GEUS

Report file no.

13563

Sedimentology and Basin Evolution of the Cretaceous-Early Tertiary Kangerlussuaq Basin, Southern East Greenland
Prepared for SAGA Petroleum a/s, Dansk Olie- og Gasproduktion A/S (DOPAS) and Danish Lithosphere Centre (DLC)

Larsen, M.

Copenhagen

13-12-1996

DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 1996/35

Sedimentology and Basin Evolution of the Cretaceous-Early Tertiary Kangerlussuaq Basin, Southern East Greenland

Prepared for SAGA Petroleum a/s, Dansk Olie- og Gasproduktion A/S (DOPAS) and Danish Lithosphere Centre (DLC)

Michael Larsen

DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE
MILJØMINISTERIET

GEUS

DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 1996/35

Sedimentology and Basin Evolution of the Cretaceous-Early Tertiary Kangerlussuaq Basin, Southern East Greenland

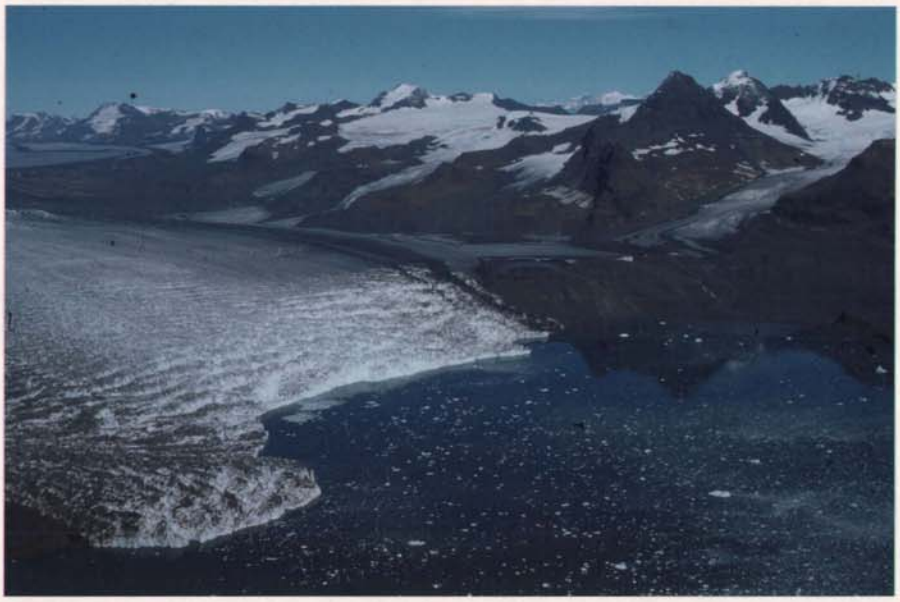
Prepared for SAGA Petroleum a/s,
Dansk Olie- og Gasproduktion A/S (DOPAS)
and Danish Lithosphere Centre (DLC)

Michael Larsen

DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE
MILJØMINISTERIET

GEUS

Sedimentology and Basin Evolution of the Cretaceous–Early Tertiary Kangerlussuaq Basin, Southern East Greenland



Ryberg Fjord and Sorgenfri Gletcher, Kangerlussuaq, southern East Greenland

Report of the field work in southern East Greenland, 1995, prepared for SAGA Petroleum a.s., Dansk Olie- og Gasproduktion A/S (DOPAS) on behalf of the Amarada Hess Faroe Group (Amarada Hess Ltd., LASMO, Norsk Hydro a.s. and DOPAS A/S) and Danish Lithosphere Centre, April 1996.

SUMMARY

This report describes the sedimentology of the mid-Cretaceous to Early Tertiary succession in the Kangerlussuaq region, southern East Greenland. The Kangerlussuaq region is situated along the south western margin of the North Atlantic, and represents one of the best outcrop analogues for the deep offshore areas along the Faroe, Møre and Vøring plateaus.

The clastic succession reaches c. 1 km in stratigraphic thickness and is divided into four facies associations: 1) An 150 m thick, Upper Aptian to Albian, fluvial to estuarine association of coarse grained sandstones with thin shale interbeds. The sandstones show dominantly easterly palaeocurrent directions. The interbedded brackish to marine shales contain up to 9% TOC. 2) A c. 400 m thick, Upper Cretaceous to Lower Paleocene submarine fan association, with a lower shale dominated part that passes upward into channelised sandy turbidites. The channelised turbidites consist of sharp based, amalgamated, fine grained sandstones forming up to 35 m thick fining-upwards successions and separated by heterolithic shales. Palaeocurrents were towards the east and southeast. The offshore marine shales contain 1-2% TOC. 3) An Upper Paleocene fluvial channel sandstone and fine grained floodplain association, which overlies a regional erosional unconformity. The fluvial deposits form a laterally continuous sheet of pebbly trough cross-bedded sandstones, up to 20 m thick, showing southeasterly palaeocurrents. TOC content show significant local variations and reach 32% in lacustrine carbonaceous shales. 4) An Upper Paleocene association of volcanoclastic sediments interbedded with thin lava flows. This succession shows pronounced local thickness variations, locally reaching thicknesses of up to 250 m. It consists of fluvial sandstones interbedded with lacustrine tuffs, subaerial debris flows and hyaloclastites, which updip pass into basaltic lava flows. Marine incursions occur locally in the lower part of the volcanic succession.

The basin received coarse clastic input in the Aptian–Albian, followed by a Late Cretaceous deepening. An abrupt shallowing occurred in the Late Paleocene and following a basin wide erosional unconformity continental sediments were deposited over most of the region. During this probably regional uplift, vast amounts of coarse clastic material was shed into the basinal areas southeast of Kangerlussuaq. The unconformity marks onset of volcanism in the area and the overlying sediments show an upward increasing content of volcanic material. Following the uplift a number of local basins with differentiated subsidence rates developed and significant thickness variations occur in the Upper Paleocene–Lower Eocene volcanoclastic succession.

A 4–5 km thick succession of plateau basalts accumulated during the Late Paleocene–Early Eocene. In association with the initial volcanism and continental break-up a large scale coastal flexure and fault system developed, accompanied by the intrusion of several generations of dykes and sills. The area was exposed to erosion following regional uplift in the mid-Oligocene.

CONTENTS

INTRODUCTION

Field work was carried out in the summer 1995 in the Cretaceous-Paleocene clastic sediments exposed in the Kangerlussuaq area at 68°30'N on the east coast of Greenland (Fig. 1). A geological team of 2 geologists workined from field camps in the terrain. Logistic support was provided from a base camp in Sødalen, assisted by helicopters. The coastal areas are characterised by high peaks and steep promontories next to deep fjords with a topography mainly controlled by a coast-parallel dyke swarm. The inland area is rough gneissic terrain alternating with broad plateaus (often ice covered) of plateau basalts. The area is covered by glaciers except for the coastal region, inland valleys and isolated nunataks.

During the field work focus was on stratigraphy, sedimentary facies and depositional environments, sand distribution and sediment transport directions (source areas and drainage patterns). Six key-sections in the main outcrop area and a number of reconnaissance localities were studied (Fig. 1.). A total of 1100 m of vertical section were measured in the scale 1:50 (Appendix A), and supplemented with lateral sketches and photographs. Rock samples were collected systematically in order to provide material for palynological and geochemical studies. An extensive lateral outcrop of a mid-Cretaceous sandy succession at locality 3, "Watkins" was documented by a series of overlapping photographs in order to provide a database for multimodel stereogeographic measurements (c.f. Dueholm & Pedersen, 1991).

The presence of two helicopters in the area during the field season allowed visits to hitherto undescribed sections and for the first time a collection of data for sedimentological, stratigraphic and sequence stratigraphic analysis of the entire region have been achieved.

The 1995 field work was concentrated on the following localities numbered from southwest towards the northeast:

Locality 1, Vandfaldsdalen: Upper Cretaceous–Upper Paleocene marine shales and turbidites overlain by coarse conglomerates and volcanics.

Locality 2, Sødalen / Canyondal: Upper Cretaceous–Paleocene shallow marine shales and sandstones unconformably overlain by fluvial sandstones.

Locality 3, "Watkins": Mid–Cretaceous coastal plain and estuarine sandstones overlain by marine shales. This locality provided new data on the Cretaceous succession with implication for the timing of basin evolution.

Locality 4, "Sorgenfri": Paleocene? marine shales and sandy turbidites.

Locality 5, "Tempelbjerg": Upper Cretaceous–Lower Paleocene marine shale and turbidite succession unconformably overlain by Paleocene fluvial sandstones and lacustrine shales interfingering with volcanoclastic sediments and lava flows.

Locality 6, Nansen Fjord: Lower Paleocene shales and fluvial sandstones overlain by a thick volcanoclastic succession.

The following localities were studied and sampled during brief helicopter reconnaissances:

Pyramiden: Cretaceous–Paleocene? marine shales and turbidites.

Nansen Fjord A, B: Paleocene fluvial meander belt sandstones and lacustrine shales. Reference localities to the main profile of Nansen Fjord (Locality 6).

Skærmen: Conglomerates and estuarine sandstones of uncertain age onlapping the crystalline basement.

Sortekap and Narren: Reconnaissance on the footwall block of the Sortekap Fault.

The Kangerlussuaq region is situated at the south western side of the North Atlantic, and forms one of the best outcrop analogues for the offshore areas along the Faroe, Møre and Vøring plateaus. The Cretaceous-Tertiary sedimentary basins in the North Atlantic region have acquired increased interest as petroleum exploration has started in these deep offshore areas (e.g. Hinz *et al.*, 1993; Mitchell *et al.*, 1993). The main objective of the present study is to describe the Cretaceous–Tertiary sedimentary basin fill of the Kangerlussuaq area in terms of timing and type of sedimentation, basin evolution and interaction with volcanics. The study aimed to supplement the volcanic rifted margin investigations carried out by the Danish Lithosphere Centre (DLC).

The present study is economically supported by SAGA Petroleum a.s., Norway, Dansk Olie- og Gasproduktion (DOPAS) on behalf of the Amarada Hess Group (Amerada Hess Ltd, LASMO, Norsk Hydro and DOPAS A/S), and Danish Lithosphere Centre (DLC). The project forms part of a major research project on petroleum systems in the sedimentary basins of North and East Greenland supported by the Danish Research Councils (Stemmerik *et al.*, in press).

PREVIOUS STUDIES

The dykes and the volcanic succession has been intensively studied (for references see Brooks & Nielsen, 1982; Brooks, 1994) due to the excellent exposures providing insight to the early stages of continental break-up but little attention have been awarded the sedimentary succession. Sedimentary sections from the area were first measured by Wager (1934) and Wager & Deer (1939), in the coastal areas around Miki Fjord (Vandfaldsdalen, Sødalen), Rybjerg Fjord and Sorgenfri Gletcher. Wager (1947) described the first geological map (1:500 000) of the area based on the previously measured sections and data from field work in the inland areas.

Detailed stratigraphic studies were made by Soper *et al.* (1976a), and the pre-basaltic sedimentary succession was divided into three formations: the Sorgenfri Formation (Albian–Cenomanian), the Rybjerg Formation (Campanian?–Danian) and the Vandfaldsdalen Formation (Upper Paleocene–Lower Eocene). Higgins & Soper (1981) discussed the Late Cretaceous and Early Tertiary basin evolutionb and suggested that the Eocene basin margin to north was located at the present nunatak Kulhøje. The relations between sediments and the initial volcanics were discussed by Nielsen *et al.* (1981), and new sedimentological work on the coastal sections was presented together with a detailed geological map (1:40 000) of the Miki Fjord area. Modern sedimentological studies of isolated outcrops were carried out by Hamberg and Nørgaard-Pedersen during field work in 1988, 1990 and 1991 (Hamberg, 1990; Nørgaard-Pedersen, 1991, 1992).

NORTH ATLANTIC PALAEOGEOGRAPHY

Palaeogeographic reconstructions of the North Atlantic region prior to Cenozoic sea-floor spreading have been presented in a number of studies (e.g. Ziegler, 1981, 1988; V. Larsen, 1987; H.C. Larsen, 1988; Doré, 1991; Knott *et al.*, 1993). Of special interest to the present study is the suggested pre-drift position of the present day Faroe Islands only c. 100 km southeast of the Kangerlussuaq area (e.g. Larsen, 1988; Myhre *et al.*, 1992; Knott *et al.*, 1993)(Fig. 2).

During the Cretaceous, proto-North Atlantic seafloor spreading occurred along the Rockall Trough associated with extension in the Faroe-Møre-Vøring basins (Smythe, 1989; Doré, 1991; Knott *et al.*, 1993). The presence of Cretaceous extensional basin along the proto-Atlantic transect close to the east coast of Greenland have been suggested (Doré, 1991; Knott *et al.*, 1993) and may find parallels in the early basin formation in Kangerlussuaq. The axes of seafloor spreading later shifted to the North Atlantic (*sensu stricto*) leaving the Rockall Plateau and the failed Rockall Trough attached to Eurasia (Knott *et al.*, 1993). Seafloor spreading between the Kangerlussuaq region (Greenland) and the present day Faroe Islands (Eurasia) started at chron 24R - 53 Ma (Brooks & Gleadow, 1977; Larsen, 1978; Larsen & Jacobsen, 1982; Srivastava & Tapscott, 1986). The sea-floor spreading was associated with extensive volcanism.

GEOLOGICAL SETTING

The Kangerlussuaq basin probably forms the southwards extension of the well-known Mesozoic rift system exposed onshore East Greenland from Scoresby Sund at about 70°N and northwards. Between Scoresby Sund and Kangerlussuaq Tertiary plateau basalts cover older sediments and knowledge of the basin-fill is restricted to a few metres of Upper Cretaceous black mudstones exposed in an extensive faulted terrain at Kap Brewster (Watt & Wrang, 1984). In the Kangerlussuaq region, however, Oligocene uplift and later erosion have exposed a c. 1 km thick clastic sedimentary succession below the basalts.

Precambrian gneisses form the basement in the Kangerlussuaq area (Fig. 1). The crystalline basement formed an irregular depositional surface onto which the Cretaceous–Lower Tertiary sediments onlap (Soper *et al.*, 1976a). The Cretaceous sedimentary basin was bounded by the crystalline basement rising to the west and north. The lower boundary of the sediment succession and the contact to the crystalline basement is exposed at the basin margins. The oldest sediments discovered to date are of Early Cretaceous age. A deep marine basin developed in the Late Cretaceous to Early Tertiary followed by rapid uplift during the Late Paleocene.

Early volcanic accumulation was confined to the old sedimentary basin and consists of lavas that pass laterally into hyaloclastites, breccias, tuffs and tuffaceous sandstones of which the major part was deposited in a shallow marine basin (Nielsen *et al.*, 1981). The volcanic activity continued with the extrusion of thick continental plateau basalts (up to 4-5 km) over the entire area.

Major Tertiary gabbroic and syenitic intrusions are found in the area and gave rise to greenschist facies metamorphism of the sediments around Miki Fjord. The coastal region is otherwise dominated by coast-parallel dyke swarms with an increase in dyke intensity towards the coast (Wager, 1934). The dyke swarms are related to tension associated with continental rifting, and dyke emplacement occurred over a period of at least 20 m.y. (Brooks & Nielsen, 1982). Dolerite sills are prominent in the inland areas and locally sediments occur as rafted units in major sill complexes. The area was exposed to regional uplift and erosion started during the mid-Oligocene.

LOCAL TECTONICS AND STRUCTURES

The Sortekap Fault is a major normal fault striking northeast–southwest with downthrow to the south-east of 800-1000 m (Fig 1). It forms a prominent morphological element in the northern part of the sediment area and probably influenced the basin evolution and sediment distribution (Wager, 1947, Higgins & Soper, 1981). The sediments are furthermore displaced by a number of less prominent fault zones striking approximately 60°.

The sedimentary succession shows roughly coast parallel strikes but opposite dip directions were noted between some localities. The sediments dip most frequently 6-22° towards the south-east whereas a few sections show dips of 11-24° towards the north-west. The rather high dip values measured on bedding planes as compared to the estimated regional dip 8-12°S (Wager & Deer, 1939; Wager, 1947; Soper *et al.*, 1976a) was already noted by Nielsen & Brooks (1981) and explained by the presence of a system of coast parallel antithetic faults associated with the Sorte Kap Fault. The orientation of the sedimentary succession, however, suggest the presence of a more complex system of both synthetic and antithetic faults. This is supported by direct observation of minor faults, the age relations between outcrops and variations in orientation of the sedimentary successions. These faults were probably activated during a regional uplift prior to Late Paleocene volcanism. In Vandfaldsdalen a normal fault with downthrow towards the northwest thus offsets deltaic and shallow marine sediments of the Ryberg Formation and is truncated by conglomerates of the Vandfaldsdalen Formation, Schjelderup Member (Fig. 3). It is possible that faults in other places of the basin continued to control basin formation and subsidence during initial volcanism. The presence of a major angular unconformity at Gabbrofjeld as suggested by Wager (1947), can not confirmed by the present study.

STRATIGRAPHY

The pre-drift sediments belong to the Kangerdlugssuaq and the Blosseville Groups. The Kangerdlugssuaq Group was defined by Wager (1947) and later subdivided into the Sorgenfri and the Ryberg Formations (Soper *et al.* 1976a)(Fig. 4). The Blosseville Group in the Kangerlussuaq region comprises the main basalt series and has been divided into four formations (Wager, 1947; Soper *et al.*, 1976a; Nielsen *et al.*, 1981) of which only the oldest, the Vandfaldsdalen Formation will be considered. The stratigraphic thickness reaches close to 1 km.

During the 1995 field season, a hitherto undescribed sandstone dominated succession of Early Cretaceous age was recorded below the Sorgenfri Formation. This succession is more than 150 m thick, and consists of fluvial and estuarine sandstones of Late Aptian age. The sandy succession passes upwards into marine shales and thin turbidites presumed to belong to the Sorgenfri Formation (Fig. 4).

The Sorgenfri Formation was defined on the basis of c. 30 m of grey sandy shales of Late Albian–Cenomanian age exposed in an isolated outcrop on the eastern side of Sorgenfri Gletcher (Soper *et al.* 1976a). The formation is here defined to include deep marine sediments of Late Cretaceous age. Equivalents to the Sorgenfri Formation are found at the base of the section in Pyramiden and overlie the Lower Cretaceous succession at locality 3. The stratigraphic thickness is suggested to be close to 400 m (Figs. 4, 5).

The Ryberg Formation includes the main part of the pre-basaltic sedimentary succession. The formation consists of shales and channelised fine to medium-grained, locally coarse-grained sandstones (Soper *et al.*, 1976a; Hamberg, 1990). The sediments are exposed in Vandfaldsdalen, Sødalen, Ryberg Fjord and east of Sorgenfri Gletcher. The formation consists of a general coarsening-upward succession with a maximum thickness of c. 200-300 m (Hamberg, 1990). The formation is unconformably overlain by conglomerates of the Vandfaldsdalen Formation (Soper *et al.*, 1976a; Nielsen *et al.*, 1981; Hamberg, 1990). The Ryberg Formation has been dated as Campanian?–Danian (Soper *et al.*, 1976a) (Figs 4, 5).

