Holocene Landscape Evolution in the Mellemfjord Area, Disko Island, Central West Greenland: Area Presentation and Preliminary Results

Humlum, Christiansen, Hansen, Hasholt, Jakobsen, Nielsen & Rasch

Humlum, Christiansen, Hansen, Hasholt, Jakobsen & Nielsen: Institute of Geography, University of Copenhagen, Øster Voldgade 10, DK-1350 Copenhagen K, Denmark.
M.Rasch: Arctic Station, 3953 Qeqertarsuaq/Godhavn, Greenland.

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A study area at the northeastern shore of Mellemfjord, in the western part of Disko Island, near the western maximum limit of the Greenland Ice Sheet during the Quaternary, was chosen for an analytic landscape study. Interactions between climate and landscape processes are designated for future detailed process research and monitoring. The project will focus on climatology, hydrology, energy exchanges at the terrain surface, mass fluxes and terrain element dynamics. Glacial, periglacial, fluvial and coastal landforms, soils and ecosystem record (in e.g. lakes and estuaries) will be used as geoindicators in this interdisciplinary analytic landscape investigation. Investigations in the about 100 km² test area were initiated during the summer of 1993 and preliminary results are presented below.

Key words: *West Greenland, Disko, Holocene landscape evolution, palaeoclimatology*

High-latitude, cold-climate regions are recognised to be vital components in shaping global climate and are likely to respond significantly to future climate changes. The boreal and arctic regions are thought to be particularly sensitive to regional or global climatic changes (see, e.g. Eddy et al. 1988, Etkin 1990, Maxwell 1992, Koster 1993). The seasonal snow cover is important in this respect, causing wide fluctuations to occur annually in surface energy balance because of ice and snow phase changes. During snowmelt the overall terrain albedo often changes from a high of 0.8 to a low of 0.2 at a time when the incoming solar radiation is near an annual maximum. Therefore, the seasons that characterise the climate of temperate regions are exaggerated in polar regions in both duration and amplitude. Also on timescales of decades or longer, climate variability is greater than in other climatic regions (Koster 1993). Any assessment of the effects of global climatic change clearly requires a thorough understanding of contemporary geomorphic processes operating in the arctic and antarctic realms.

In the past half-decade or so, Washburn (1985) and French (1987) have attempted to identify research problems in arctic geomorphology and to highlight research themes and trends in the field. Several general as well as specific topics were recognised such as palaeoenvironmental studies, frost-related processes, pingos, palsas, mass wasting processes, nivation, and ground ice.

Generally speaking, palaeoclimatic inferences drawn from geomorphologic data should be based on an understanding of the relationship between climate and terrain element dynamic, such as e.g. glacier fluctuations. Complex interactions exist between prevailing regional and local climatic conditions, regional and local topography, energy exchange at the terrain surface, mass-fluxes and terrain element dynamics. The individual terrain element dynamics represents integrated responses to these factors. Due to differences in the above factors, even similar terrain elements within a geographically restricted area may display different responses to identical climatic changes. This obviously represents a potential pitfall for palaeoclimatic and modern-climatic studies using observational data on isolated terrain elements such as i.e. glaciers, moraines, rockglaciers, pingos, ice wedges, dunes, rivers, soils and coastal features. However, by adopting a broader approach, including many different terrain elements, local and regional climatic influences may be identified and evaluated. Preliminary results from the initiation of such a study are outlined below.

General Topography and Climate within Disko Island

Disko Island (8600 km^2) is situated in central West Greenland, outside the coast of the mainland (Fig.1). The island is mainly made up by Tertiary lavas, and the landscape is a typical, arctic, plateau basalt landscape with cirque carved lava plateaus and U-shaped valleys and fjords. The upper land surface rises gradually from about 800 m asl. in the southwestern part of the island to more than 1900 m asl. in the northeastern part (Fig.2A).

Climatic conditions within Disko Island can be inferred only in general outline, because only one meteorological station is presently being operated on Disko at the town Godhavn (Fig.1). This climate station has been operated since 1923. In Godhavn the present (1960-1990) mean annual air temperature is -3.9°C; the coolest month is March (-15.1°C), while July is the warmest month (7.1°C). The mean annual precipitation at Godhavn is about 400 mm w.e. Most of the precipitation (75 %) usually falls during the period June to December with advection of moist, maritime air masses from the south and southwest along the Davis Strait. The remaining period is comparatively dry, as it is dominated by cold and dry continental polar air masses from the Inland Ice. Approximately 60-70 % of the mean annual precipitation is snow and in Godhavn persistent snow cover is registered from late September to late May.

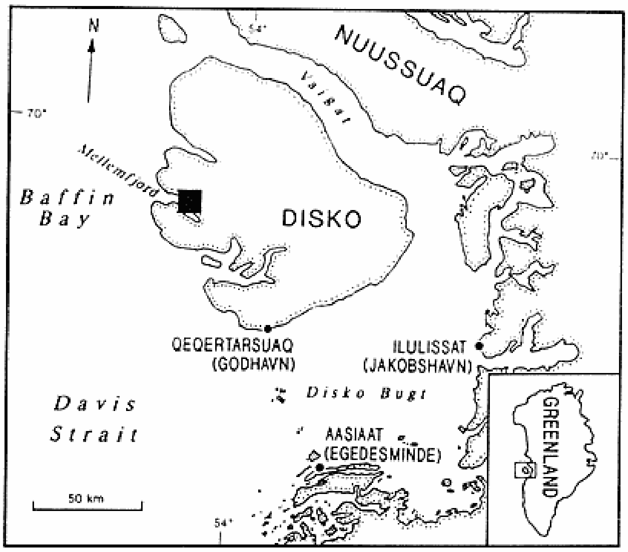


Figure 1: Location map showing Disko Island place names and the study area (black square)

The prevailing wind at Godhavn is from the east (44.6 %), but in the period May to August westerly winds (21.6 %) dominate. Mean wind speed is at a maximum during the autumn and early winter, while minimum values occur in February to April, and in this period calms are frequent (20-30 %). In general the wind directions are greatly influenced by orographic conditions, and valley winds are widespread . In the day-time up-valley winds dominate in the summer period and down-valley winds dominate during the night-time and the winter period.

