part. West of the active dune area, along the southern part of the delta, aeolian sediment could be found only a few centimetres below the vegetated terrain surface, indicating a former extension of the dune area in this direction. Here the aeolian sediment was partly covered by a solifluction sheet. Probably the active part of this greater dune area has been migrating towards the east synchronously with the advancing delta front during the Holocene.

A sample from the aeolian sand sediment has been collected close to the western (oldest) limit of the inactive part of the dune area and dated by the luminescence technique. The age is 6,481 ± 650 BP. This result indicates that delta sedimentation must have started immediately after the area was deglaciated and that the period with northerly winds has persisted since that time.

Snowpatches

All over the area, the prevailing location of both annual and perennial snowpatches is a leeward position, facing south, demonstrating the control exerted by the wind rather than insolation.

Several nival processes associated with the different parts of snowpatches have been observed and their geomorphological significance investigated (Christiansen, in prep). The snowpatches have been found to exert a major influence on the present geomorphological development within the study area, especially on the slopes of the Aucellabjerg mountain in the eastern part of the area (Fig.

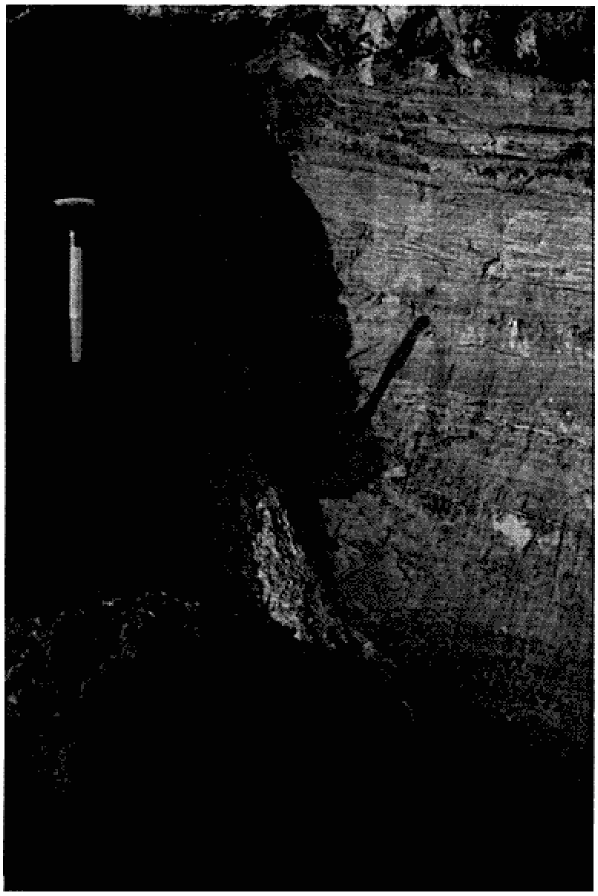

Fig. 10. Icewedge exposed in coastal cliff of the Late Glacial Zackenberg delta. August 1992.

13). Furthermore nival processes appear to be responsible for the deepening of some valleys in the central Zackenberg lowland (Christiansen, in prep).

In front of some snowpatches, small sinks for niveoaeolian sediment redeposited by pronival processes have been found. In these basins, distinctly layered sediment is supposed to reveal different palaeoclimatic periods when nival processes where either more active or less important than now, thus indirectly indicating the former extent and geomorphic activity of the snowpatches. Dating this special type of sediment has been accomplished by use of the luminescence technique and the results showed nival activity already at 9000 ± 1000 BP in a south exposed valley called Favoritdalen on the Zackenberg mountain, at about 600 m a.s.l (Christiansen, in press).

Solifluction

Together with the above-mentioned nival processes, soli-

Fig. 11. Debris islands at about 30 m a.s.l. in the Zackenberg lowland. July 1992.

Fig. 12. View towards the north across a glaciofluvial delta in the Store Sødal valley. The western end of the Store Sødal lake is seen to the right. In the lower right corner a sand dune area is seen. The valley bottom is about 160 m a.s.l., while the surrounding mountains reach altitudes of about 1,400 m a.s.l. August 1992.

fluction is an important process in the present development of the sloping parts of the landscape.

On the sedimentary slopes of the Aucellabjerg mountain, solifluction sheets dominate nearly all the way from the basalt-capped mountaintops down to the lowland: an almost 4 km distance only interrupted by snowpatches, as shown on Fig. 13. On the steeper slopes of the western bedrock part of the investigation area, smaller solifluction lobes were present. Also in the eastern part of the study area, distinct lobes with thicknesses up to 1 m and covering several tens of square metres were found.