The Vandfaldsdalen Formation forms the lowest formation in the Blosseville Group and marks the beginning of the phase of uplift and volcanic activity. The formation has been divided into four members (Nielsen *et al.*, 1981), of which only the lowest, the Schjelderup Member, comprises significant non-volcanoclastic sediments. The Schjelderup Member in the lower part consists of sandstones and conglomerates c. 20 m thick; it passes up into basaltic flows, hyaloclastic breccias and marine tuffs. The sediments are best exposed in Vandfaldsdalen and in the coastal areas (Sødalen, Jacobsen Fjord Inlier, Brecciadal, Schjelderup, and Ryberg Fjord) (Soper *et al.*, 1976a; Nielsen *et al.*, 1981). It has been dated as latest Paleocene–earliest Eocene, Late Thanetian–Early Ypresian? (Sparnacian of Soper *et al.*, 1976a)(Figs. 4, 5).

Ammonite stratigraphy

A few horizons in the Cretaceous succession have been dated by ammonites although the fauna is sparse and datings often rely on the identification of a single specimen (Fig. 5). From the section at Ryberg Fjord ammonites of early Cenomanian age (*Mantelli* zone, *Mantelliceras saxbii* subzone) were described from the Sorgenfri Formation (Soper *et al.*, 1976a). *Pachydiscus gollevillensis* (d'Orbigny) of Early Maastrichtian or Late Campanian age was described by the same authors from the Ryberg Formation east of Sorgenfri Gletcher. Nørgaard-Pedersen (1991) found a single specimen of presumed Cretaceous age from the Ryberg Formation? in the lowermost outcrops at Kulhøje.

During the 1995 field work ammonites were found in three horizons at locality 3, "Watkins". The specimens were determined by Professor J. H. Callomon, University College, London. The lowest horizon contains *Tropaeum subarcticum* Casey (1960) of Late Aptian age (*Nutfieldiensis* Zone). The middle horizon includes specimens of Middle Albian age whereas a single specimen of a long ranging, pelagic affinity (*Phylloceras*) was found the uppermost horizon . The succession thus represents the oldest sediments yet described from the Kangerlussuaq region.

Palynological studies

A total number of 60 siltstone and shale samples collected during the 1995 field work have been processed in order to evaluate the palynological potential of the sediments. The samples are not fully described and work are still in progress, however, all of the processed samples seem to have been exposed to extensive heating (see section on geochemistry).

SEDIMENTOLOGY

Upper Aptian to Albian, fluvial to estuarine sandstones

Locality 3, "Watkins"

Mid-Cretaceous sediments are described from a down-faulted succession at locality 3 (Fig. 6, appendix A). It is divided into two main stratigraphic units:

1) A lower unit of Late Aptian age which is up to 55 m thick and consists of fluvial to coastal plain sediments including meandering channel, bay fill and thin prograding shoreface deposits. An equal area plot of foreset dip azimuths of the fluvial sandstones shows easterly palaeocurrent directions (vector mean 87°) (Fig. 7). The coastal plain deposits are truncated by a distinct ravinement surface overlain by a conglomerate bed, that is suggested to have formed by winnowing during the ravinement process. The ravinement conglomerate is overlain by sandy marls interbedded with shale. The marls contain a marine macro-fauna with ammonites and the bivalve *Camptonectes* (Fig. 8).

2) An Lower–Middle Albian?, sandstone-dominated estuarine unit up to 100 m thick. The estuarine succession consists of coarse to very coarse grained quartzitic sandstones forming elongate sandstone bodies (Figs. 9, 10). The sandstones are bioturbated and contains marine burrows such as *Diplocraterion*, *Arenicolites* and *Ophiomorpha*. Ammonites of Mid-Albian age were found in a shale horizon c. 10 m

below the top of the sandstones. The sandstone succession is overlain by marine shales several hundred metres thick.

The sandstone bodies are up to 20 m thick and have been traced along strike for several kilometres (Fig. 9). In the lower part they are amalgamated, showing erosional lower boundaries with a relief of up to 3 metres. In the upper part very large-scale to giant-scale cross-bedded units occur. These units have conformable boundaries and form isolated sandstone bodies separated by thin marine shales. The sandstone bodies wedge out in shales in a northerly and northeasterly direction. The palaeocurrent directions are towards the east (vector mean 74°). Within individual sandstone bodies foreset dip azimuths of the large scale foresets are consistently unimodal, however, with a marked bimodal population (55° and 129°) (Fig. 11). The stacked sandstone bodies show lateral offset and thickness variations controlled by the underlying units.

The sandstones are interpreted to have formed in an estuarine setting dominated by ebb currents. The upwards change from amalgamated locally channelised to large-scale cross-bedded sandstone bodies separated by shales suggests increasing accommodation space possibly related to an overall rise in relative sea-level. The large-scale to giant-scale cross-bedding formed by lateral accretion on the downstream end of large-scale sand bars in estuarine channels.

Upper Cretaceous to Lower Paleocene submarine fans

During the Late Cretaceous to Early Paleocene sedimentation was characterised by marine shales and sandy turbidites of submarine fan origin. The succession belong to the Kangerdlugssuaq Group and is illustrated by sections exposed at locality 4, "Sorgenfri" and locality 5, "Tempelbjerg". The succession have also been studied in Sødalen/Canyondal, at Pyramiden, and north of Ryberg Fjord (cf. Soper *et al.*, 1976a; Nielsen *et al.*, 1981; Hamberg, 1990).

Locality 4, "Sorgenfri"

The measured section is 170 m thick and dominated by laminated, marine silty shales interbedded with sandy turbidites. The succession shows an overall increase in sand/mud ratio upwards which is related to a thickening-upwards of the turbidite bed thickness. A lenticular sandstone body up to 8 m thick and with erosional lower boundary, is found in the upper part of the section. The succession is unconformably overlain by lava and fluvial volcanoclastic sediments.

The sandy turbidites consist of well-sorted very fine grained sandstones 4 cm to 1 m thick. The thinner beds are parallel laminated or show current ripple cross-lamination with sharp lower boundaries and gradual upper boundaries into flaser bedded heteroliths and silty shales. Beds thicker than 35 cm are usually amalgamated and consist of sandstones separated by thin shale drapings. The thickest beds have a lower massive part overlain by parallel laminated and finally small-scale cross-laminated sandstones. Slump structures e.g. overturned folds, contorted bedding and water escape structures are common in the thicker sandstone beds. The sandy heterolithic shales and some of the sandy turbidites are intensely bioturbated. The burrows are dominantly horizontal burrows of the *Planolites* type.

The sandy turbidites form 0.5-8 m thick, thickening-upwards successions that can be traced laterally for a few hundred metres. The stacked thickening-upward successions form compensation cycles (cf. Mutti, 1977), and are interpreted as distal submarine fan lobes.

The lenticular sandstone body exposed in the upper part of the succession consists of fine grained, locally medium grained, massive to crudely bedded sandstones. The bedding is due to parallel arrangement of thin shale rip-up clasts and carbonaceous detritus. The sandstone succession consists of up to 1.5 m thick, amalgamated sandstone beds separated by deformed silty shales up to 8 cm thick. The lower boundary is strongly erosional and cuts down into laminated silty shales. The erosional surface shows a relief of c. 20 m and can be traced laterally (c. 500 m) into a shale-shale contact. The surface is associated with strong deformation of the surrounding sediments with an angular unconformity of 4° between shale successions below and above the surface. The lenticular sandstone is interpreted the fill of a submarine fan channel filled by sandy debris flows and turbidites. The channel geometry suggests palaeoflows towards the south.

Locality 5, "Tempelbjerg"

A c. 170 m thick submarine fan to offshore marine succession is exposed at locality 5. It consists of five stacked sandstone dominated units forming an overall fining-upward grain-size trend. The sandstone units are interpreted as turbidite channel fills at the proximal part of an submarine fan. Upwards the offshore marine deposits pass rapidly into shallow marine sandstones and laminated mudstones of the transition zone, lower shoreface and finally fluvial conglomerates forming the top of the measured section (Fig. 12).

The sandstone dominated turbidite channels are characterised by fining-upwards grain-size trends and are up to 35 m thick, separated by heterolithic intervals of silty shales and fine grained sandstones up to 8 m thick (Fig. 13). They are characterised by amalgamated lenticular sandstone beds showing sharp erosional lower boundaries in the lower part (Figs. 14, 15). Bed thickness varies between 20 cm and up to 1 m. The sandstones are massive with scattered clasts of pebble sized quartz grains and shale rip-up clasts, slumped units and sandstone beds with water-escape structures are common. An upwards change into parallel sided sandstones beds are observed, these beds are massive or parallel to small-scale cross-laminated. The sole of the sandstone beds commonly show parting lineation or flute marks (Fig. 16), indicating palaeoflow towards the east–southeast (Fig. 17). The sandstones are bioturbated and contain *Planolites*, *Arenicolites* and *Monocraterion* burrows.

The sandstones form large-scale lenticular bodies which over a lateral distance of 200-800 m pass into shale dominated successions characterised by thin classical turbidites (Fig. 18, 19), with internal low angle unconformities interpreted as slump scours (Fig. 20). The presence of these low angle erosional surfaces suggests that deposition occurred on gently sloping depositional surfaces exposed to synsedimentary slumping possibly in a levee/channel environment on a submarine fan. Shallow and broad crevasse channel sandstone bodies are common in the interchannel areas and were filled by a single depositional event. (cf. Mutti, 1977).

Paleocene fluvial channel sandstones and floodplain deposits

The fluvial channel sandstones belong to the Vandfaldsdalen Formation of the Blosseville Group and consist of up to 15 m thick amalgamated, pebbly to coarse grained, erosionally based sandstones, which abruptly overlie marine shales of the Kangerdlugssuaq Group (Fig. 21, 22). They are trough cross-bedded and locally in the finer grained portions parallel laminated (Fig. 22, 23). The pebbles are dominated by clasts with affinity to the local crystalline basement and varies from vein quartz pebbles to mixed assemblages of gneiss, vein quartz and sedimentary rocks (Fig. 22). Carbonaceous detritus and locally rafted logs are common. The sandstones are poorly cemented (or decemented). The pebbly fluvial sheet sandstones are associated with coarse grained crevasse channel fill, lacustrine shales and overbank heteroliths characterised by fine grained sandstones, carbonaceous shales and root horizons (Fig. 24). Readings on foreset azimuths show palaeocurrents towards the east and southeast, although with significant local variations (Fig. 25). The channel sandstones form a continuous sheet which can be followed for tens of kilometres in outcrop (Fig. 26). Correlation between the measured sections is based on lithological resemblance.

It is suggested that this unit formed in response to regional uplift that caused erosion and shed vast amounts of coarse clastic sediments into the sedimentary basin.

Paleocene volcanoclastic sediments and early lava flows

The early lava flows are thin, commonly less than 10 m, and interbedded with fluvial volcanoclastic sediments, laminated lacustrine tuffs or lahars. The lava flows and the volcanoclastic sediments belong to the Vandfaldsdalen Formation of the Blosseville Group and were described from five sections of which locality 6 is situated east of the hitherto known outcrop area. The lavas in locality 1, Vandfaldsdalen and locality 2, Sødalen/Canyondal are thick and have a very pronounced columnar jointing (Fig. 27). They form the lowermost units in a several hundred metres thick pile of stacked lava flows with rare siliciclastic sediment intercalations (Fig. 28).

The lavas in localities 4-6, "Sorgenfri", "Tempelbjerg" and Nansen Fjord occur as subordinate flows in an otherwise siliciclastic and volcanoclastic sedimentary succession. The lavas are poorly exposed due to weathering, but locally show remnants of radiating cooling structure interpreted as pillows. The sediments below the flows are deformed due to the loading of basalts into partly consolidated sediment. Minor erosion of the sediments occurred before or in association with the emplacement of the lava flows. Sediments that directly overlie lava flows drape the hummocky surface of the pillows and fill in cracks and depressions. The lavas accumulated in a waterlocked alluvial plain or in lacustrine or shallow marine embayments based on their structures and the associated sediments.

Extremely well-sorted, paper laminated black tuffaceous shales with a very hard splintery cementation are interbedded with carbonate cemented siltstones and very fine-grained sandstones (Fig. 29). The sandstones are planar laminated, starved ripple cross-laminated and locally small scale hummocky cross-stratified. Well-preserved leave imprints are common on bedding planes (Fig. 30). The laminated tuffs form up to 12 m thick successions associated with fluvial plain deposits and channelised fluvial sandstones and are suggested to have formed in ponds and lakes.

Medium to coarse grained, locally pebbly, sandstones are associated with the lacustrine shales. They are poorly consolidated and dominated by volcanoclastic material and abundant coalified wood fragments. The sandstones show low angle trough cross-bedding with palaeocurrent directions towards the south-east, south and north-west. They are interpreted as fluvial deposits.

A matrix supported breccia with clasts of pillows, boulders of laminated carbonates, coalified wood with bedding planes inclined towards the east and south-east was described at locality 6 (Fig. 31). This unit is very poorly consolidated and is interpreted to have formed by a lahar/subaerial mass flow.

TERTIARY SILLS

Tertiary sills are prominent in the sedimentary succession, and locally form major complexes several hundred metres thick (Figs. 12, 26). They can make up almost 100% of the succession with sediments occurring only as rafted units. The sill complexes show a clear geographic variation with increasing intensity from the coast towards inland, whereas no stratigraphic relationship was observed between the sills and the sedimentary succession. Individual sills commonly follow lithological boundaries e.g. sandstone beds for a few hundred metres, but traced along outcrop they abruptly change course crossing the lithological boundaries. Major sill complexes show severe heat impact on the surrounding sedimentary rocks. The sills in the Kangerlussuaq area show very pronounced columnar jointing developed perpendicular to the sill boundaries.

The distribution, geometry and chemical composition of the Tertiary sill complexes are subject to detailed studies by DLC based on the 1995 field work (C. Tegner, pers. comm., 1996).

GEOCHEMISTRY

During the 1995 field season a total of 313 rock samples were collected for later laboratory studies, 174 of these samples are shales/mudstones. Fifty of the shale/mudstone samples representing the primary sections were examined with geochemical screening analysis on LECO IR-212/ROCK EVAL II. The resulting geochemical parameters are listed in table 1, appendix B.

In summary, the Cretaceous–Lower Paleocene marine shales show a range in Total Organic Carbon (TOC) from 0.06-2.07% (mean 1.38%), whereas Paleocene lacustrine/alluvial plain shales and mudstones range from 0.16-32.6% (mean 4.00%). The very high values are found in black mudstones rich in disseminated carbonaceous detritus and associated with alluvial plain deposits and root horizons. A remarkable high TOC value of 8.7% was found in estuarine shales from the Aptian–Albian section at locality 3. The Hydrogen Index, HI, is low in all of the analyzed samples from 0-83 (mean 16). This indicates dominance of land derived organic material.

T_{max} values are generally high to very high and range from 438°C (one sample shows 290), to more than 574°C (mean of estimated values 523°C). However, estimates of T_{max} are depending on measured S1 and S2 values and as they are consistently low, the liability of the estimated Tmax demand precaution. The high T_{max} values reflect heating from major sill complexes at almost all localities. The sediments were covered by at least 4–5 km of Tertiary plateau basalts. The high heat flow have had severe influence on the preservation potential of dinoflaggelate cysts and thus on the ability to date the sedimentary successions. TOC, T_{max} and HI are plotted against facies on the vertical sections in appendix B.

BASIN EVOLUTION

Based on preliminary analyses of sedimentological and stratigraphic data collected during the 1995 field season and previous studies in the region, the evolution of the basin is summarised in four maps showing the suggested palaeogeography of the Kangerlussuaq area during 1) deposition of alluvial/estuarine sediments in the mid-Cretaceous 2) submarine fan deposition during the Late Cretaceous-Early Paleocene 3) uplift and development of a fluvial drainage systems in the Late Paleocene and 4) early volcanism in the Late Paleocene (Fig. 32a–d).

The mid-Cretaceous sediments form a sandstone-dominated, coarse clastic wedge which may have formed in response to mid-Cretaceous basin-margin uplift. The consistent quartz-dominated lithology and well-sorted nature of the estuarine sandstone complex suggests that a source area of mature sediments was situated west of the Kangerlussuaq area in mid-Cretaceous time. The marine basins deepened towards the east (Fig. 32a). The northeasterly to easterly palaeocurrent directions suggest that estuaries formed parallel to the axis of fault blocks controlled by northeast–southwest striking faults. This is in contrast with the overlying Late Cretaceous to Early Tertiary submarine fan and alluvial depositional systems in the area which show southeasterly palaeocurrents.

The basin deepened during the Late Cretaceous as a result of a global sea-level rise and the mid-Cretaceous shallow marine sandstones are overlain by deep offshore shales and sandy turbidites. In Early Paleocene? time a major turbidite channel complex filled by amalgamated channel sandstone successions formed in the central part of the area. Palaeocurrents were from the north and north-west (Fig. 32b). At the fan margins sedimentation was dominated by laminated siltstones deposited from suspension fall-out interbedded with thin, laterally consistent fine-grained sandy turbidites.

A regional erosional unconformity formed in Late Paleocene time. The unconformity everywhere marks a change from deep marine to continental sedimentation and it probably reflects uplift prior to initial volcanism. The unconformity truncates Paleocene lower shoreface deposits in the central part of the basin at localities 1 and 5, Palaeocene turbidites at locality 4, at Pyramiden and Ryberg Fjord, and Cretaceous shales in the northern part of Sorgenfri Gletcher and at Kulhøje. This pattern is suggested to reflect block faulting associated with the uplift. The duration of the unconformity and the depth of incision increase towards the basin margins.

The unconformity is overlain by pebbly, braided channel sandstones, which prograded from the western and north-western basin margin (Fig. 32c). These fluvial pebbly sandstones formed as a response to the uplift and erosion of the hinterlands and vast amounts of coarse clastics were probably shed into the basinal areas towards the east and south-east.

The pebbly channel sandstones are overlain by fluvial floodplain facies and laminated lacustrine shales showing a significant content of volcanoclastic material (Fig. 32d). Deposition took place in local basins probably controlled by differential subsidence of the underlying fault blocks. The local variations in subsidence rate are seen in the marked thickness variations of the floodplain-lacustrine deposits and are reflected in the observed variance of palaeocurrents e.g. towards east in locality 6, towards southeast in locality 1, and towards north-west at Kulhøje (N. Nørgaard-Pedersen, pers. comm. 1995)(Fig. 32d).

The first lava flows and the early volcanoclastic rocks appear to be confined to the Cretaceous-Paleocene sedimentary basin and consist of picritic to andesitic subaerial flows, hyaloclastites, pillow breccias, laminated tuffs and tuffaceous sandstones of subaqueous origin (Nielsen *et al.*, 1981; Brooks & Nielsen, 1982). The volcanic succession shows strong lateral variation probably related to continued existence of local basins and the formation of several almost contemporaneous volcanic centres in the area. Sedimentary horizons in the lower part of the lava succession indicate shallow marine submergence of some flows. One of these horizons, 60 m above the base of the Vandfaldsdalen Formation, was dated as Late Paleocene (NP 9) by means of microplanktons (Soper *et al.*, 1976b). The volcanic activity continued into Eocene time, with the extrusion of a several kilometres thick continental plateau basalt succession with units correlatable along the entire Blosseville coast to Scoresby Sund and Milne Land (Wager, 1947; Soper *et al.*, 1976b; Larsen *et al.*, 1989).

Associated with the volcanic activity and continental break-up a large scale coast parallel flexure and fault system developed in the area accompanied by the intrusion of several generations of dykes and sills (Wager, 1947; Nielsen, 1975; Brooks & Nielsen, 1981). The Kangerlussuaq area was uplifted during the mid-Oligocene.

