Jurassic and Cretaceous palaeogeography and stratigraphic comparisons in the North Greenland–Svalbard region

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We present sedimentological comparisons and stratigraphical correlations of the Jurassic and Cretaceous epicontinental shelf deposits of Svalbard and updated descriptions of the shallow-marine North Greenland sediments of East Peary Land and Kronprins Christians Land (Kilen). The Callovian to Volgian Agardhfjellet Formation of Svalbard is correlated to the lower part of the Ladegårdsåen Formation on East Peary Land, and to the Birkelund Fjeld, Splitbæk, and Kuglelejet formations of Kronprins Christian Land (Kilen). The Berriasian to Hauterivian Rurikfjellet Formation (Svalbard) correlates with the Dromledome and Lichen Ryg formations from Kilen and the middle part of the Ladegårdsåen Formation from East Peary Land. The Galadriel Fjeld Formation from Kilen and the upper part of the Ladegårdsåen Formation (East Peary Land) are comparable to the Helvetiafjellet and Carolinefjellet formations of Svalbard. These comparisons between Svalbard and North Greenland are combined with stratigraphical information from neighbouring regions in palaeogeographical reconstructions. Five selected time slices are presented within a setting of the most recent plate tectonic reconstructions for the area.

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The Mesozoic successions of the Arctic reflect generally marine shelf to terrestrial depositional conditions (Parker 1967; Håkansson, Heinberg & Stemmerik 1981; Balkwill et al. 1983; Århus et al. 1990; Århus 1991a; Dypvik et al. 1991; Embry 1991; Håkansson et al. 1991). The stratigraphy of these successions is relatively well known. The correlations and paleogeographic maps of Jurassic and Cretaceous formations presented herein are based both on published information and on recent field observations. During the last 25 years, plate tectonic reconstructions of the Arctic have been the main focus of several geophysical investigations (e.g. Herron et al. 1974; Talwani & Eldholm 1977; Lawver et al. 1990; Faleide et al. 1993; Eldholm et al. 1994; Skogseid et al. 2000). The newly presented plate configurations of Lawver et al. (1999) have been used in the palaeogeographic reconstructions presented herein.

Break-up of the north-east Atlantic rift system (chron 24r) about 55–55.5 Mya (Eldholm et al. 1994; Skogseid et al. 2000) took place along the Mohns and Knipovich ridges and was accompanied by strike–slip movements between Svalbard and North Greenland (Fig. 1). Extension and development of a rift margin between Svalbard and North Greenland started some time after the change in relative plate motion (chron 13) about 34 Mya (Lawver et al. 1990; Faleide et al. 1993; Eldholm et al. 1994).

North Greenland and Svalbard are key areas for the geological reconstruction of the Jurassic and

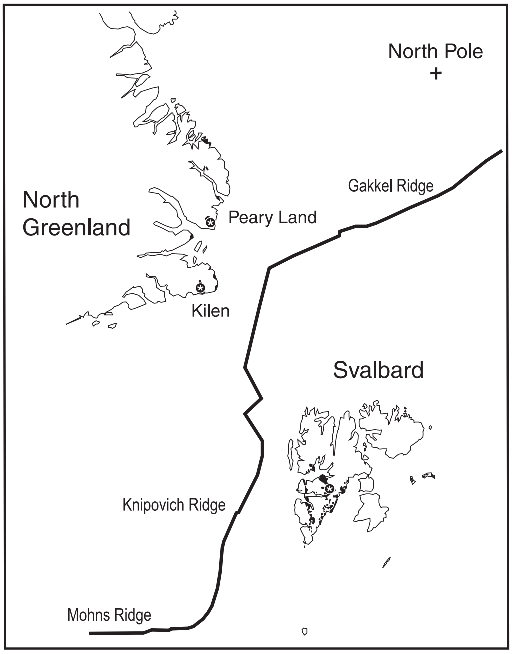


Fig. 1. Map of Svalbard and North Greenland with the present positions of plate boundaries marked. Jurassic and Cretaceous outcrops discussed in the paper are marked with black. The stars show the study locations on Svalbard (Oppdalsåta, Lardyfjellet and Aasgardfjellet) and North Greenland (Kilen, i.e. Dromledomen, and East Peary Land, i.e. Sildredomen).