At Qutdligssat, at the northeastern coast of the island, a meteorological station was operated 1961-72. The mean annual air temperature was -4.3°C (sea level), coolest

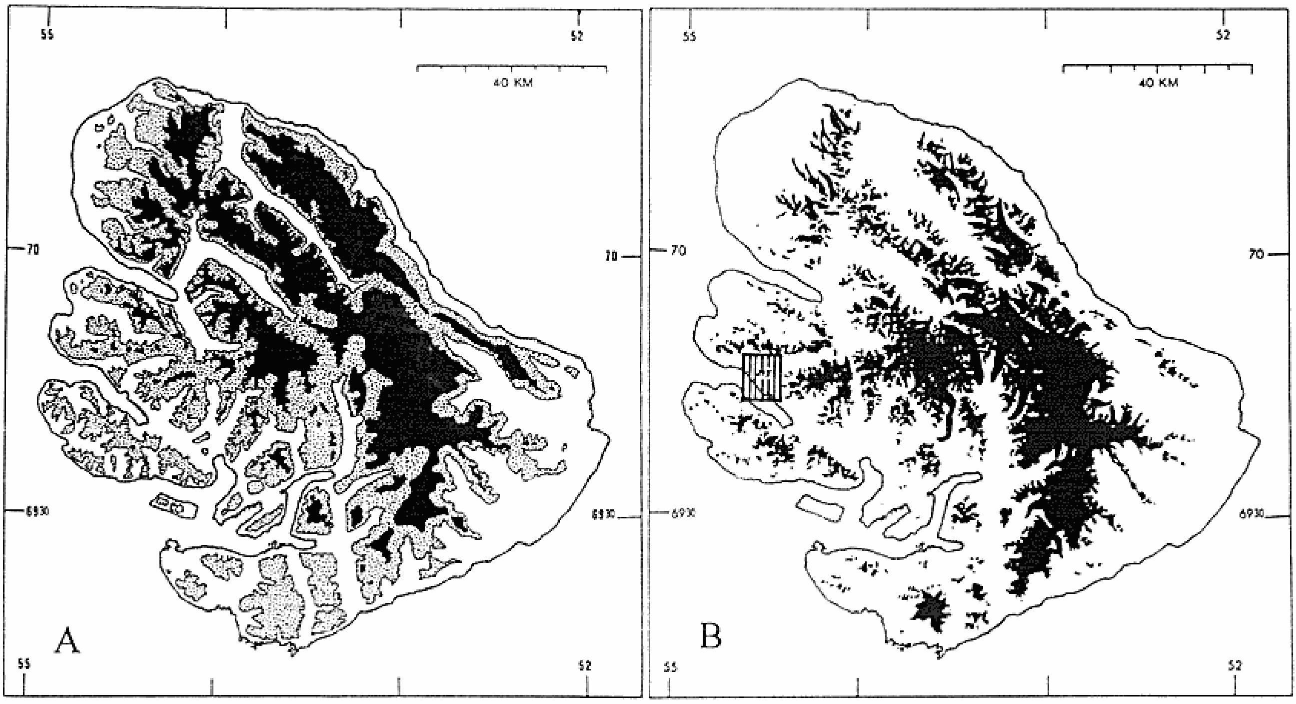


Figure 2: A: Topographic map of Disko Island. Areas below 500 m are shown as white, while areas above 1000 m are shown in black. Dotted areas 500-1000 m asl. B: Present ice cover of Disko Island. Glaciers and isolated firn areas (black) are mapped from aerial photographs taken in the late summers of 1953 and 1964. The Mellemfjord study area is outlined

month was March (-17.0°C), warmest month was July (6.6°C). The mean yearly precipitation was low, about 200 mm w.e. Generally speaking, from what little is known, it appears that climate along the southwestern coast of the island is a polar, maritime climate, while along the northern and eastern coasts the climate is more continental. Also the central part of the island is probably rather dry; at least this is what the flora and glaciation level (Humlum 1985, 1986) indicate. Precipitation shadow due to local topography and the neighbourhood of the Greenland Ice Sheet further to the east is assumed to be responsible for these overall climatic contrasts within Disko Island.

The sea around Disko Island is usually ice-covered from late December to late May. Break-up of the ice cover primary depends on the occurrence of large swelles caused by strong southerly and southwesterly winds, associated with increased cyclonic activity in the Davis Strait during the spring and early summer. At sea level, the resultant wind is from NE and E during October-February, while winds with westerly component dominate during the summer. The zonal flow from E is probably the result of cold air flowing off the Greenland Ice Sheet due to the almost permanent surface inversion, caused by strong radiational cooling. During summer, this outflow is interrupted in the coastal regions by the advection of warm air from S and SW along the Davis Strait. At higher levels meridional air flow from S and SSE dominate, according to upper-air observations from Egedesminde 65 km S of Godhavn (Humlum 1987).

Present Glaciation of Disko Island

At present Disko Island supports an extensive local glaciation, covering about 20% of the island (Fig.2B). A total of 954 ice caps, valley glaciers, cirque glaciers and isolated firn areas were mapped from aerial photographs taken late in the summer of 1953 and 1964. Although the largest glaciers are found around the 900 km^2 ice cap Sermerssuaq in the eastern part of the island, glaciers occur in almost every part of Disko Island.

The surface form of the glaciation level shows the effect of the above mentioned climatic differences within the island (Humlum 1985, 1986). Generally, the glaciation level (GL) rises inland from about 600-800 m asl. at the southwestern coasts, reaching above 1500 m asl. in the northeastern part of the island. The isoglacihypses curve around the west and south side of the island. Gradients of the GL-surface are variable, ranging from 5m/km to more than 60 m/km. Small values are usually met over the central part of the island, while large values occur near the coasts. Interpretations of the geometry of GL-surfaces are affected by the time-transgressive nature of the glaciation level. Probably climatic and topographic controls are integrated over a period of decades or even centuries in the case of high-arctic glaciers. However, the local GL must in some way be related to an elevation, where, over several years, the net balance is zero on glaciers. As such, information on the integrated control of net radiation, air temperature, precipitation and snow drift must be contained within the elevation and surface form of the glaciation level.

On aerial photographs large-scale niveoeolian accumulation- and deflation forms are clearly visible above the equilibrium line for many glaciers on Disko Island. These features display a local relief of 5-30 m, and are probably quite permanent forms, caused by snow drift by dominant winds from SSE during several years (Humlum 1987). Observations on upper-air conditions at Egedesminde, 65 km SE of Godhavn, lend support to this conjection. At sea level, the resultant wind is from NE and E during October-February, while winds with westerly component dominate during the summer, just as is the case at Godhavn. However, at the 850 Mb level (usually at 1150-1450 m asl.) the air flow is primarily meridional from S and SSE in all seasons, with maximum southerly component from January to June (Humlum 1987). This is according to the recurrent suggestion that the atmospheric circulation in the Greenland area includes a substantial meridional component (Putnis 1970). The mean monthly wind speed recorded at the 850 Mb level is often more than 20 knots. The mountain plateaus on Disko Island are thus exposed to significant snow drift from S and SSE during the winter, a feature that appears to represent a major control on the present glaciation (Humlum 1987).