COMPARISON WITH CONTEMPORANEOUS SUCCESSIONS

The basin evolution onshore East Greenland have strong implications for the understanding of the evolution of the Faroe-Shetland Basin and the Møre and Vøring Basins on the European side of the North Atlantic Ocean. The succession is contemporaneous with the mid-Cretaceous Atlantic rift systems offshore eastern Canada, in West Greenland, Ireland, the UK and with clastic wedges offshore Norway e.g. the Agat area.

Onshore East Greenland and the Vøring Basin

The Kangerlussuaq region forms the southwards extension of the well-known and intensively studied Mesozoic rift system exposed onshore East Greenland from Scoresby Sund at about 70°N and northwards (Surlyk, 1973; 1978; 1990, Surlyk *et al.*, 1981; 1984; Stemmerik *et al.*, 1993). The rift basins extends south of Scoresby Sund but are largely covered by Tertiary plateau basalts and knowledge of the basin-fill is very limited (Larsen & Marcussen, 1992). Post-Caledonian basin formation started in the Devonian and continued into the Cretaceous.

The Cretaceous succession exposed in Jameson Land is restricted to the Ryazanian–lowermost Valanginian (Surlyk, 1991). North of Kong Oscars Fjord at 72°30'N a succession of dominantly marine offshore shales and local fault controlled conglomerates of mid-Cretaceous to Late Cretaceous age is exposed. The successions in Wollaston Forland and Hold with Hope are overlain by Tertiary basalts. Recent field work, however, have revealed shallow marine sandstones of supposed mid-Cretaceous age (L. Stemmerik, pers. comm., 1995). The Traill Ø–Geographical Society Ø–Hold with Hope region forms the conjugate margin to the Vøring Basin on the Norwegian shelf and is key area for sedimentological field work during the summer 1996.

Faroe Islands

The existence of a sedimentary succession below the basalts in the Faroe Islands is suggested on the basis of seismic surveys around the Lopra well on Suderoya (Kiørboe & Petersen, 1995). The base of the basalts were estimated to a depth of 2.34 km below the land surface.

Based on data from the Kangerlussuaq region, which forms the conjugate margin to the Faroe platform, the sedimentary basins most likely reflects extension and subsidence during the mid-Cretaceous to Early Paleocene. Prior to rifting these basins may have received coarse clastic sediments from the western margin (e.g. East Greenland) which was situated only c. 100 km to the northwest (Fig. 2). The sedimentary succession is likely to be strongly intruded by Tertiary sills and may have been exposed to extensive heat flow.

Møre Basin

The evolution and basin fill of the Møre basin is mainly interpreted from seismics. The basin history is related to extension during initial seafloor spreading in the Cretaceous (cf. Knott *et al.*, 1993). In the Agat area on the southwards extension of the Møre Basin an Aptian–Albian prograding clastic wedge have been penetrated by wells (Gulbrandsen, 1987). The sediments are dominated by sandy massflows deposited in submarine channels. The progradation of coarse clastics into the otherwise mud-dominated basin may be related to basin margin uplift or a regional sea-level lowstand. The event is contemporaneous with deposition of a thick sandy succession in the Kangerlussuaq basin suggesting that basin margin uplift may have occurred contemporaneous throughout the North Atlantic region. The Møre Basin is separated from the East Greenland rift basins by the Jan Mayen Block, which may have acted as an intrabasinal high during the Mesozoic (cf. Larsen, 1987, Doré, 1991).

West Greenland

The Cretaceous–Tertiary sedimentary history in the central West Greenland show many similarities with the Kangerlussuaq region although the timing of volcanism and continental break-up is different. Cretaceous and Early Tertiary sediments and Early Tertiary volcanic rocks related to the development and opening of the Labrador Sea and Davis Strait are exposed on the island of Disko and the peninsulas of Nuussuaq and Svartenhuk Halvø (69–72°N)(Rosenkrantz, 1970; Chalmers & Pulvertaft, 1993). The onshore Cretaceous sediments consist of Albian–Santonian fluvial deltaic sediments passing northwest-wards into organic rich marine shales of Turonian–Maastrichtian age (Henderson *et al.*, 1976) Detailed sedimentological studies on slope channels and incised valley fill have been undertaken by Dam & Sønderholm,

(1994) and Dam & Sønderholm (in press.). Important faulting took place near the end of the Maastrichtian, resulting in an angular unconformity between the Cretaceous and the Tertiary sediments in much of the area. The faulting was associated with deep erosion of the Cretaceous sediments and deposition of coarse conglomerates in proximal areas and turbidite fans in more distal settings (Rosenkrantz & Pulvertaft, 1969; Christiansen *et al.*, 1992). Recent drillings in the summers 1993, 1995 through oil impregnated basalts on Nuussuaq and Svartenhuk Halvø have provided new data on petroleum potential of the region (Dam & Christiansen, 1994, Christiansen *et al.*, 1995).

On the west coast of Greenland volcanism started already in the Early Paleocene chron 27 (Piasecki *et al.*, 1992), with the extrusion of subaqueous picritic pillow lavas and breccias (Clark & Pedersen, 1976). The continued accumulation of volcanic products caused the formation a dammed lakes (Pedersen, 1989) and the lavas were finally extruded as subaerial flood basalts. The exploration history of southern West Greenland have been summarised by Chalmers & Pulvertaft (1993) and Chalmers *et al.*, 1993).

IMPLICATIONS FOR PETROLEUM EXPLORATION

Hydrocarbons in southern East Greenland

Migrated hydrocarbons occur in basalts associated with a major fault zone on the southern side of Scoresby Sund (Watt & Wrang, 1984). The hydrocarbons were extracted from a surface sample and were affected by extensive biodegradation and water washing. Because of the biodegradation no indications of the possible source of the material were found, but it was interpreted as migrated oil from the Mesozoic sedimentary succession presumed to exist at a depth of 800 m below the plateau basalts (Watt & Wrang, 1984; Larsen & Marcussen, 1992). Other although somewhat questionable indications for hydrocarbons below the plateau lavas on the Blosseville coast are found in methane gas reported from warm springs in the basalts at Rømer Fjord (Halliday *et al.*, 1974). The methane content in gas samples reaches 30% (CH_4), with no traces of typical volcanic gases.

Basin evolution

The area provides unique opportunities to study the sedimentological development and the interplay between local basin evolution and the regional uplift prior to the volcanism and rifting of the North Atlantic. The parallels in evolution of the West

Greenland and the Kangerlussuaq basins allow comparisons of the mechanisms of continental break-up (test of plume models?) although the timing of break-up differs slightly in age.

The evolution of the Kangerlussuaq provides information on the development and stratigraphy of the sedimentary basins in the Faroe-Shetland area, and if supplemented with data from northern East Greenland also the Møre and Vøring basins. East Greenland may thus have acted as the western sediment source to the northern Atlantic Cretaceous-Early Paleocene basins. A similar setting existed during the Carboniferous-Permian where sediment input to the western Shetland basin area from East Greenland (c.f. Allen & Mange–Rajetzky, 1992)

The interpretation of the turbidite succession at locality 5, "Tempelbjerg" as deposited in a submarine fan channel suggests that a considerable amount of sandy sediments may have bypassed the Kangerlussuaq area in Late Cretaceous-Early Tertiary time. This material has to be found in basins below the Tertiary basalts southeast of Kangerlussuaq.

Upper Paleocene regional uplift and erosion in the Kangerlussuaq area shed large amounts of coarse grained clastic material into the basins southeast of the present day coast line. Deposition may have occurred in the present day Faroe Island area or it may have been trapped in fault basins in the initial rift. Provenance studies on the sediments onshore may, thus provide a reference if sediments are recovered from scientific or exploration drillings in the future (e.g. the Lopra well on the Faroe Islands). The suggested play type of basin floor fans related to Early Tertiary thermal uplift parallels the post-rift play type of the North Sea and of the western margin of the UK continental shelf (c.f. Knott *et al.* (1993), Anderton, 1993).

Outcrop based reservoir models

Detailed outcrop descriptions of sandstones bodies provide possibilities to evaluate the potential reservoir properties of sandstones deposited in different depositional environments. The outcrops further provide information on large scale geometric relations between sediments and Tertiary sill complexes intruded during the volcanic phase associated with the rifting.

Laboratory studies

The systematic sampling of sedimentary rocks during the field work provides a data base for future laboratory work on provenance, porosity/permeability, and diagenesis of sandstones and on geochemistry, and palynology/micropaleontology of shale samples. It is the hope that interbedding of fossiliferrous clastic sediments and the initial lava flows can improve the age constrain on the continental break-up and early volcanic activity in the region.

SUMMARY AND CONCLUSIONS

The following can be concluded on the mid-Cretaceous to Early Tertiary basin evolution in the Kangerlussuaq area, southern East Greenland.

1) An hitherto unknown, more than 160 m thick sandstone succession indicates input of coarse siliciclastic material on the western margin of the North Atlantic during the mid-Cretaceous (Aptian-Albian).

2) Upper Cretaceous offshore marine shales are overlain by thick sandstone dominated submarine fan deposits formed in response to increasing sediment input during the Early Paleocene.

3) The Lower Paleocene submarine fan deposits form up to 35 m thick fining-upwards successions of sharp-based, amalgamated turbidites interpreted as the fill of large submarine channels.

4) Regional uplift associated with normal faulting occurred prior to volcanism in the Late Paleocene, new palynological data on interbedded marine shales and volcanoclastic sediments may date the earliest lava succession.

5) The Late Paleocene uplift caused strong erosion of the basin margins and deposition of pebbly, proximal braided river deposits in Kangerlussuaq. It is suggested that large amounts of coarse siliciclastic sediments bypassed the area and were deposited in basins southeast of the area.

6) Differentiated subsidence rates in local basins controlled volcanoclastic deposition and lava accumulation during the Late Paleocene.

7) Sedimentary successions related to the North Atlantic rifted margin are likely to be intruded by sills. In the Kangerlussuaq area no stratigraphic relationship was observed between the sills and the sediments.

REFERENCES

Allen, P.A. & Mange-Rajetzky, M.A., 1992: Devonian–Carboniferous sedimentary evolution of the Clair area, offshore north-west UK: Impact of changing provenance. Marine and Petroleum Geology, 9, p. 29-52.

Anderton, R., 1993: Sedimentation and basin evolution in the Paleogene of the Northern North Sea and Faroe–Shetland basins. *In* Parker, J. R. (ed.) *Petroleum geology of Northwest Europe: Proceedings of the 4th conference*, 31. London: Geological Society.

Brooks, C.K., 1994: The Kangerdlugssuaq Project, twenty years of research on the evolution of a volcanic rifted continental margin. Report Geologisk Institut & Dansk Lithosfære center, Copenhagen 1994.

Brooks C.K. & Gleadow, A. J. W., 1977: A fission track age for the Skaergaard intrusion and the age of the East Greenland basalts. Geology, 5, 539-540.

Brooks C.K. & Nielsen, T.F.D., 1982: The Phanerozoic development of the Kangerdlugssuaq area, East Greenland. Meddelelser om Grønland, Geosciences 9, 30 pp.

Chalmers, J.A. and Pulvertaft, T.C.R., 1993: The southern West Greenland continental shelf – was petroleum exploration abandoned prematurely? *In*: Vorren, T.O., Bergsager, E., Dahl-Stamnes, Ø.A., Holter, E., Johansen, B., Lie, E. & Lund, T.B. (Eds) Arctic geology and petroleum potential. NPF Special publication 2, Elsevier, Amsterdam, p. 55-66.

Chalmers, J.A., Pulvertaft, T.C.R., Christiansen, F.G., Larsen, H.C., Lauersen, K.H. and Ottesen, T.G., 1993: The southern West Greenlaand continental margin: rifting history, basin development, and petroleum potential. *In* Parker, J. R. (ed.) *Petroleum geology of Northwest Europe: Proceedings of the 4th conference*, 915-931. London: Geological Society.

Christiansen, F.G., Dam, G., McIntyre, D., Nøhr-Hansen, H., Pedersen, G. K. and Sønderholm, M., 1992: Renewed petroleum geological studies onshore West Greenland. Rapport Grønlands Geologiske Undersøgelse, 155, 31-35.

Christiansen, F.G., Marcussen, C. and Chalmers, J. A., 1995: Geophysical and petroleum geological activities in the Nuussuaq–Svartenhuuk Halvø area 1994: promising results for an onshore exploration potential. Rapport Grønlands Geologiske Undersøgelse, 165, 32-41.

Christensen, W.K. & Hoch, E., 1983: *Actinocamax* cf. *manitobensis* from the Kangerdlugssuaq area, southern East Greenland. Bulletin geological Society of Denmark, 32, p. 33-42.

Clarke, D. B., and Pedersen, A. K., 1976: Tertiary volcanic province of West Greenland. *In* A. Escher and W. S. Watt (Eds) *Geology of Greenland.* Geological Survey of Greenland, Copenhagen, 365-385.

Dam, G. and Christiansen, F. G., 1994: Discovery of live oil at Marrat, Nussuaq: field work, drilling and logging. Rapport, Grønlands geologiske Undersøgelse, 160, 57-63.

Dam, G. and Sønderholm, M., 1994: Lowstand slope channels of the Itilli succession (Maastrichtian–Lower Paleocene), Nuussuaq, West Greenland. Sedimentary Geology, 94: 49-71.

Dam, G. and Sønderholm, M., in press: Sedimentological evolution of an incised valley system, Lower Paleocene Quikavsak Member, Nuussuaq, West Greenland. *In* Shanley, K.W., and McCabe, P.J., (Eds.) Relative role of eustasy, climate, and tectonism in continental rocks. Society of Sedimentary Geology (SEPM) Special Publication.

Doré, A.G., 1991. The structural foundation and evolution of Mesozoic seaways between Europe and the Arctic. Palaeogeography, Palaeoclimatology, Palaeoecology, 87: 441-492.

Dueholm, K.S. & Pedersen, A.K. (Eds), 1992: Geological analysis and mapping using multi-model photogrammetry. Rapport, Grønlands geologiske Undersøgelse, 156, 72 pp.

Halliday, G., Kliim–Nielsen, L. and Smart, I.H.M., 1974: Studies of the flora of the North Blosseville Kyst and on the hot springs of Greenland. Meddelelser om Grønland, 134 (2), p. 30-32.

Hamberg, L., 1990: The pre-basaltic upper Cretaceous-Tertiary sediments of the Kangerdlugssuaq area: Evidence of submarine syn-rift deposits. *In* C.K. Brooks (ed.) Kangerdlugssuaq studies: Processes at a continental rifted margin. Proceedings from meeting 24. January 1990. Copenhagen 1990. p. 46-55.

Henderson, G., Rosenkrantz, and Schiener, E. J., 1976: Cretaceous–Tertiary sedimentary rocks of West Greenland. *In* A. Escher and W. S. Watt (Eds) *Geology of Greenland.* geological Survey of Greenland, Copenhagen, 341-362.

Higgins, A.C., & Soper, N.J., 1981: Cretaceous-Palaeogene subbasaltic and intrabasaltic sediments of the Kangerdlugssuaq area, Central East Greenland. Geological Magazine 118, p. 337-448.

Hinz, K., Eldholm, O., Block, M. & Skogseid, J. 1993: Evolution of North Atlantic volcanic continental margins. *In* Parker, J. R. (ed.) *Petroleum geology of Northwest Europe: Proceedings of the 4th conference*, 901-913. London: Geological Society.

Kiørbo, L. & Petersen, S. A., 1995: Seismic investigation of the Faeroe basalts and their substratum. *In* R.A. Scrutton, M. S. Stoker, G. B. Shimmield and A. W.

Tudhope (Eds) *The tectonics, sedimentation and Palaeooceanography of the North Atlantic Region.* Geological Society Special Publication, 90, 111-122.

Knott, S. D., Burchell, M. T., Jolley, E. J., and Fraser, A. J., 1993: Mesozoic to Cenozoic plate reconstructions of the North Atlantic and hydrocarbon plays of the Atlantic margins. *In* Parker, J. R. (ed.) *Petroleum geology of Northwest Europe: Proceedings of the 4th conference*, 953-974. London: Geological Society.

Larsen, H.C. 1978: Offshore continuation of East Greenland dyke swarm and North Atlantic formation. Nature, 274, 220-223.

Larsen, H.C. 1988: A multiple and propagating rift model for the NE Atlantic. *In* A. C. Morton and L. M. Parson (Eds) *Early Tertiary volcanism and the opening of the NE Atlantic*, Geological Society Special Publication, 39, 157-158.

Larsen, H.C. & Jacobsen, N., 1982: Paleogene spreading along the Northern Reykjanes Ridge: New evidence from offshore East Greenland, Earth and Planetary Science Letters

Larsen, H.C. and Marcussen, C., 1992. Sill-intrusion, flood basalt emplacement and deep crustal structure of the Scoresby Sund region, East Greenland. In: B.C. Storey, T. Alabaster and R.J. Pankhurst (Editors), Magmatism and the causes of continental break-up. Geological Society, Special Publication, 68: pp. 365-386.

Larsen, L. M., Watt, W., & Watt, M. 1989: Geology and petrology of the Lower Tertiary plateau basalts of the Scoresby Sund region, East Greenland. *Bull. Grønlands Geol. Unders.* **157**, 164 pp.

Larsen, V., 1987: A synthesis of tectonically-related stratigraphy in the North Atlantic–Arctic region from Aalenian to Cenomanian time. Norsk Geologisk Tidskrift, 67, 281-293.

Mitchell, S. M., Beamish, G. W. J., Wood, M. V., Malacek, S. J., Armentrout, J. A., Damuth, J. E. & Olson, H. C. 1993: Paleogene sequence stratigraphic framework of the Faeroe Basin. *In* Parker, J. R. (ed.) *Petroleum geology of Northwest Europe: Proceedings of the 4th conference*, 1011-1023. London: Geological Society.

Mutti 1977: Distinctive thin-bedded turbidite facies and related depositional environments in the Eocene Hecho Group (south-central Pyrenees, Spain). Sedimentology, 24, 107-131.

Nielsen, T.D.F., 1975: Possible mechanism of continental break-up in the North Atlantic. Nature, 253, 182-184.

Nielsen, T.D.F., Brooks, C.K., 1981: The E Greenland rifted continental margin: an examination of the coastal flexure. Journal Geological Society London, 138, 559-568.

Nielsen, T.D.F., Soper, N.J., Brooks, C.K., Faller, A.M., Higgins, A.C., & Matthews, D.W., 1981: The pre-basaltic sediments and the Lower lavas at Kangerdlugssuaq, East Greenland. Their stratigraphy, lithology, palaeomagnetism and petrology. Meddelelser om Grønland, Geosciences 6, 25 pp.

Nørgaard-Pedersen, N., 1991: A sedimentological approach to the Paleocene coastal environments at Kulhøje, East Greenland. *in* C.K. Brooks & T. Stærmose (eds) Kangerdlugssuaq studies: Processes at a continental rifted margin II. Proceedings from meeting January 1991. Copenhagen 1991. p. 53-58.

Nørgaard-Pedersen, N., 1992: Delta sequences and initial volcanism in the Paleocene Kangerdlugssuaq basin, East Greenland. *in* C.K. Brooks, E. Hoch & A.K. Brantsen (eds) Kangerdlugssuaq studies: Processes at a continental rifted margin III. Proceedings from meeting May 1992. Copenhagen 1992. p. 24-31.

Pedersen, G.K., 1989: A fluvial-dominated lacustrine delta in a volcanic province, W. Greenland. *In* M.K.G., Whatley & K.T., Pickering (ed.) Delta: sites and traps for fossil fuels. Geological Society, London, Special Publication, 41, p. 139–146.