Cretaceous Arctic because they provide important links between the Canadian and Siberian basins. An understanding of the structural and sedimentological evolution of the North Greenland–Svalbard regions, and their mutual stratigraphical relations, is therefore important for understanding the evolution of the entire Arctic province.

Detailed stratigraphic and sedimentological investigations have been performed in the Jurassic and Cretaceous succession, in Svalbard (e.g. Parker 1967; Pchelina 1967; Major & Nagy 1972; Harland 1973; Steel et al. 1978; Birkenmajer et al. 1982; Bäckström & Nagy 1985; Dypvik et al. 1991, 1992; Nemec 1992; Gjelberg & Steel 1995) and North Greenland (e.g. Håkansson, Heinberg & Stemmerik 1981; Håkansson et al. 1991; Håkansson et al. 1993; Håkansson, Heinberg, Madsen et al. 1994; Heinberg & Håkansson 1994). While the Jurassic and Cretaceous Svalbard succession is accessible in extensive outcrops, the North Greenland exposures are more restricted, and structural and stratigraphic relationships are more complex (Fig. 2).

Recent palaeogeographical models for the region (Dorè & Gage 1987; Larsen 1987; Kelly 1988; Ziegler 1988; Dorè 1991) are based mainly on published sedimentological and stratigraphical compilations. Consequently, their maps are generalized and represent time slices of long duration. Owen (1988), however, presented detailed reconstructions for the Albian at the ammonite zonal level.

General geology

The relative positions of Svalbard and North Greenland in the Mesozoic have now been clarified by the most recent palinspastic tectonic recontructions of Lawver et al. (1990), Faleide et al. (1993) and Lawver et al. (1999).

In North Greenland a well developed Jurassic to Tertiary succession rests on Upper Paleozoic and Triassic strata, with Oxfordian sandstones being the oldest Jurassic beds present (Heinberg & Håkansson 1994) (Fig. 2). The overlying Jurassic and Cretaceous section is dominated by shales and siltstones (Håkansson et al. 1991), which in the Kilen area are represented by six shallow-marine stratigraphic formations (Birkelund Fjeld, Splitbæk, Kuglelejet, Dromledome, Lichen Ryg and Galdriel Fjeld formations) (Heinberg & Håkansson 1994). The East Peary Land succession has not yet been described in detail. Through the Middle Jurassic and the Early Cretaceous, the North Greenland and Svalbard region was dominated by a deep to shallow-marine, epicontinental shelf sea with marginal marine to terrestrial conditions at the basin margin.

The Wilhelmøya Subgroup (Figs. 2, 5) of Svalbard comprises an Upper Triassic to Lower Jurassic succession of shallow-marine and deltaic strata. A significant mid-Jurassic transgression was followed by the establishment of fluvio-deltaic to deep marine depositional conditions, represented by the Adventdalen Group. This transgression was initiated in the mid-Bathonian, followed by mid-Callovian regression and then by renewed transgression in the Late Callovian (Smelror, pers. comm. 2000). After a major regression in the Barremian, there was then a long-term transgression through the Albian (Gjelberg & Steel 1995). No post-Albian Cretaceous deposits have yet been found on Spitsbergen, a

