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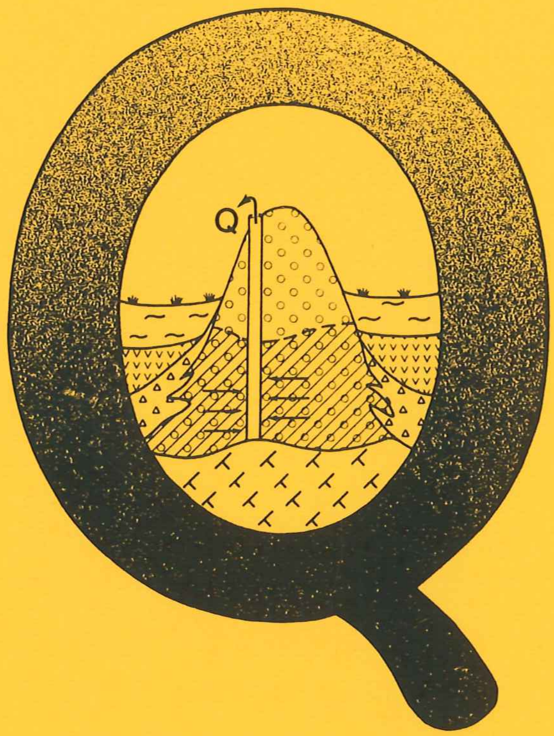

A sedimentological study of glacial deposits in the upper Sjællandselv area, Jameson Land, East Greenland

Torbjörn Andersson

Lund 1994 Examensarbete, 20 p Nr 57
Geologiska Institutionen, Lunds Universitet

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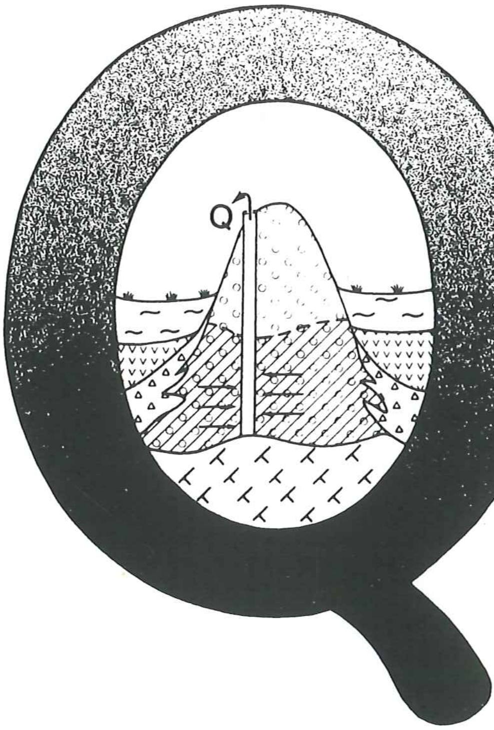

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Preface

This report constitutes a Master degree thesis in the four-year Programme of Natural Sciences at the University of Lund. The report has been prepared at the Department of Quaternary Geology, University of Lund, within the frame of the ESF- (European Science Foundation) PONAM- (Polar North Atlantic Margins; Late Cenozoic Evolution) programme.

The fieldwork took place during late July and August 1992. The laboratory work was for the most part completed during the fall of 1992. The final work on the compilation was done during late winter and early spring 1994.

First of all I want to thank my supervisor Lena Adrielsson, who provided lots of help and inspiration during the weeks of fieldwork as well as during the work on the compilation while at home.

I also want to thank Per Möller who helped me a lot with questions and problems that arose both during the work on the compilation as well as during the first weeks of fieldwork. He also helped me with the final editing work on the report.

A special thank you goes to Christian Hjort, Per Möller and Lena Adrielsson who gave me the opportunity and offer to participate in the expedition.

Finally my love and thank you goes to my girlfriend Cicci, who has always provided great support and love during my years in Lund.

Lund, april 1994

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Summary

The fieldwork preceding this Master degree thesis took place in Jameson Land, East Greenland, within the frame of the PONAM (Polar North Atlantic Margins; Late Cenozoic evolution) project.

In central Jameson Land, a plateau area at approximately 500 m a.s.l. forms a marked height in the area around the uppermost reaches of Jyllandselv. A c. 2 km wide valley, where river ravines are cut down more than 100 m into the Jurassic bedrock, divides the plateau into a northern and a southern part. The investigated area is located in the southern part of the plateau area, between the two deep river valleys of upper Sjællandselv and upper Jyllandselv, where two elongated hills with top surfaces at approximately 510 m a.s.l. form a 5 km long till covered complex. The eastern hill has gentle slopes, whereas the western hill has terraced slopes on the northern, eastern and southern sides. Seven sites have been investigated through detailed sedimentological logging of excavated sections and four lithostratigraphic units, A-D, have been distinguished.

Unit A shows fine sand and coarse silt sediments dominated by type A and type B ripple cross-lamination and planar parallel-lamination. These sediments are interpreted to be formed by rapid deposition from turbidity currents along a prodelta slope or at the distal parts of a subaqueous fan. Palaeocurrents show a dispersed pattern towards the south, south-east, east, north-east and the north.

Unit B consists of a diamicton with a coarse to medium sand matrix and boulders up to 1 m in diameter occur. The diamicton is interpreted to be a till. It covers the two elongated hills and lies on top of unit A. A fabric analysis shows an ice-movement towards the south-east.

Unit C comprises sandy fluvial bedforms. Trough cross-lamination formed by the migration of 3-D dunes is the most common lithofacies and is interpreted as in channel deposition of a sandy braided river. Palaeocurrents are opposed to the present drainage system.

Unit D is a diamicton with a high silt and clay content in the matrix. It can be found on top of the fluvial terraces. The diamicton is interpreted to be a till. At one of the sites this till is intensely deformed and folded and interpreted as a B-horizon in a subglacial deformation zone. The strike of fold axes show a direction of stress approximately towards the south-west.

The sediment successions reveal the former existence of a glacial lake in front of a damming glacier in the west. Since the palaeocurrents are approximately opposed to the present drainage system, the glacier margin is assumed to have been located relatively near. The absence of coarse-grained upper delta slope sediments as well as topset sediments of an ice-contact delta indicates that the sediments of unit A are prodelta or distal subaqueous fan deposits. Unit B represents the deposition of an advancing glacier from the west, that most likely was the same glacier that dammed the glacial lake. During deglaciation, proglacial meltwater erosion and fluvial terrace sediment deposition took place as revealed by unit C sediments. Palaeocurrents that are approximately opposed to the present drainage system, indicate that the glacier still existed in the west. The last recorded event in the area is a new glacial advance from the north-east. This is shown by the deformation till of unit D.

1 Introduction

This Master degree thesis has been prepared at the Department of Quaternary Geology, University of Lund, within the frame of the PONAM (Polar North Atlantic Margins; Late Cenozoic Evolution) project. PONAM is an Associated Project within the European Science Foundations (ESF) Polar Network. The Project is divided into three subprograms with the main aims to investigate:

A) Long term climate variations and their effect on the sedimentation environment at the continental margins, in particular the shelf areas.

B) The latest interglacial/glacial cycle, with the establishment of an absolute chronology as well as a high resolution stratigraphy.

C) The present interglacial marine sedimentation environment, as a tool to interpret ancient sediments and sedimentation processes.

My work falls within the frame of theme B, which concerns glacial and climatic development during the last interglacial/glacial cycle - roughly the last 125,000 years but with concentration within the project on the pre-Holocene part of the period.

The project was scheduled for four field seasons. Two of these field seasons - the summers of 1990 and 1992 - have taken place in the large ice-free areas of East Greenland, mainly the Scoresby Sund/Jameson Land area. This is an area influenced by the cold, south-flowing East Greenland Current. The other two field seasons - the summers of 1991 and 1993 - took place in the Svalbard/Barents Sea area, influenced by northward flowing warmer Atlantic water, thereby completing the field part of the project.

The overall aim of the work has been to provide dated records of such events as glaciations, transgression/regression cycles, as well as other climatic and oceanographic changes. In combination with comparable information from adjacent shelves and oceans these data will be worked into a model of climatic change and ice sheet behaviour in the North Atlantic region during the last interglacial/glacial cycle.

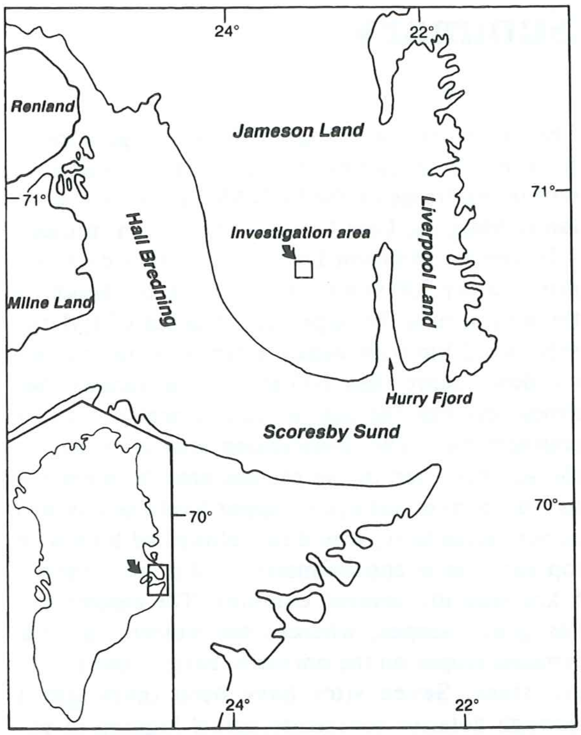


Fig. 1. Map showing the location of Jameson Land and its surroundings. The location of the investigation area can also be seen on the map.

The fieldwork preceding this Master degree thesis took place in Jameson Land, East Greenland (Fig. 1) during the late summer of 1992. Seven sites have been studied through detailed sedimentological logging of excavated sections and samples have been collected for laboratory work. My aim with this work has been to give an account of the processes responsible for the deposition of the sediments. This would allow me to make a reconstruction of the palaeoenvironmental development in the studied area.

The correlations that have been made are based solely on lithostratigraphical and morphostratigraphical conditions. This is because neither was any dateable material found in the studied excavations, nor were any samples collected for thermoluminescence dating.

2 Bedrock geology, topography, climate, permafrost, oceanography and biogeography of the investigation area

The investigation area is situated in the Scoresby Sund region in East Greenland (Fig. 1).

2.1 Bedrock geology

The general outline of the bedrock geology (Fig. 2) of the investigation area follows that of Henriksen (1986).

The Scoresby Sund region, (69° -72° N) includes the southernmost part of the N-S trending East Greenland Caledonian fold belt. Adjacent to it is a coast-parallel sedimentary basin with Upper Palaeozoic continental deposits and Upper Perm - Mesozoic shallow water and marine sediments. Tertiary plateau basalts dominate the southern part of the region while Tertiary intrusive complexes occur in the north-east part of the region.

Within the Caledonian fold belt in this region it is possible to distinguish Archean, Early Proterozoic, Middle Proterozoic and Caledonian complexes. The western limit of the Caledonian fold belt is to be found in the borderzone close to the Inland Ice, where pre-Caledonian foreland crops out in tectonic windows beneath the westward directed Caledonian thrust units. The central fjord zone is made up of crystalline complexes and represents the inner, deep-seated parts of the Caledonian fold belt, while furthest to the east a N-S trending horst area (Liverpool Land) of Caledonian and older crystalline rocks occur, bordering the eastern side of the Mesozoic sedimentary basin.

The post-Caledonian development began with uplift and erosion of the mountain belt, that gave rise to the deposition of continental Devonian-Lower Permian, clastic sediments. These are

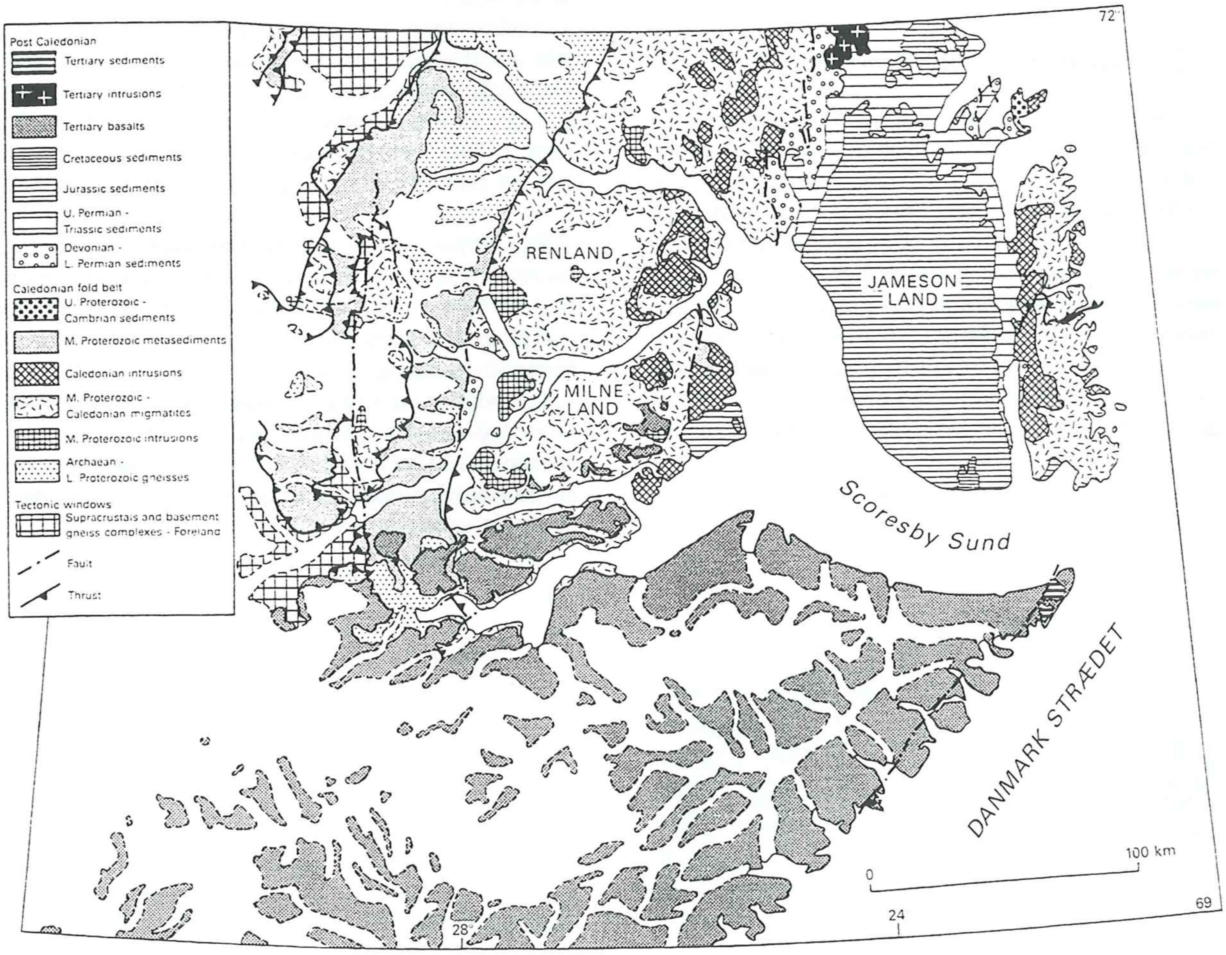


Fig. 2. Simplified geological map of the Scoresby Sund region. From Henriksen (1986).

mainly preserved along the western boundary of the Jameson Land basin. A marine transgression during the Upper Permian marks the beginning of a new phase during which a succession of mainly marine shallow water sediments of Jurassic-Lower Cretaceous ages were deposited (Birkelund & Perch-Nielsen 1976).

The Jameson Land basin was formed as a N-S trending basin between the Caledonian crystalline region to the west and the horst area on Liverpool Land to the east. The basin widens to the north while its continuation to the south is hidden beneath the Tertiary plateau basalts. The Tertiary basalt sequence, several kilometres thick, also conceals the southern continuation of the Caledonian fold belt and overlaps younger sediments.

Geophysical investigations in the Jameson Land basin area have been carried out during recent years. Among other things these reveal that a thick sequence of Tertiary sediments outside the coast to the east and south of the entrance to Scoresby Sund overlies the basalts, whereas Mesozoic or older sediments may be found under the Tertiary sediments on the shelf area to the east of Liverpool Land. The Jameson Land basin continues under the waters of Scoresby Sund with a cover of Tertiary-Quaternary sediments.

2.2 Topography

The following description of the topography in the region has also been drawn from Henriksen (1986).

The crystalline complexes in the Caledonian fold belt as well as the Tertiary basalts are characterised by a rugged, alpine topography with large, local ice caps and numerous glaciers. Along the borderline of the Inland Ice there is a wide zone where nunataks occur. The average summit levels in the central fjord zone lie between 1500-2000 m a.s.l., whereas the levels in the nunatak zone and in the Stauning Alper often reach 2000-2500 m a.s.l.. The highest summit within the region is found in Stauning Alper and reaches 2795 m.

In contrast to the rugged topography in the crystalline areas, Jameson Land with its sedimentary rocks is characterised by an undulating, rounded topography, with heights seldom reaching over 1000 m a.s.l..

The inner, main fjords are extremely deep, with depths of around 1000 m, locally reaching 1200-1400 m. The average depths in Hall Bredning and Scoresby Sund lie around 300-600 m, with increasing depths towards the Greenland Sea. The altitude difference between the mountain tops and the bottom of the deepest fjords indicates a total topographic relief of 3000-4000 m.

2.3 Climate, permafrost, oceanography and biogeography

The following short outline of the climate, permafrost, oceanography and biogeography in the region follows that of Funder (1989, 1990).

The region is situated north of the southern limit of continual permafrost, which in turn closely follows the mean annual temperature isotherm of -5 oC, with permafrost depths reaching 220 m (Kirchner 1963). In the coastal areas the thickness of the active layer varies between 0.5 - 2 m.

According to Publikationer fra det Meteorologiske Institut, the mean temperature for the warmest and coldest months in the village of Scoresby Sund during the period 1969-1979, was 3 °C and -20 °C respectively. During that same period the mean annual precipitation in Scoresby Sund was 549 mm.