Piasecki, S., Larsen, L. M., Pedersen, A. K., and Pedersen, G. K., 1992: Palynostratigraphy of the Lower Tertiary volcanics and marine sediments in the southern part of the West Greenland basin: implications for timing and duration of the volcanism. Rapport GrønlandsGeologiske Undersøgelse, 154, 13-31.

Rosenkrantz, A., 1970: Matrine Upper Cretaceous and lowermost Tertiary deposits in West Greenland. Meddelelser Dansk Geologisk Forening, 19, 406-453.

Rosenkrantz, A., and Pulvertaft, T.C.R., 1969: Cretaceous–Tertiary stratigraphy and tectonics in northern West Greenland. American Association of Petroleum Geologists, Memoir, 12, 883-898.

Smythe, D. K., 1989: Rockall Trough–Cretaceous or Late Paleozoic? Scottish Journal of Geology, 25, 5-43.

Soper, N.J., Higgins, A.C., Matthews, D.W. & Brown, P.E., 1976a: Late Cretaceous-early Tertiary stratigraphy of the Kangerdlugssuaq area, East Greenland, and the age of the opening of the North-Atlantic. Journal of the Geological Society London 132, p. 85-104.

Soper, N.J., Downie, C., Higgins, A.C. & Costa, L.I., 1976b: Biostratigraphic ages of Tertiary basalts on the East Greenland continental margin and their relationship to plate separation in the northeast Atlantic. Earth and Planetary Science Letters, 32, p. 149-157.

Srivastava, S. P. and Tapscott, C. R., 1986: Plate kinematics of the North Atlantic. *In* P. R. Vogt and B. E. Tucholke (Eds) *The Geology of North America, M, The Western North Atlantic Region* DNAG–GSA Series, 379-404.

Stemmerik, L., Christiansen, F.G., Piasecki, S., Jordt, B., Marcussen, C. & Nøhr–Hansen, H., 1993: Depositional history and petroleum geology of the Carboniferous to Cretaceous sediments in the Northern part of East Greenland.

In: Vorren, T.O., Bergsager, E., Dahl-Stamnes, Ø.A., Holter, E., Johansen, B., Lie, E. & Lund, T.B. (Eds) Arctic geology and petroleum potential. NPF Special publication 2, Elsevier, Amsterdam, p. 67-86.

Surlyk, F., 1973. The Jurassic-Cretaceous boundary in Jameson Land, East Greenland. In: R. Casey and P.F. Rawson (Editors), The Boreal Lower Cretaceous. Geological Journal Special Issue, 5: 81-100.

Surlyk, F., 1978. Jurassic basin evolution of East Greenland. Nature, 274: 130-133.

Surlyk, F., 1990. Timing, style and sedimentary evolution of Late Palaeozoic - Mesozoic extensional basins of East Greenland. In: R.F.P. Hardman and J.Brooks (Editors), Tectonic events responsible for Britain's oil and gas reserves. Geological Society, Special Publication, 55: pp. 107-155.

Surlyk, F., 1991. Sequence stratigraphy of the Jurassic-lowermost Cretaceous of East Greenland. American Association of Petroleum Geologists Bulletin, 75: 1468-1488.

Surlyk, F., Callomon, J.H., Bromley, R.G. and Birkelund, T., 1973. Stratigraphy of the Jurassic-Lower Cretaceous sediments of Jameson Land and Scoresby Land, East Greenland. Bulletin Grønlands geologiske Undersøgelse, 105: 1-76.

Surlyk, F., Clemmensen, L., and Larsen, H. C., 1981: Post-Paleozoic evolution of the East Greenland continental margin. *In* J. W. Kerr and A. J. Fergusson (Eds) *Geology of the North Atlantic borderlands.* Canadian Society of Petroleum Geologists Memoir, 7, 611-645.

Surlyk, F., Hurst, J.M., Marcussen, C., Piasecki, S., Rolle, F., Scholle, P., Stemmerik, L. and Thomsen, E., 1984. Oil geological studies in the Jameson Land basin, East Greenland. Rapport Grønlands geologiske Undersøgelse, 120: 85-90.

Wager, L.R., 1934: Geological investigations in East Greenland. Part I: General Geology from Angmagssalik to Kap Dalton. Meddelelser om Grønland, 105, 46 pp.

Wager, L.R., 1947: Geological investigations in East Greenland. Part IV: The Stratigraphy and tectonics of Knud Rasmussens Land and the Kangerdlugssuaq region. Meddelelser om Grønland, 134, 64 pp.

Wager, L.R. & Deer, W.A., 1939: Geological investigations in East Greenland. Part III: The petrology of the Skaergaard intrusion, Kangerdlugssuaq, East Greenland. Meddelelser om Grønland, 105, 352 pp.

Watt, W.S. and Wrang, P., 1984: Migrated hydrocarbons in basalts on the south side of Scoresby Sund. Rapport, Grønlands geologiske Undersøgelse, 120, p. 84-85.

Ziegler, P. A., 1981: Geological atlas of Western and Central Europe. Amsterdam, Elsevier, 130 pp.

Ziegler, P. A., 1988: Evolution of the Arctic–North Atlantic and the Western Tethys. Memoir American Association of Petroleum Geologists, 43 pp.

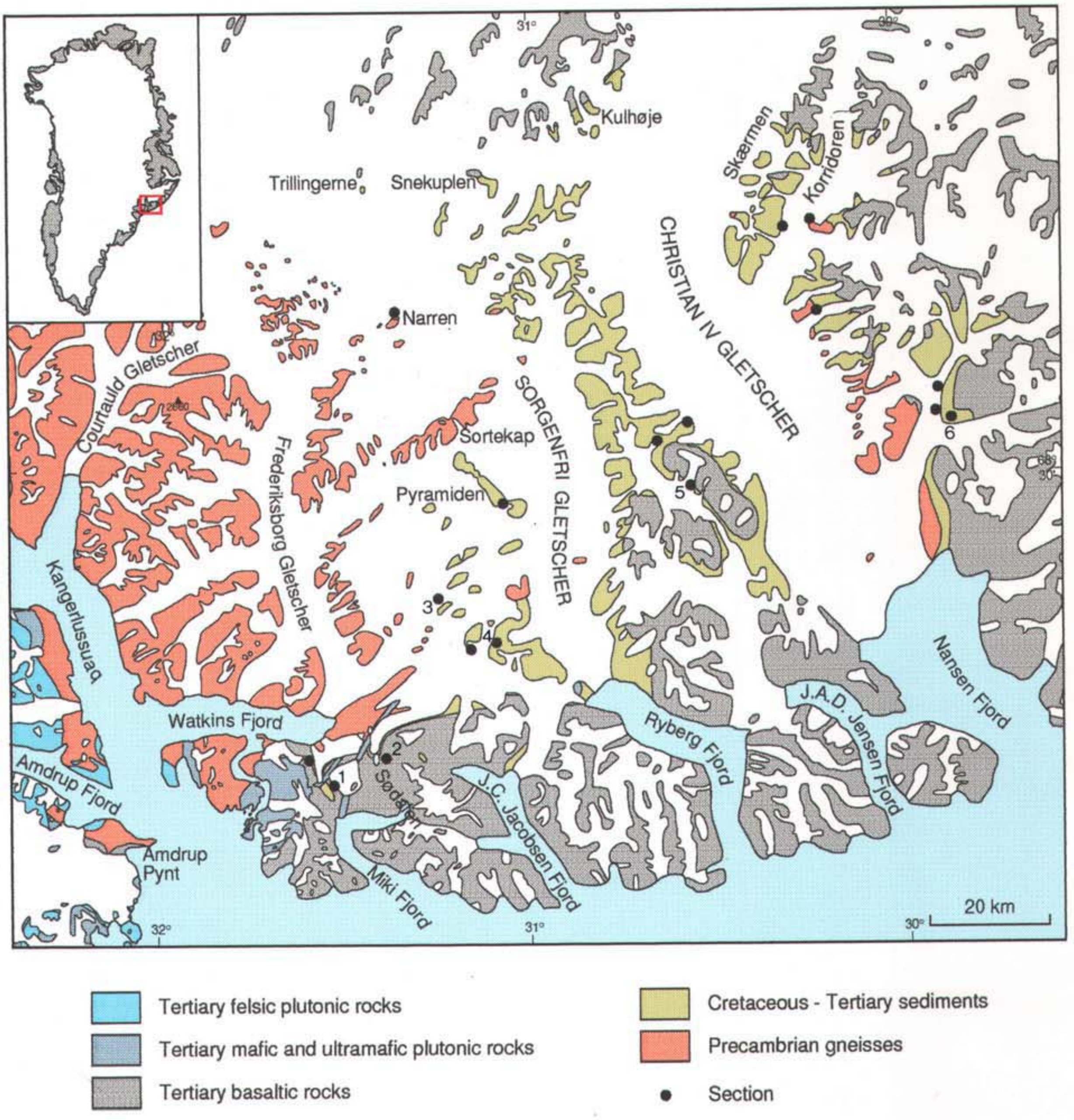


Fig. 1. Geological and location map of the Kangerlussuaq area at 68°30′N on the east coast of Greenland showing the distribution of the pre-drift sediments. The Cretaceous and Tertiary sediments are exposed in a c. 10 000 km^2 area situated northeast of the fjord Kangerlussuaq. The position of the main measured sections and locations mentioned in the text are indicated.

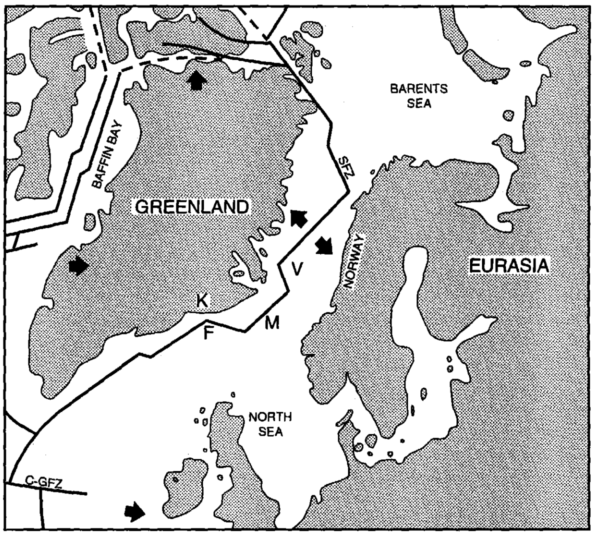


Fig. 2. Reconstruction of the North Atlantic during chron 24R near the Paleocene-Eocene boundary. Note the pre-drift position of the present day Faroe Islands (F) southeast of the Kangerlussuaq (K). The Møre Basin is marked by (M), the Vøring Basin by (V). Modified from Myhre *et al.* (1992).

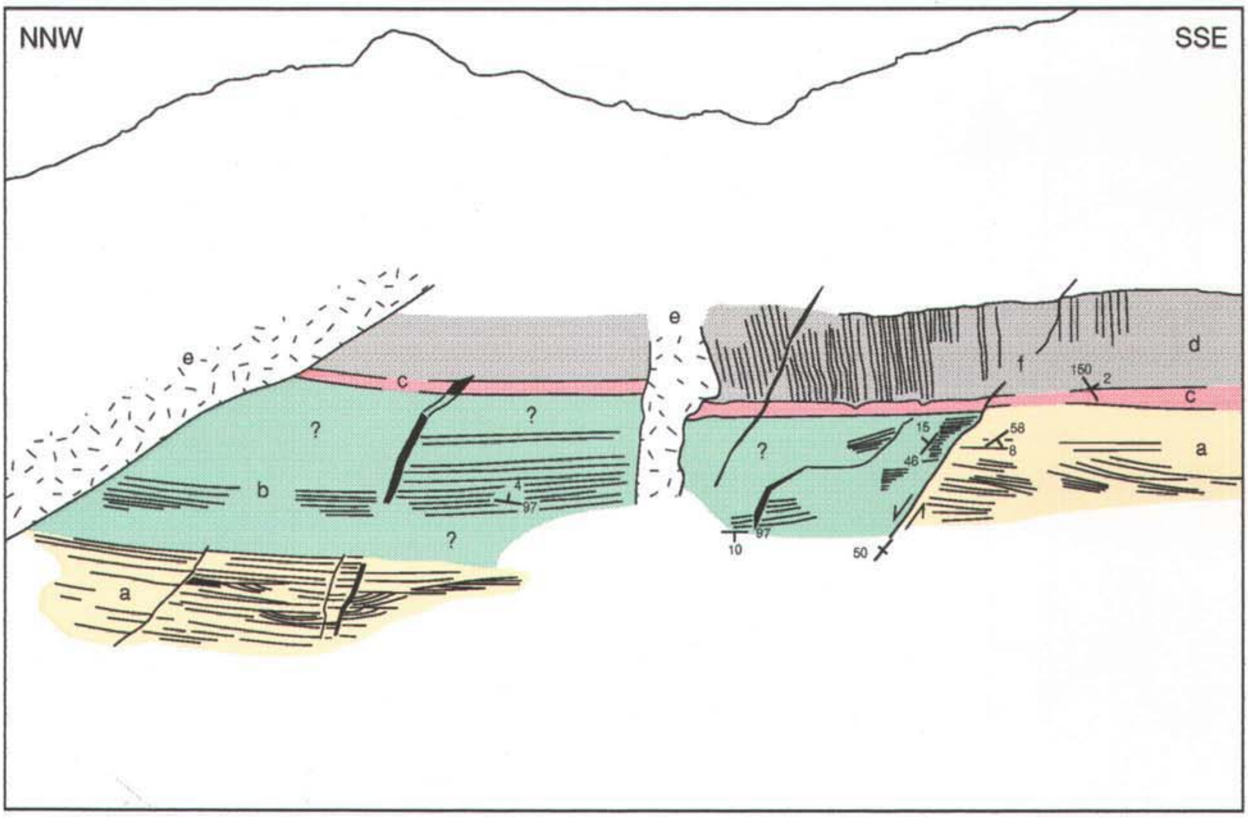


Fig. 3. Sketch of the Vandfaldsdalen area showing faulting of the Ryberg Formation prior to erosion and deposition of the Schjelderup Member. Drawn from photograph. a) Ryberg Formation, medium to coarse grained trough cross-bedded sandstones. b) Ryberg Formation, sandy shales. c) Vandfaldsdalen Formation, Schjelderup Member pebble conglomerate. d) Vandfaldsdalen Formation, Schjelderup Member columnar jointed basalts forming the first lava flow in the area. e) Intrusive dyke complex. f) Normal fault striking 60° and with downthrow (30 m) towards the northwest. The fault offsets units a and b, whereas unit c show only minor offset due to inversion related to the intrusion of e.

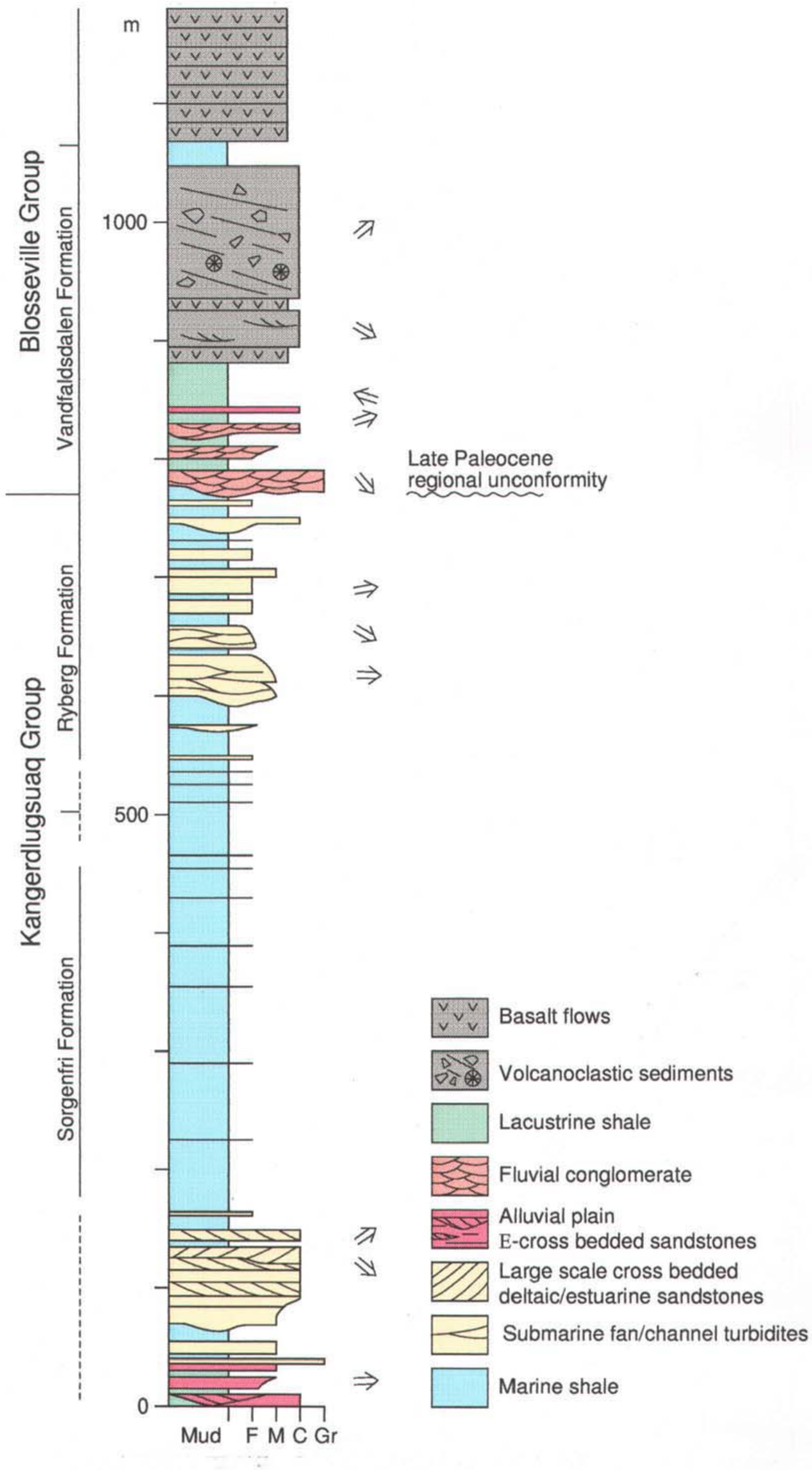
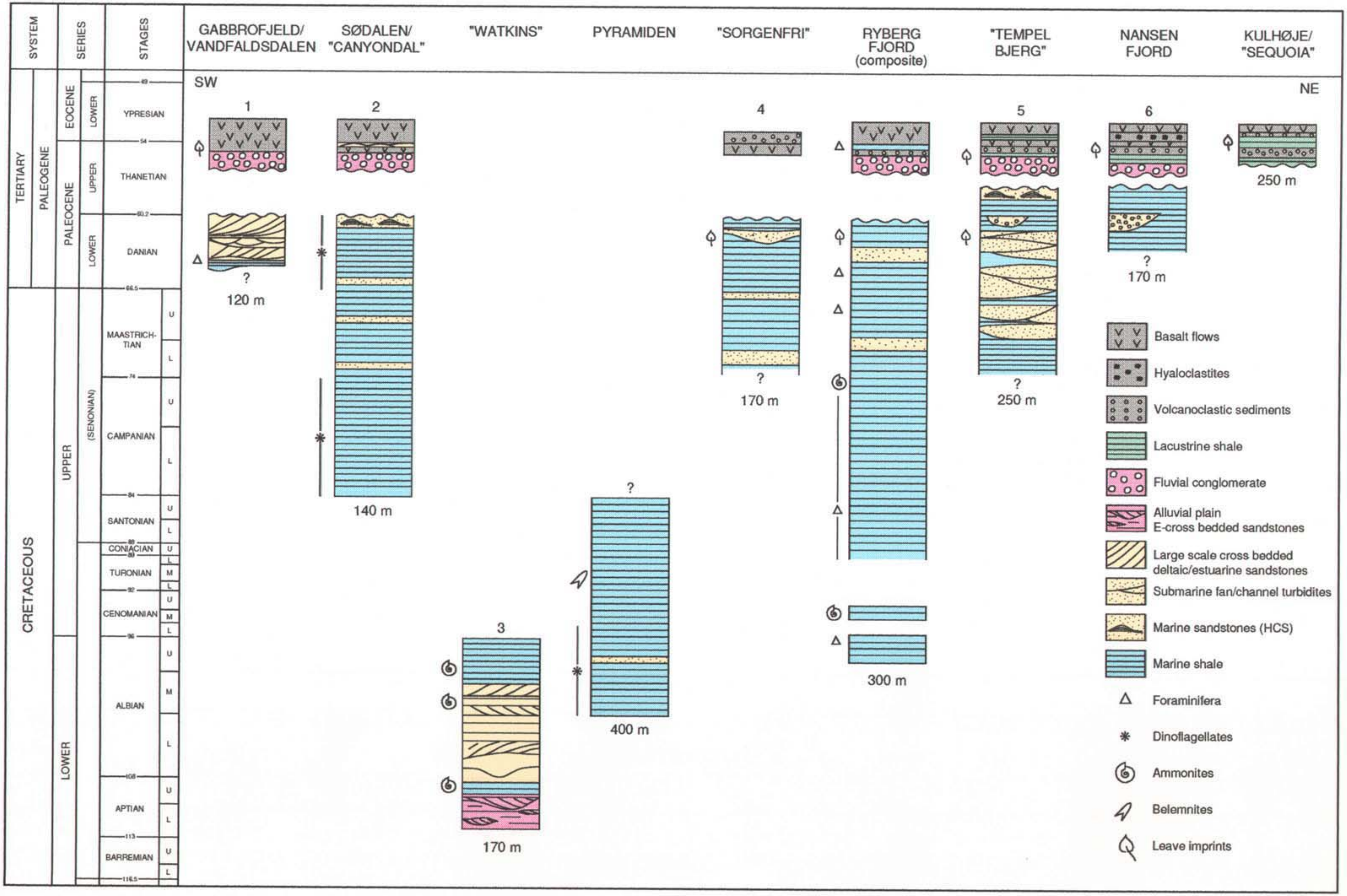