The Mellemfjord Study Area

The Mellemfjord study area (Fig.1 and 2B) was chosen for several reasons. The region is situated in the western part of Disko Island and is thus near the western maximum limit of the area reached by the Greenland Ice Sheet during the Quaternary. Deglaciation was probably early, and the potential ice-free period covered by different terrain archives therefore long. The terrain is varied, with both al-

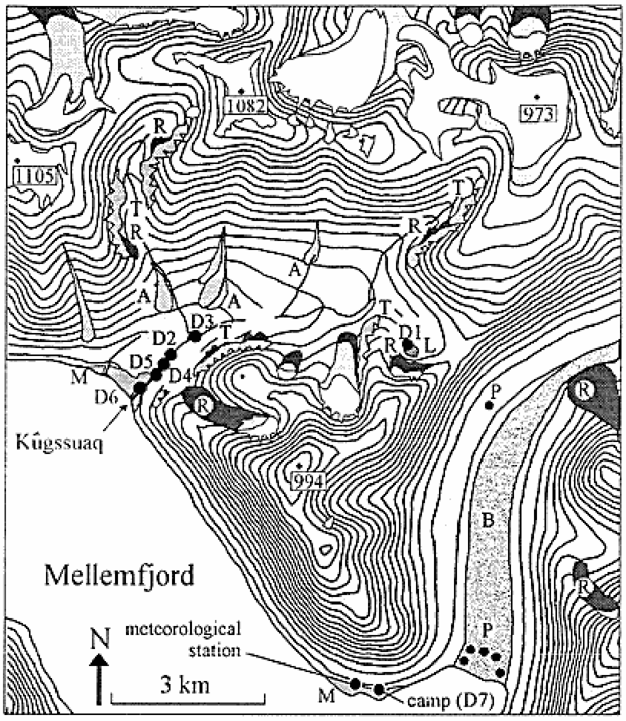


Figure 3: Geomorphic map of the Kûgssuaq area, showing main terrain elements. Glaciers and permanent snow cover are white, areas deglaciated since the Little Ice Age are shown in medium grey. L=lakes. A=avalance tracks. R=rockglaciers. T=talus slopes. B=fluvial plain. P=pingos. M=raised marine terrases. D1-D7=water sampling stations. Position of camp and meteorological station at Sarqardlît Ilordlît is shown in the lower part of the figure. Numbers in brackets are altitudes in meters asl. Curve equidistance 50 m.

pine and plateau topography represented. Terrain elements are asymmetrically distributed, with clear NS contrasts, creating a landscape with great geomorphic diversity.

The 25 km long Mellemfjord is 3-5 km wide. Preliminary echo soundings indicate water depths of 80-170 m. During the Wisconsin, Mellemfjord was partly filled with a large valley glacier, terminating on the shelf shortly outside the present fjord mouth. This glacier drained local ice from valleys north and south of Mellemfjord. The fjord is exposed towards the southern Baffin Bay, and the potential for preservation of geomorphic results of past variations of both sea ice cover and wave activity is good, especially around river mouths, where sediments are fed into the fjord. Earlier investigations (see, e.g. Ingólfsson et al. 1990) show the upper marine limit to be situated about 60 m (9000 BP) above the present sea level in the Mellemfjord area.

A 105 km^2 study area situated on the northeastern shore of Mellemfjord was designated for future detailed research (Fig.2B and 3). From a topographic point of view this test area consists of three main terrain units. 1. The 60 km^2 Kûgssuaq valley to the northwest. 2. A 35 km^2 mountain (994 m asl., no official name) south of the Kûgssuaq valley. 3. A 1.5 km wide glaciofluvial plain in the Iterdlagssûp kûgssua valley with associated delta, ending into the inner part of Mellemfjord. Below, these three areas will be addressed collectively as the Kûgssuaq area.

Climate

An automatic weather station was established in the Kûgssuaq area in August 1993. The station is placed 35 m a.s.l. on a representative surface at the northeastern shore of Mellemfjord, west of Sarqardlît Ilordlît (Fig.3).

Global solar radiation, reflected solar radiation and the incoming and outgoing net radiation are measured at a 2 meter level as well as air temperature, relative humidity, wind speed and wind direction. Soil temperatures are measured at the 3- and 75-cm levels. All sensors are measured and integrated over a 2 hour period for storage with a solid state data logger. In figure 4, a temperature record is shown from the period August 1993 to October 1994. The daily mean air temperature in Mellemfjord is approximately 5 °C below the daily mean air temperature in Godhavn.

The somewhat colder climate in Mellemfjord, when compared to Godhavn, is primarily due to a stronger effect

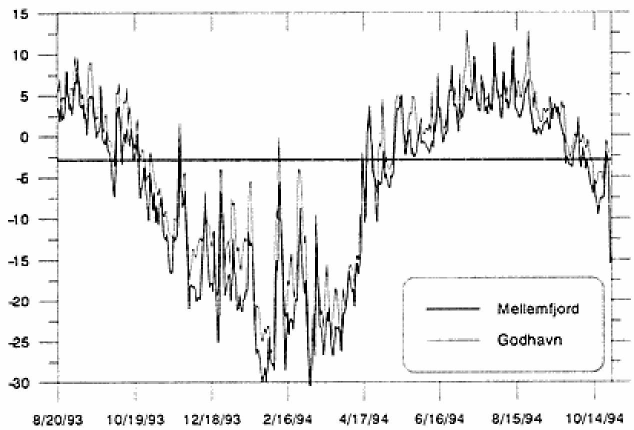


Figure 4: Air temperatures at Godhavn and Mellemfjord in the period from 20 August 1993, to 25 October 1994. Mean temperature 1 September 1993 - 31 August 1994: Mellemfjord -7.8 °C, Godhavn -4.9 °C.

of shadows from the surrounding mountains and a more prevalent cloud cover, by which a smaller amount of solar energy reaches the ground. The sun is below the horizon from late November to mid January, and in this period the daily mean air temperature is -15 to -20 °C. In the autumn, calms prevail for days, whereas in the winter and spring cold catabatic winds (-20 to -30 °C) are blowing from the easterly directions, only interrupted by "warm" winds (-5 to -15 °C) blowing from westerly directions, when moist, maritime air masses reach the area. During the summer season, up-valley winds (NW) dominate during the day-time, while down-valley winds (SE) dominate during the night-time.

Present Glaciation

Three cirque glaciers are found along the steep south-eastern side of Kûgssuaq valley. The opposite valley side, exposed towards SE, is without glaciers and the general terrain gradient is smaller. On mountain plateaus (900-1100 m asl.) NW of the valley, however, three ice caps are situated (Fig.3). All glaciers are small, between 0.1 and 2 km^2. No mass balance measurements have yet been carried out on the glaciers within the study area. Later in this paper, the result of a computer simulation experiment on the glaciers within the study area will be outlined.

The cirque glaciers are situated within deep cirques, and substantial amounts of talus are supplied to the glacier surface from the free rock faces above. Below the equilibrium line these glaciers are therefore partly covered by supraglacial debris and the fronting Little Ice Age moraines are very conspicuous. Some of these even have a rockglacier as regards appearance. In contrast, no prominent moraines are found around the plateau ice caps, probably due to the lack of supraglacial debris sources. Their former Little Ice Age extension is shown by zones of less vegetation cover and less weathering of boulders. In general, the glaciers have melted 100-300 m back from their maximum Little Ice Age position.