The climate in the region is strongly influenced by the oceanographic circulation pattern, the main feature being the East Greenland Polar Current, carrying cold polar water from the Arctic Ocean southwards along the east coast.

The region is, from a biogeographical point of view, located in the High Arctic zone. This zone is characterised by a vegetation dominated by dwarf shrub heaths, composed of dwarf-birch and a number of ericaceous dwarf-bushes.

3 Review of the earlier investigations in the Quaternary geology of the area and an outline of the Quaternary stratigraphy

The following chapter has, if not otherwise stated, been drawn from Funder (1989, 1990)

3.1 Introduction

In general terms the Quaternary in the region has been a period of erosion. This is demonstrated, among other features, by the greatly over-deepened fjords. These are the deepest on the northern hemisphere. The Quaternary sediments are usually less than 10 m thick and occur as a thin veneer over the bedrock surface. Exception to this are valley mouths, high mountain plateaus and the coast of Jameson Land, where thick deposits have been preserved. The sediments comprise till and marine and fluvial deposits along the coasts and in the major valleys. On the surface, the sediments have been transformed by periglacial processes such as solifluction and cryoturbation, as well as the formation of ice-wedges and pingos. This is especially pronounced in the areas that was not covered by ice during Late Weichselian time.

The Quaternary record is dated by palaeontological, amino acid correlation and C-14 dates. During the PONAM programme, the use of TL/OSL - dating has also been in practice.

The stratigraphy reaches back to the Plio-Pleistocene boundary, but from this time up to the Late Quaternary there is a major hiatus.

Four periods of glaciations have been distinguished, each one of them less extensive then the other: The Lollandselv glaciation (pre-Saale according to Möller *et al.* (in press)), The Scoresby Sund glaciation (Saalian?), The Flakkerhuk glaciation (Late Weichselian according to Funder *et al.* (1991)) and the Milne Land stade (Late Weichselian and Early Holocene).

3.2 Quaternary sediments and landforms

3.2.1 Till

Coarse, sandy till is a common feature in the lowlands and along the fjords as well as on some higher mountain plateaus. The occurrence is however patchy and discontinuous. The thickness rarely exceeds a few meters. The thickest till cover is found on the high mountain plateaus.These deposits were described already early in this century and referred to as the Jameson Land Drift (Nordenskiöld 1907).

These till and till-like deposits cover the high plateaus of sedimentary bedrock in the central parts of Jameson Land over extensive areas between 500-1100 m a.s.l.. The sediments range from sorted gravel and boulders to matrix-supported sandy and clayey till, with a thickness rarely exceeding 10 m (Funder 1972). Yet, investigations carried out during recent years reveal a much more complex composition and origin of this so-called Jameson Land Drift (Hjort & Möller 1991). More than 50 % of the clast fragments is made up by far-travelled, crystalline rocks and among these the enigmatic *Scolithos* quartzite (Fig. 3) can be found. According to Hjort & Möller (1991), most of the boulders, and also between 75-80 % of the cobble grade, are crystalline or sedimentary rocks originating from the Caledonide mountains to the west. They also show that the *Scolithos* quartzite is present in most of their counts at a 1:3 frequency. The *Scolithos* quartzite has never been found *in situ* but is expected to be found somewhere under the extension of the present Inland Ice, or maybe under the present sea-level, in the deep fjords.

The surface of the deposits is to a very high degree weathered, with fines removed and surface of clasts wind-polished or disintegrating in other ways . The lithology of the "drift" indicates an ice movement over Jameson Land from the west to the east. The age of this glaciation, referred to as the

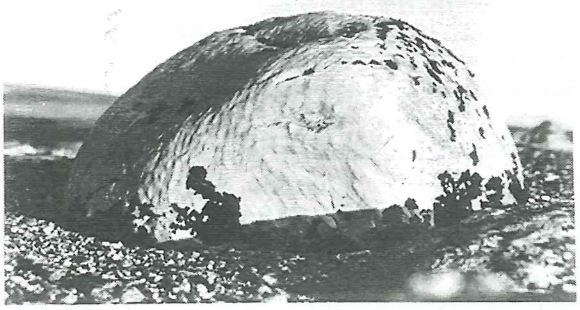


Fig. 3. A wind polished boulder of Scolithos quartzite. The diameter of the boulder is approximately 70 cm.

Scoresby Sund Glaciation (see part 3.3.2) by Funder (1984, 1989), is considered to be of pre-Weichselian age and it is at present correlated with the Saalian (Möller *et al.* in press).

3.2.2 Moraines

Moraines occur along the fjords and in the valleys, usually located at topographical breaks at fjord junctions and bends and at valley mouths. This indicates that their location is controlled by topographical rather than climatic factors. The most conspicuous among these moraines are the Milne Land-moraines (see part 3.3.7). These are usually located at the junction between the narrow, inner fjords and the great Scoresby Sund/Hall Bredning basin. In the Scoresby Sund area these moraines occur in swarms and individual ridges have been found to be 50 m high and 5-10 km long. They are composed of a coarse, sandy till with boulders reaching a diameter over 10 m on the surface.

3.2.3 Glaciofluvial and fluvial deposits

Glaciofluvial deposits composed of poorly sorted gravel and sand form outwash plains on the valley floors and kame terraces along the fjords and valleys. These were for the most part deposited during the Holocene part of the ice recession. Along the west coast of Jameson Land, sediments and landforms associated with dead ice disintegration - kames, kame and kettle topography, hummocky moraine and kame deltas - occupy an up to 10 km wide zone. Fluvial sand and gravel, deposited from braided rivers, form extensive plains in all major valleys.

3.2.4 Marine deposits

These deposits are represented by prodeltaic, massive or laminated silt as well as littoral and deltaic sand and gravel. The deposits occurs up to 130 m a.s.l., which is the Holocene marine limit in the region. A matrix-supported, silty diamicton containing large boulders and resembling a lodgement till occur in certain areas. The location of these deposits have however been used to interpret them as a marine ice-drop sediment (Nordenskiöld 1907; Feyling-Hansen *et al.* 1983).

Unique to this region are the Jameson Land marine beds (see part 3.3.5), represented by thick Quaternary sediments that covers the lowland areas at the mouths of the major fjords. Locally these reaches a thickness of 100 m. They are generally composed of a basal, laminated and homogenous silt with large boulders that grades upward into a stratified sand and silt with small and large scale cross bedding and channel infills. Mollusc shells that are situated *in situ* occur throughout the whole section and show, together with the lithology and the structures of the sediment, that these were laid down in a shallow marine, deltaic environment. The mollusc fauna is poor and represented by species that are common in present arctic waters, in particular *Mya truncata* and *Hiatella arctica.*

3.2.5 Periglacial features

The whole of the East Greenland fjord zone lies within the area of continuous permafrost and cryoturbation structures as well as frost wedge polygons occur in the Quaternary deposits throughout the whole of the region (Poser 1932; Sørensen 1935; Washburn 1965, 1967, 1969). Open system pingos have developed in the fluvial deposits as far south as 71° N on Jameson Land (Müller 1959; Cruickshank & Colhoun 1965; OBrien 1971). Small turf hummocks are a common feature in mossy meadows, and may be related to palsas (Raup 1965).

3.3 Quaternary stratigraphy

As stated above, the following outline of the Quaternary stratigraphy in the Scoresby Sund region has, if not otherwise noted, been drawn from Funder (1989, 1990). A scheme over the ages, isotope stages, chronostratigraphy and stratigraphy can be seen in Table 1.

3.3.1 The Lodin Elv Formation

This formation is only known from an isolated erosional remnant on the west coast of Jameson Land. It comprises a 40 m thick sequence of prodeltaic sand and silt and silty diamicton. The foraminifer fauna in the deposits together with the amino acid ratios of the mollusc shells implies an age at the Plio-Pleistocene boundary (Feyling-Hansen et al. 1983). The diamicton is interpreted as an ice-drop sediment and together with similar evidence from North Greenland it provides the earliest evidence of glaciation over the land areas of Greenland.

3.3.2 The Scoresby Sund glaciation

This glaciation represents the last time that the entire region was overridden by the Inland ice, including even the high mountain plateaus of central Jameson Land, and thereby the Scoresby Sund glaciation predates the last interglaciation. This

Table 1. The Quaternary stratigraphy on Jameson Land. Modified from Funder et al. *(1991).*

AGE (Ka)	ISOTOPIC STAGES	CHRONOSTRATIGRAPHY		STRATIGRAPHY	
10	1	Holocene		Milne Land stade	
20	2	Weichsel	Late -	Flakkerhuk stade	
30 40 50 60	3		Middle -	Hiatus	
70	4		Early -	"Jameson Land marine episode"	Mønselv Interstade
80 90	5 a-d				Jyllandselv stade
100					Hugin Sø Interstade
110 120					Aucellaelv stade
130	5 e	Eem		Langelandselv Interglaciation	
		Saale		Scoresby Sund glaciation	
		pre - Saale		Lollandselv glaciation	

has been suggested by the results of oxygen isotope analyses from the nearby Renland ice core, which indicate that the Inland Ice never overrode the high mountain plateaus of interior Jameson Land during the Weichselian (Johnsen *et al.* 1992). The earlier described far distance travelled erratics on central Jameson Land (Hjort & Möller 1991) together with the channel and tor-landscape described by Hjort & Salvigsen (1991) constitute further evidence of this old phase glaciation.

As mentioned above, the trajectories which can be derived from erratics, implies an ice sheet movement from the west to the east over the region, independent of the present topography (Funder 1972; Funder & Hjort 1973; Funder 1989).

In the coastal areas the ice thickness exceeded 500-1000 m, and the ice margin must have been located on the shelf at a considerable distance from the present coast.

3.3.4 The Langelandselv interglaciation

The Langelandselv interglaciation has been identified at two sites (Funder *et al.* 1991). One of these is located on the southwest coast of Jameson Land at Langelandselv, and forms the base of the above described Jameson Land marine beds. The second site is located at Hesteelv. The identification of the interglaciation is based on the identification of plant, insect and mollusc remains, showing higher summer temperatures than known during the Holocene. The diverse molluscfauna, described by Petersen (1982), include some subarctic species that are now absent from the area. The fauna implies that the influx of subarctic water to the region was greater than during Holocene time. Böcher & Bennike (1991) point to the fact that the most warmth demanding plant species of their fossil assemblages is *Betula pubescens*, which indicates an increase in mean summer temperatures of about 5 °C as compared to the present, and 3-4 °C as compared to the Holocene climatic optimum. From these climatic considerations the Langelandselv interglaciation is correlated with isotopic substage 5e.

3.3.5 Jameson Land marine episode

The thick piles of marine and deltaic sediments that comprise the Jameson Land marine beds have been described above. On the basis of amino acid analyses, Funder (1984) suggested that these sediments, immediately overlying the Langelandselv interglacial beds, represented one continuous depositional episode during a high sea level stand in oxygen isotope stage 5. However, the stratigraphy described by Landvik & Lyså (1991) shows that the deposition of these marine sediments were interrupted by advancing fjord glaciers that filled up the Scoresby Sund basin, with the subsequent deposition of till beds. Two ice advances have been recognized. Based on amino acid ratios, Landvik & Lyså (1991) correlate these marine sequences with the early Weichselian, i.e. isotope stages 5a-5d.

3.3.6 The Flakkerhuk glaciation

The Flakkerhuk glaciation is defined by the 50 km long moraine at the south coast of Jameson Land (Funder 1972) as well as by draping till and a superficial lag deposit in the Langelandselv area (Funder 1984, 1990). The moraine was formed by a push from a glacier in Scoresby Sund and according to Funder *et al.* (1991) this glacial event seems to have immediately succeeded the Jameson Land marine episode in the early Weichselian.

The extent and the age of the glaciation is not known , even though Funder (1990), assumed the glaciation to be of a Middle or Late Weichselian age. However, recent marine geologic investigations (Dowdeswell *et al.* 1991), indicate that it was extensive since the entire Scoresby Sund/Hall Bredning basin was cleaned of its loose bottom sediment by glacier movement shortly before the Holocene and this would then date the glaciation to the Late Weichselian. The duration of this glaciation has yet not been determined and Landvik & Lyså (1991) presents a duofold explanation to the hiatus that exists between the Jameson Land marine beds of Early Weichselian age and this Late Weichselian glaciation: either the ice advance occurred shortly after the deposition of the marine sediments and remained over the area until the end of the late Weichselian, or that the hiatus exists due to the eustatic low sea level stand during the period.

3.3.7 The Milne Land stade

Following the ice recession of The Flakkerhuk stade was the Milne Land stade. During this stade the fjord and valley glaciers advanced again but this time they did not fill the wide outer fjords, but ended with their calving fronts where the steep interior fjords joined the wider coastal fjords. The evidence for this readvance can be found in well preserved lateral moraines and outwash plains. In the southern area of Scoresby Sund as well as in Hochstetter Forland to the north these moraines occur in swarms, indicating small glacier fluctuations during the period (Funder 1978). Throughout the whole area, the moraines are correlated by C-14 dating of marine molluscs in deposits that are contemporaneous with or postdate the moraines. The results of these datings have been discussed by Funder (1978) and by Hjort (1979, 1981) who showed that the oldest moraines were formed at c. 10.3 ka and the youngest at c. 9.5 ka.

3.3.8 The Holocene

During early Holocene time the outlet glaciers of the Milne Land stade rapidly melted back through the fjords and valleys. The retreat was interrupted by short periods of stillstand and possible minor readvances. This is reflected by kame terraces and lateral moraines along the fjords and terminal moraines in some valleys. These interruptions in the recession of the glaciers have been considered to be the result of topographical effects and interactions between the glaciers, rather than changes in the climatic factors (Funder 1978). After c. 7 ka the glaciers had retreated behind their present margins.

Moraines with a fresh and unvegetated surface occur in front of most of the fjord and valley glaciers in the area and they mark the Late Holocene (Neoglacial) maximum of glaciation in the region. Ahlmann (1941), suggested that these moraines were formed sometime between the years 1750-1850, and Hjort (1988) dated this advance in northeasternmost Greenland to post c. 1680 AD (270±50 BP).

Pollen diagrams from Holocene lake sediments presented by Funder (1978) points to a three-phase development, from a pioneering stage through a stage with a dense cover of rich and diverse dwarf shrub heaths, to a decline stage with expansion of a poor dwarf shrub heath or, in the eastern areas, a recurrence of fell field vegetation.

The vegetation history shows that following the Milne Land stade, summer temperatures rose rapidly and by c. 8.5 ka they were somewhat higher than those of present time. They remained high until c. 5.5 ka when decline set in and transformed the vegetation in the coastal parts. According to Funder (1990), the outlet glaciers in the interior probably also began their readvance at this time. This scenario was closely parallelled by changes in the marine conditions, as indicated by the presence of the blue mussel *Mytilus edulis* in the East Greenland fjords between 8 and 5 ka (Hjort & Funder 1974).

4 Methods

4.1 Field methods

4.1.1 Documentation of the excavated sections

The sections are usually located on the steep slopes in river gullies cut down by fluvial erosion. This location made the excavation and preparation of the sections rather easy and was to a certain degree determinating the choosing of the sections. The only problem with this location are the solifluction processes that are in progress along the steep slopes, obliterating the primary structures of the sediments and making the documentation of these difficult. A great deal of effort was put down to find sections were these processes were absent or at least not that pronounced, leaving the sediments *in situ*, with the sedimentary structures preserved

The sections were dug out in a step-wise manner with the depth of each step being determined by the depth of the permafrost, usually 0.5 - 2 m. The final preparation of each step was done with a trowel in order to make the walls as vertical and clean as possible, thereby facilitating the documentation. The strike of the sections was measured by the use of a compass and the altitude was determined by the use of a digital altimeter, with an uncertainty of the measured altitudes of 10 m. The type of sediment, structures, bed boundarys and faults was drawn schematically on lithologic logs or as section charts at a scale of 1:10. The structures of the different lithologic units were described by the use of lithofacies codes. The codes that have been used in this work (Table 2) follows that of Eyles and Eyles & Miall (1983) with modifications by Möller (1987). The classification of the climbing ripple sequences follows that of Jopling & Walker (1968), with two end-member types: Type A - where stoss-side laminae of ripples are eroded and Type B - where stoss-side laminae are preserved. Each section was documented with pictures taken using both a polaroid camera and a standard 35 mm camera. This was done in order to facilitate the interpretations and the drawing of the fair copies while at home.

Table 2. Lithofacies descriptions and their codes as used in this work. From Eyles et al. *(1983) and modified by Möller (1987).*

Lithofacies code:	***Lithofacies type description:*** Grain size, grain support system, internal structures
Gmm	Gravel, matrix-supported, massive
Gpp	Gravel, planar parallel-laminated
Gcpp	Gravel, clast-supported planar parallel-laminated
Sm	Sand, massive
Spp	Sand, planar parallel-laminated
Spp(def)	Sand, planar parallel-laminated, deformed
Spc	Sand, planar cross-laminated
Stc	Sand, trough cross-laminated
Sr	Sand, ripple laminated
Sr(def)	Sand, ripple laminated, deformed
Sr(Atab)	Sand, type A ripple planar cross-laminated
Sr(Atc)	Sand, type A ripple trough cross-laminated
Sr(B)	Sand, type B ripple laminated
Sr(S)	Sand, type S ripple laminated
S(def)	Sand, deformed
Sim	Silt, massive
Si(d)	Silt, draped lamination
Si(def)	Silt, deformed
Cm(d)	Clay, draped lamination
D(S/Si/C)--	Diamicton, sandy, silty or clayey. One or more grain-size code letters within brackets.
D(-)mm	Diamicton, matrix-supported, massive
D(-)ms	Diamicton, matrix-supported, stratified
D(-)c/mm	Diamicton, clast- to matrix-supported, massive

4.1.2 Measurement of palaeocurrent directions

The palaeocurrent directions were determined by the use of a compass equipped with a clinometer. All the measurements were performed using the structures of cross bedding, though in some cases the actual form of the trough was used. In the greater trough cross-laminated beds, two measurements perpendicular to each other were made on the direction and dip of each trough in order to get hold of the true dip. The true dip of the ripple bed units was determined by an approximation of the eye during preparation in the field.

4.1.3 Fabric analyses and tectonic measurements

A fabric analyses was carried out at one of the sites. The direction and dip of 25 particles were measured by the use of a compass equipped with a clinometer.