Fig. 4. Composite sedimentological section of the Mid-Cretaceous to Paleocene sedimentary succession in the Kangerlussuaq area.

Fig. 5. (Following page) Stratigraphy of the pre-drift sediments of the Kangerlussuaq region based on new findings of ammonites and on previously published studies on dinoflagellates, foraminifera and belemnites (Soper *et al.*, 1976a; Nielsen *et al.*, 1981; Christensen & Hoch, 1983; L. Hamberg, pers.comm. 1995). Palynological samples from recent field work (1995) are still under preparation.



SYSTEM
SERIES
STAGES
GABBROFJELD/ VANDFALDSDALEN
SØDALEN/ "CANYONDAL"
"WATKINS"
PYRAMIDEN
"SORGENFRI"
RYBERG FJORD (composite)
"TEMPEL BJERG"
NANSEN FJORD
KULHØJE/ "SEQUOIA"
SW
NE
TERTIARY
PALEOGENE
EOCENE
PALEOCENE
LOWER
UPPER
YPRESIAN
THANETIAN
DANIAN
CRETACEOUS
(SENONIAN)
MAASTRICHTIAN
CAMPANIAN
SANTONIAN
CONIACIAN
TURONIAN
CENOMANIAN
ALBIAN
APTIAN
BARREMIAN
1
2
3
4
5
6
120 m
140 m
170 m
400 m
170 m
300 m
250 m
170 m
250 m
Basalt flows
Hyaloclastites
Volcanoclastic sediments
Lacustrine shale
Fluvial conglomerate
Alluvial plain E-cross bedded sandstones
Large scale cross bedded deltaic/estuarine sandstones
Submarine fan/channel turbidites
Marine sandstones (HCS)
Marine shale
Foraminifera
Dinoflagellates
Ammonites
Belemnites
Leave imprints

Fig. 6. Upper Aptian to Albian sandstone succession exposed at locality 3, "Watkins". The sandstones are overlain by offshore marine shale. Note lateral pinchout of sandstones towards the north. Cliff face is c. 100 m high. Photo courtesy by DLC, 1995. See also Figs 9 and 10.

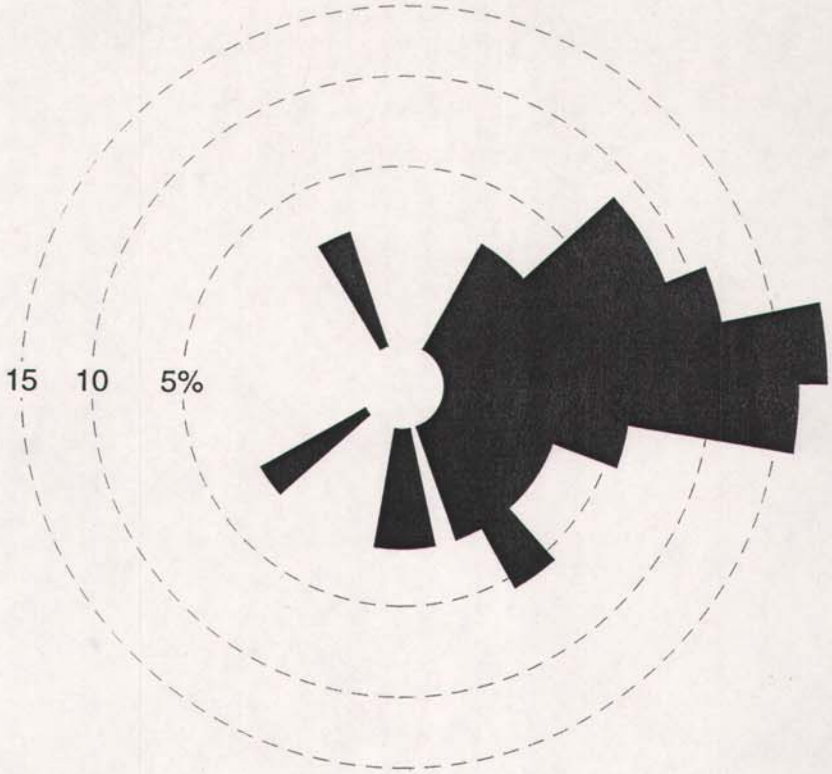


Fig. 7. Equal area palaeocurrent roses based on measurements of foreset dip azimuth of Upper Aptian fluvial sandstones from locality 3. Total number of data N=37, Vector mean=87°.

Fig. 8. Shell lag of the bivalve *Camptonectes* marking the marine transgression of the lower alluvial succession. Photo from section 3, 42 metres above the base.

Fig. 9. (Following page) Lateral profile showing the distribution of mid-Cretaceous sandstone bodies in a near vertical cliff face at locality 3, "Watkins". The apparent opposing orientation of the large scale foresets is caused by a bimodal palaeocurrent pattern where flow directions are separated by an angle of 45°. Drawing based photographs. See also Figs. 6, 10 and 11.

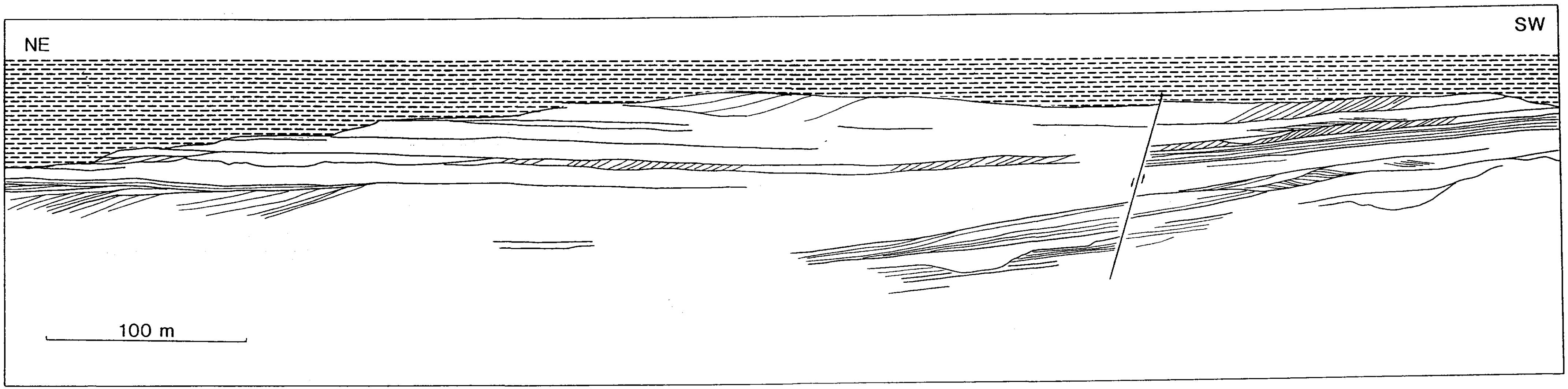

NE
SW
100 m

Fig. 10. Outcrop photo of the mid-Cretaceous estuarine sandstone unit showing the internal large-scale to giant-scale cross-bedding. Note the bimodal dip azimuth of foresets. Person encircled for scale. Height of cliff face is c. 80 m.

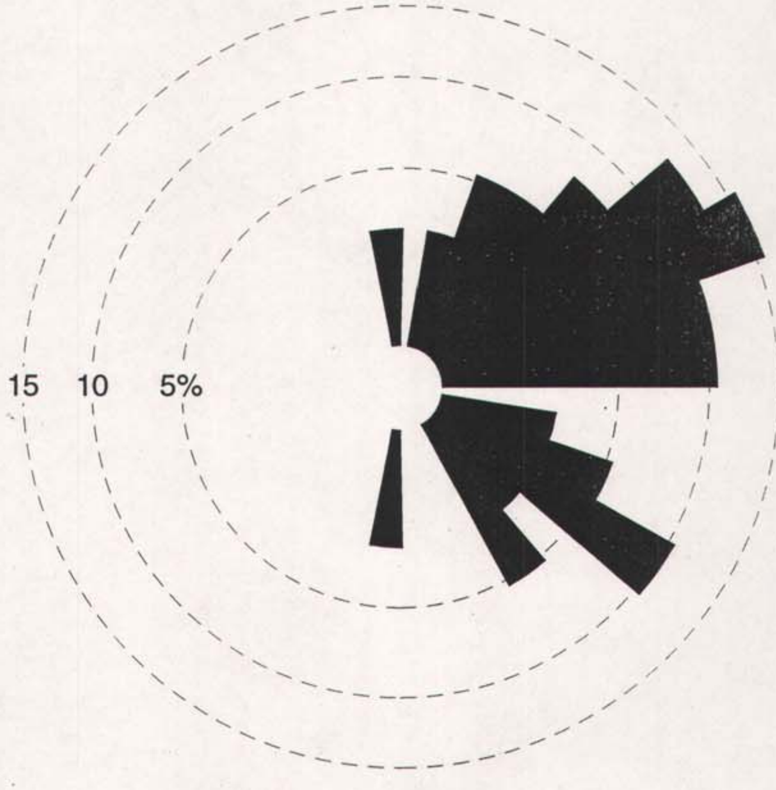


Fig. 11. Equal area palaeocurrent roses based on measurements of large scale foreset dip azimuth of estuarine sandstones from locality 3. Total number of data N=39, Note the bimodal population with vector mean=55° and 129° respectively.

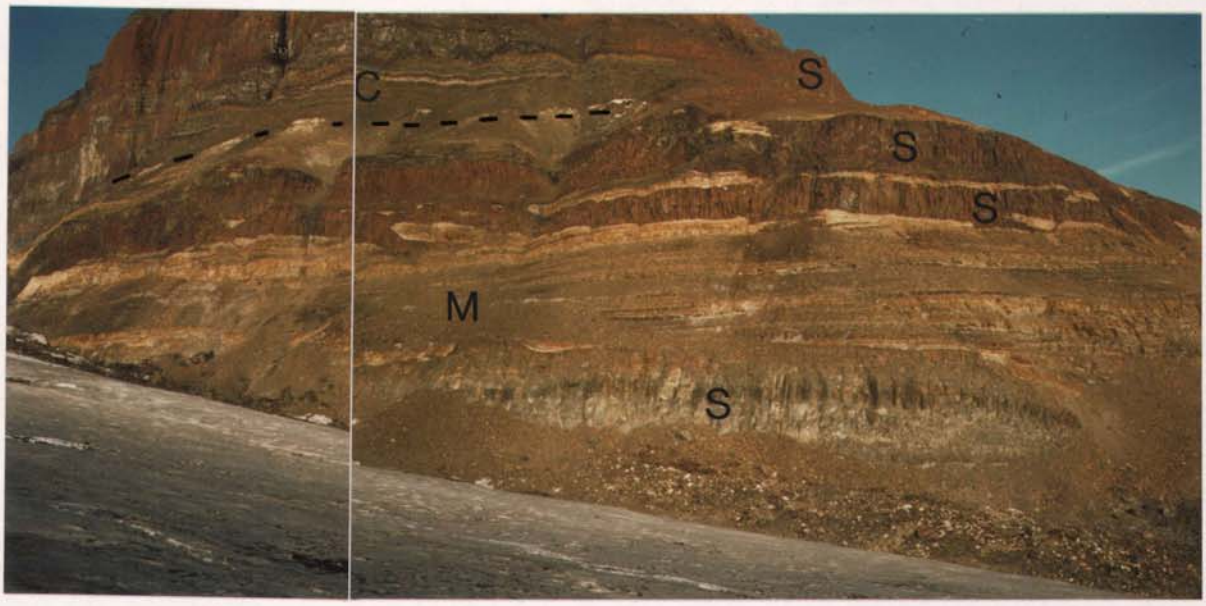


Fig. 12. Outcrop photo of the Upper Cretaceous–Lower Paleocene sedimentary succession at locality 5, "Tempelbjerg". The succession reflects a general shallowing upward and a change from a relatively deep marine (M) to continental deposits (C). The sedimentary succession is overlain by fluvial volcanoclastic sediments, lacustrine tuffs and lava flows marking the onset of volcanism in the area. Tertiary sills marked by S. Photo courtesy by L. Hamberg.

Fig. 13. Lower Paleocene? sandstone dominated succession of amalgamated turbidite beds. The sandstones form fining- and thinning-upwards successions and are interpreted as channel fills on submarine fan. Ryberg Formation, locality 5, level 0–115 m. Person (encircled) for scale.

Fig. 14. Geologist describing Lower Paleocene? sharp based turbidite channel sandstones at locality 5, "Tempelbjerg". The sandstones form thinning-upwards sandstone successions up to 23 m thick and traceable laterally for a few hundred metres. These sandstone dominated successions are separated by heterolithic intervals.

Fig. 15. Sharp based, fine-grained sandstone bed composed of amalgamated turbidites of Early Paleocene? age. The turbidites consist of a lower massive part overlain by plane laminated occasionally rippled upper part rich in mud rip-up clasts. Notebook is 17 cm high. Photo courtesy by L. Hamberg.

Fig. 16. Flute marks at the sole of a sandy turbidite. The flute marks are use to determine the palaeoflow direction of the turbidity currents. Note circular burrows indicating marine bioturbation of the turbidite following deposition. Scale is 20 cm long. Lower Paleocene sandstones at locality 5.

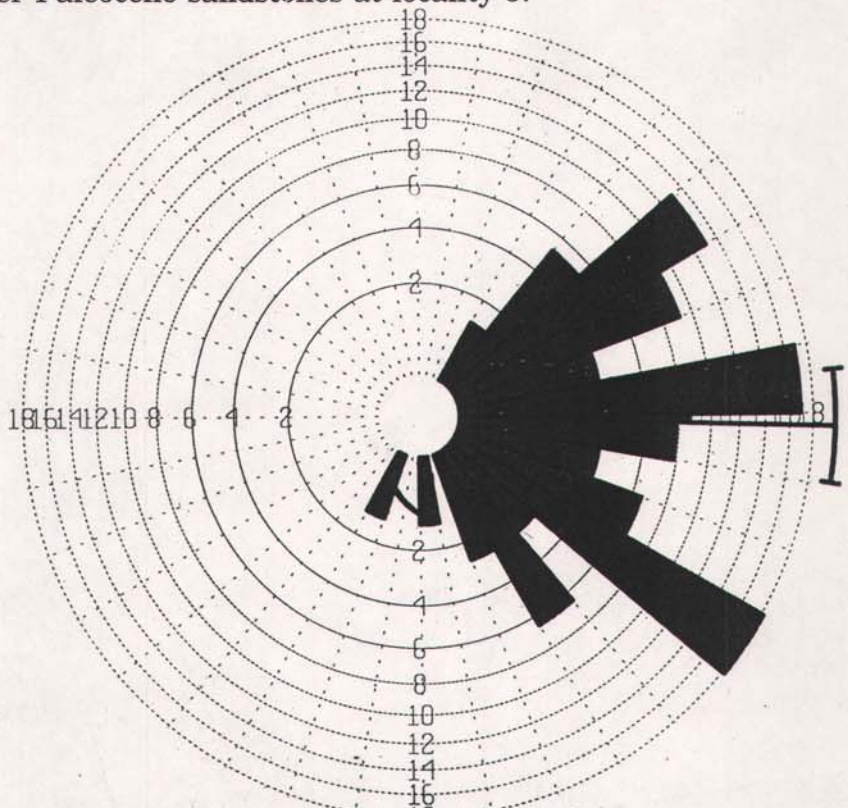


Fig. 17. Equal area palaeocurrent rose of Early Paleocene sandstone turbidites estimated from primary current lamination, current ripples and flute marks at locality 4. Total number of data N=77, Vector mean=92°.

Fig. 18. Lower Paleocene, distal submarine fan deposits of parallel bedded, laterally persistent turbidites interbedded with marine shales. The turbidites show a thickening-upwards trend characteristic for depositional lobes. Locality 2, Canyondal. Cliff face is c. 40 m high. Photo courtesy by L. Hamberg.

Fig. 19. Lower Paleocene?, fine-grained sandstone turbidites interbedded with marine heteroliths and silty shales. The succession formed in a distal submarine fan environment. Section 4, level 25 m. Hammer for scale.

Fig. 20. Lower Paleocene, marine shales and fine-grained sandstones of turbidites filling an erosional slump scour or minor channel-cut on the flanks of a submarine fan channel. The fill reach 15 m in thickness and is overlain by parallel laminated shales and turbidites.

Fig. 21. Outcrop photo of the transition from deep marine submarine fan deposits (M) of the Lower? Paleocene Ryberg Formation to continental deposits (C) of the Upper? Paleocene Vandfaldsdalen Formation at locality 5, "Tempelbjerg". The cliff face is c. 100 m thick. Tertiary sill marked by (S).