Probably the glaciers within the study area reached their Little Ice Age maximum extension around 1900 AD, as is known to be the case for glaciers in the southern part of the island, around Godhavn. There exist, however, no earlier observations on glaciers in the Mellemfjord area.

Periglacial Landforms

Periglacial landforms are widespread, underlining that the area is situated within the zone of permafrost, probably in the southern part of the continuous permafrost zone. The daily mean air temperature in Mellemfjord appears to be considerably below the daily mean air temperature in Godhavn (see above). Judging from the initial meteorological observations 1993-94, the mean yearly air temperature at sea level may be as low as about -8 C°. Deglaciation was probably early, about 9,100-8,000 BP (Donner 1978, Ingolfsson et al. 1990) and periglacial processes have been dominant within the study area since then.

Several rockglaciers, both fossile and active, line the valley sides exposed toward NW and N. Some rockglaciers are extending all the way from a free face to the main valley bottom while others only cover the lower part of the valley sides. The largest rockglaciers are glacier-derived while the smaller ones seem to be talus-derived (Humlum 1983, 1988a). Active talus cones are found particularly on the steepest NW exposed mountain sides. It seems as if they have been even more active in an earlier period, as the lower part of the talus cones in several places is partly covered by a solifluction sheet.

Large active avalanche tracks (Fig.3) covered by large angular boulders are leading from many funnel-shaped ravines on the NW-side of the main Kûgssuaq valley, showing that huge amounts of snow accumulate in these valleys during wintertime. Accumulation of drifting snow by winds from S may be important in this respect (see above). On the plateaus north of the Kûgssuaq valley nivation processes and solifluction are especially important.

Prominent solifluction lobes are widespread on most parts of the Kûgssuaq valley sides, revealing that solifluction is a dominant process. This indicates precipitation in the study area to be relatively large, reflecting the position close to the western coast of Disko Island.

Concerning minor periglacial landforms, particularly the pingo remnants streaching across the glaciofluvial plain at the mouth of the Iterdlagssûp Kûgssuaq valley are of interest. The position of these pingos on the highest parts of the salt marsh flats at the junction between the glaciofluvial plain and the delta, compared with the knowledge of Holocene sea-level changes in the western part of Disko Island (Donner 1978, Frich & Ingólfsson 1990, Ingólfsson et al. 1990), has led to the conclusion that these pingos probably evolved as open system pingos during the Little Ice Age period 1400 to 1900 A.D. (Christiansen, manuscript).

The raised marine terraces at Sarqardlît Ilordlît (Fig.10, discussed below) are important for an indirect dating of

***Figure 5:** Raised marine terraces at Sarqardlît Hordlît. In the front of the lower terrace (a fossil coastal cliff) active ravines with small alluvial cones can be seen. Person for scale.*

several periglacial terrain features developed on the terraces. The front of the lowermost terrace is furrowed by ravines 3-4 m deep and 10 to 20 m long, some still active. In front of the ravines small sediment cones are found, probably accumulated during snowmelt in the early spring (Fig.5). At the fronts of the two higher raised marine terraces only remnants of ravines are found and today sliding and solifluction are the active periglacial processes. In contrast to the uppermost terraces the lowermost terrace front has no vegetation and is steeper. Being positioned close to sea level, particularly the front of this terrace is exposed to snowdrift during wintertime. The result is large accumulation of drifting snow in the ravines, which keep the ravines growing, especially during the snow melt season. On the higher terraces deposition of drifting snow is smaller and solifluction seems to represent the dominant process. Earlier in the Holocene, when the uppermost terraces were situated close to sea level, with substantial snow drift during winter, they probably had the same appearance as the lower terrace today.

Monitoring of some of the smaller periglacial terrain features within the study area has been initiated by way of recurrent photography in order to detect changes in form and size.

Hydrology and Fluvial Geomorphology

The Kûgssuaq valley drainage basin (55 km^2) opens towards SW. The topographic divide follows basalt plateaus partly covered by glaciers (Fig.3). The valley slopes of the basin are of marked asymmetry, the S-facing slope is rather gentle with many watercourses. The N-facing slope is dissected by cirque glaciers feeding the few streams.

The main stream originates in the eastern part of the basin. From the topographic map it is seen that this stream has five rather long and branching tributaries coming from the S-facing slope and only three rather short tributaries from the N-facing slope. According to the Strahler classification the basin is of fourth order. Considering the topographic map, there are 2 3rd order, 5 2nd order and 18 1st order streams in the catchment. The main stream passes basalt benches in minor canyons; between these canyons braided reaches are found. Near the outlet to the sea the main stream runs through a 30 m deep steep-sided valley eroded into a major till ridge running across the valley mouth. The lower part of the profile is carved in solid rock. The bottom width varies from 5 - 10 meters.

Near the outlet of the main stream a stable cross-section (D6) suitable for discharge measurements was found (Fig.3) and a gauging of the water table was carried out simultaneously with discharge measurements. At the same cross-section samples of water were collected below minor falls where total mixing could be assumed. The water samples were used for calibration of a Partech IR transmissometer that was installed together with a datalogger for continuos recording of sediment concentration. A reconnaissance trip was carried out along the main stream and the lower part of its tributaries. Water samples were collected and filtered through Whatman GF/F filters with a nominal retention diameter of 0.7 micron. Also the conductivity and the temperature of water in the tributaries and the main-stream were measured.

During a four-day period in mid-August the maximum water depth at the gauging station dropped from 0.56 m to 0.52 m. This lowering was interrupted by a rise of app. 5 cm on 22 August caused by a rainfall of 11 mm. A daily variation of app. 2 cm was observed with a maximum around 09h PM. The measured discharge varied from 0.914 to 0.627 m^3s^{-1}, a preliminary stage discharge relationship: $Q\ (m^3s^{-1}) = 8.35*(\text{max.depth (m)})^{3.86}$ was found, yielding r=0.984. Due to the low range of depths this relationship should be tested at higher stages before general use. The water temperature at the gauging station varied from 2 - 4 °C. The conductivity varied from 36.4 to 37.1 μS/cm. Measured concentration of suspended sediment varied from 3.7 to 4.2 mg/l, however, the transmissometer registrations showed a multipeaked maximum on 22 August indicating concentrations up to 80 mg/l (Fig.6).

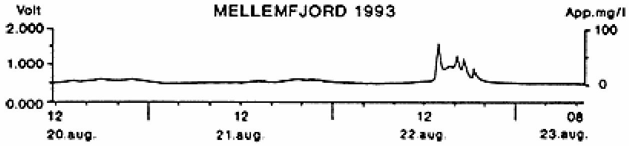


Figure 6: *Approximate concentration of suspended sediment measured in the Kûgssuaq river.*

The transmissometer registration also indicates a slight daily variation in concentration, probably due to a contribution of sediment rich meltwater from the glaciers. The multipeaked appearance indicates a contribution from different sources reacting differently on the rainfall event. Sediment transport during periods without rainfall was normally 200 - 400 kg/d during the observation period. The concentration during the rainfall event on 22 August, however, indicates that transport could be as much as 20 times higher, which shows the importance of a continuos registration for a reliable computation of the fluvial sediment transport.