At one of the sites, the strike of fold axes were measured in a glaciotectonically deformed bed. The measurements were made on prepared surfaces of the syncline fold axes.

4.1.4 Sampling

Samples for grain-size analysis were collected at certain levels in order to get a picture of how these parameters change vertically through the section.

As mentioned above, no samples were collected for absolute dating of the deposits due to the lack of dateable material.

4.2 Laboratory methods and treatment of data

4.2.1 Grain-size analysis and grain-size parameters

The grain-size is classified according to the Wentworth/phi grade scale (Table 3). The table also shows the field classification of the grain-sizes. The grain-size distribution of the sediment samples was determined through sieving and sedimentation analyses. The sand and gravel fraction (-4.25 to +4 phi/20-0.063 mm) was sieved with the interval of 0.5 phi, while material less than +4 phi/0.0063 mm was analyzed using the hydrometer method according to Gandahl (1952).

Calculation and drawing of the curves was performed both by hand and by the use of a computer. The grain-size parameters - median, mean, sorting, skewness and curtosis - were calculated from the cumulative grain-size curves according to Folk & Ward (1957).

4.2.2 Palaeocurrent directions, tectonics and fabric analyses

In two of the sections the palaeocurrent directions were plotted in a rose diagram by the use of a computer.

The measured fold axes were plotted in a Schmidt-net by the use of a computer.

The orientation data were statistically evaluated by the use of a computer, using the eigenvalue method according to Mark (1973, 1974). The method gives the eigenvalues $\lambda_1 \geq \lambda_2 \geq \lambda_3$ together with their mutually orthogonal eigenvectors V_1, V_2 and V_3, respectively. The sum of the eigenvalues is N, which is the number of observations.

Table 3. Metric and phi grain-size grade scale.

Millimetres	Phi scale	Wentworth Scale	Field classification
		Boulder	
256	-8	Large Cobble	
128	-7	Small Cobble	
64	-6	Very Large Pebble	Gravel
32	-5	Large Pebble	
16	-4	Medium Pebble	
8	-3	Small Pebble	
4	-2	Granule	
2	-1	Very Coarse Sand	Coarse Sand
1	0	Coarse Sand	
0.50	+1	Medium Sand	Medium Sand
0.25	+2	Fine Sand	Fine Sand
0.125	+3	Very Fine Sand	
0.063	+4	Coarse Silt	Silt
0.031	+5	Medium Silt	
0.0156	+6	Fine Silt	
0.0078	+7	Very Fine Silt	
0.0039	+8	(Coarse Clay)	
0.002	+9	Clay	Clay

Eigenvector V_1 is parallel to the axis of maximum clustering and represents the preferred or mean axis of the fabric. Eigenvector V_3 indicates the direction of minimum clustering and is thus orthogonal to the preferred plane through the data. V_2 lies normal to V_1 and V_3. The strength in the degree of clustering of the pebbles about the eigenvectors is computed by dividing the eigenvalues by the total number of readings: $S_i = \lambda_i / N$. This gives the significance values S_1, S_2 and S_3, were $S_1 \geq S_2 \geq S_3$ and $S_1 + S_2 + S_3 = 1$. S_1 is a measure of the strength of clustering about the mean axis, whereas S3 is inversely proportional to the strength of the best plane through the data. A polar distribution of pebble axis is thus described by $S_1 >> S_2 > S_3$, an equatorial distribution by $S_1 \approx S_2 >> S_3$, and a spherical distribution by $S1 \approx S_2 \approx S_3$.

5 Description and interpretation of the excavated sections

5.1 General description of the study area

The investigated area lies between the two deep river valleys of the upper Sjællandselv and the upper Jyllandselv (Fig. 4). The river ravines are cut down more than 100 m into the Jurassic bedrock. Small gullies drain towards the north into the Jyllandselv, while the main part of the area consists of shallow tributary basins draining towards the Sjællandselv in the south and the Blokelv in the west.

Just to the south of the Jyllandselv there are two elongated hills with top surfaces at approximately 510 m a.s.l.. The hills form a 5 km long till covered complex and can be considered as a south-western outlier to the flat plateau of the area described by Zander (1993) and Möller *et al.* (in press).

The eastern hill has gentle slopes. Boulders are frequent on the surface. Frostboils show a diamicton with a high content of silt and clay in the matrix. The absence of gullies into the hill prevents stratigraphic studies and the high content of silt and clay might be a cryoturbation mixture between a till and a glacial lake sediment, or it might be the primary composition of a till matrix. A minor excavation in an erosive terrace cut into the flat ground moraine area 1 km south-east of the hill reveals fine sand and silt glacial lake sediments beneath the diamicton (Möller *et al.* in press). Escarpments in the upper part of the Jyllandselv ravine to the north of the hill shows that the bedrock surface lies at approximately 470 m a.s.l. and that it is overlain by fluvial sand. No glacio-lacustrine sediments were found on the northern side of the hill.

All but one of the sites that are described and interpreted below were excavated in the western hill. This hill has terraced slopes on the northern, eastern and southern sides. Excavations in the steep slopes on the northern and eastern sides of the hill show fine sand and coarse silt sediments and these can be traced from approximately 420 m up to 480-490 m a.s.l.. Excavations in some small gullies cut perpendicular through the terraces show sandy fluvial bedforms.

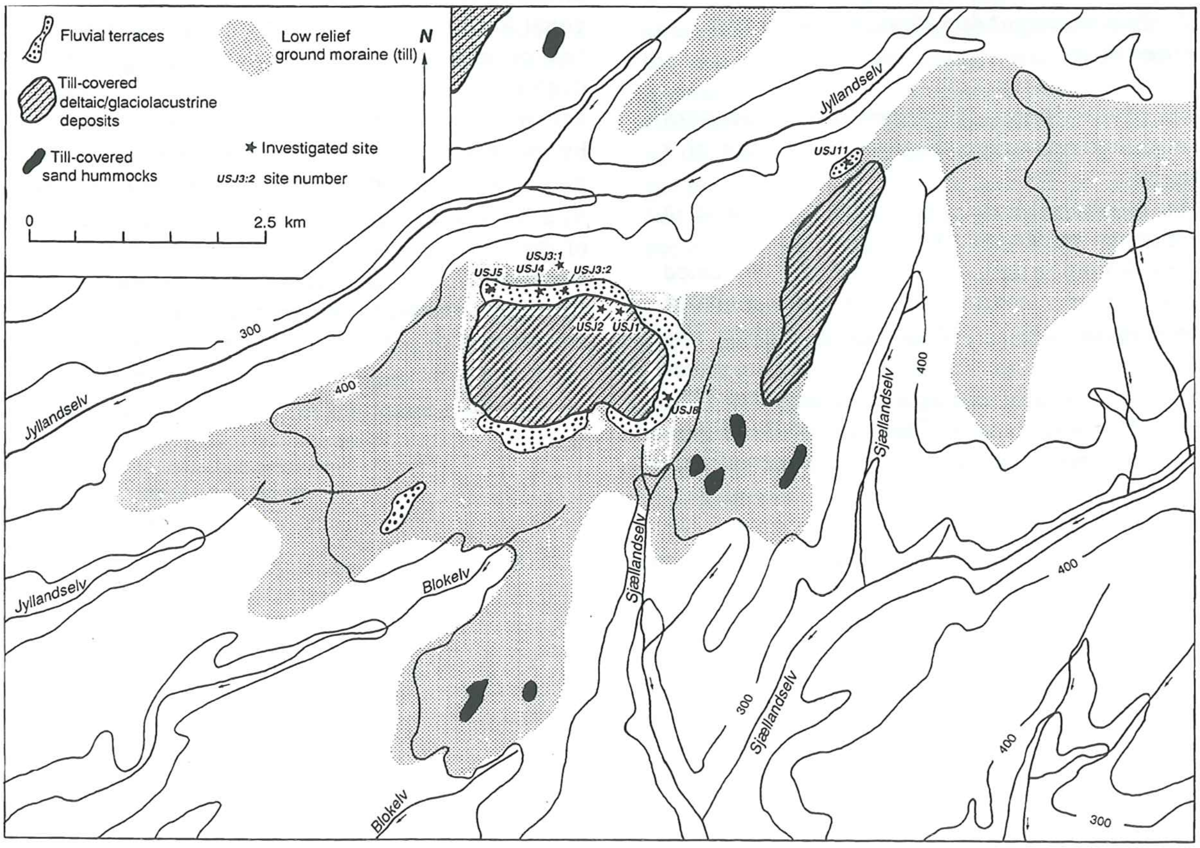


Fig. 4. Map showing the investigation area with the two till-covered hills situated between upper Jyllandselv and upper Sjællandselv. The map also gives the location of the investigated sites.

Fig. 5. Standing east of site USJ1 and looking west along the steep northern slope of the western hill. Terraces can be noticed where the slope flattens out along the valley side to the north.

The southern limit of the low relief ground moraine area is close to the water divide between the headwaters of Jyllandselv and Sjællandselv. The transition into a driftless felsenmeer area is sharp, and within a few kilometres the flat Jurassic bedrock ridges change into a weathered tor landscape (Hjort & Salvigsen 1991).

5.2 Site descriptions: lithostratigraphy and sedimentological interpretations

Sites USJ1-5 were excavated in the steep slopes and in the terraces of the western hill (Fig. 5) and they are spread out in an approximately east-westerly direction along the valley side. Fig. 6 shows four profiles along the valley side as well as the location of four of the sites.The profiles were levelled by hand and they clearly show a 25 - 30 m high slope that flattens out to a 200 - 400 m wide gentle slope, with an upper and a lower terrace.

Three of the sites were excavated elsewhere than along any of the profiles and these are USJ1, USJ8 and USJ11. The excavation and field-documentation of sites USJ2, USJ3:1/section III, USJ3:2/section II, USJ4, USJ8 and USJ 11 was made by Lena Adrielsson. The drawing of the fair copies as well as the descriptions and interpretations of these sites has been done by the author.

Site USJ3 is a c. 300 m long gully that is cut down through both the upper and the lower terrace and it has been subdivided into two sites. Site USJ3:1 comprise three sections that were excavated in the lower terrace and site USJ3:2 comprise two sections that were excavated in the upper terrace.

5.2.1 Description of site USJ3:1

A c. 2.5 m high erosional cliff in the lower terrace (Fig. 7), on the northern side of the western hill (Fig. 6). Three sections, I, II & III were excavated and studied.

Section I:

The section is 2.2 m high and strikes 112° facing the south-west. One lithostratigraphic unit, A, has been identified and described (Fig. 8).

Unit A - The unit is 2.2 m thick and is characterized by alternating beds of planar parallel-laminated fine sand and ripple-laminated fine sand. The

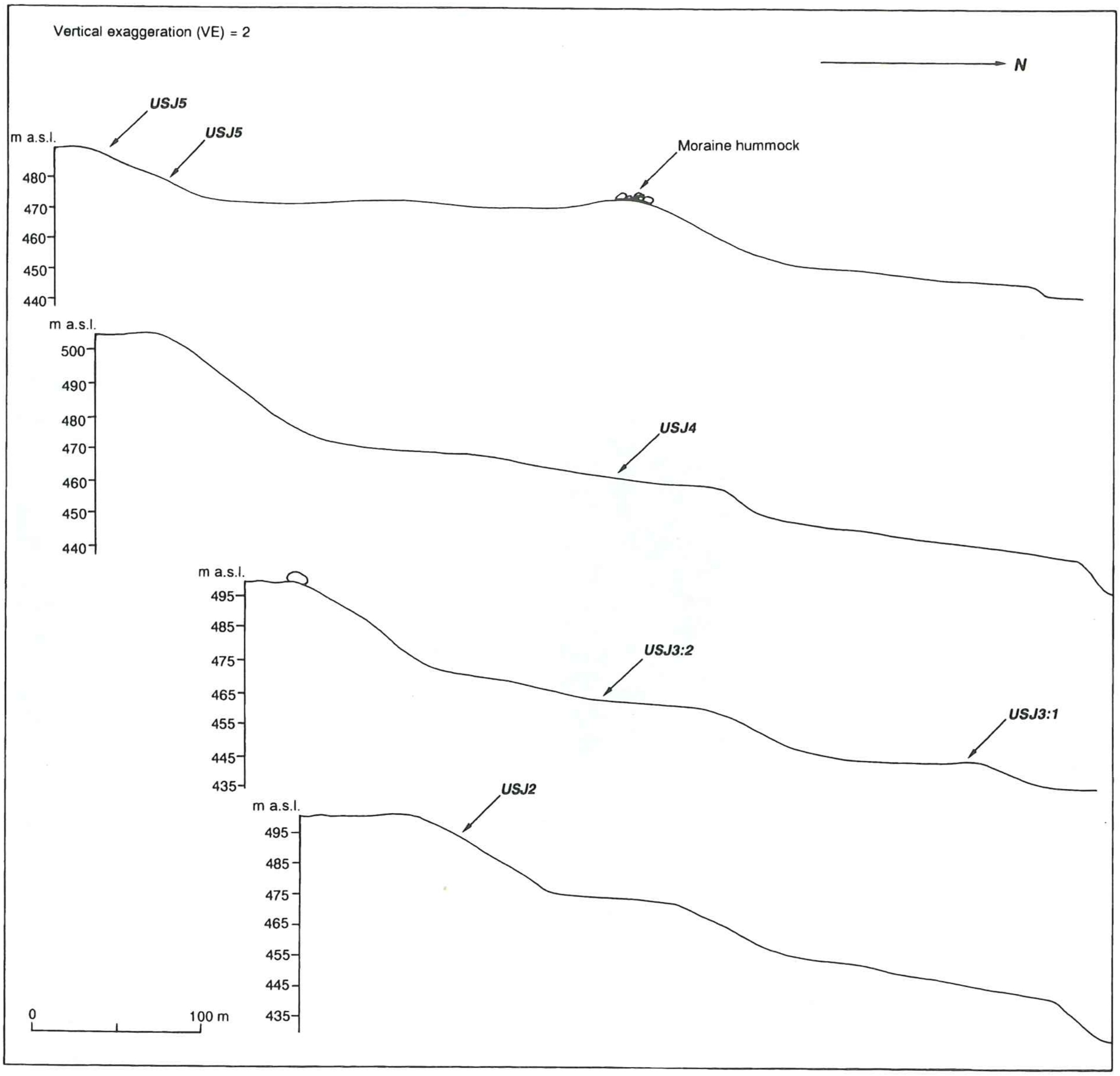


Fig. 6. The figure shows the four hand levelled profiles along the northern side of the western hill as well as the location of four of the sites. From the bottom to the top, the direction is from the east to the west.

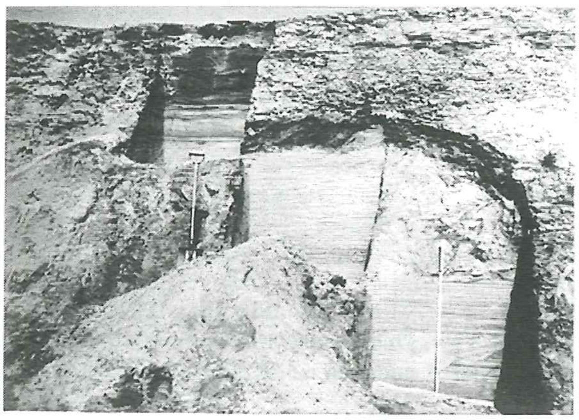


Fig. 7. Site USJ3:1/Section I. For location, see Figs. 4 & 6.

thickness of the planar parallel-laminated beds varies between 13 and 113 cm and the thickness of each laminae varies between c. 2 mm and 2 cm (Fig. 9). The grain-size is uniform throughout these beds, with no grading observed. One of the planar parallel-laminated beds shows inclusion of silt intraclasts at the upper 15 cm of the bed (Fig. 9). In this bed there is also, in the lower part, a 30 cm deep erosional trough infilled by massive, as well as diffuse, type B ripple-laminated sand (Fig. 10).

The thickness of the ripple-laminated sets varies between 17 and 100 cm and they show a uniform grain-size of fine sand throughout the whole unit. All but one of these sets consist of type A ripples with lower erosive boundaries. The uppermost of the ripple-laminated sets is very disturbed and it is only in the upper 20 cm of the set that one can recognize some kind of ripple-lamination, in this case type B ripples. In the lower 30 cm of this set, the signs of deformation and solifluction processes are shown by the inclusion of 1-5 cm thick lenses and clasts of clayey silt containing individual gravel particles up to 5 cm in diameter.

The uppermost 15 cm of the unit consists of solifluction material with the primary sedimentary

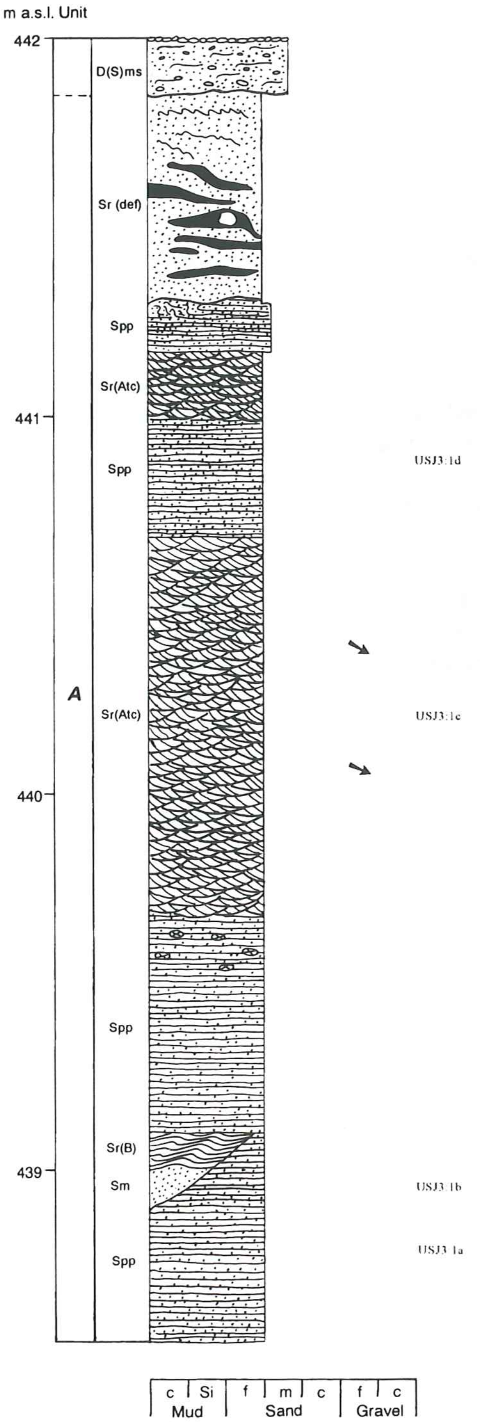


Fig. 8. Logged sequence at site USJ3:1/Section I. For location, see Figs. 4 & 6.