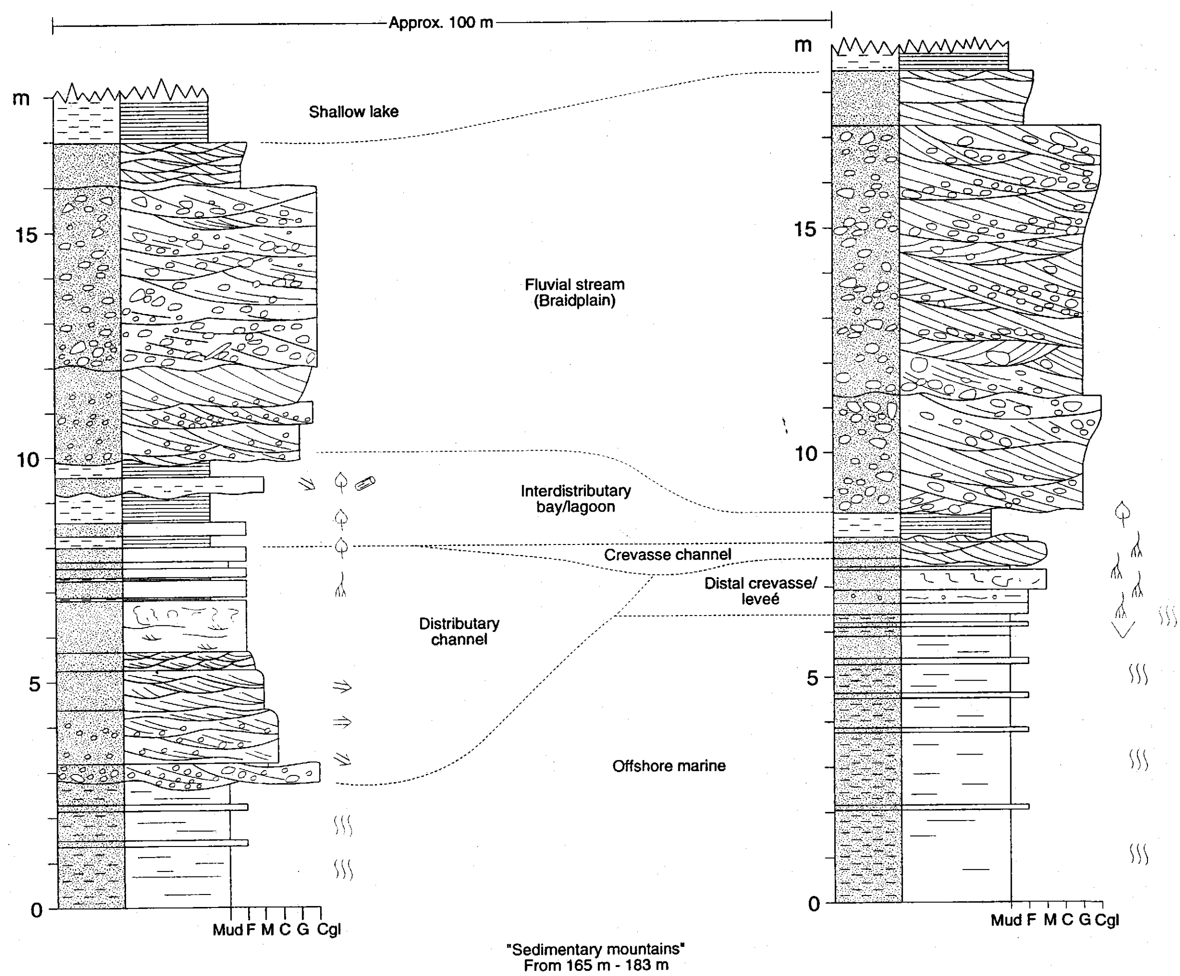


Fig. 22. Vertical section of the unconformable transition from Lower? Paleocene marine shales to Upper Paleocene braided river deposits at locality 5, "Tempelbjerg". The abrupt shallowing reflects a regional uplift prior to the onset of volcanism which is recognised all sections in the Kangerlussuaq region.

Fig. 23. Upper? Paleocene, poorly consolidated, pebbly sandstones deposited in a braided river system. The pebbles are up to 25 cm long and consist of quartz and gneiss. The channel sandstones are cross-bedded, up to 16 m thick and form laterally continuous sheet sandstones, which are correlated between outcrops in the area. Locality 5, "Tempelbjerg", level 175 m. Hammer for scale.

Fig. 24. Upper? Paleocene, organic rich shale preserved as an erosional remnant below fluvial pebbly channel sandstones. The sandstone below the organic rich shale locally show roots. The shales are interpreted as deposited in a lacustrine or ephemeral pond on the alluvial plain. The shale show total organic carbon (TOC) values up to 2.2%.

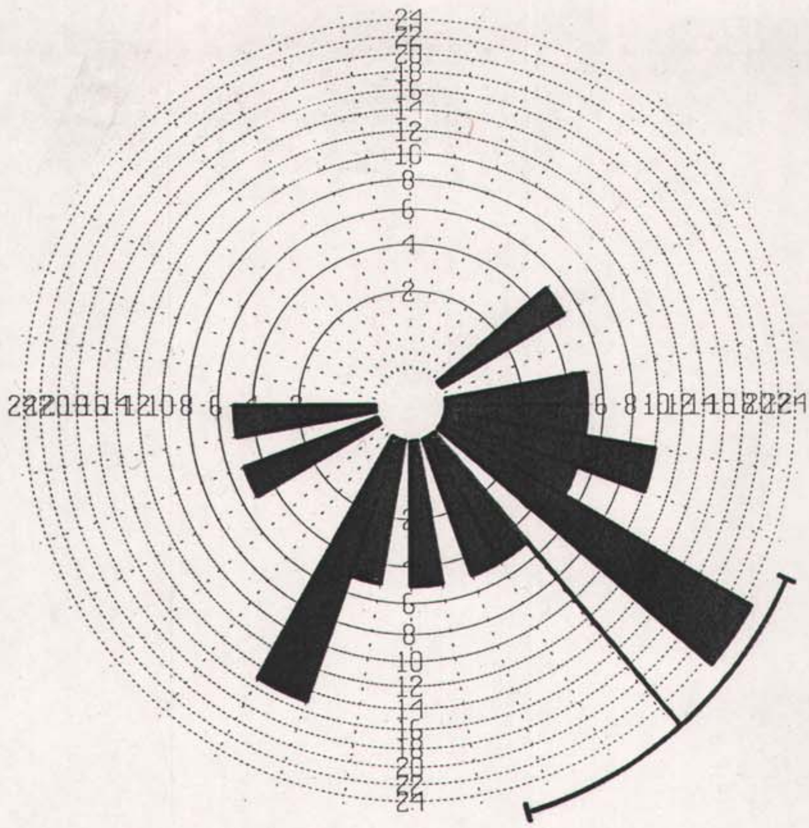


Fig. 25. Equal area palaeocurrent rose of Late? Paleocene braided river deposits. The rose is based on estimates of foreset azimuths and trough axes of trough cross-bedded pebbly sandstones. Total number of data N=20, Vector mean=139°.

Fig. 26. Upper Paleocene braided river conglomerate forming an extensive white sheet deposit in the Kangerlussuaq area. The fluvial sheet sandstone can be correlated throughout the area and probably mark a regional uplift. Locality 6, Nansen Fjord. Sandstone bluff i c. 20 m thick. Tertiary sill marked by (S).

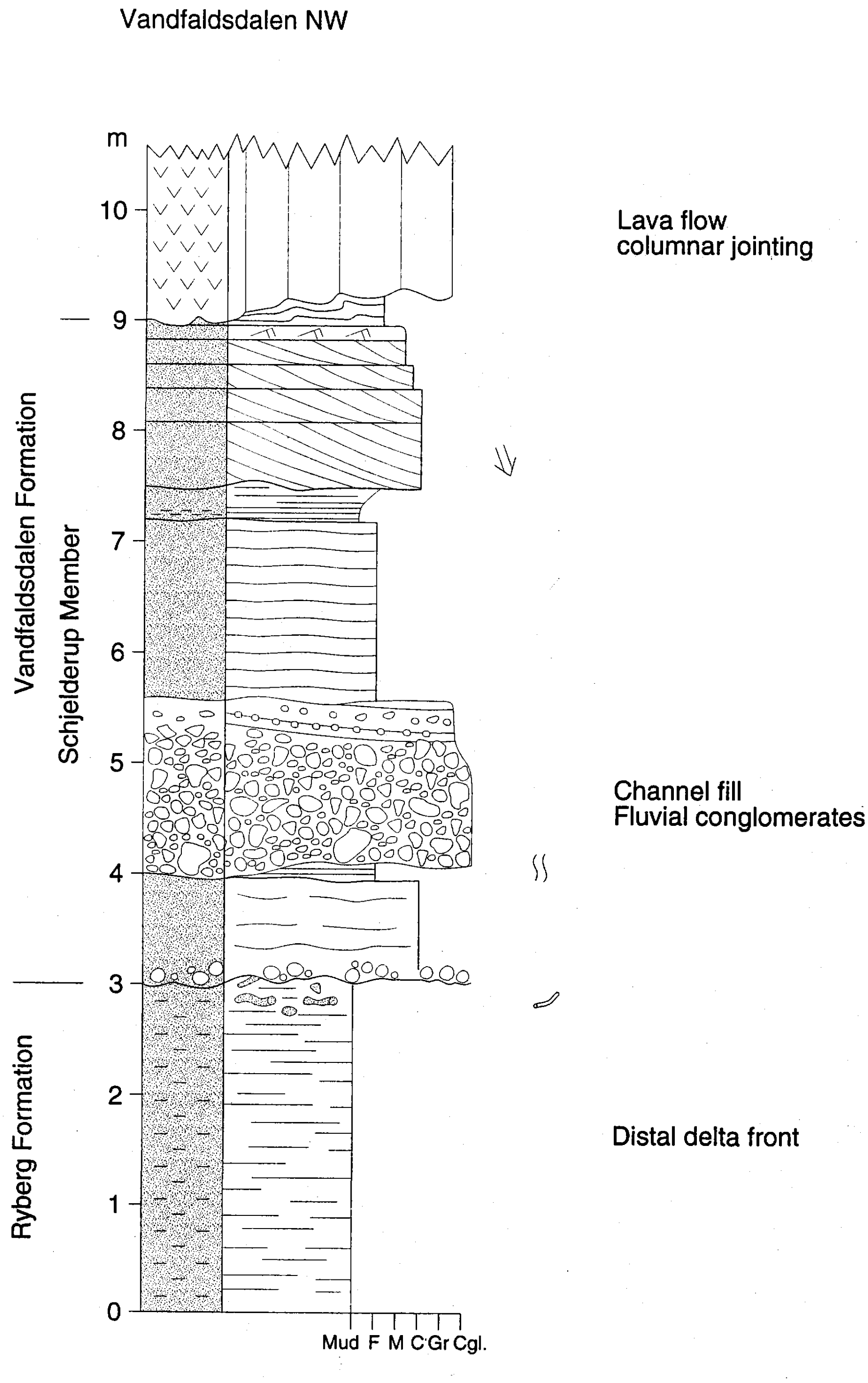


Fig. 27. Vertical section of the transition from marine shales of the Ryberg Formation to continental deposits of channelised braided river conglomerates, the Schjelderup Member. Note the position of the significant erosional unconformity below the fluvial conglomerates. The section is topped by lavas.

Fig. 28. Upper Paleocene, hummocky cross-stratified very fine grained sandstones form an intrabasaltic layer in the lower part of the Vandfaldsdalen formation indicating a shallow marine incursion. Pillows of the overlying lava flow has sunk into and deformed the partly consolidated sandstones. Locality 2, Sødalen, first sandstone marker. Hammer for scale.

Fig. 29. Upper Paleocene, laminated tuffs deposited in a shallow pond or lake on the alluvial plain. Pencil for scale.

Fig. 30. Imprint of leave on the bedding surface of Upper Paleocene, lacustrine tuff. Scale in cm.

Fig. 31. Matrix supported Upper Paleocene, volcanoclastic breccia with boulder-sized clasts of laminated carbonates and pillows of basalts. The matrix consists of poorly consolidated coarse-grained volcanoclastic sandstones. The breccia is interpreted as formed by a subaerial massflow (lahar). Section 6, level 165 m. Hammer for scale.

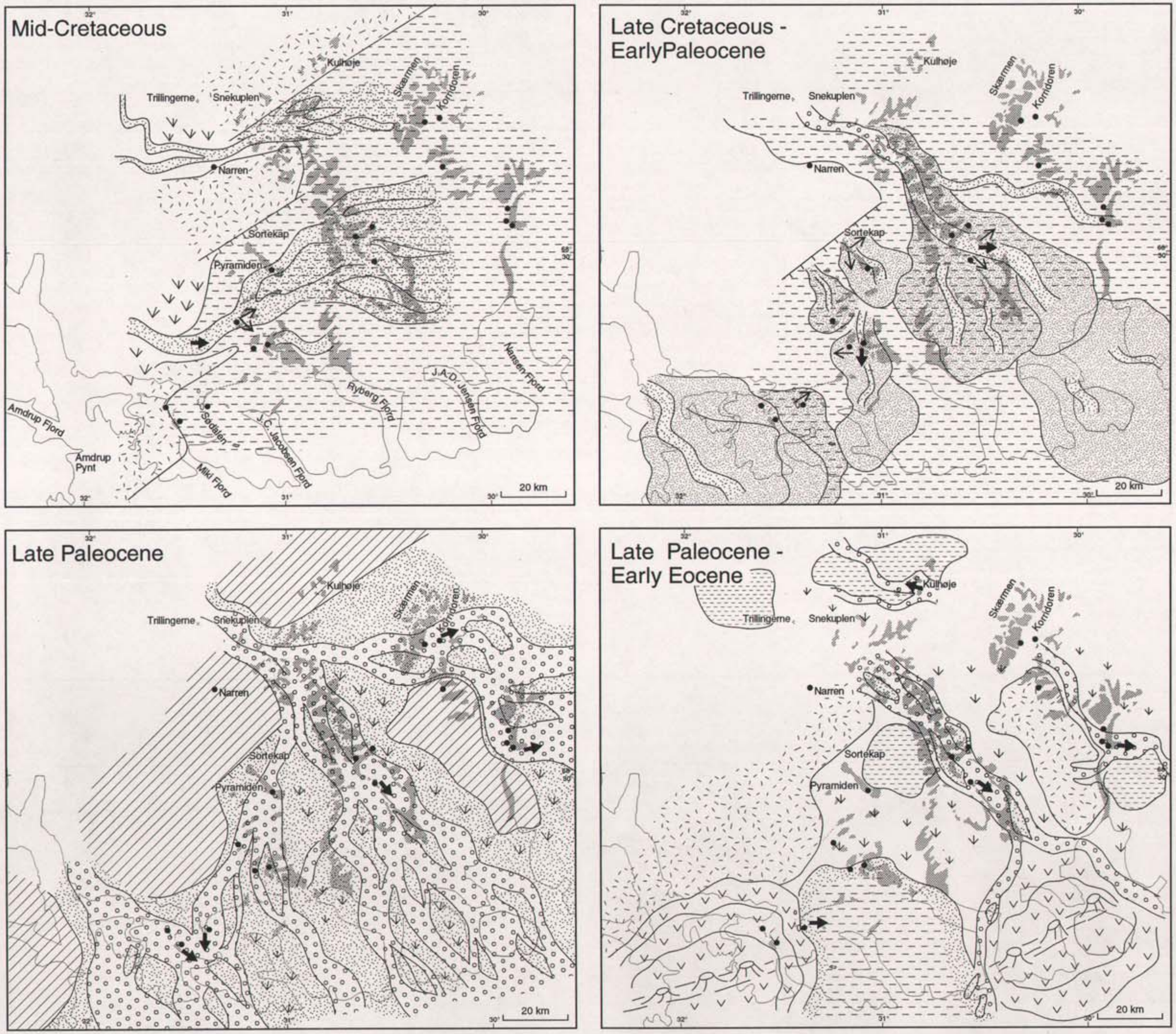


Fig. 32. Paleogeographic reconstructions of the Kangerlussuaq region during mid-Cretaceous to Late Paleocene.