The reconnaissance trip showed that it was possible to distinguish among three main types of water courses in the basin: Firstly, watercourses mainly fed by rainfall and nonperennial snowpatches. These watercourses are characterised by being dry or with very low discharge values during the investigation period in August. Conductivity was around 35 μS/cm and sediment concentration 1 - 2 mg/l. They are situated on the lower part of the south facing slope. Secondly, watercourses fed by rain and snow through sources from the basalt benches, major accumulations of loose sediment and swamps. The discharge is large and rather stable. Conductivity showed a variation from 24 - 55 μS/cm indicating a possibility for further classification. Sediment concentration was low, about 2 - 4 mg/l. Thirdly, watercourses fed by perennial snowpatches or glaciers. The discharge is high showing a daily variation. The temperature was 0.8 - 2 °C. The conductivity was around 35 μS/cm. The water from the glaciers was clearly sedimentladen, the colour varied from white to brown depending on the lithology. Measured sediment concentration was quite low: 35 - 38 mg/l but significantly higher than in the other watercourses within the test area.

The chemical composition of water samples from the study area was analysed. Sampling localities are shown in figure 3. The precipitation sample was collected at the camp site (D7). The results of the chemical analysis are shown in table 1. In general the content of ions is very low ranging from app. 4 to app. 9 ppm., which is in good accordance with the low conductivity values. However, three types of water could be distinguished: 1. Low alkalinity and low content of ions. 2. Higher alkalinity and higher content of ions. 3. Intermediate with higher iron content.

Water type 1 is represented by samples D1 and D4 (Fig.3). The samples are characterised by runoff from glaciers. Type 2 is represented by D2, D3, D6 and D7 , the three first samples are from watercourses with bare soil during the summer period. It is interesting that the precipitation sample is very similar, partly because of a higher concentration of NaCl, compared with type 1 that receives runoff from winter precipitation. Mainly it can be concluded that the summer precipitation has a higher content of salt from the sea than the winter precipitation, because

Table 1: *Chemical analyses of water samples from the test area*

Sample	*pH*	*L* $\mu S\ cm^{-1}$	*Alk.* *meq/l*	Cl^- *ppm*	NO_3^- *ppm*	SO_4^{--} *ppm*	Na^+ *ppm*	K^+ *ppm*	Mg^{++} *ppm*	Ca^{++} *ppm*	Fe^{++} *ppm*	Mn^{++} *ppm*
D1	6.10	21	0.13	0	0	0	2.45	0.02	0.33	1.35	0.54	0
D2	6.04	39	0.30	0.2	0	0.3	3.66	0.08	0.97	2.15	0.37	0
D3	6.27	43	0.32	0.6	0	0	5.36	0.05	0.72	1.99	0.43	0
D4	6.01	20	0.13	0	0	0	1.94	0.09	0.31	1.31	0.30	0
D5	6.26	35	0.25	0.1	0	0.8	4.58	0.12	0.53	1.88	0.92	0
D6	6.38	40	0.29	0.7	0	0.6	4.40	0.08	0.78	2.10	0.53	0
D7	6.28	40	0.31	0.4	0	0	4.40	0.06	0.78	2.17	0.35	0

the sea is covered by ice during the winter. Type 3 is represented by D5 only. This is also glacial runoff, but the higher content of ions could be explained by a larger part of subglacial runoff. The iron content could be explained by weathering of the substratum.

The results from the field study proved that the selected basin was well suited for further studies of fluvial sediment transport processes in this environment that is considered typical for major parts of the western Disko Island.

Soil types

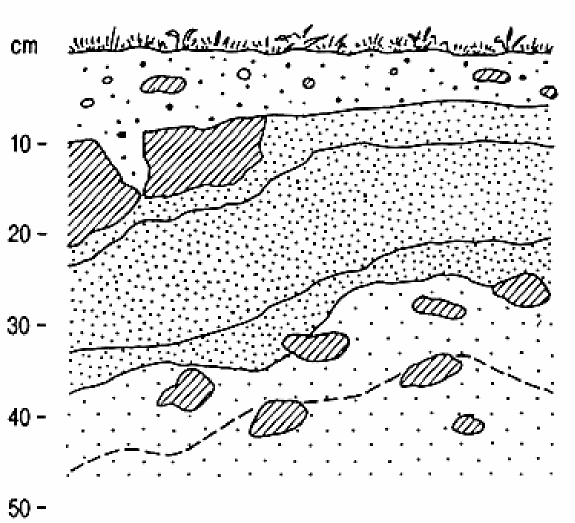
Soils in the Mellemfjord area and at other sites visited along the southern coast of Disko Island normally reveal polysequent soil profiles. Soil horizon features in fossil and buried soil profiles and the character of disturbance and cover can yield important information on past ecosystem conditions.

A specific period of soil development, probably during the early Holocene climatic warm period, has resulted in quite distinct differentiation of soil horizons. This soil type is obviously developed in a period with little horizon mixing processes by cryoturbation and with quite stable geomorphic conditions in general. The parent material of this old soil is often two-layered, which is a general characteristic of most soils in Greenland (Jakobsen, 1991 & 1992). Mostly coarse textured tills and glaciofluvial materials are covered by a mantle of late-glacial fine sand/loess. During the Late Wisconsin deglaciation, before the coverage of the landscape by vegetation, these fine grained sediments were probably eroded by winds from the extensive barren areas close to the retreating glacier margins.

At all studied sites a strong disturbance is observed of this early Holocene soil, caused by increasing geomorphic activity. Probably the intensity of especially cryoturbation, solifluction, fluvial or aeolian processes has increased markedly in the later part of the Holocene.

As an example, a typical polysequent soil profile from the study area is shown in figure 7. The oldest soil, horizons 3A, 3Bv and 3BC, is an arctic brown soil developed in the early Holocene two-layered parent material, sand-loess covering till. Two major Holocene events have occurred at this specific site. A covering by a younger aeolic sediment, horizons 2A and 2BC, and a final deposition of solifluction material, horizon AC. The disturbance and disruption of soil horizons are assumed to be due to horizon mixing caused by the latest solifluction/cryoturbation activity.

A series of variations of this typical polysequent soil is observed in the landscape. In poorly drained and/or sloping landscape segments cryoturbation and solifluction processes have been intense and caused strong mixing and disruption of the early Holocene soil horizon development. At well-drained, flat sites only little cryoturbation is seen



Horizon	%C	pH
AC	1.70	4.92
2A	4.37	4.74
2BC	2.37	4.93
3A	2.07	5.03
3Bv	0.72	5.04
3BC	0.21	5.08

Figure 7: Polysequent soil profile. Explanation in text.

in the soils, and the only observed coverage of the early Holocene soil is an aeolic soil layer. An example of this is shown in figure 8 and table 2. A buried, but undisturbed arctic Podzol is developed in a well-drained two-layered sandloess covered coarse-sandy parent material, only covered by a coarse-sandy aeolic layer. A more detailed study of the distribution of polysequent soil profiles on Disko Island and datings of larger plant fragments belonging to fossil Holocene landscape surfaces are planned, and may give an important contribution towards the understanding of Holocene landscape evolution and climate history in central West Greenland.