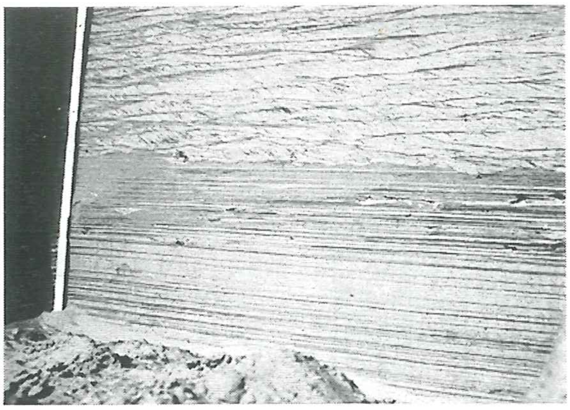


Fig. 9. Picture showing the planar parallel-laminated bed with silt intraclasts at site USJ3:1/Section I.

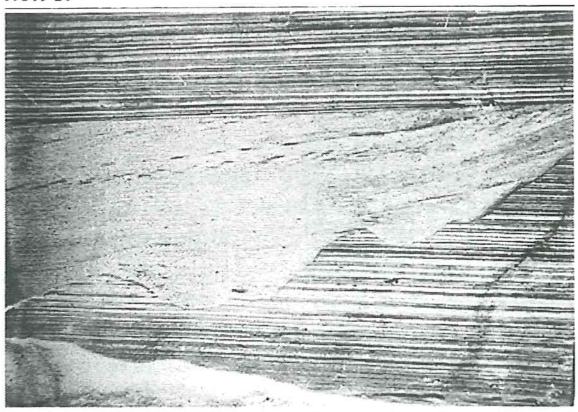


Fig. 10. Picture showing the erosional trough, infilled with massive as well as diffuse, type B ripple-laminated sand at site USJ3:1/Section I.

structures obliterated. Measurements performed on ripples in the unit indicate a palaeocurrent direction towards the SE (Fig. 8).

Section II:

The section is 153 cm high and strikes 162° facing the south-west (Fig. 11). It lies c. 15 m to the east of section I. One unit, A, has been identified and described.

Unit A - In the lower parts the section consists of alternating sets of planar parallel-laminated fine sand and ripple-laminated fine sand with individual thickness of the Spp- and the Sr-sets lying between 4-15 cm and 4-5 cm respectively. Characterizing the section are the multiple cosets showing a development from type A → type B ripple-lamination in fine sand. The thickness of these cosets varies between 10-33 cm and a fining upward trend can be observed within the cosets (Fig. 12). In the uppermost part of the section the structures are disturbed and deformed due to solifluction processes and it is hard to recognize the transition from type A to type B ripples. A massive, clayey siltlayer separates the two Sr-sets at the top

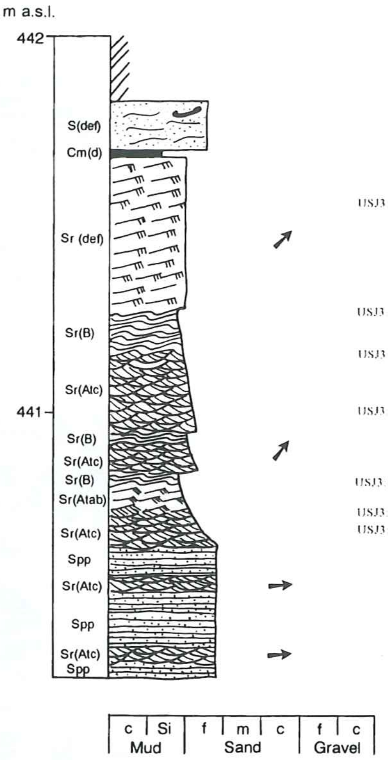


Fig. 11. Logged sequence at site USJ3:1/Section II. For location, see Figs. 4 & 6.

of the section.Measurements performed on ripples indicate a palaeocurrent direction towards the ENE (Fig. 11).

Section III:

The section is located some 50 meters to the north of sections I and II. It is c. 1 m thick and one lithostratigraphic unit, D, has been identified and described (Fig. 13).

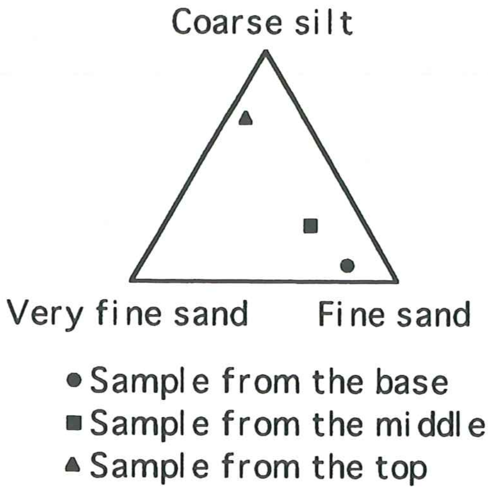


Fig. 12. Triangel diagram showing the decreasing grain-size from the bottom to the top in a coset of type A ripples that grades upward into type B ripples at site USJ3:1/Section II. For location of sample points, see Fig. 11. Sample numbers are USJ3:1e-g.

Unit D - The unit is 1 m thick and it has been divided into two zones, one lower (D1) and one upper (D2) zone. The lower zone shows deformed and intensely folded silt and sand on top of a decollement surface. The folds are of the overturned tight or isoclinal type (Fig. 14). The strike of the syncline fold axes lies in the range 290° - 345° (Fig. 15). The upper zone shows silt and fine sand without any primary sedimentary structures preserved that gradually grades upward into a s silty clayey diamicton with scattered gravel and cobble particles.

5.2.2 Interpretation of site USJ3:1

Given the similarities and closeness of sections I and II at the site, they are interpreted as deposited in the same environment and thus treated together.

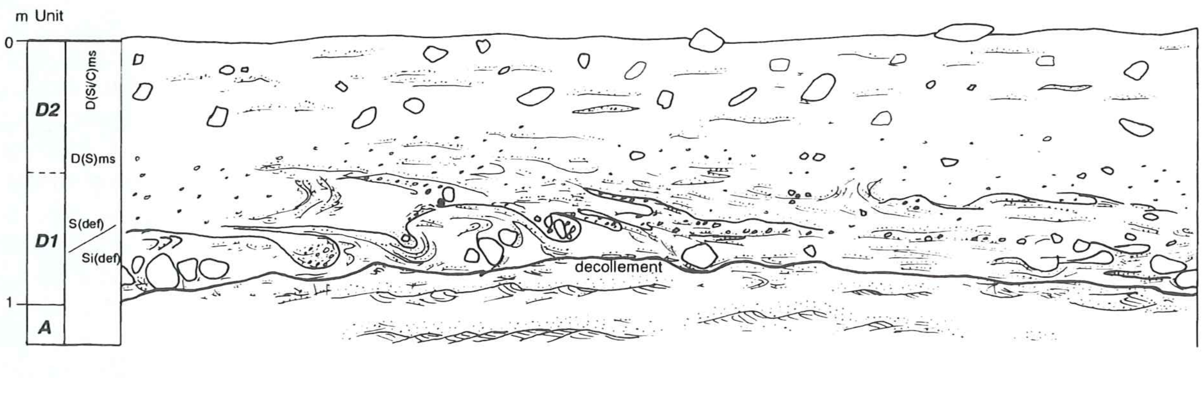


Fig. 13. Section chart showing ite USJ 3:1/Section III. For location, see Figs. 4 & 6.

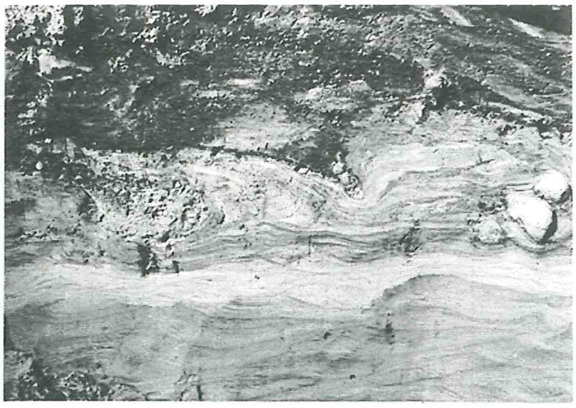


Fig. 14. Picture showing an overturned, tight fold at site USJ3:1/Section III. Stress directions are oblique to the section and directed up-slope.

Section I & II:

Unit A - The fine sand and coarse silt sediments with type A and type B ripple cross-lamination and planar parallel-lamination are interpreted to be formed by rapid deposition from low-density turbidity currents along a prodelta slope in a glacial lake, or at the distal parts of a subaqueous fan.

Underflows, often referred to as "turbidity currents", are generated due to the density difference between the incoming meltwater from a glacier and the water in the lake. The incoming meltwater possesses densities greater than those of the lake as a result of the high suspended sediment content it carries (Ashley 1988; Drewry 1986; Smith & Ashley 1985). As meltwater streams enter the lake there will be a gradual decrease in velocity which causes the coarsest fractions to be deposited, and the underflow continues downslope along the delta slope and onto the lakefloor (Smith & Ashley 1985). During waning flow, density underflows carrying turbid mixtures of sand, silt and clay frequently deposit climbing ripple-drift sequences capped by silt drapes on the lower delta foresets (Smith & Ashley 1985). Sequences like these, with the development from type A ripples to type B ripples and a final silt drape have been described by Jopling & Walker (1968) and Gustavson *et al.* (1975). According to Jopling & Walker (1968), type A and type B ripples form a continuum ripple types representing a shift during a waning flow from rapidly migrating ripples with low vertical aggradation rates to slowly migrating ripples with high vertical aggradation rates. When ripple migration ceases the sequence is draped by sediment falling out from suspension. By a series of flume experiments, Ashley *et al.* (1982) produced climbing ripple-drift sequences similar to natural ones with accretion rates of 30 cm/hour. This shows that the deposition can be very rapid, with the development of a 20 cm thick bed taking only 40 minutes.

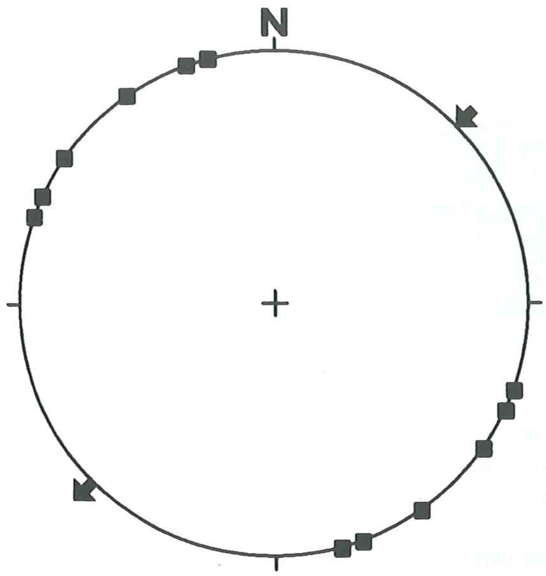


Fig. 15. Stereographic plot of fold axes at site USJ3:1/Section III. The arrows indicate the direction of deformation.

The planar parallel-laminated beds record upper flow regime plane bed, while the ripple beds record a weaker current in the lower flow regime and the whole assemblage depicts a decelerating flow with material being deposited from suspension throughout (Collinson & Thompson 1989).

As the lithofacies combinations of unit A strongly resembles the above described, unit A is interpreted as formed along a prodelta slope. Yet, it should be stressed that the same lithofacies combinations also develop along the distal parts of subaqueous outwash deposits (Ashley 1988), and since there are no signs of actual Gilbert-type delta foresets within the unit, this is also a possible environment of formation.

The palaeocurrent directions, interpreted from current ripples, show a dispersed pattern with directions towards the SE, E and the NE. This indicates a complex current pattern in front of a damming glacier in the west, which corresponds to the interpretations from the upper Jyllandselv area made by Zander (1993) and Möller *et al.* (in press).

Section III:

The structures in the lower zone, (D1), are interpreted to be the result of subglacial deformation. The upper zone, (D2), is interpreted to be a so-called deformation till.

In the examination of sedimentary structures that reflect processes of subglacial deformation Boulton (1987) suggested two modes of response to stress: a viscous response in a rapidly deforming

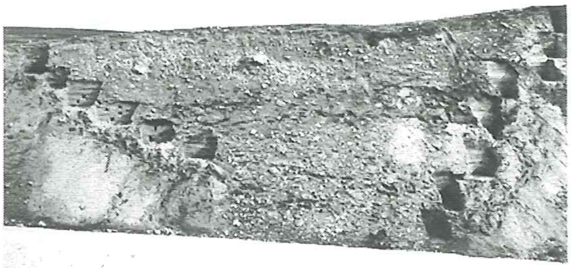


Fig. 16. Site USJ3:2/Sections I & II. For location, see Figs. 4 & 6. Section I is situated to the right in the picture.

and dilating A-horizon, and an elastic plastic response in a much more slowly deforming and denser B1-horizon immediately beneath it. The A-horizon would represent relatively far-travelled allochthonous materials with highly attenuated structures, while the material in the B1/B2-horizon would be locally derived parautochthonous (or unmoved autochthonous) sediments. Using Boultons (1987) terminology, the upper zone in the section would be the A-horizon and the lower zone the B1/B2-horizon. Further on Boulton suggests three possible causes for the folding of the sediments. Of these three, the most reasonable to explain the folds in the section would be the longitudinal stiffening of a slowly deforming B1-horizon so that it becomes a stable B2-horizon, causing the decollement plane to rise to the A/B interface so that B1 will be folded into A.

Even though Boulton (1987) found the term deformation till appropriate to describe the tectonically mixed, homogenised and poorly sorted sediment in the A-horizon, Hart & Boulton (1991) suggested that this term should be abandoned since most till is homogeneous, making it very difficult to tell wether it is undeformed or highly deformed. Nevertheless, the upper zone in section III is thought to be the result of a complex subglacial transport history, which have caused the sediment to become highly attenuated. Further evidence that points to this conclusion comes from the fact that the fine sediments - clay and silt - in the upper zone, can not be found anywhere in the immediate vicinity of the site. This indicates that the fines must have been transported from a more distant source area.

The strike of the syncline fold axes show stress directions that are directed approximately up-hill the valley slope (Fig. 15) and this implies that the deformation structures cannot be the result of solifluction processes along the slope.

5.2.3 Description of site USJ3:2

This site is located in the upper terrace. A c. 9 m high bluff (Fig. 16) is exposed in a gully that cuts perpendicular through both the lower and upper

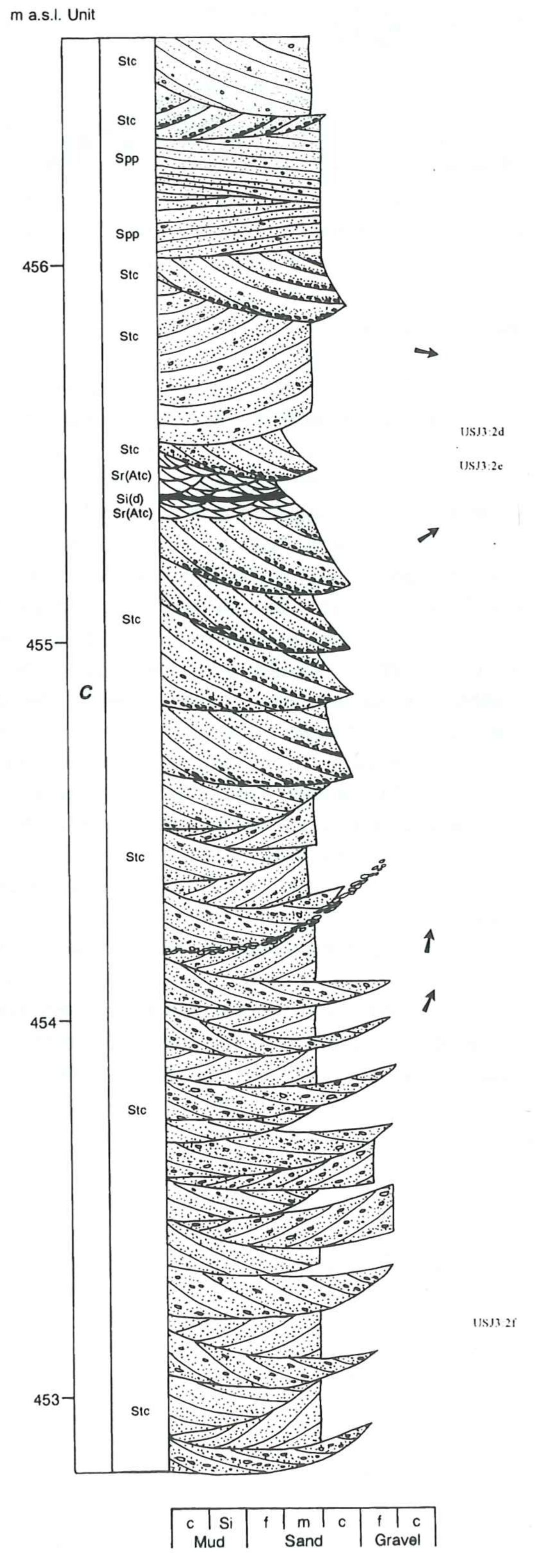
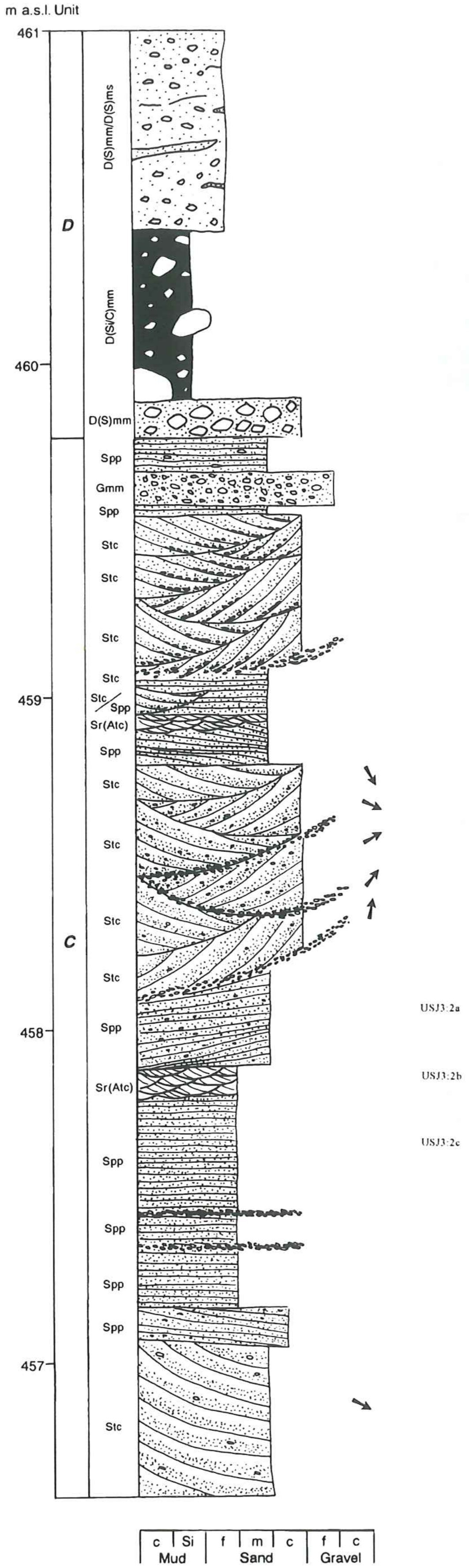


Fig. 17. Logged sequence at site USJ3:2/Section I. For location, see Figs. 4 & 6.



terrace. The site is situated a few hundred meters to the south of site USJ3:1 in the same gully, but on a c. 25 m higher altitude (Figs. 4 & 6). Two sections were excavated and studied.