Fig. 13. Mountain slope with perennial snowpatches and solifluction sheets northeast of the Zackenberg lowland. Shallow depressions are produced by various sediment transport processes around the snowpatches, as are small valleys draining meltwater from the snowpatches during the ablation period. Solifluction sheets surround the snowpatches. View towards northeast. August 1992.

These solifluction sheets and lobes are primarily active during the snowmelt- and thaw-period in spring and early summer and are caused by the considerable water soaking of the terrain surface, enhanced by the presence of permafrost at shallow depths.

At the south-eastern corner of the Zackenberg mountain, the lower part of the slope is also covered by small solifluction sheets all the way from the lowermost distinct Late Glacial lateral moraine down to the present coastline. In these sheets boulder-stripes were present, about 1-3 m wide, consisting of angular and subangular block fragments with an average size of about 0.4 m. As several of the boulder-stripes were found to extend across the recent beach into the sea (Fig. 14), it appears that the relative sea level at present must be rising within this part of northeastern Greenland.

Free rock faces and accumulation of talus

Free rock faces are found both along the northern and southern part of the Zackenberg mountain and along the western side of the Lindemansdalen valley; all localities situated within the bedrock part of the study area. These rock faces are covered with substantial accumulations of talus along their foot (Fig. 15), probably representing the result of Holocene weathering during the past 8,000 years, since the last deglaciation. Most talus accumulations appear to be active at present, judging from the high fre-

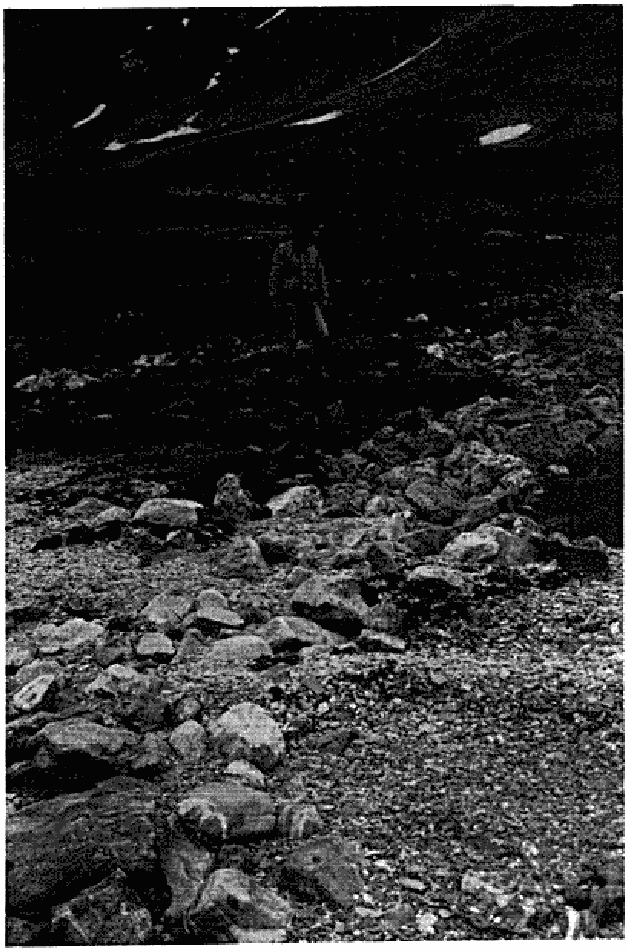

Fig. 14. Boulder-stripe caused by solifluction, extending in the foreground across the present unvegetated beach zone, thus indicating a recent relative rise in sea level. July 1992.

quency of fresh and unvegetated rock fragments. The talus mainly accumulates in large cones consisting of large (0.2-2 m) angular boulders, produced by the disintegration processes on the free faces. During the summer meltwater from accumulations of drifting snow along the top of free rock faces seeps down the rock-wall and penetrates crevasses and small gorges in the bedrock. Here the water is trapped and exposed to recurrent freeze-thaw cycles which may eventually release block fragments by frost splitting. In this way, the present weathering of solid bedrock within the area appears to be controlled both by snow drift and wind activity as well as by solar radiation.

Rock glaciers

Several rock glaciers are found at the foot of talus slopes within the study area. Most rock glaciers are talus-derived, and they are, in general, envisaged as being ice-cemented by interstitial ice (Humlum 1983, 1988). Only one rock glacier situated in the northern part of the study area appears to be glacier-derived and may contain larger bodies of solid ice. A direct investigation of the internal structure of the rock glaciers has, however, not been possible due to the lack of natural sections. Most rock glaciers appear to be active features as their termini are partly covered by an apron of fresh, unvegetated rock fragments which have rolled down from the upper part of the front.