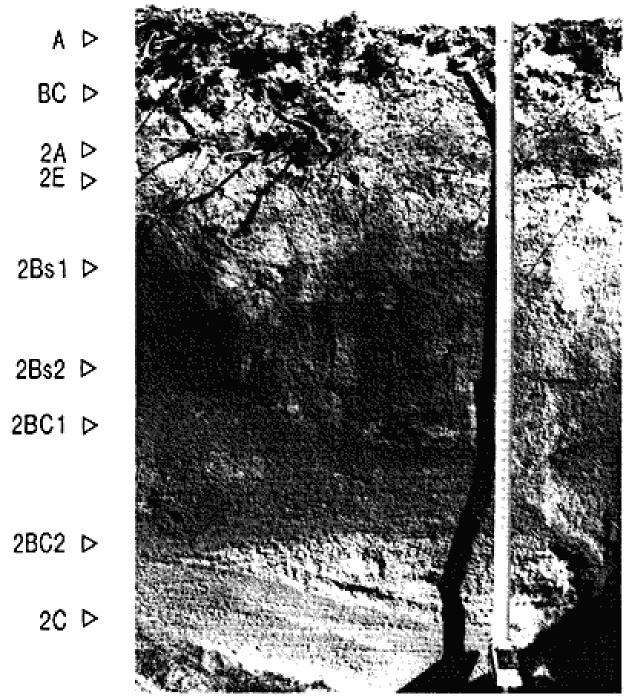


Figure 8: A buried podzol. Profile about 65 cm high.

Ecosystem Records in Lake Sediments

In the northern part of the Kûgssuaq valley a small lake is located close to the watershed. The terrain around the lake was probably deglaciated early in the Late Wisconsin. An evaluation of the lake surroundings shows a small catchment area comprising several landscape thresholds. At present, the sediment influx to the lake is assumed to be small, but changing climatic conditions during the Holocene and probably even earlier must have left an interesting sedimentological, palynological and geochemical archive in sediments accumulated in the lake. Generally, a low rate of sedimentation is expected during the Holocene period and the lake sediments are assumed to be dominated by various types of fine grained low carbon containing gyttja. Lake sediment corings as those carried out in several

Table 2: Profile characteristics of the buried podzol in Fig. 8. Colour: Munsell Soil Colour (dry). %C analysed by LECO and pH measured in a 1:2.5 w/w soil: 0.01 M $CaCl_2$ suspension.

Horizon	*Depth/cm*	*Morphological features*	*%C*	*pH*
A	0-2	Coarse sand, brown (10YR 5/2)	1.19	4.13
BC	2-9	Coarse sand, brown (10YR5/3)	0.65	4.23
2A	9-11	Fine sandy loam, brown (10YR 4/2)	4.88	4.11
2E	11-18	Fine sandy loam/gravelly coarse sand, grey (10YR 6/1)	0.25	4.37
2Bs1	18-25	Gravelly coarse sand, brown (7.5YR 4/3), orange (10YR 6/4), mottled	0.35	4.70
2Bs2	25-35	Gravelly coarse sand, orange (10YR 6/4), brown (5YR 4/4), mottled	0.20	4.85
2BC1	35-48	Gravelly coarse sand, orange (7.5YR 6/4)	0.14	5.12
2BC2	48-70	Gravelly coarse sand, orange (10YR 7/3)	0.11	5.17
2C	70-	Gravelly coarse sand, grey (10YR 8/1)	0.08	5.24

Figure 9: A series of recurved beach ridges, which indicate littoral drift from the west (right), characterises the cuspate foreland at Sarqardlît Ilordlît.

lakes in East Greenland, on Ammassalik Island, are planned for the project period.

Coastal Studies

Several coastal stretches in Mellemfjord offer excellent subjects studying Holocene relative sea-level changes and recent marine impact on the arctic environment. In 1993 the coastal investigations were carried out at a coast section called Sarqardlît Ilordlît at the NE shore of Mellemfjord (Fig.3).

The Holocene marine limit in Mellemfjord is about 60 m and the relative sea level history of Disko was one of steady uplift before 3 ka BP (Donner 1978, Frich & Ingólfsson 1990, Ingólfsson et al. 1990). Extensive transgressive barriers at several localities on Disko, sometimes situated in front of a fossil coastal cliff (Rasch and Nielsen 1994), suggest that the relative sea level has been below the present one during late Holocene and that the relative sea level variation of the nearest past was one of submergence.

Sarqardlît Ilordlît is situated at the mouth of a large valley, Iterdlagssûp kûgssua, joining the Mellemfjord from the north (Fig. 3). At the mouth of this valley an extensive, tidal influenced delta is deposited, The delta flat is dominated by low wave energy and low littoral drift. No detailed fieldwork was carried out in 1993 on the delta, except for reconnaissance surveying including an echo sounding profile. These preliminary observations indicate potentials for studying undisturbed sequences of Holocene submarine sedimentation.

West of the delta three cuspate forelands have developed, the easternmost is shown in fig. 9. The forelands terminate in a series of marine terraces at 41, 38, 33, 25, 18 and 8 m asl.. The terraces indicate marine deposition throughout the Holocene (Donner 1978). A fossil coastal cliff separates the lowermost terrace from the cuspate forelands.(Fig. 5).

The geometric pattern of the recent and sub-recent beach ridges constituting the forelands indicates that the forelands originate from easterly directed littoral drift. The beach ridges are exclusively built-up by pebbles derived from local alluvial fans. Each foreland encloses lagoon deposits. On the easternmost foreland the lagoon is still in connection with the fjord. During the 1993 investigation, the geomorphology of the forelands was mapped (Fig.10), profile surveyings were carried out and three cores were obtained from the lagoon deposits.