Section I:

The section is 8.2 m high and strikes 354° facing the W. Two lithostratigraphical units, C & D, have been identified and described (Fig. 17).

Unit C - The unit is 7 m thick and is characterized by sandy fluvial bedforms with a predominance of trough cross-laminated medium to coarse sand and gravel over planar parallel-laminated sand, low angle crossbeds, gravel lags and a few infilled erosive troughs.

The thickness of the parallel-laminated beds varies between 3 and 63 cm, with the thickest one showing two gravel horizons at the bottom. These beds are mainly composed of medium sand. In one of the parallel-laminated beds there is an erosional trough, infilled with cross-bedded sand and gravel particles. Five of the planar parallel-laminated beds show low angle ($\leq 10°$) crossbedding. These beds are composed of medium to coarse sand, sometimes with abundant gravel particles in the range from 2 mm to 1 cm (Fig. 18). Very often these beds are wedge-shaped, thinning out in one direction due to the eroding effect of the overlying bed.

The thickness of the trough cross-laminated sets varies between 10 and 60 cm, with a higher representation of the thinner sets at the bottom of the unit. Apart from the sets at the bottom of the unit, which are composed of coarse sand to fine gravel, the grain-size in the trough-forms varies between medium and coarse sand. There is an even distribution of gravel particles within each trough-form, but within each foreset laminae there is a concentration of coarser particles at the bottom, forming a gravel lag within each laminae. This is especially pronounced in the lower parts of each trough-form

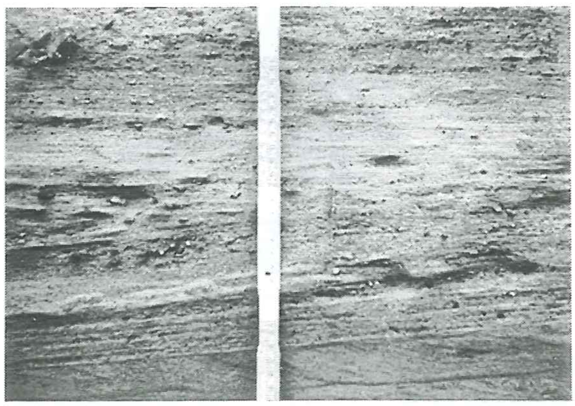


Fig. 18. Picture showing the low angle crossbeds at site USJ3:2/Section I.

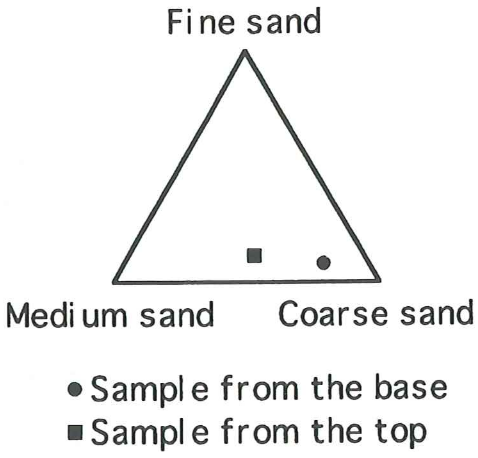


Fig. 19. Triangel diagram showing the decreasing grain-size from the bottom to the top in a trough-form set at site USJ3:2/Section I. For location of sample points, see Fig. 17. Sample numbers are USJ3:2e-d.

set. Some of the trough-form sets also show a fining upward trend, with a decreasing grain-size from the bottom to the top of the set (Fig. 19). Three minor cross-laminated ripple beds has also been observed within the unit, the thickest one being c. 20 cm, showing a fining upward trend ending with a draping silt layer within the bed.

Measurements performed on the true dip and direction of the foresets within the trough-forms indicate a palaeocurrent direction towards a north-eastern sector, approximately opposed to the present drainage system (Fig. 17 and 20).

Unit D - The unit is 1.22 m thick and consists of two diamictons, each with a different appearance and composition (Fig. 21). At the bottom of the unit there is a 62 cm thick diamicton. In the lower 12 cm this diamicton is massive, matrix-supported and sandy, but it grades upward into a 50 cm thick massive, matrix-supported, clayey diamicton with a maximum particle size of 15 cm. At the top of the unit lies a massive to weakly stratified, matrix-supported, silty sandy diamicton with a maximum particle size of 2 cm. This diamicton shows the inclusion of a few sorted and contorted sand-lenses. The contact to the underlying diamicton is undulating and rather diffuse and measurements on the fabric within the unit was not performed.

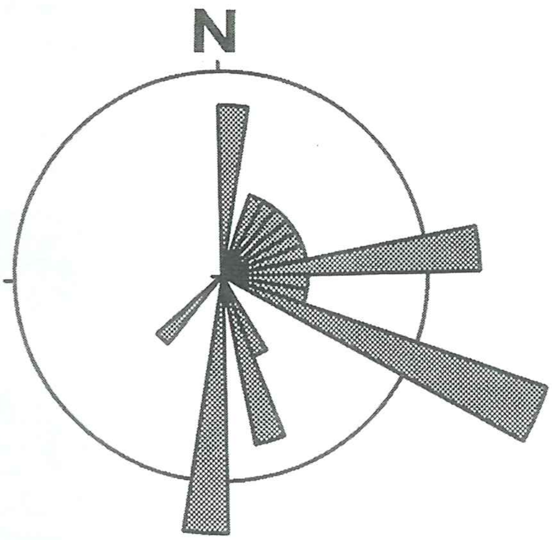


Fig. 20. Rose diagram showing 24 readings of palaeocurrent directions for cross-laminated beds at site USJ3:2/Sections I & II. The data are plotted in 10 ° classes.

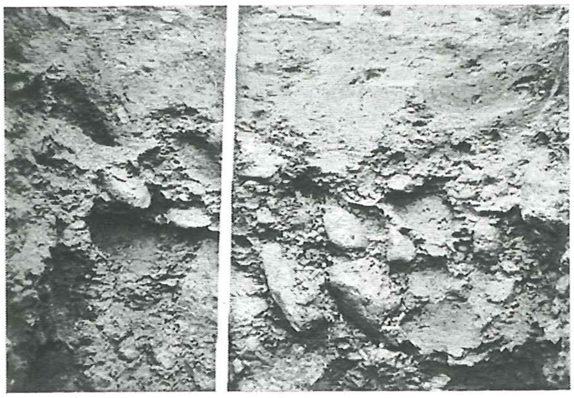


Fig. 21. Picture showing the two diamictons of unit D at site USJ3:2/Section I.

Section II:

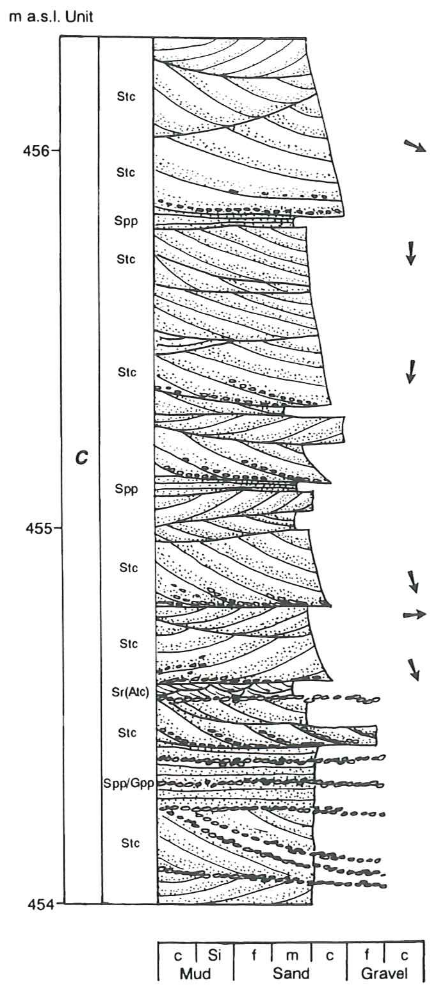
The section is 6 m thick and it is located to the south and right next to section I (Fig. 16). As for section I, two lithostratigraphical units, C & D, have been identified and described (Fig. 22). The similarities of section I and II are obvious and a closer description of the bedforms and lithofacies units in section II is not made, instead reference is made to the lithologic log (Fig. 22). Palaeocurrent directions show a direction of flow towards the ESE (Fig. 22 and 20).

5.2.4 Interpretation of site USJ3:2

Section I:

Unit C - The troughforms and the related trough cross-lamination are formed as in-channel deposition by the migration of 3-D dunes (Walker & Cant 1984), and the whole unit is interpreted to be deposited in a sandy braided river environment. The lithofacies combinations within the unit reflects intermediate-type conditions, but with neither any coarse-grained gravelly deposits nor any significant beds with fines being observed, the application of the vertical profile models described by Miall (1978) becomes difficult. This absence of any real cyclic deposits within the unit is ascribed to the fact that the upper, bar-top deposits possesses a very low potential of being preserved, since they are removed through subsequent erosion (Bristow & Best 1993). According to the same authors a particular weakness of existing braided river facies models arises, since they are largely based on sections measured from exposed bars or river banks.

The 3-D dunes are interpreted as deposited from bedload transport on a channel floor (Walker & Cant 1984) during lower flow regime conditions (Miall 1978). The sizes of individual dunes are related to flow depth and largely independent of grain-size, with deeper flows generating higher and longer dunes (Collinson & Thompson 1989). The low angle cross-beds are interpreted to be formed by the lateral spreading of the flow, or where the flow is forced by channel patterns to flow obliquely across the main river system (Walker & Cant 1984). These cross-channel bars sometimes leads to the accretion and aggradation of a sandflat with the development of the parallel-laminated beds taking place during the aggradation. Compared to the parallel-laminated beds, the rip-



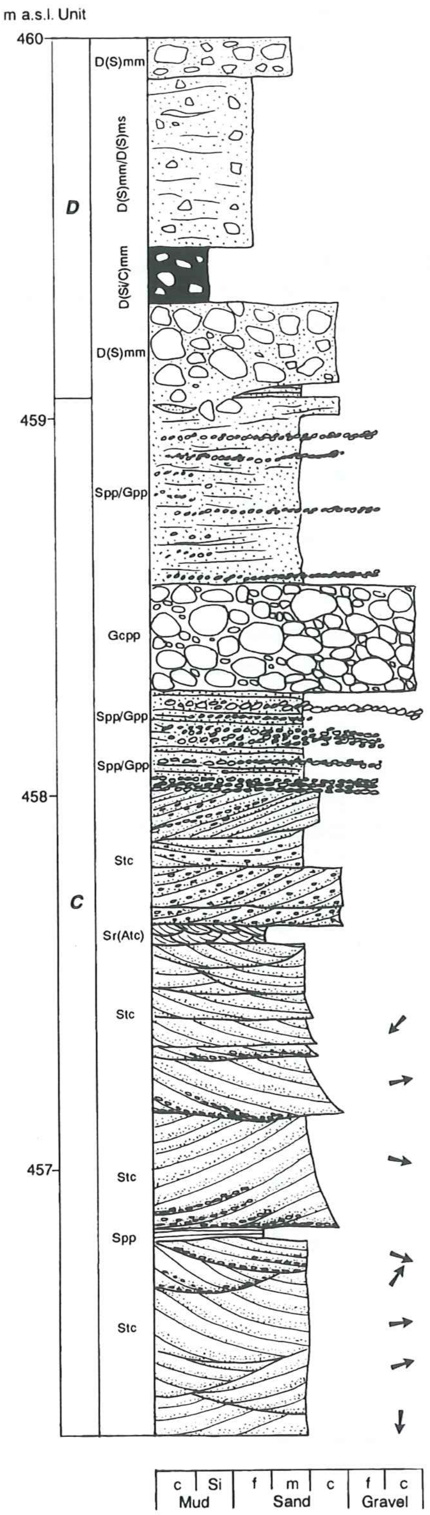


Fig. 22. Logged sequence at site USJ3:2/Section II. For location, see Figs. 4 & 6.

ple-laminated sets indicates a reduction in the flow velocity and deposition during lower flow regime conditions.

Unit D - The upper diamicton is interpreted to be the result of solifluction processes, which is indicated by internal sedimentary structures as well as the contact to the underlying diamicton.

The lower diamicton is interpreted to be a till deposited subglacially from a glacier carrying a high proportion of fines, given the silty clayey matrix of the diamicton.

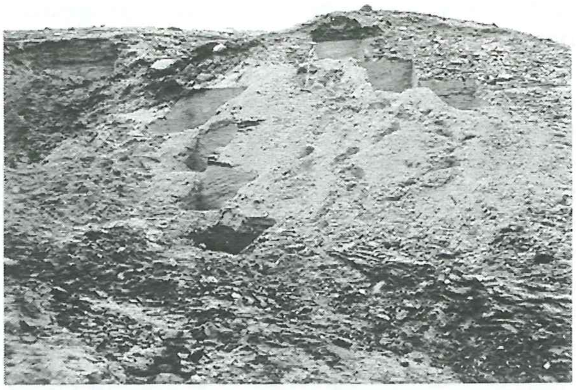


Fig. 23. Site USJ1/Sections I & II. For location, see Fig. 4. Section I is located to the left in the picture.

Section II:

As stated above, section II show great similarities to section I at the site and it is interpreted to be formed by the same processes and in the same environment as section I. For an outline of these processes, reference is made to the interpretation of section I.

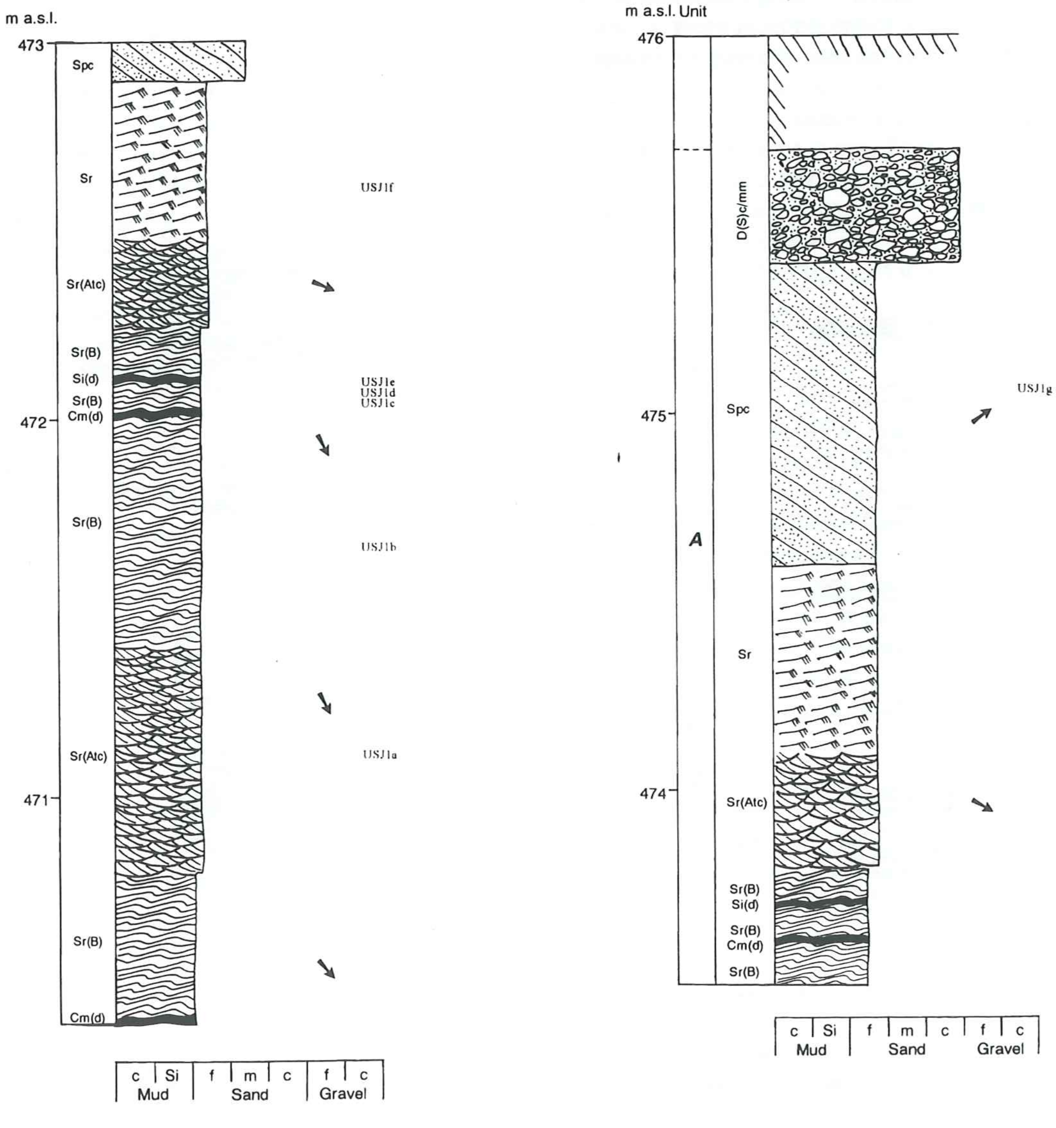


Fig. 24. Logged sequence at site USJ1/Sections I & II. For location, see Fig. 4.