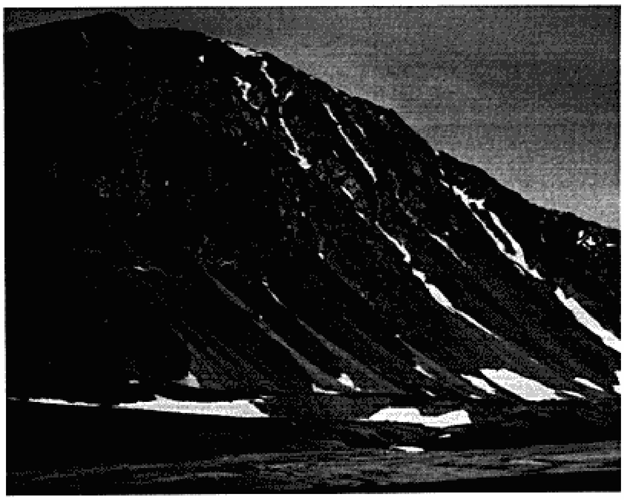

Fig. 15. Eastern slope of the mountain Dombjerget. A free rock face extends from about 1,300 m a.s.l. down to about 400 m a.s.l. The lower part of the slope is covered by active talus accumulations. From the lower part of the talus, a 30-50 m thick lobate talus-derived rock glacier extends as a terrace. View towards northwest. August 1992.

Four of the observed rock glaciers are tongue-shaped (Humlum, 1983) and originate within well-defined valleys. One of these is considered as being glacier-derived as a small glacier exists between the rock glacier head and the foot of the free rock-face above. The maximum length is about 600 m. The vertical thickness may be as much as 60 m. One of these tongue-shaped rock glaciers displays two generations (Fig. 16), in this way demonstrating that favourable conditions for rock glacier formation have existed within the area at least twice during the Holocene. The remaining rock glaciers within the study area are all rather small (less than 200 m in length) and, from a geometrical point of view, belong to the lobate type (Humlum, 1983).

MONITORING

As part of the ZERO Programme within the Zackenberg area, a long-term geomorphological monitoring of climatically sensitive terrain elements was initiated. Eleven test

Fig. 16. Two generations of tongue-shaped, talus-derived rock glaciers extending out from a small valley in the eastern slope of the mountain Dombjerget. The valley bottom is about 300 m a.s.l. and the mountain top is about 1,300 m a.s.l. View towards north-west. August 1992.

field sites covering 6 different terrain elements were established. At four of the sites snowpatches will be followed. Four coastal spits, one beach ridge, one snow-avalanche track, the above-mentioned sand-dune area and one solifluction lobe, will be monitored in order to detect even minor changes in the geomorphological processes and examine how these changes relate to climatic changes.

A monitoring manual, describing location, field procedure and containing photos from each test field site, has been produced (Christiansen, 1992), enabling future investigators to do field-checks at the sites. This has all been made possible because the monitoring is mainly accomplished by taking a pair of stereo photos or only one normal photo at marked positions in front of each test field site. Pairs of stereo pictures are taken for use in the multimodel photogrammetric method (Dueholm, 1992) to produce detailed maps of the different geomorphological features (Humlum, 1992) instead of only judging possible changes from normal non-stereographic photographs. Quantifying future changes in the geomorphological processes will be made possible in this way.

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Fig. 16. Two generations of tongue-shaped, talus-derived rock glaciers extending out from a small valley in the eastern slope of the mountain Dombjerget. The valley bottom is about 300 m a.s.l. and the mountain top is about 1,300 m a.s.l. View towards north-west. August 1992.

field sites covering 6 different terrain elements were established. At four of the sites snowpatches will be followed. Four coastal spits, one beach ridge, one snow-avalanche track, the above-mentioned sand-dune area and one solifluction lobe, will be monitored in order to detect even minor changes in the geomorphological processes and examine how these changes relate to climatic changes.

A monitoring manual, describing location, field procedure and containing photos from each test field site, has been produced (Christiansen, 1992), enabling future investigators to do field-checks at the sites. This has all been made possible because the monitoring is mainly accomplished by taking a pair of stereo photos or only one normal photo at marked positions in front of each test field site. Pairs of stereo pictures are taken for use in the multimodel photogrammetric method (Dueholm, 1992) to produce detailed maps of the different geomorphological features (Humlum, 1992) instead of only judging possible changes from normal non-stereographic photographs. Quantifying future changes in the geomorphological processes will be made possible in this way.

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