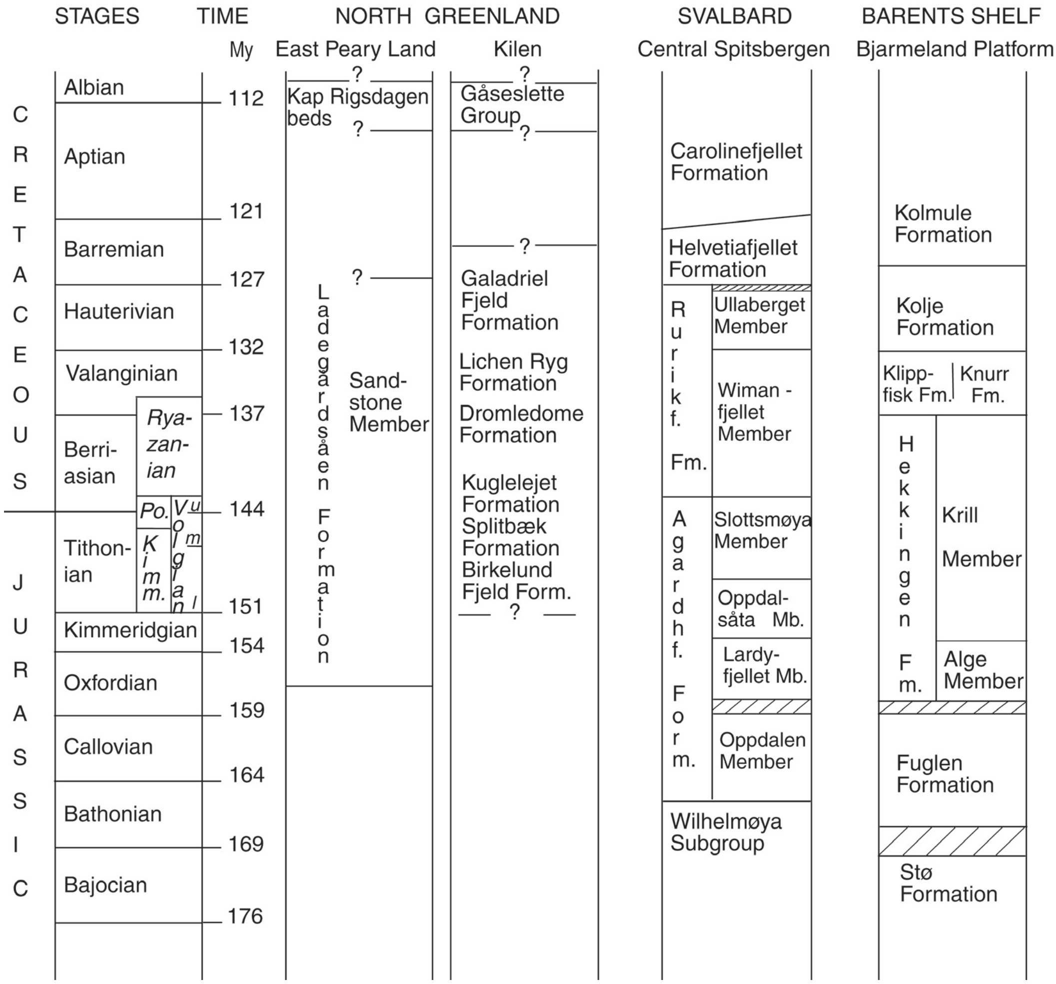


Fig. 2. Stratigraphic correlation between North Greenland, Svalbard and the Barents Sea successions. Based on Dypvik et al. (1991), Håkansson et al. (1993), Gradstein et al. (1994), Heinberg & Håkansson (1994), Mørk et al. (1999) and Smelror (pers. comm. 2000). The inset subdivision in the stage column marks the boreal stratigraphical subdivision where Po = Portlandian, Kimm = Kimmeridgian.

result of extensive Late Cretaceous uplift and erosion (Major & Nagy 1972; Faleide et al. 1993). However, according to Smelror (pers. comm. 2000), reworked late Cretaceous fossils are present in the Middle to Upper Paleocene beds of Sørkapp Land, suggesting that some Late Cretaceous sedimentation occurred somewhere in the region.

In the Barents Sea, the Adventdalen Group is represented by six formations. The Bathonian to Ryazanian Fuglen and Hekkingen formations can be correlated to the Agardhfjellet Formation on Svalbard, whereas the Lower Cretaceous Knurr and Klippfisk formations can be correlated to the Rurikfjellet Formation. The overlying Barremian–Albian Kolje and Kolmule formations are correlative with the Helvetiafjellet and Carolinefjellet formations, respectively (Worsley et al. 1988; Nøttvedt et al. 1992; Mørk & Smelror 1998; Smelror et al. 1998; Mørk et al. 1999) (Fig. 2). Late Cretaceous uplift and erosion was not as severe in the southern Barents Sea as in Svalbard to the north; consequently, condensed Upper Cretaceous sediments of the Nygrunnen Group are preserved in the Barents Sea (Mørk & Smelror 1998). The Jurassic and Cretaceous Barents Sea succession is made up of deep to shallow-marine shelf deposits (Mørk et al. 1999). Juras-