5.2.5 Description of site USJ1

A c. 6 m high bluff situated in a small ravine a few hundred meters to the east of site USJ2. Two sections, I & II, were excavated and studied (Fig. 23). The two sections are overlapping and are therefore treated and described as one continuous section.

Section I & II:

Section I is 2.6 m high and strikes 288° facing the NE and section II is 2.2 m high and strikes 70° facing the NNW. Considering the overlapping of the two sections and looking at them as one continuous section, it is 3.6 m high. Due to a slight dislocation of the sediments by slope failure, there is an altitude difference where the two sections overlap, with section I situated in a relatively lower position. This dislocation has also caused the sediments to become tectonically tilted but through the recording of the degree and direction of the tilt of one of the clay layers, the whole section could be rectified. One lithostratigraphic unit, A, have been identified and described (Fig. 24).

Unit A - The studied part of the unit is 3.6 m thick and it is characterized by alternating ripple-drift successions, one of them showing a development of a complete ripple-drift sequence as described by Gustavson *et al.* (1975). The sequence begins with a thin draped laminae overlain by a thin unit of type B followed by a relatively thick unit of type A ripple-drift cross-lamination. The type A grades upward into a likewise relatively thick unit of type B ripple-drift cross-lamination and with the final formation of draped lamination, the sequence is complete and bedload transport has ceased. All of the type A ripple-laminated sets have lower erosive boundaries.

At the base of the studied part, the unit begins with a clay layer that is followed by a 40 cm thick set of type B ripples. A coset of type A → type B ripples followed by a draping of clayey silt appears next, with the individual thickness of the type A and type B sets both being 60 cm. The clayey silt drape gradually grades upward into fine sand and a 10 cm thick set of type B ripples showing a weak fining upward trend (Fig. 24), which again ends with a silt drape that grades upward into a 15 cm thick set of type B ripples. Following this is a 65 cm thick ripple-laminated set, with the lower 25 cm consisting of type A ripples. The remaining 40 cm of the set are strongly disturbed, showing a normal fault and associated signs of drag- flexures, and it is hard to caterogize between type A and type B ripples even though the cross-bedding of the ripple foresets can be weakly recognized. Measurements performed on ripples in the unit indicates a palaeocurrent direction towards the SE (Fig. 24).

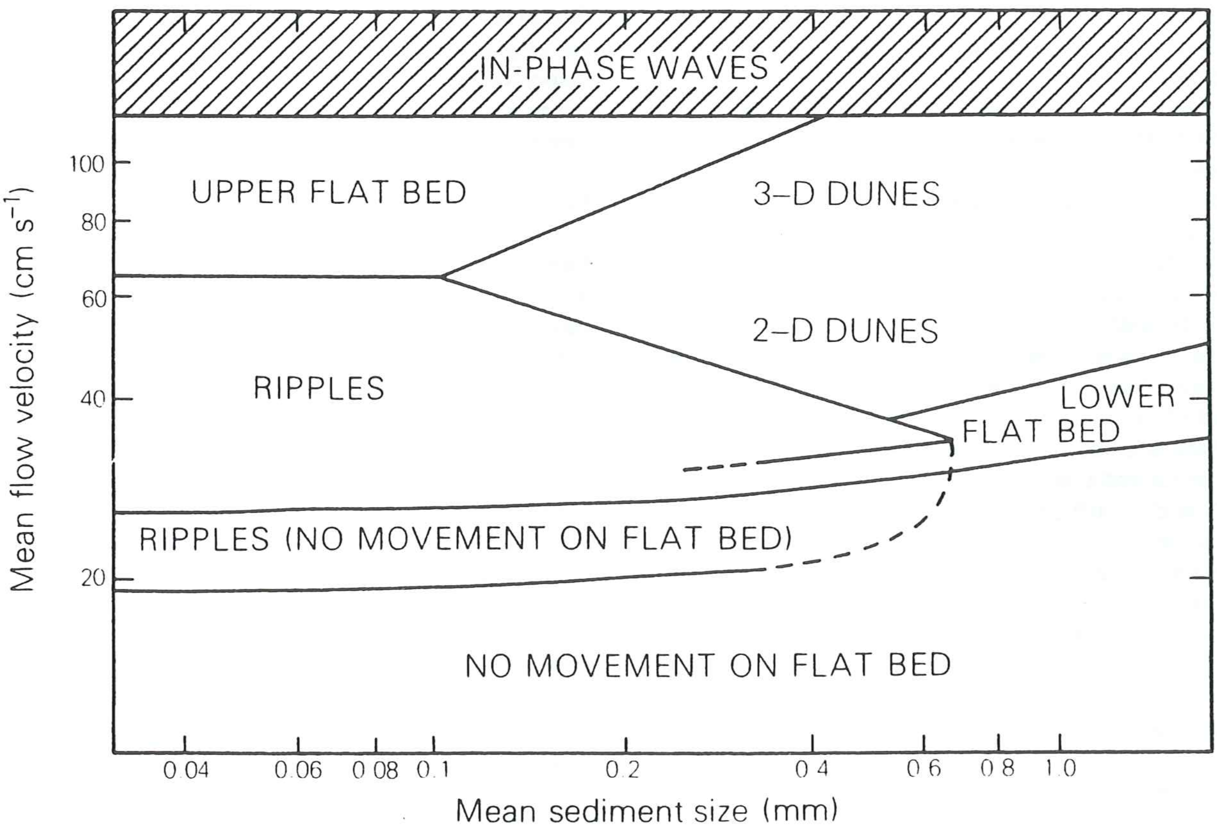


Fig. 25. The stability fields of different bedforms in relation to flow velocity and grain-size for water depth of 20 cm. After Harms et al. *(1975).*

At the upper part of the unit there is an 80 cm thick bed of planar cross-laminated fine to medium sand. The true dip and direction of the foresets are 14°/52°, which indicates a palaeocurrent direction towards the north-east. The foresets are tangential at the base. Superimposed on the top is a form set of small scale current ripples.

The uppermost 30 cm of the unit comprise solifluced sediments showing a weak and diffuse layering with scattered gravel and cobble particles.

5.2.6 Interpretation of site USJ1

Section I & II:

Unit A - The ripple-drift sequences within the unit are interpreted as formed in the same way as unit A in section I and II of site USJ3:1, that is by rapid deposition from the previous described low-density underflows. The lithofacies combinations are typical for those of the lower delta slope (Smith & Ashley 1985), but as stated above they do also develop along the distal parts of subaqueous outwash deposits (Ashley 1988).

According to Gustavson *et al.* (1975), the complete ripple-drift sequence described above reflects a relatively rapid decrease in the ratio of rates of deposition from suspension to bed-load transport followed by a gradual increase, which implies that flow strength increase quickly, then decrease.

The planar cross-laminated bed at the top of the unit is interpreted as formed by a density underflow in one of the two environments mentioned above. The diagram of Harms *et al.* (1975), showing the stability fields of different bedforms in relation to flow velocity and grain size (Fig. 25), shows that compared to the ripple-drift sequences, the deposition of the 2-D dune requires a higher flow velocity given the relative equal grain size distribution of the two beds. The deposition of the bed shows that the density current must have been relative steady and continuous. The tangential foresets are a result of a separated flow in the lee of the dune which gives rise to a backflow component that helps produce a tangential slip face (Collinson & Thompson 1989) and even though not observed within the subunit, sometimes with countercurrent ripples.

5.2.7 Description of site USJ2:

The site comprise one section that was excavated in the steep slope on the northern side of the western hill (Fig. 26). It is located midways between sites USJ1 and USJ3 in the uppermost part of the slope, only 3 m below the surface cover of the hill (Fig. 6).The total thickness of the studied part of the section is 2.7 m and two lithostratigraphical units, A & B, have been identified and described (Fig. 27). Due to lithological and sedimentological differences within unit B, this unit has been subdivided into B1 and B2.

Fig. 26. Site USJ2. For location, see Figs. 4 & 6. The studied part of the section comprise the upper 2.7 m of the total excavated section.

Unit A - The unit is 70 cm thick and is characterized by ripple cross-laminated fine and medium sand. At the bottom there is a 15 cm thick set of type B ripples in fine sand. This set is followed by a 30 cm thick set of type A ripples in medium sand that grades upward into fine sand. A 10 cm thick set of planar parallel-laminated coarse sand with dispersed fine gravel particles is sandwiched between this set and a 15 cm thick set of type A ripples at the top of the unit. Palaeocurrent directions performed on ripples indicate a direction of flow towards the SE.

Subunit B1 - The subunit is 1.2 m thick and the dominating facies is a massive to stratified, clast-supported gravel with a sand matrix. Minor and subordinate facies are thin sets of planar parallel-laminated coarse sand and fine gravel. Boulders, up to 60 cm in diameter, are dispersed in the sediment. The contact to the underlying unit is erosive.

A fabric analysis, carried out on 25 particles, shows a major trend with a-axes aligned in a NE - SW direction and a minor trend with a-axes aligned perpendicular to the main trend and dipping towards the NW (Fig. 28).

Subunit B2 - The subunit is c. 1 m thick and shows a massive, matrix-supported, sandy diamicton with a maximum particle size reaching up to 1 m in the studied section. The lowermost part of the unit shows the inclusion of intraclasts, up to 60 cm in length and composed of cross-laminated fine sand.

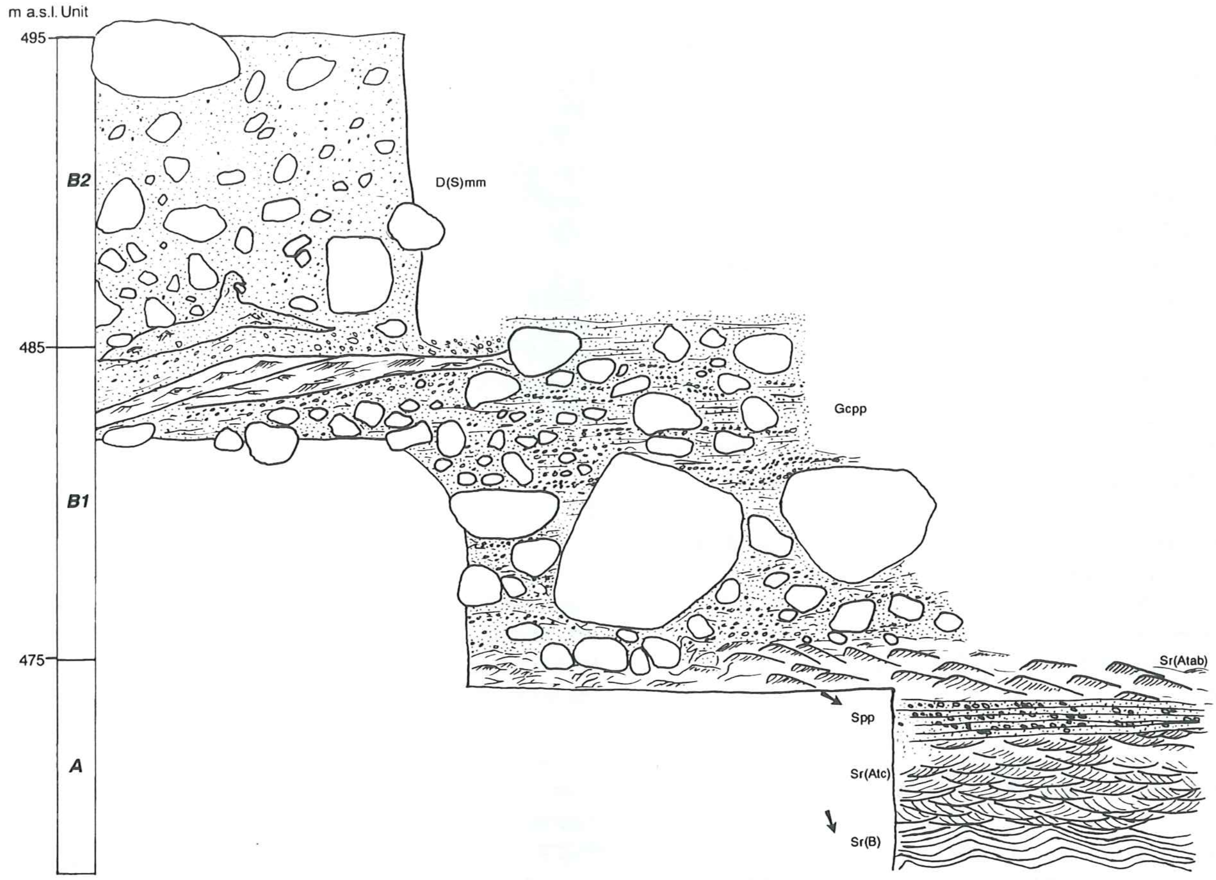


Fig. 27. Section chart showing site USJ2. For location, see Figs. 4 & 6.

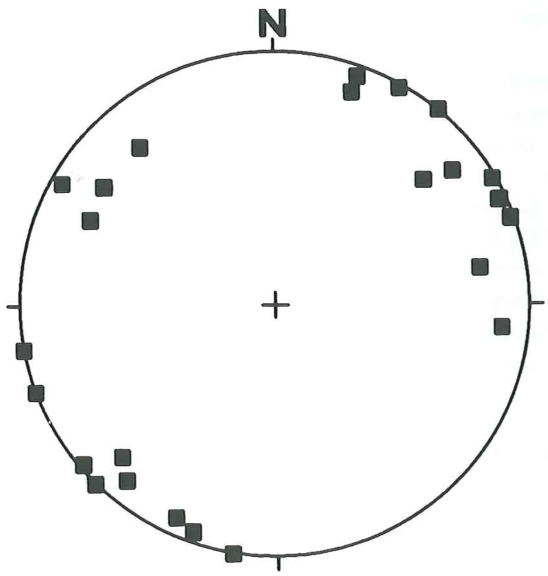


Fig. 28. Scatter diagram of pebble fabric in subunit B1 at site USJ2. Mean axis orientation (V_1) is 53°/2° with a normalized eigenvalue (S_1) of 0.716.

5.2.8 Interpretation of site USJ2:

Unit A - The sediment sequence in the unit show great similarities to those recorded for unit A of sites USJ1 and USJ3:1 and it is interpreted as deposited in the same manner.

Subunit B1 - The sediment within the subunit is interpreted to be deposited in a subglacial fluvial environment with high flow velocities. A look at the Hjulström - Sundborg diagram show a critical erosion velocity close to 1 m/s before particles with a size of 10 mm begin to move as bedload (Collinson & Thompson 1989). Flow velocities of this magnitude are likely to occur as channelized flows in a subglacial environment. Shaw (1985) discusses the probability that a large increase in discharge would cause a sudden rise in subglacial water pressure leading to the spill-over of water from the established drainage system, which in turn would cause the water to flow in sheets. Further on he points to the fact that there is geomorphological and sedimentological evidence for extensive sheets of meltwater flow beneath Pleistocene ice sheets. Even though of a much larger magnitude than is required to form the sediment in subunit B1, continuous flows of subglacial meltwater has also been discussed by Shaw *et al.* (1989).

The fabric of the particles shows that the direction of flow was towards the SE since, in the case of imbrication, the dip of the particles is always directed towards the upstream direction (Collinson & Thompson 1989). The main trend, with clast a-axes aligned transverse to flow, is ascribed to the rolling of clasts on the sediment surface. Since there are no signs of clustered bedforms, the dispersed boulders are interpreted to have melted out directly from the base of the glacier. This absence of clustered bedforms combined with the fact that the material is sorted and clast supported suggests a subglacial fluvial environment of deposition.

Subunit B2 - The diamicton is interpreted to be a subglacially deposited till. The intraclasts at he bottom of the unit are interpreted to have been formed by the last fluvial subglacial deposition before direct deposition from the glacier commenced.

5.2.9 Description of site USJ4

The site comprise one section that was excavated in the upper terrace, and it is situated approximately midways between sites USJ3 and USJ5 (Figs. 4 & 6). Two units, C and D, have been identified and described (Fig. 29).

Unit C - The unit is 1.25 m high and shows sandy fluvial bedforms with a total predominance of trough cross-laminated medium to coarse sand. It is only in the lower 25 cm of the unit that ripple cross-laminated sets in fine sand and a low angle crossbed in medium sand can be observed. The lower part also shows an erosional trough infilled with planar parallel-laminated gravel that is overlain by a set of ripples in fine sand. Occasional trough-forms have gravel particles dispersed in them, sometimes with a tendency to accumulate towards the bottom of the troughs. Measurements on palaeocurrent directions performed on foreset laminae in the trough-forms, show a direction of flow towards an approximately south-eastern sector.

Unit D - The unit is 1 m thick and it is inhomogeneous. At the bottom of the unit there is a c. 30 cm thick bed of a massive, matrix-supported, silty clayey diamicton that is interrupted by a 5 cm thick bed of fine to medium sand in the lower part. This diamicton grades upward into a c. 30 cm thick zone of deformed sand, showing diffuse planar parallel-lamination or no structures at all, that again grades upward into a silty clayey diamicton.