LEGEND

Laminated shale

massive sandstone

large-scale cross-bedded sandstone

planar cross-bedded sandstone

trough cross-bedded sandstone

planar bedded sandstone

hummocky cross-stratified sandstone

pebbly sandstone

matrix supported breccia

volcanoclastic breccia

basaltic lava

sill

SB sequence boundary

FS flooding surface

RS ravinement surface

TST transgressive systems tract

HST highstand systems tract

FRST forced regressive systems tract

LST lowstand systems tract

current ripples

load structures

palaeocurrent direction from cross-bedding

palaeocurrent direction from cross-lamination

bioturbation, weak

bioturbation, moderate

bioturbation, strong

Planolites

Taenidium

Monocraterion

Arenicolites

Diplocraterion

Ophiomorfa

bivalve *Camptonectes*

bivalve

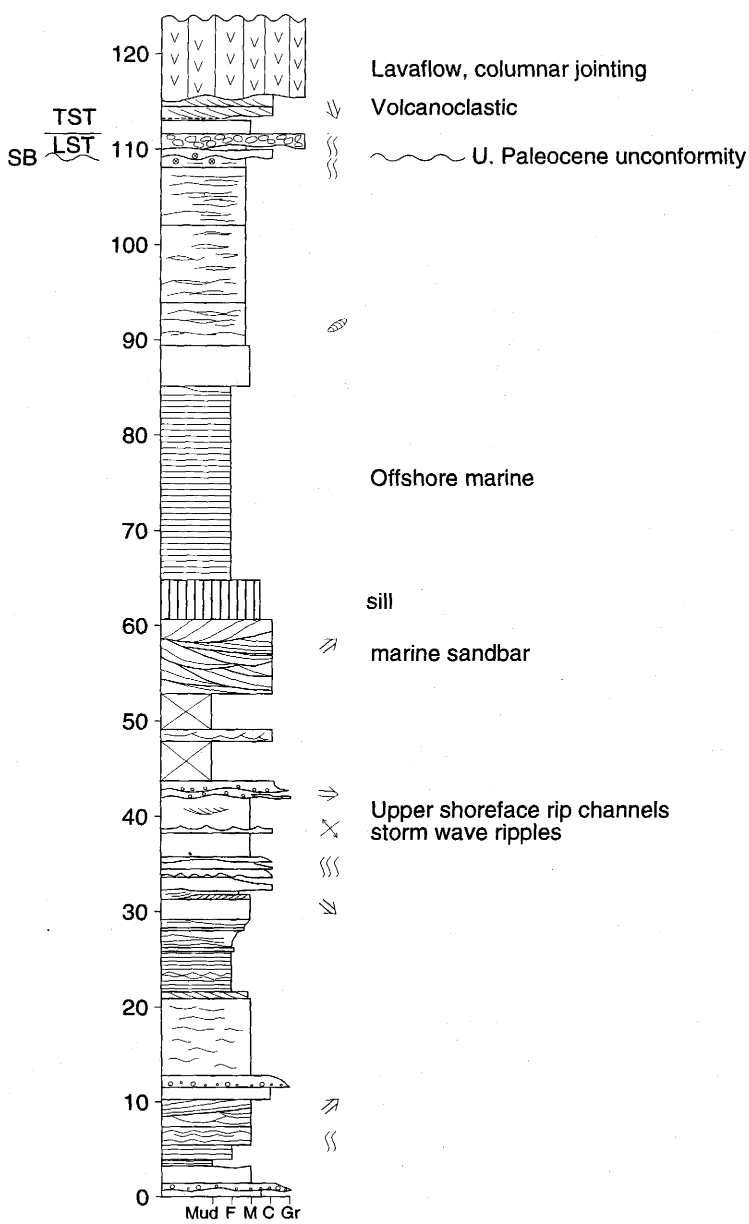
ammonite

carbonaceous debris

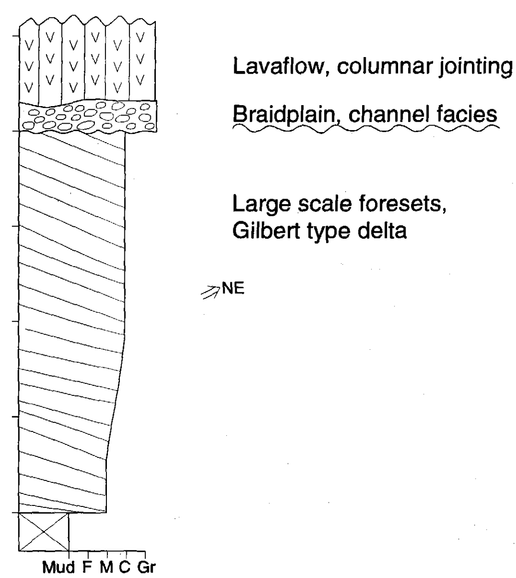
leave imprints

roots

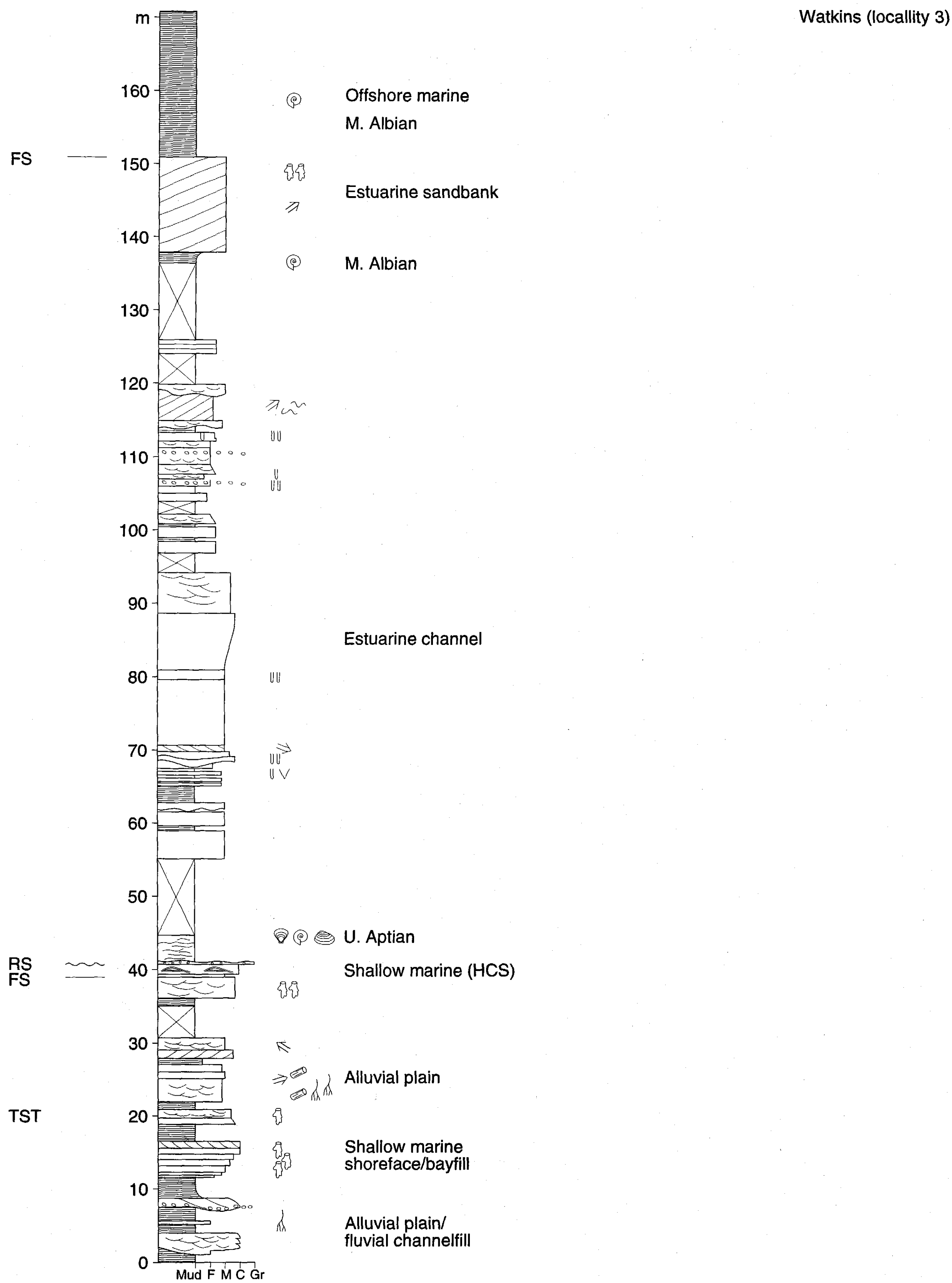
Vandfaldsdalen NW (locality 1)



Gabbrofjeld



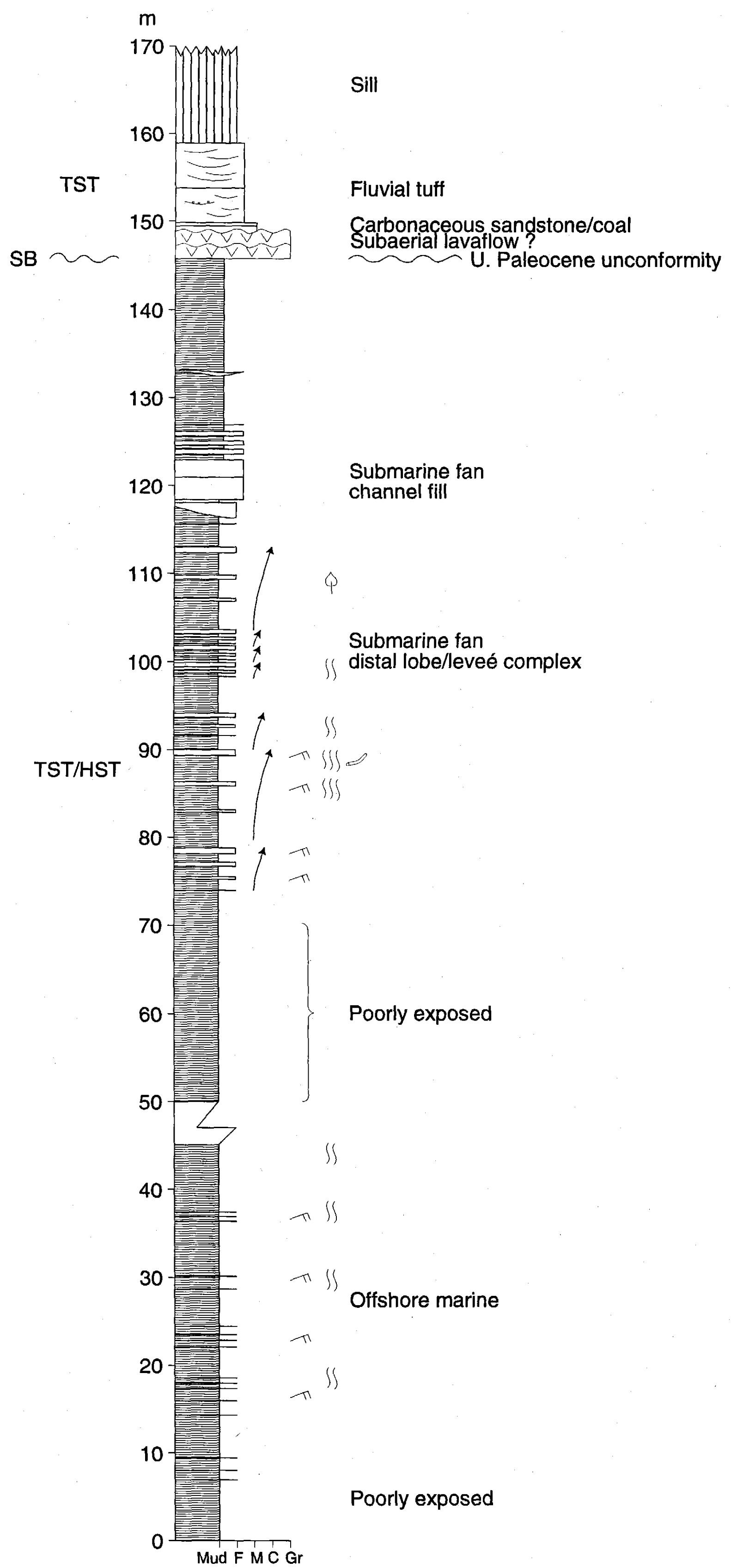
G6.1-95.042-ML



Watkins (locallity 3)
m
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Mud F M C Gr
FS
RS
FS
TST
Offshore marine
M. Albian
Estuarine sandbank
M. Albian
Estuarine channel
U. Aptian
Shallow marine (HCS)
Alluvial plain
Shallow marine
shoreface/bayfill
Alluvial plain/
fluvial channelfill

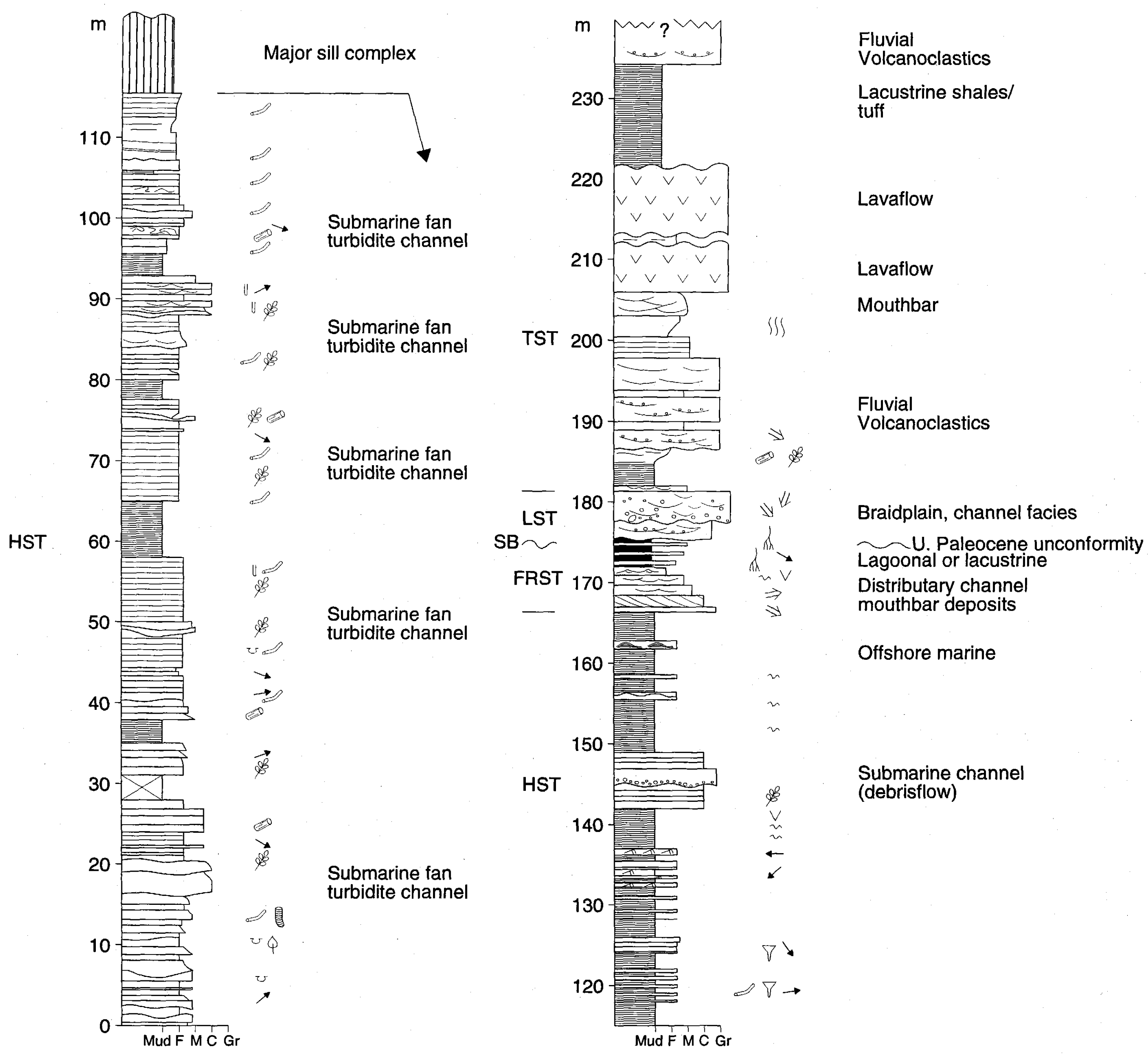
G6.1-95.036-ML

Sorgenfri (locality 4)



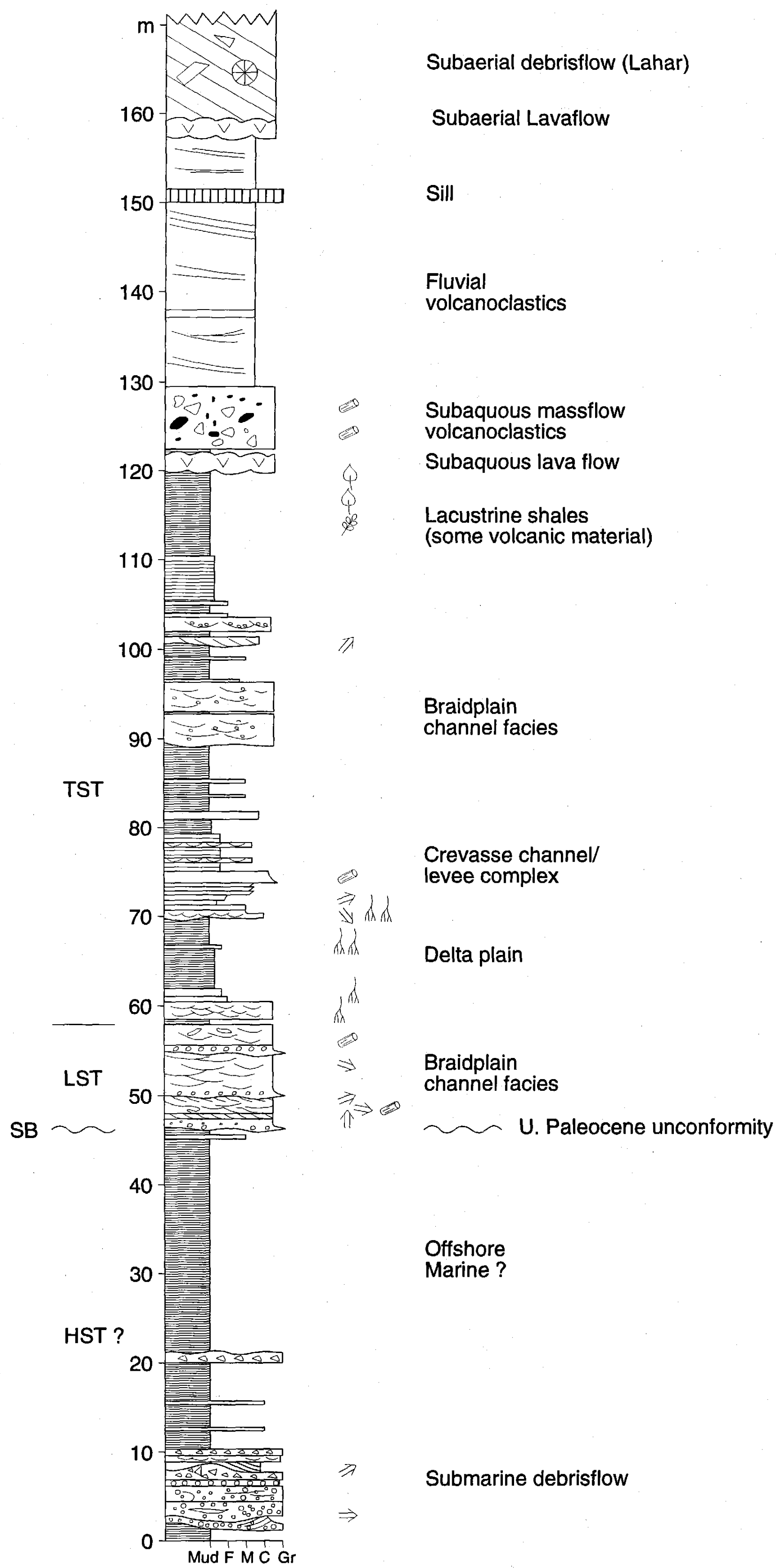
G6.1-95.037-ML

"Sedimentary mountains" (locality 5)



G6.1-95.034-ML

Nansen Fjord profil (locality 6)