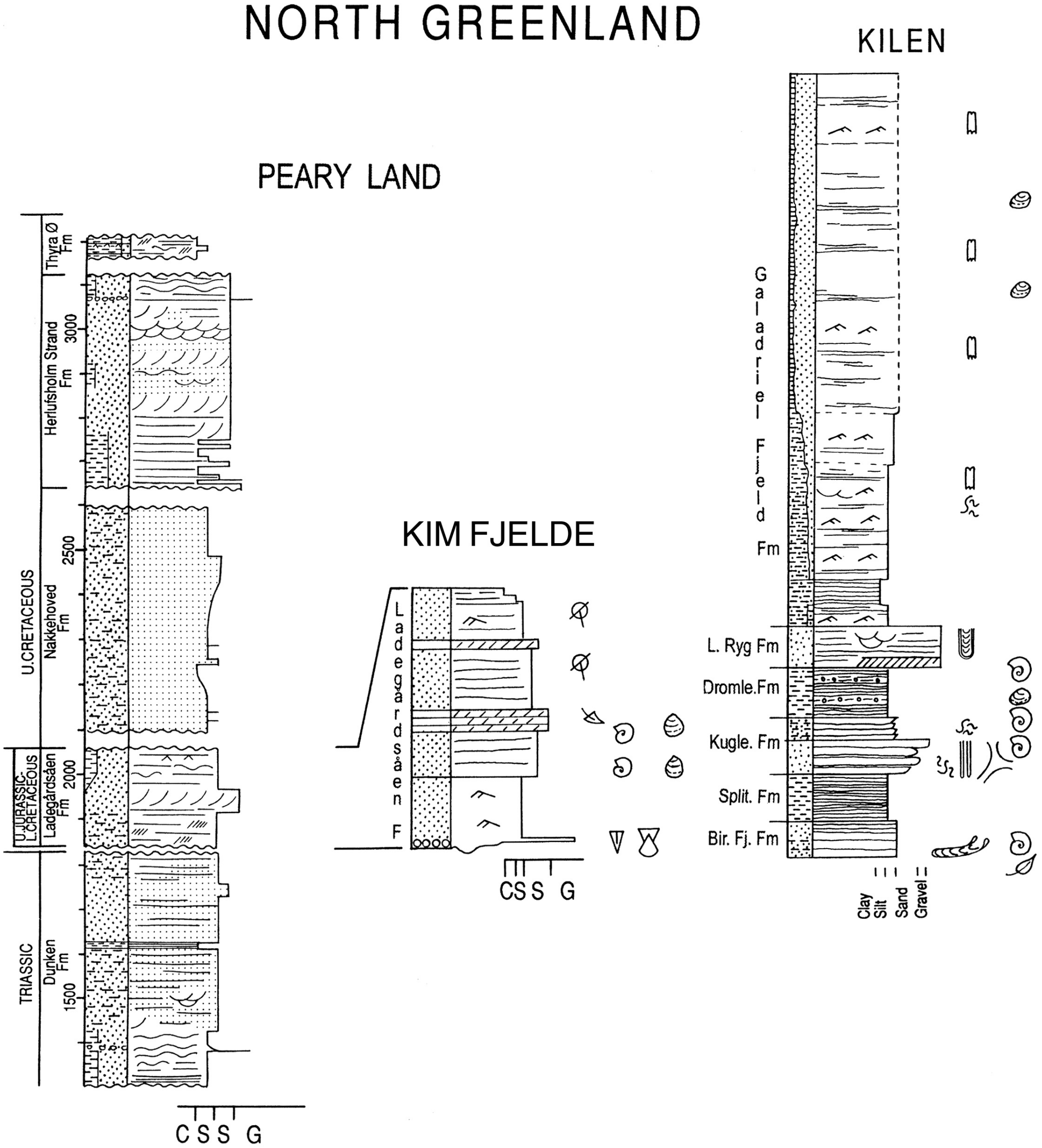


Fig. 3. Stratigraphic columns of the Jurassic and Cretaceous sections on North Greenland. Sildredomen section of the Ladegårdsåen Formation in the left column. The sections are presented in Håkansson (1979) and Håkansson, Birkelund et al. (1981).