5.2.10 Interpretation of site USJ4

Unit C - The sediments in the unit show great similarities to those of unit C at site USJ3:2 and is thus interpreted to be formed in the same way, that is, mainly in-channel deposition by the migration of 3-D dunes in a sandy braided river environment.

Unit D - Given the resemblance of both the deformed sediments as well as the silty clayey diamicton of this unit and unit D of section III at site USJ3:1, these two u its are interpreted to be formed in the same way.

5.2.11 Description of site USJ5

The site comprises two sections, I & II, that were excavated in the more gentle slope along the western part of the valley side (Fig. 30). The site is located c. 1 km to the west of site USJ3, close to the western limit of the hill (Figs. 4 & 6).

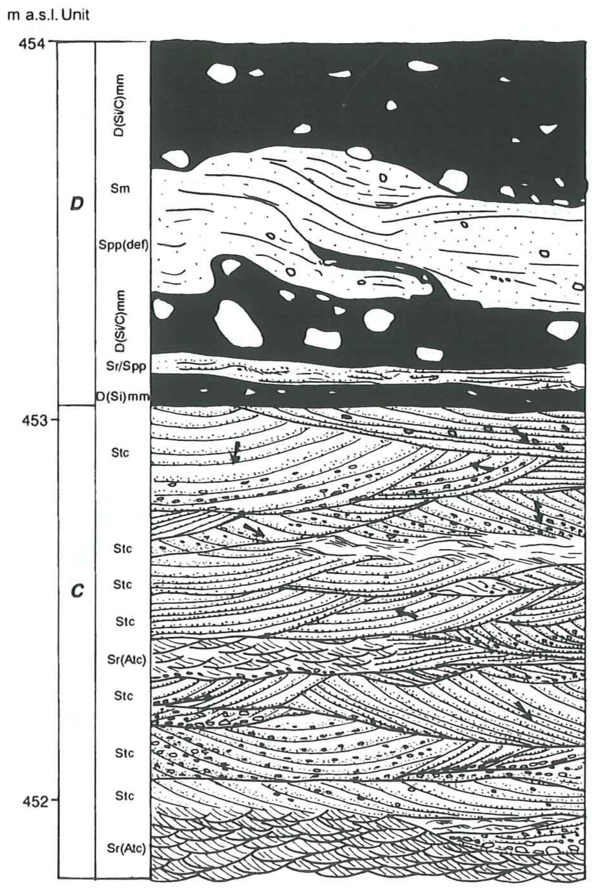


Fig. 29. Section chart showing site USJ4. For location, see Figs. 4 & 6.

Fig. 30. Site USJ5/Section II. For location, see Figs. 4 & 6.

Section I:

The section is 2.85 m high and strikes 330° facing the NE. One lithostratigraphical unit, A, has been identified and described (Fig. 31).

Unit A - Characterizing the unit are the alternating beds of ripple-drift cross-lamination, planar cross-laminated beds and planar parallel-laminated beds, with the ripple-drift cross-laminated beds often showing a development from type A → type B ripples. The alternation of the beds shows the development of planar parallel-lamination followed by planar cross-lamination and ending with ripple-drift cross-lamination, as well as just the succession of the latter two. Subordinate to these bedforms in occurrence is the 50 cm thick sequence of trough cross-laminated sets at the lowermost part of the unit. The thickness of the ripple-drift sequences varies between 10 and 40 cm, often showing a decreasing trend in gain-size from type A to type B ripples.

Two of the planar parallel-laminated beds show a fining upward trend from fine to medium sand, while the planar cross-laminated beds show a normal grading from fine gravel to coarse sand on two occasions. The planar cross-laminated sets contain coarse grained sand and fine gravel, the latter with a tendency to concentrate towards the bottom of the sets. The thickness of the parallel-laminated sets varies between 3 and 20 cm and the thickness of the planar cross-laminated sets varies between 5 and 14 cm.

Measurements on the palaeocurrent direction, performed on ripples as well as the true dip and direction of the trough-form sets, indicate a flow towards an approximately eastern sector (Fig. 31).

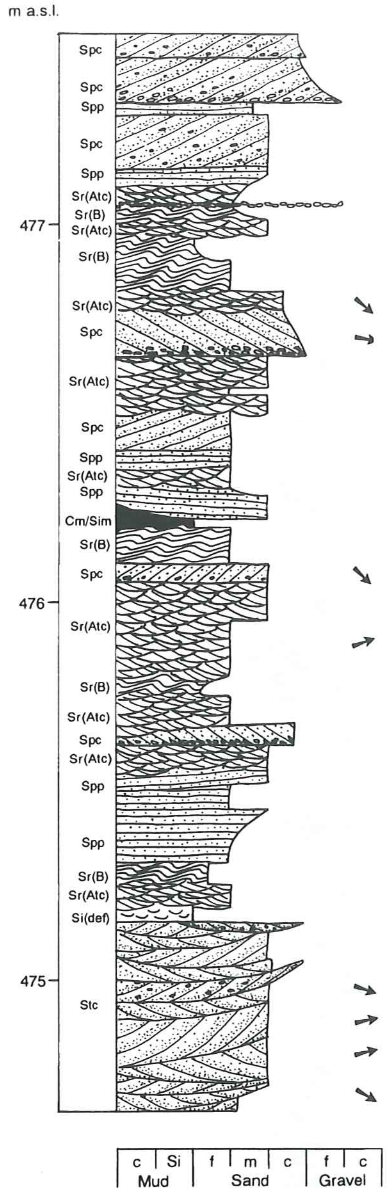


Fig. 31. Logged sequence USJ5/Section I. For location, see Figs. 4 & 6.

Section II:

The section is 4.3 m high and strikes 74° facing the NNW. It is situated just above section I. One lithostratigraphical unit, A, has been identified and described (Fig. 32).

Unit A - The unit is dominated and characterized by thick ripple-drift sequences in fine sand. These sometimes shows the development of type A → type B ripples with a final draping of silt. The thickness of individual ripple sets varies between 6 and 125 cm, the thickest one being a continuous deposition of type B ripples. The unit also shows a 30 cm thick set of sinusoidal ripple-lamination, as described by Jopling & Walker (1968), that climbs almost vertically or at high angle, in the

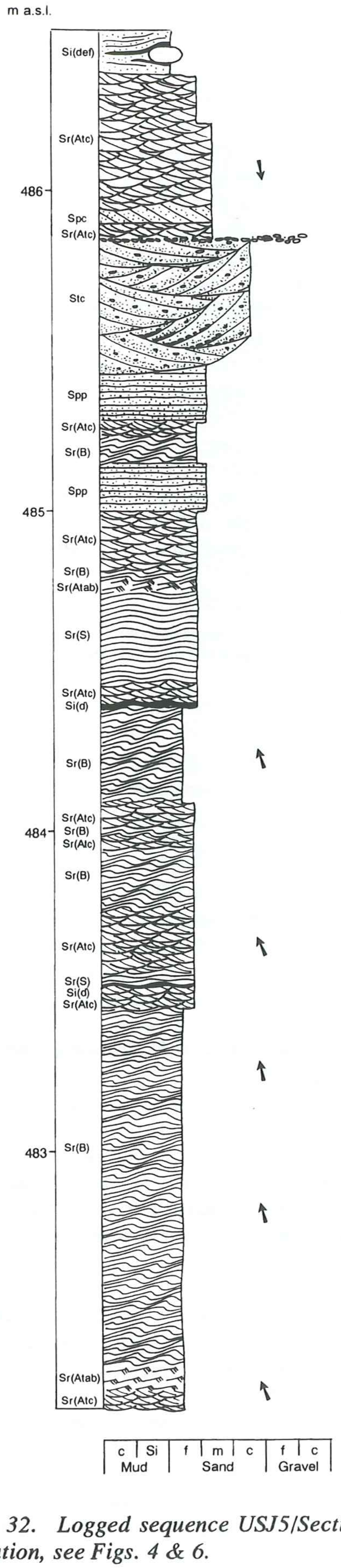


Fig. 32. Logged sequence USJ5/Section II. For location, see Figs. 4 & 6.

same direction as the underlying ripples. Two sets of planar parallel-laminated medium sand, each one being 15 cm thick, have also been observed. The uppermost 1 m of the unit shows a 40 cm thick bed of trough cross-laminated coarse sand capped by a lag of small pebbles. This is followed by a 60 cm thick set of type A ripples, only interrupted by a 5 cm thick set of planar cross-laminated medium sand in the lowermost part. The ripple set shows a decreasing grain-size upwards within the set. The upper 15 cm of this set is strongly deformed, showing shearing of the sediments as well as the inclusion of larger pebbles and cobbles.

Measurements on the palaeocurrent direction, performed on ripples, are very consistent towards the NNW, except for the ripple set at the top of the unit which show an opposite direction towards the SSE (Fig. 32).

5.2.12 Interpretation of site USJ5

Unit A of section I is correlated with unit A of section II and the two sections are interpreted as deposited in the same environment.

Section I & II:

Unit A - The lithofacies combinations and bedforms that make up the unit are interpreted to be deposited along the intermediate - distal parts of a subaqueous fan (Gorrel & Shaw 1991; Rust & Romanelli 1975; Shaw 1975, 1985) or on a prodelta slope. This interpretation is based on the lithofacies combinations as well as the changing palaeocurrent direction within the unit.

According to Shaw (1985), the gravel that is deposited in the more proximal part of the fan passes upward and distally into sets of trough cross-laminated, planar cross-laminated and planar parallel-laminated sand, all of them associated with occasional sets of ripple cross-lamination, while climbing ripple-drift sequences dominates the upper part of the sequence. Except for the more gravelly and proximal parts, all of these lithofacies combinations have been observed within unit A.

The depositional sequences in subaqueous fans show rapid lateral changes in both direction and strength of flows, and a large number of flow events has been shown to build a fan (Gorrel & Shaw 1991). The change in grain-size, bedforms and especially the palaeocurrent, when passing upward through unit A, is interpreted to reflect the rapidly changing conditions in this environment.

The trough cross-laminated sets at the bottom as well as in the upper part of the unit are interpreted to be deposited in distributary channels on the fan (Shaw 1975). The repeated sequence of planar parallel-laminated → planar cross-laminated →

Fig. 33. Standing on the eastern side of the western hill and looking towards the north and site USJ8 in the upper right part of the picture.

ripple cross-laminated sand indicates a decrease in flow velocity, whereas the inverse grading of two of the planar parallel-laminated beds indicates an increase in flow velocity. The sequence with sinusoidal ripple-lamination is interpreted to be formed through the steady decrease in the rate of tractive sediment transport relative to the amount of suspended material settling on the bed (Jopling & Walker 1968).

Given the similarities of the units, the unit is correlated with unit A of site USJ1 and USJ3:1. It follows from this correlation that the most likely environment of deposition for the latter two, also are the distal parts of a subaqueous fan, or along a prodelta slope.

5.2.13 Description of site USJ8

A branch of the upper terrace can be traced into the shallow depression between the eastern and the western hill. The site is situated in a gully and comprise one section that was excavated in the terrace (Fig. 33). It is located c. 1.5 to the SE of site USJ1. Two lithostratigraphical units, C & D, have been identified and described (Fig. 34). The section strikes 105°, while the terrace strikes 160° facing the east.

Unit C - The unit is 1.9 m thick and shows sandy fluvial bedforms, with a predominance of trough cross-laminated medium sand to fine gravel. At the top of the unit lies a 15 cm thick bed of planar parallel-laminated gravel, with a maximum particle size of 5-8 cm. Measurements on the palaeocurrent direction indicate a direction of flow towards a south-eastern sector (Fig. 34).

Unit D - The unit is 30 cm thick and consists of a massive diamicton with a matrix of silt as well as coarse sand.

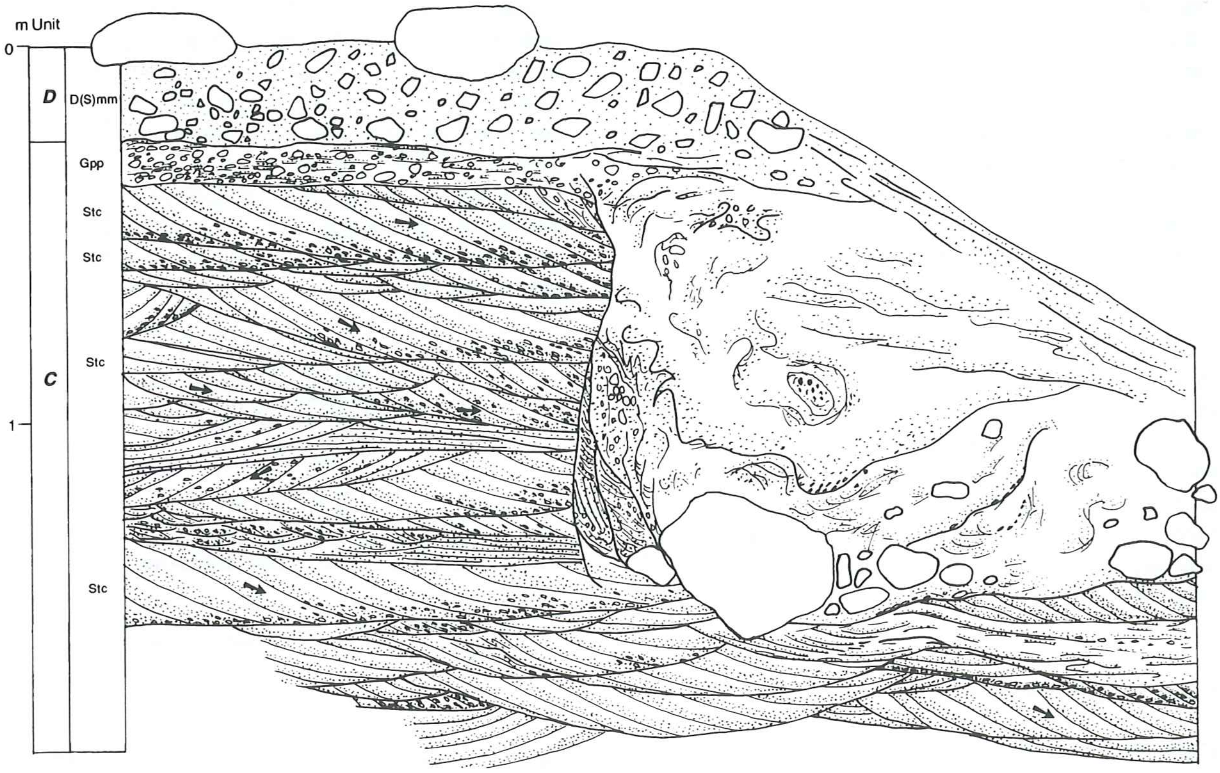


Fig. 34. Section chart showing site USJ8. For location, see Fig. 4.

Lying right next to unit C and unit D with an erosional contact is a sediment that appears to be a diamicton with a sandy matrix, occasionally with lenses of silt and fine sand. It contains boulders up to 60 cm in diameter in the studied section. The sediments are believed to be part of unit D.

5.2.14 Interpretation of site USJ8

Unit C - The unit shows great similarities to unit C at sites USJ3:2 and USJ4 and it is interpreted to be formed in the same way, that is by in-channel deposition through the migration of 3-D dunes in a sandy braided river environment. The planar parallel-laminated gravel bed at the top of the unit indicate high flow velocities in the upper flow regime (Collinson & Thompson 1989).

Unit D - A formation by solifluction processes does not seem likely, since it is hard to imagine the transport of boulders reaching over 1 m in diameter down the gentle slope, and thus the unit is interpreted to be a subglacially deposited till. The parent material is probably a mixture of a till and glaciolacustrine deposits.

5.2.15 Description of site USJ11

The site comprise one section that was excavated in the upper part of the Jyllandselv ravine, to the north of the eastern plateau hill (Fig. 35). The studied part of the section is c. 2 m high and one lithostratigraphic unit, C, has been identified and described (Fig. 36).

Unit C - The unit is 1.9 m thick and it is characterized by sandy fluvial bedforms. Starting at the lower part of the unit there is a 10 cm thick bed of planar parallel-laminated sand and gravel. The maximum particle size in this bed lies around 4-5 cm. Following this bed upwards in the unit are alternating beds of trough cross-laminated, ripple cross-laminated and planar cross-laminated sand as well as low angle crossbeds. The trough-forms show dispersed gravel particles throughout, with a tendency of these to accumulate at the bottom of each trough. Measurements on palaeocurrent directions, performed on the dip and direction of the foresets within the trough-forms as well as on ripples, show a direction of flow towards the SSE (Fig. 36).

5.2.16 Interpretation of site USJ11

Unit C - The unit shows the same bedforms and lithofacies combinations that has been registered for unit C at sites USJ3:2, USJ4 and USJ8, and is thus interpreted to be formed by the same processes in the same environment.

Fig. 35. Standing in the upper part of the Jyllandselv ravine, at site USJ11, and looking towards the west. The western hill and the terraces can be noticed on the left side of the ravine at the horizon in the upper part of the picture.

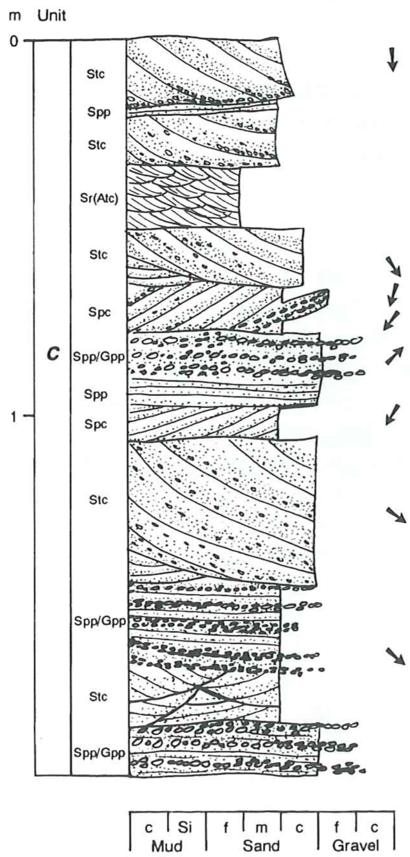


Fig. 36. Logged sequence at site USJ11. For location, see Fig. 4.