The distribution of the individual ridge heights and the degree of weathering and lichen coverage of the surface particles (indicative of age) are of special interest. These parameters together with information from the lagoon cores will contribute to the superficial knowledge of late Holocene relative sea-level variations in central West Greenland. The morphostratigraphy of the cuspate forelands suggests that the late Holocene coastal history was one of regression followed by transgression again followed

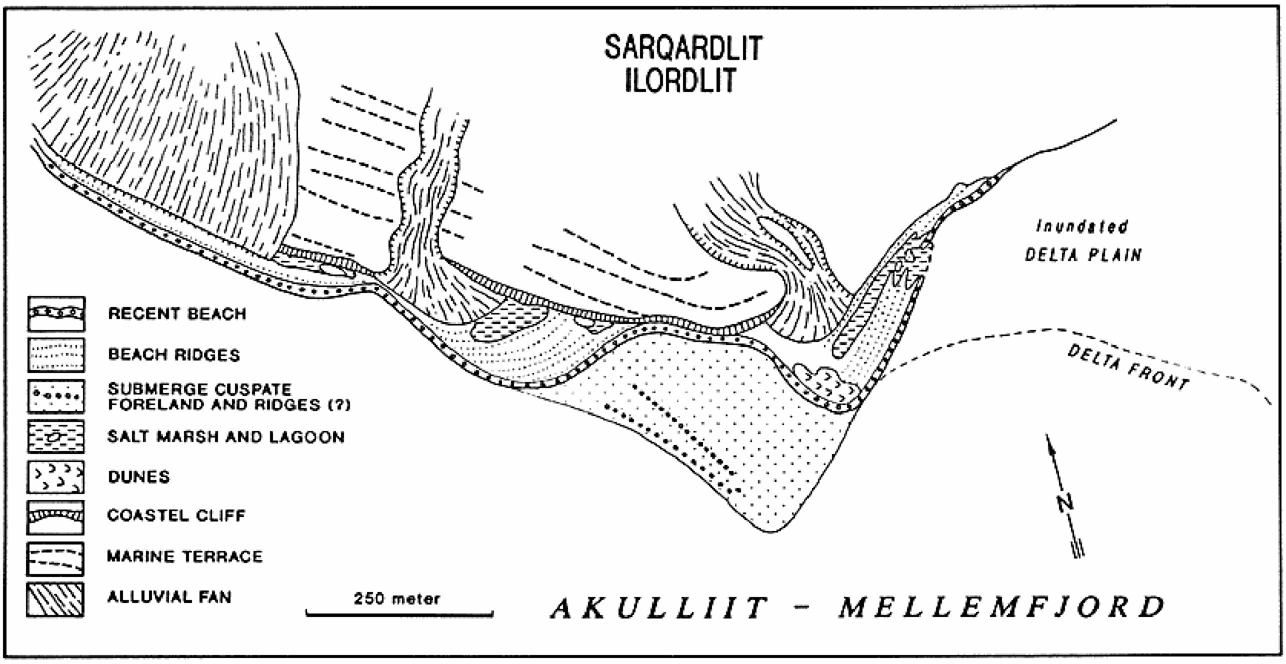


Figure 10: *Map indicating the main structures of the geomorphology at Sarqardlît Ilordlît, including the outline of an assumed submerged cuspate foreland.*

by regression and transgression. As the lagoon cores contain organic material absolute dating of these sea level events may be possible.

Preliminary surveyings and echo soundings revealed a special submarine configuration and sediment distribution about 2 m below the present mean sea level offshore the easternmost cuspate foreland (Fig.10). The configuration might be the submerged remnants of a cuspate foreland. If further investigations verify this interpretation, Sarqardlît Ilordlît may become an important research area for the study of Neoglacial relative sea-level fluctuations in West Greenland.

Analytic Computer Studies

A 3D digital terrain model has been established for the Kûgssuaq area (Fig.11). Topographic data were digitised from official 1:250,000 maps. These and associated data on geomorphic terrain types have been used as input in an analytical terrain model, to calculate e.g. radiation for the individual terrain segments, given certain meteorological parameters.

As an example, illustrating the potential of this approach, the calculated net energy input (net short-wave radiation + net long-wave radiation + sensible heat flux) for July is shown in figure 11. From this it is seen that the net energy input is at maximum (about 250 Wm^{-2}) for the sea surface, due to the low albedo for water. On the other hand, certain terrain units (Fig.5) such as narrow valleys, free rock faces exposed towards NW and glaciated areas are characterised by very low values (<75 Wm^{-2}), partly due to topographic induced shadow, partly due to high albedo. Gently sloping valley sides and valley bottoms receive intermediate values about 100-170 Wm^{-2}.

Concerning the present glaciation, energy considerations are important. In figure 12 the mean July net energy input is shown as a function of terrain segment altitude, with glaciated terrain segments emphasised. Considering only the glaciated terrain segments, these are seen to fall in two groups, representing glacier surface segments above and below the equilibrium line (ELA), respectively. At ELA 20-50 Wm^{-2} are received at the glacier surface during July, lowest values at ELA's situated around 500 m asl. (glaciers situated within deep cirques) and maximum values at ELA's found on ice caps on the 900-1100 m asl. mountain plateaus. Taking the whole ablation season June-August as a 100 day period, and calculating the appropriate mean values for each month, about 350 mm w.e. are lost each sum