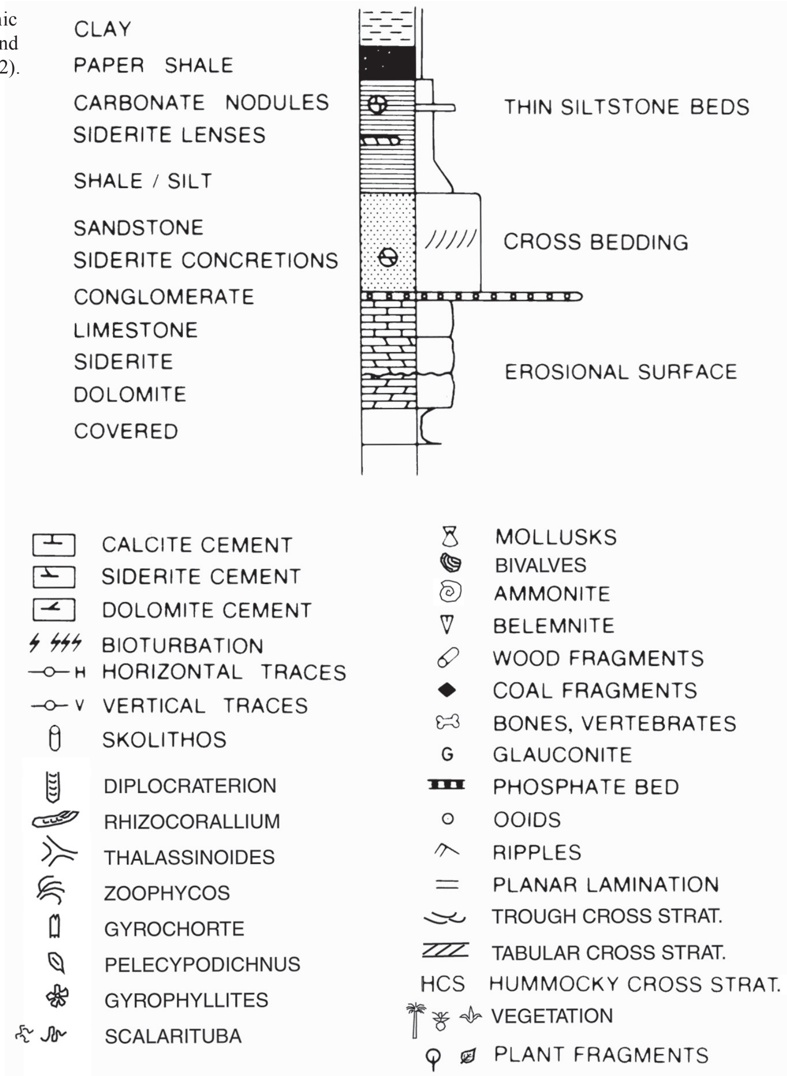
sic and Cretaceous sedimentation in the basins of North Greenland, Svalbard and the Barents Sea was highly influenced by their proximity to tectonically active neighbouring plate boundaries (Lawver et al. 1990; Faleide et al. 1993; Håkansson & Pedersen 2001; Lawver, pers. comm. 2001). In North Greenland, late Cretaceous sedimentation took place in fault-controlled "pull-apart" basins (Birkelund & Håkansson 1983; Håkansson et al. 1991).

Stratigraphy

North Greenland

The two main Jurassic/Cretaceous sedimentary successions in North Greenland are located in East Peary Land and at Kilen (Håkansson, Birkelund et al. 1981; Håkansson, Heinberg & Stemmerik 1981; Håkansson et al. 1991; Håkansson, Heinberg, Madsen et al. 1994; Håkansson, Hein-

Fig. 4. Legend for the stratigraphic logs shown in Figs. 3 and 5 - 11 and palaeogeographical maps (Fig. 12).



berg & Pedersen 1994; Heinberg & Håkansson 1994) (Figs. 1 - 4, 6 - 9). In both areas, Oxfordian / Kimmeridgian to Albian deposits are present.

The Ladegårdsåen Formation (> 250 m thick) of East Peary Land (Figs. 1 - 3, 6 - 7) comprises shallow-marine shales, siltsones and sandstones of Middle Oxfordian to early Cretaceous age. In the lower part of the formation (Fig. 6), well-bedded to parallel laminated, dark grey shales and shaley sandstones, commonly containing plant fragments, form 10 - 30 cm thick upward-coarsening units. Faint remnants of possible current ripples have been observed. These coarsening-upward units normally terminate in 5 - 20 cm thick beds of bioturbated, poorly to moderately sorted, grey silty sandstones. The succeeding units from the middle part of the Ladegårdsåen Formation are sand-dominated, highly bioturbated and the poorly sorted sandstones, are locally rich in plant fragments and may contain siderite concretions. At this stratigraphical level, in the lower part of the middle Ladegårdsåen Formation (Fig. 6), the upward-coarsening units are somewhat thicker than below, forming 2 - 6 m thick units that possibly reflect deposition in shallow-marine bars.