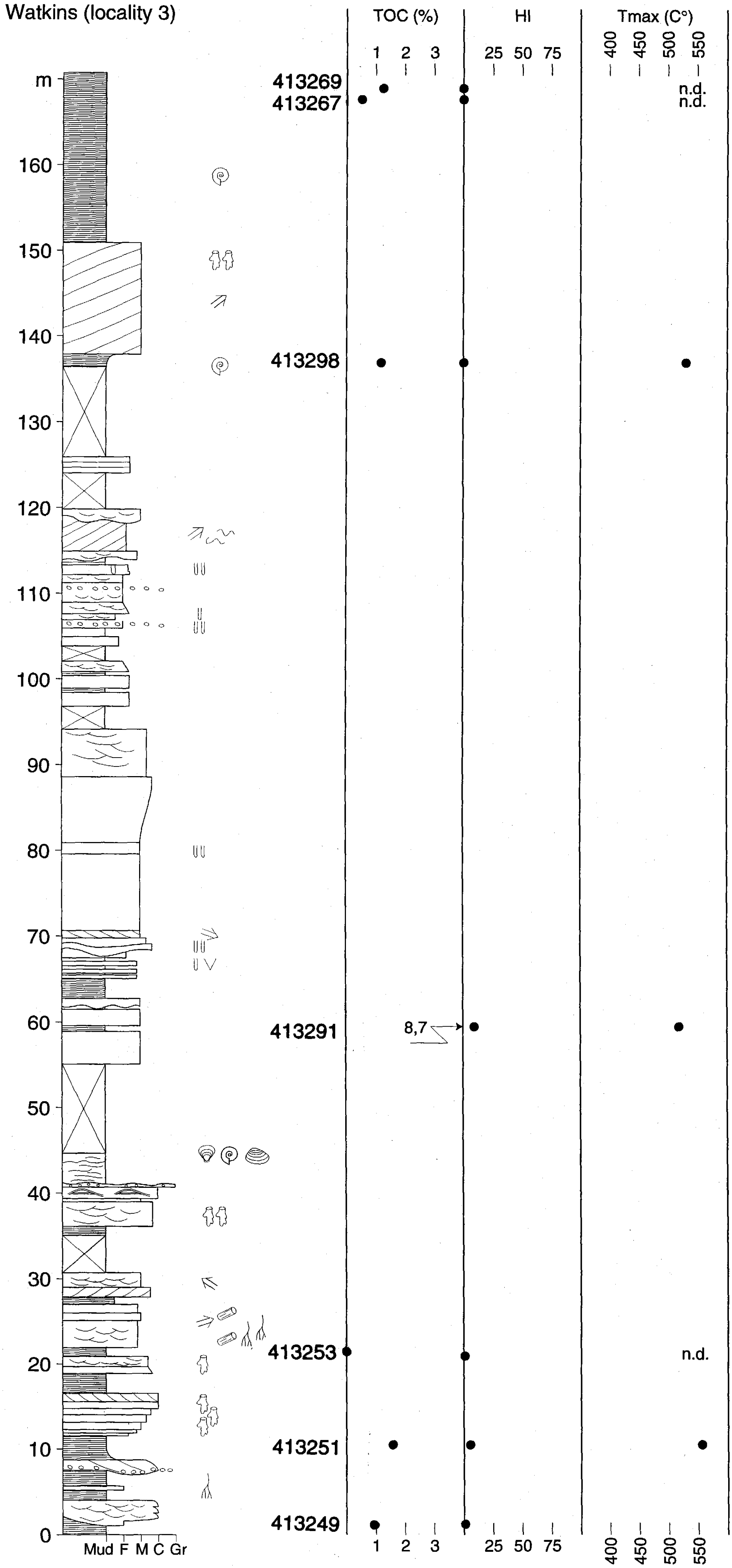


G6.1-95.035-ML

SAMPLE	TOC (wt-%)	Tmax (C)	S1 (mg HC/g)	S2 (mg HC/g)	PI	PC	HI
412704[1]	1,16		0,00	0,00			
412710[1]	1,16		0,00	0,00			
412714[1]	1,39		0,00	0,00			
412730[2]	0,11		0,00	0,02			18
412741[2]	0,40		0,00	0,00			
412745[2]	0,37		0,00	0,00			
412761	2,00	565	0,00	0,12			6
412763	1,95	564	0,00	0,14			7
412764	1,87	568	0,00	0,12			6
412767	1,93	564	0,00	0,14			7
412769	1,65	569	0,00	0,14			8
412771	1,73	574	0,00	0,08			5
412775	1,63		0,00	0,00			
412781	1,42		0,00	0,00			
412790	1,78	566	0,00	0,12			7
412796	1,76	571	0,00	0,08			5
413106	1,52	550	0,02	0,16	0,11	0,01	11
413111	0,93		0,02	0,00			
413126	1,53	563	0,02	0,04	0,33	0,00	3
413128	2,07	496	0,04	0,02	0,67	0,00	1
413131	0,85	522	0,01	0,09	0,10	0,01	11
413134	1,54	514	0,01	0,13	0,07	0,01	8
413139	1,63	438	0,03	0,03	0,50	0,00	2
413142	1,09		0,02	0,00			
413147	2,17	290	0,19	0,01	0,95	0,02	0
413156	0,13		0,00	0,00			
413159	2,05	528	0,01	0,29	0,03	0,02	14
413163	0,06		0,00	0,00			
413179	8,46	453	0,36	6,03	0,06	0,53	71
413181	32,60	461	2,10	27,05	0,07	2,42	83
413186	0,78		0,00	0,00			
413189	1,62		0,00	0,00			
413191	1,69		0,00	0,00			
413193	1,96	456	0,31	1,06	0,23	0,11	54
413198	1,10	460	0,17	0,35	0,33	0,04	32
413219[3]	1,03		0,01	0,00			
413225[4]	6,69	548	0,06	0,22	0,21	0,02	3
413228[4]	2,64	451	0,02	0,50	0,04	0,04	19
413232[4]	1,67	548	0,01	0,15	0,06	0,01	9
413233[4]	1,58	472	0,07	0,86	0,08	0,08	54
413249	0,95		0,00	0,00			
413251	1,56	556	0,00	0,06			4
413253	0,16		0,00	0,00			
413267	0,66		0,00	0,00			
413269	1,39		0,00	0,00			
413272[5]	1,37		0,00	0,00			
413273[5]	0,83		0,00	0,00			
413275[5]	1,49		0,00	0,00			
413291	8,68	520	0,04	0,92	0,04	0,08	11
413298	1,24	535	0,00	0,03			2

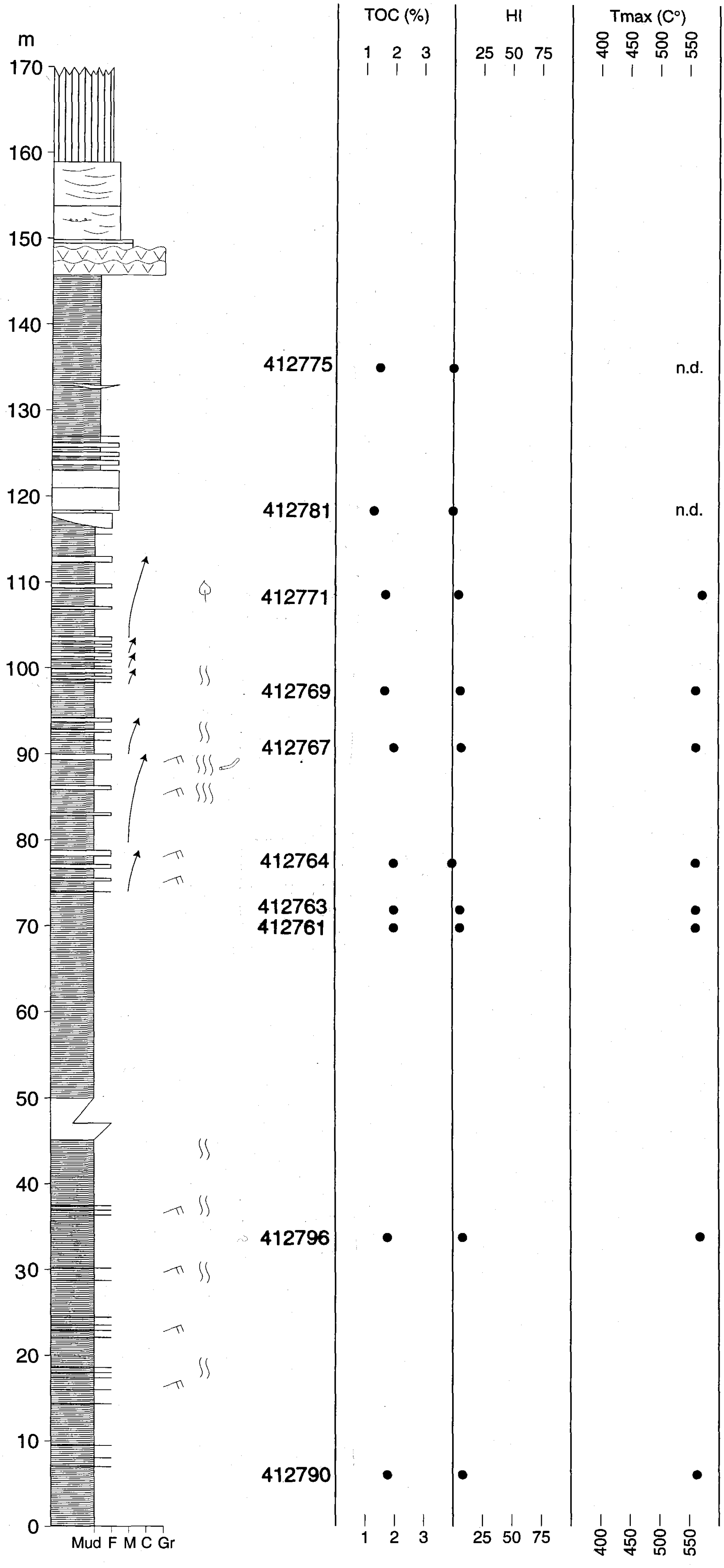
Table 1. Sample numbers are indicated on the vertical sections.
Additional samples: 1) Pyramiden, 2) Vandfaldsdalen, 3) Skærmen, 4) Nansen Fjord A+B, 5) Canyondal

Watkins (locality 3)



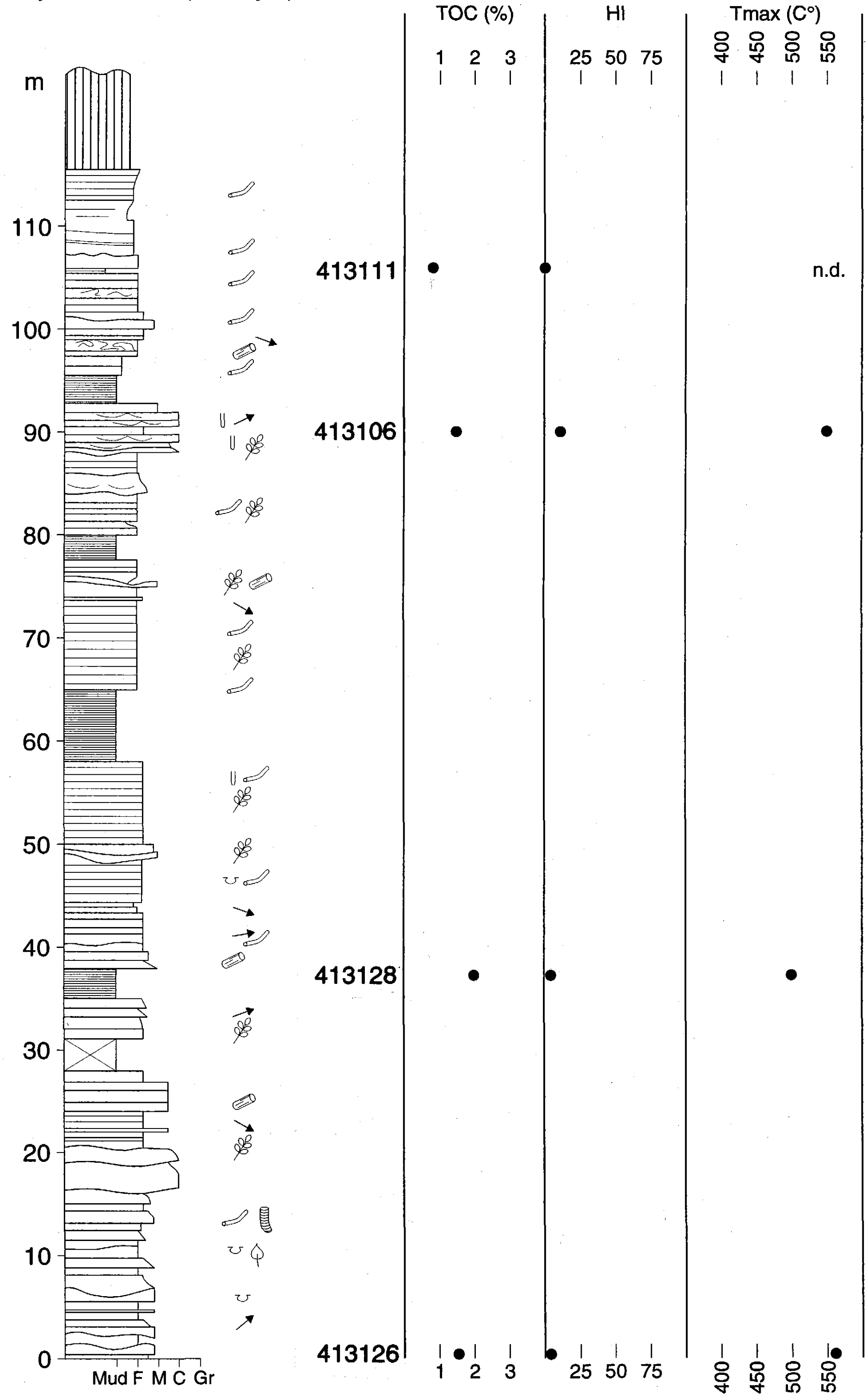
G6.1-95.036.01-ML

Sorgenfri (locality 4)



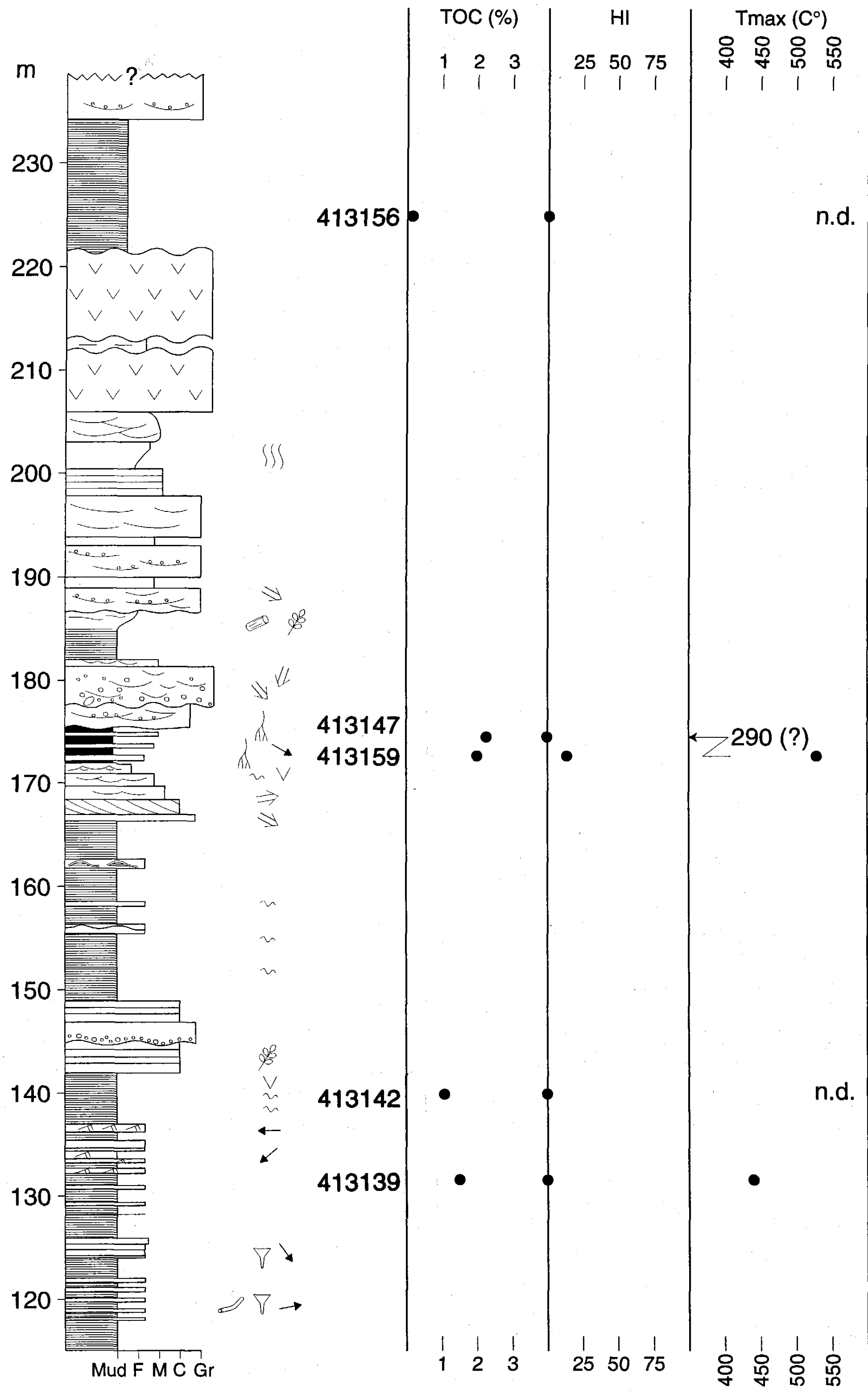
G6.1-95.037-ML

"Sedimentary mountains" (locality 5)

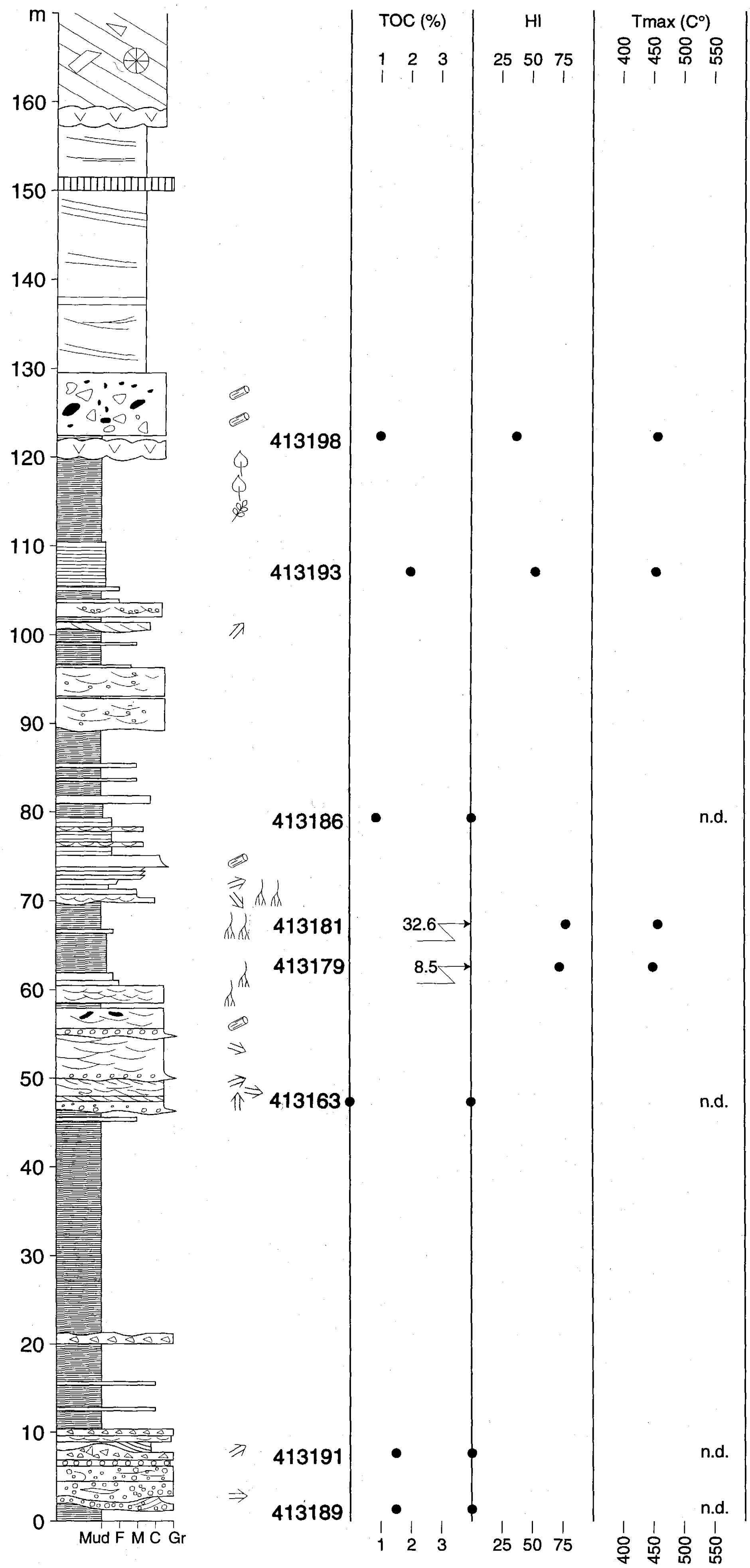


G6.1-95.034.01-ML

"Sedimentary mountains" (locality 5)



Nansen Fjord profil (locality 6)



G6.1-95.035.01-ML