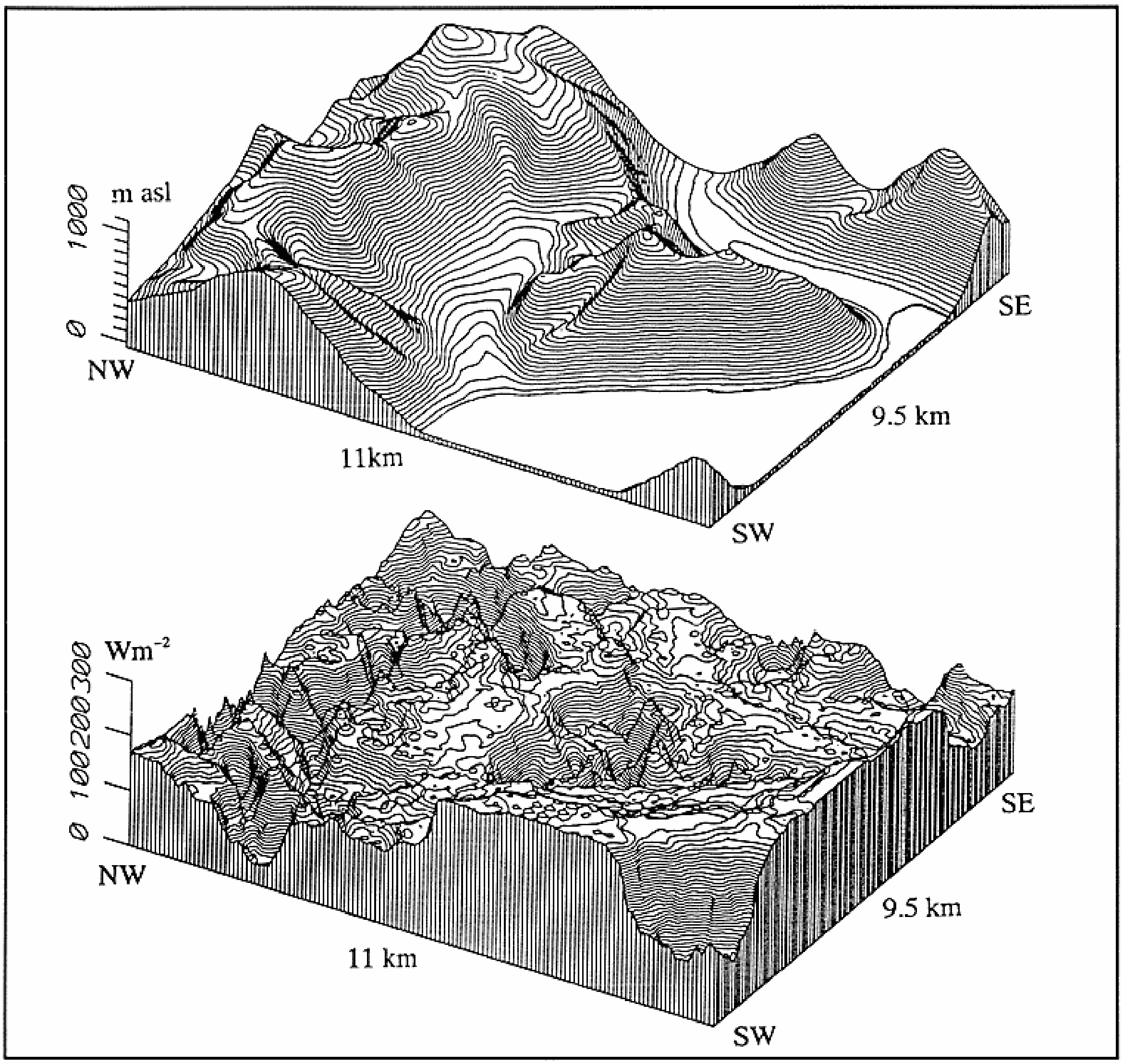


Figure 11: *The Mellemfjord test area as seen in 3D perspective from SW. The lower diagram shows the spatial distribution of the mean energy balance for July, as seen from the same viewpoint as the upper diagram. Values were calculated using a monthly mean air temperature at sea level of 7 °C, a mean cloud cover of 40%, a mean wind speed of 2ms^{-1} and mean lapse rate of 0.0065 °C m*

mer at ELA for the cirque glaciers, while about 650 mm w.e. are lost at ELA on the ice caps. Typical meteorological summer values as regards air temperature, cloud cover and wind speed measured at Godhavn were adopted for this experiment, as the Mellemfjord meteorological station is still in its first year of operation.

If glaciers within the Kûgssuaq area are assumed to be in equilibrium at present, the above estimated ablation values must represent the winter accumulation at ELA's. The low accumulation values calculated for the cirque glaciers indicate the low snow accumulation requirement for glaciers within topographical incised valleys like the cirque valleys. On the other hand, the high accumulation requirement estimated for the ice caps points towards the very exposed nature of these glaciers, situated on mountain plateaus. Probably they only exist due to accumulation from winter snow drift across the plateaus by the southerly meridional upper-air flow discussed above.

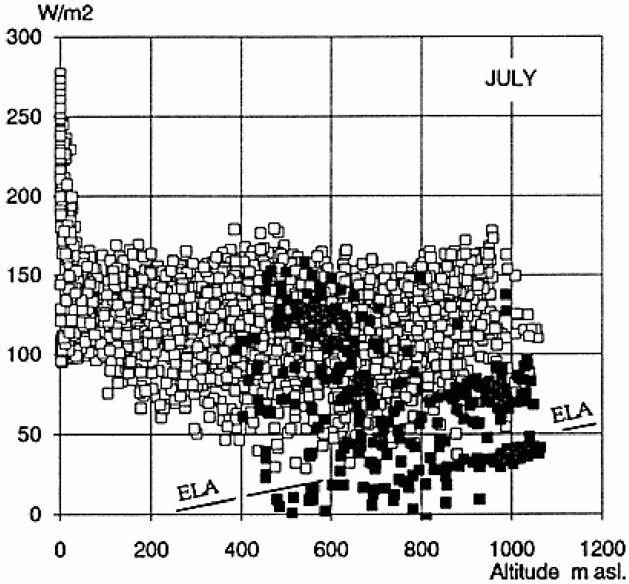


Figure 12: Mean July energy balance for the individual terrain elements within the Mellemfjord test area. Values were calculated using a monthly mean air temperature at sea level of 7 °C, a mean cloud cover of 40%, a mean wind speed of 2ms^{-1} and a mean lapse rate of 0.0065 °C m^{-1}. Terrain segments covered by snow or glacier ice are shown in dark grey. Compare with lower diagram in figure 11.

Access to improved data on meteorological parameters and geomorphological data obtained from the now-operating automatic weather station in Mellemfjord, as well as improved geomorphological mapping will clearly contribute towards a higher-quality output from computer models such as that outlined above. This is important, as the purpose of the present model is to provide data to obtain knowledge of various climatic controls on the distribution of geomorphic- and vegetational units within the study area.

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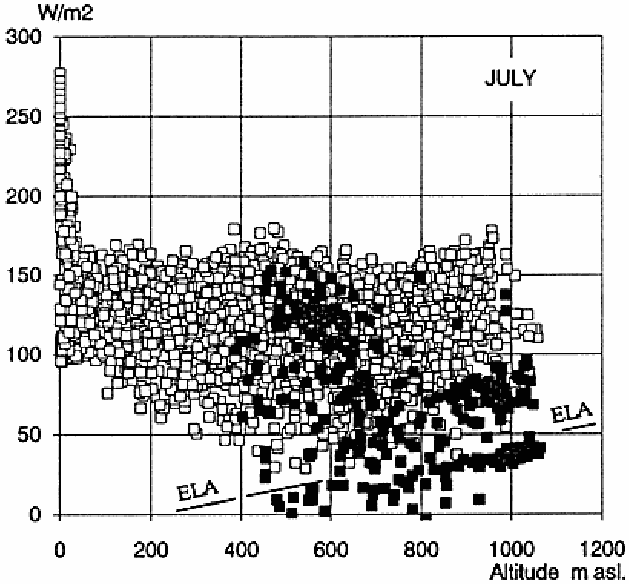

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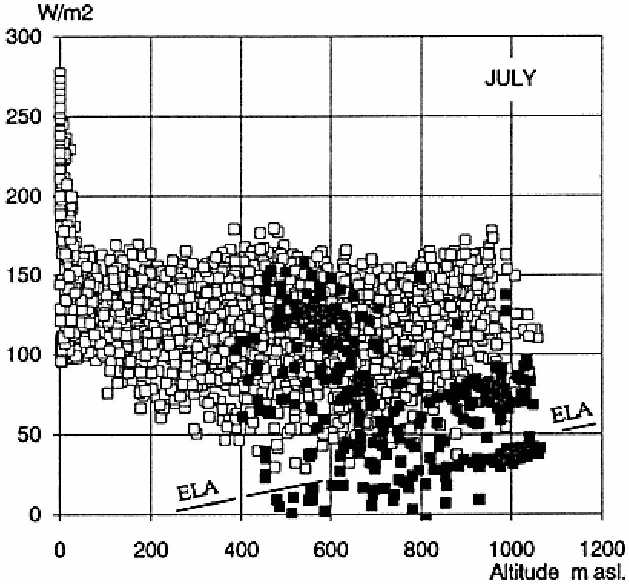

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