6 Conclusions

The sediment successions reveal four (I-IV) separated depositional events, represented by units A-D respectively. Fig. 37 shows a summary sketch of the four different units (A-D) and their relative positions along the northern slope of the western plateau hill. The total thickness of the Quaternary sediments in the western hill is approximately 80 m.

Event I is the oldest recorded event and it is represented by the unit A sediments. The bulk of the unit A sediments consists of ripple cross-laminated fine sand, often showing repeated successions of type A →type B ripple lamination. Palaeocurrent directions are towards the south-east. The unit A sediments are interpreted to be deposited from turbidity currents along a prodelta slope or at the distal parts of a subaqueous fan. This indicates that there once was a glacial lake dammed between an advancing glacier from the west and the watershed area to the east. Palaeocurrents opposed to the present drainage system indicate that the damming glacier must have been located in the near vicinity. The absence of any real Gilbert-type delta foreset and topset sediments makes a more precise determination of the former glacial lake level hazardous, but since the unit A sediments reaches up to approximately 490 m a.s.l. (Fig. 37) this would represent a minimum glacial lake level.

Event II is represented by the unit B sediments. The lower part of the unit B sediments is a clast supported gravel that reflects a subglacial fluvial environment. Scattered boulders, up to 60 cm in diameter, which probably fell directly from the base of the glacier occur in this part of the unit. The flow of subglacial meltwater was indirectly controlled by ice movement and the flow direction was towards the south-east. This is indicated by a fabric analyses carried out in the lower part of the unit that shows clast a-axes horizontal with a NE-SW trend, that is, clast movement was mainly by rolling and the orientation was preserved after deposition. The upper part of unit B is a massive diamicton that is interpreted to be a till representing a direct deposition from the glacier. The unit B sediments show that a glacier advanced from the north-west and overrode the unit A sediments and it is proposed that it was the same glacier from which the unit A sediments were deposited.

Event III is represented by the unit C sediments, which comprise grouped cosets of trough cross-laminated sand with minor lithofacies components represented by low angle crossbeds of sand and gravel as well as sets of planar cross-laminated and ripple cross-laminated sand. The unit C sediments are interpreted to be formed in a sandy braided river environment, mainly by in-channel migration of 3-D dunes. The sediments were deposited as the glacier of events I and II retreated towards the west. This glacial retreat first led to the proglacial meltwater erosion into the unit A and B sediments, creating a valley bottom 150 m above the present day river bed. As this fluvial erosion ceased, sediment deposition commensed. This led to the build up of a fluvial terrace represented by the unit C sediments. Palaeocurrents opposed to the present drainage system in unit C indicate that the glacier still existed somewhere to the west and drainage continued towards the east and south-east. Later a new phase of erosion occured, resulting in the formation of the lower terrace. Further deglaciation caused a permanent shift of the drainage pattern towards the west, which in turn resulted in the fluvial incision of the unit C sediments.

The youngest recorded event in the area is event IV. This event is represented by a deformation till and a moraine hummock on top of the fluvial

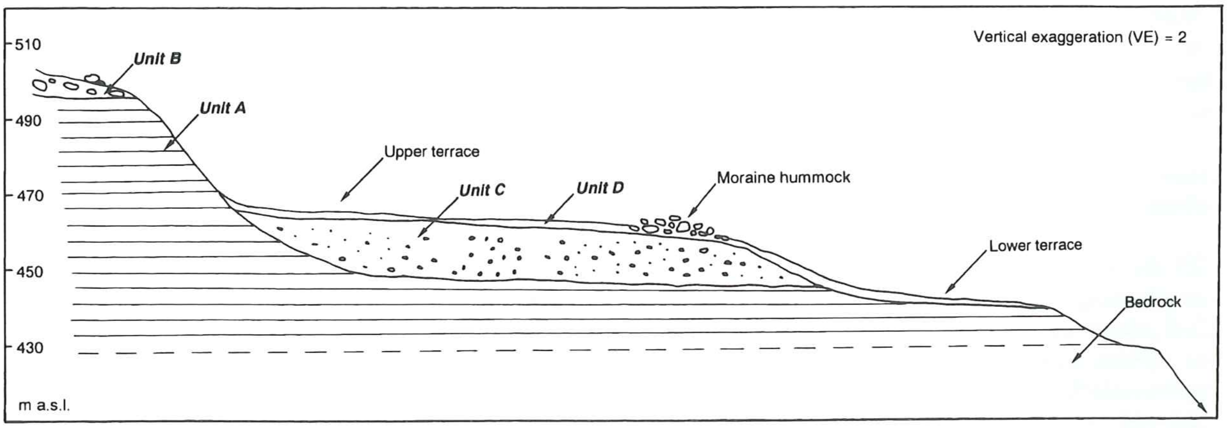


Fig. 37. A summary sketch showing the four different units (A-D) and their relative position to each other in the investigation area.

terrace (Fig. 37). The recording of the strike of fold axes shows a stress direction towards the south-west, which is interpreted to be the result of a new glacial advance from a local ice cap, probably located somewhere in the watershed area to the north-east.

7 References

Ahlmann, H.W. 1941: Studies in the northeast Greenland 1939-1940. *Geografiska Annaler 23*, 145-209.

Ashley, G.M. 1988: Classification of glaciolacustrine sediments. *In* Goldthwait, R.P. & Matsch, C.L. (eds.): *Genetic Classification of Glacigenic Deposits*, 243-260. Balkema,Rotterdam.

Ashley, G.M., Southard, J.B. & Boothroyd, J.C. 1982: Deposition of climbing-ripple beds: a flume simulation. *Sedimentology 29*, 67-79.

Birkelund, T. & Perch-Nielsen, K. 1969: Field observations in Upper Palaeozoic and Mesozoic sediments of Scoresby Land and Jameson Land. *Geological Survey of Greenland, Report 21*, 21-35.

Boulton, G.S. 1987: A theory of drumlin formation by sediment deformation. *In* Menzies, J. & Rose J. (eds.): *Drumlin Symposium*, 25-80. Balkema, Rotterdam.

Bristow, C.S. & Best, J.L. 1993: Braided rivers: perspectives and problems. *In* Best, J.L. & Bristow, C.S. (eds.): *B*raided Rivers. *Geological Society Special Publication 75,* 1-11.

Böcher, J. & Bennike, O. 1991: Interglacial land biotas of Jameson Land, East Greenland. *In* Möller, P., Hjort, C. & Ingólfsson, Ó. (eds.): The Last Interglacial - Glacial Cycle: Preliminary report on the PONAM fieldwork in Jameson Land and Scoresby Sund, East Greenland. *LUNDQUA Report 33*, 129-136.

Collinson, J.D. & Thompson, D.B. 1989: *Sedimentary Structures*. Unwin Hyman Ltd., London. 207 pp.

Cruickshank, J.G. & Colhoun, E.A. 1965: Observations on pingos and other landforms in Schuchertdal, northeast Greenland. *Geografiska Annaler 47A*, 224-236.

Dowdeswell, J.A. , Villinger, H. , Whittington, R J. & Marienfeld, P. 1991: The Quaternary marine record in the Scoresby Sund fjord system, East Greenland: preliminary results and interpretation. *In* Möller, P., Hjort, C. & Ingólfsson, Ó. (eds.): The Last Interglacial - Glacial Cycle: Preliminary report on the PONAM fieldwork in Jameson Land and Scoresby Sund, East Greenland. *LUNDQUA Report 33*, 149-155.

Eyles, D. , Eyles, C.H. & Miall, A.D. 1983: Lithofacies types and vertical profile models; an alternative approach to the description and environmental interpretation of glacial diamict and diamictite. *Sedimentology 30*, 393-410.

Drewry, D. 1986: *Glacial Geologic Processes*. Edward Arnold Ltd, London. 276 pp.

Feyling-Hansen, R.W. , Funder, S. & Petersen, K S. 1983: The Lodin Elv Formation: a Plio - Pleistocene occurence in Greenland. *Geological Society of Denmark, Bullentin 31*, 81-106

Folk, R.L. & Ward, W.C. 1957: Brazos river bar: A study in the significance of grain size parameters. *Journal of Sedimentary Petrology 27*, 3-26.

Funder, S. 1972: Remarks on the Quaternary geology of Jameson Land and adjacent areas, Scoresby Sund, East Greenland. *Geological Survey of Greenland, Report 48*, 93-98.

Funder, S. 1978: Holocene stratigraphy and vegetation history in the Scoresby Sund area, East Greenland. *Grønlands Geologiske Undersøgelse, Bullentin 129*. 66 pp.

Funder, S. 1984: Chronology of the last Interglacial/Glacial Cycle in Greenland: First Approximation. *In* Mahaney, W. C. (ed.): *Correlation of Quaternary chronologies*, 261-279. GeoBooks, Norwich.

Funder, S. 1989: Quaternary geology of the icefree areas and adjacent shelves of Greenland. Chapter 13 *in* Fulton, R. J. (ed.): *Quaternary Geology of Canada and Greenland*. Geological Survey of Canada, Geology of Canada, no 1 (also Geological Society of America, The Geology of North America, vol. K-1).

Funder, S. 1990: Quaternary map of Greenland 1:500 000, sheet 12, Scoresby Sund (map and descriptive text). *Grønlands Geologiske Undersøgelse*. Copenhagen. 24 pp.

Funder, S. & Hjort, C. 1973: Aspects of the Weichselian chronology in central East Greenland. *Boreas 2*, 69-84.

Funder, S. , Hjort, C. & Landvik, J.Y. 1991: Quaternary stratigraphy of Jameson Land - a first approximation. *In* Möller, P., Hjort, C. & Ingolfsson, O. (eds.): The Last Interglacial - Glacial Cycle: Preliminary report on the PONAM fieldwork in Jameson Land and Scoresby Sund, East Greenland. *LUNDQUA Report 33*,171-175.

Gandahl, R. 1952: Bestämning av kornstorlek med hydrometer. *Geologiska Föreningen i Stockholm Förhandlingar 74*, 497-512.

Gorrel, G. & Shaw, J. 1991: Deposition in an esker, bead and fan complex, Lanark, Ontario, Canada. *Sedimentary Geology 72*, 285-314.

Gustavson, T.C. , Ashley, G.M. & Boothroyd, J.C. 1975: Depositional sequences in glaciolacustrine deltas. *In* Jopling, A.V. & McDonald, B.C. (eds.), Glaciofluvial and glaciolacustrine sedimentation. *Society of Economic Paleontologists and Mineralogists, Spec. Publ. 23*, 264-280. Tulsa, Oklahoma.

Harms, J.C., Southard, J.B., Spearing, D.R. & Walker, R.G. 1975: Depositional environments as interpreted from primary sedimentary structures and stratification sequences. *Society of Economic Paleontologists and Mineralogists (SEPM) Short Course Notes no. 2.* Tulsa, Oklahoma.

Hart, J.K. & Boulton, G.S. 1991: The interrelation of glaciotectonic and glaciodepositional processes within the glacial environment. *Quaternary Science Reviews 10*, 335-350.

Henriksen, N. 1986: Descriptive text to 1:500 000 sheet 12 Scoresby Sund. *Grønlands Geologiske Undersøgelse.* 27 pp.

Hjort, C. 1979: Glaciation in northern East Greenland during the late Weichselian and early Flandrian. *Boreas 8*, 251-296.

Hjort, C. 1981: A glacial chronology for northern East Greenland. *Boreas 10*, 259-274.

Hjort, C. 1988: Weichselian versus Flandrian glacial developments on Kilen, northeasternmost Greenland - a case of interglacial ice-cap expansion. Abstract 18. Nordiske Geologiske Vintermøde, København.

Hjort, C. & Funder, S. 1974: The subfossil occurence of *Mytilus edulis* L. in central East Greenland. *Boreas 3*, 23-33.

Hjort, C. & Möller, P. 1991: Glacial deposits on the interior plateaux of Jameson Land, East Greenland. *In* Möller, P., Hjort, C. & Ingólfsson, Ó. (eds.): The Last Interglacial - Glacial Cycle: Preliminary report on the PONAM fieldwork in Jameson Land and Scoresby Sund, East Greenland. *LUNDQUA Report 33*, 7-22

Hjort, C. & Salvigsen, O. 1991: The channel and tor landscape in southeastern Jameson Land, East Greenland. *In* Möller, P., Hjort, C. & Ingólfsson, Ó. (eds.): The Last Interglacial - Glacial Cycle: Preliminary report on the Ponam fieldwork in Jameson Land and Scoresby Sund, East Greenland. *LUNDQUA Report 33*, 23-26.

Johnsen, S.J., Clausen, H.B., Dansgaard, W., Gundestrup, N.S., Hansson, M., Jonsson, P., Steffensen, J.P. & Sveinbjørnsdottir, A.E. 1992: A "deep" ice core from East Greenland. *Meddelelser om Grønland, Geoscience 29.* 22 pp.

Jopling, A.V. & Walker, R.G. 1968: Morphology and origin of ripple-drift cross lamination, with examples from the Pleistocene of Massachusetts. *Journal of Sedimentary Petrology 38*, 971-984.

Kirchner, G. 1963: Observations at bore holes sunk through the Schuchert Gletscher in North-East Greenland. *Journal of Glaciology 4*, 817-818.

Landvik, J.Y. & Lyså, A. 1991: Depositional history and regional implications of the Eemianand Weichselian sequences in the Aucellaelv - Langelandselv area, southern Jameson Land, East Greenland. *In* Möller, P., Hjort, C. & Ingólfsson, Ó. (eds.): The Last Interglacial - Glacial Cycle: Preliminary report on the PONAM fieldwork in Jameson Land and Scoresby Sund, East Greenland. *LUNDQUA Report 33*, 27-52.

Mark, D.M. 1973: Analysis of axial orientation data, including till fabrics. *Geological Society of America, Bullentin 84*, 1367-1374.

Mark, D.M. 1974: On the interpretation of till fabrics. *Geology 2*, 101-104.

Miall, A.D. 1978: Lithofacies types and vertical profile models in braided river deposits: a summary. *In* Miall, A.D. (ed.): Fluvial Sedimentology. *Memoirs of the Canadian Society of Petroleum Geologists 5*, 597-604.

Müller, F. 1959: Beobachtungen über Pingos, Detailuntersuchungen in Ostgrönland und in der Kanadischen Arktis. *Meddelelser om Grønland 153 (3)*, 127 pp.

Möller, P. 1987: Moraine morphology, till genesis and deglaciation pattern in the Åsnen area, South-central Småland, Sweden. *LUNDQUA Thesis 20*, 146 pp.

Möller, P., Hjort, C., Adrielsson, L., & Salvigsen, O. 1994: Glacial history of interior Jameson Land, East Greenland. *Boreas 23*, in press.

Nordenskiöld, O. 1907: On the Geology and Physical Geography of East Greenland. *Meddelelser om Grønland 28*, 151-284.

OBrien, R. 1971: Observations on pingos and permafrost hydrology in Schuchert Dal, N.E. Greenland. *Meddelelser om Grønland 195 (1).* 19 pp.

Petersen, K.S. 1982: Attack by predatory gastropods recognized in an interglacial marine molluscan fauna from Jameson Land, East Greenland. *Malacologia 22*, 721-726.

Poser, H. 1932: Einige Untersuchungen zur Morphologie Ostgrönlands. *Meddelelser om Gønland 94 (5).* 55 pp.

Raup, H.M. 1965: The structure and development of turf hummocks in the Mesters Vig district, Northeast Greenland. *Meddelelser om Grønland 166 (3). 112 pp.*

Rust, B.R. & Romanelli, R. 1975: Late Quaternary subaqueous outwash deposits near Ottawa, Canada. *In* Jopling, A.V. & McDonald, B.C. (eds.): Glaciofluvial and glaciolacustrine sedimentation. *Society of Economic Paleontologists and Mineralogists, Spec. Publ. 23*, 177-192.

Shaw, J. 1975: Sedimentary successions in Pleistocene ice-marginal lakes. In Jopling, A.V. & McDonald, B.C. (eds.): *Glaciofluvial and glaciolacustrine sedimentation. Society of Economic Paleontologists and Mineralogists, Spec. Publ. 23*, 281-303.

Shaw, J. 1985: Subglacial and ice marginal environments. Chapter 2 *in* Ashley, G.M., Shaw, J. & Smith, N.D. (eds.): *Glacial Sedimentary Environments*, 7-84. Society of Economic Paleontologists and Mineralogists (SEPM) Short Course no 16. Tulsa, Oklahoma.

Shaw, J., Kvill, D. & Rains, B. 1989: Drumlins and catastrophic subglacial floods. *In* Menzies, J. & Rose, J. (eds.): Subglacial Bedforms - Drumlins, Rogen Moraine and Associated Subglacial Bedforms. *Sedimentary Geology 62*, 177-202.

Smith, N.D. & Ashley, G.M. 1985: Proglacial lacustrine environments. Chapter 4 *in* Ashley, G.M., Shaw, J. & Smith, N.D. (eds.): *Glacial Sedimentary Environments*. Society of Economic Paleontologists and Mineralogists (SEPM) Short Course no 16, 135-216. Tulsa, Oklahoma.

Sørensen, T. 1935: Bodenformen und Planzendecke in Nordostgrönland. *Meddelelser om Grønland 93 (4)*. 27-43.

Walker, R.G. & Cant, D.J. 1984: Sandy Fluvial Systems. *In* Walker, R.G. (ed.): *Facies Models*. Geoscience Canada Reprint Series 1. Geological Association of Canada Publications, 71-90. Toronto, Ontario.

Washburn, A.L. 1965: Geomorphic and vegetational studies in the Mesters Vig district, northeast Greenland. *Meddelelser om Grønland 166 (1)*. 60 pp.

Washburn, A.L. 1967: Instrumental observations of mass-wasting in the Mesters Vig district, northeast Greenland. *Meddelelser om Grønland 166 (4). 296 pp.*

Washburn, A.L. 1969: Weathering, frost action and patterned ground in the Mesters Vig district, northeast Greenland. *Meddelelser om Grønland 176 (4)*. 299 pp.

Zander, M. 1993: Sedimentologisk undersökning av en kvartär deltaavlagring vid övre Jyllandselv, Jameson Land, Östgrönland. *Examensarbete i geologi vid Lunds universitet, kvartärgeologi 53*. Geologiska institutionen Lunds universitet, Lund. 36 pp.

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