Both the shales and the sandstones in the lower and middle part of the Ladegårdsåen Formation

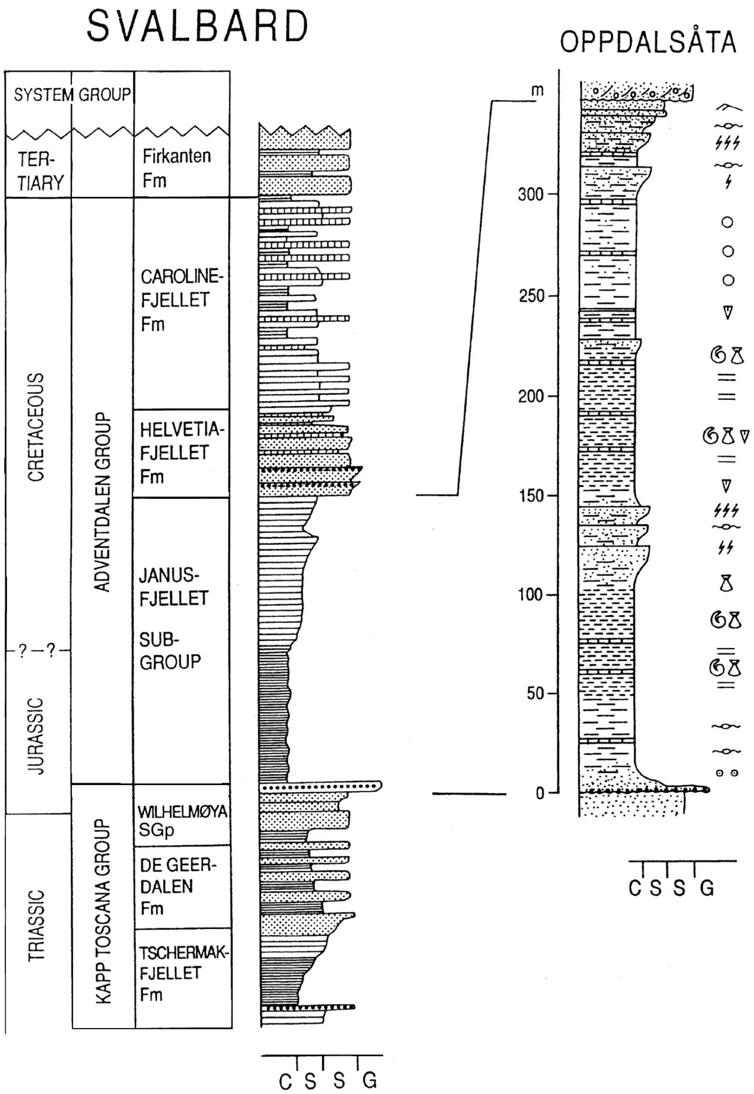


Fig. 5. Stratigraphic column of the Jurassic and Cretaceous successions on Svalbard. The sections are described and presented in Dypvik et al. (1992).

show marine bioturbation burrows (e.g. *Thalassinoides*). The silty shales and shaly sandstones are rich in plant fragments and poor in macrofossils; only a modest number of belemnites and bivalves, along with vertebrate remains (possibly of a plesiosaurid) have been found.

The silty and sandy shale-dominated packages in the middle parts of the Ladegårdsåen Formation are overlain by a prominent, cemented, cross-stratified, light grey, probably more than 100 m thick sandstone unit of Valanginian age (Figs. 6-7) (Håkansson et al. 1991). This sandstone may be correlated to the Lichen Ryg Formation, a comparable unit present in the Kilen sections (Figs. 2-3, 8). The coarse-grained Ladegårdsåen Formation sandstone units have erosional bases, with lag conglomerates overlain by well sorted, planar to tangential cross-stratified sets varying in thickness from 0.4-2 m. The lags may, in addition to coarse basement clasts, contain mud flakes, plant remains and coal fragments. These upward fining, cross-bedded sets commonly consist of about 0.2-1.5 cm thick normal graded beds, displaying overall well defined palaeocurrents measured to predominant southerly transportation directions (Fig. 6). The southerly directions are well developed, and are only in one location somewhat twisted to more eastward-directed palaeocurrents (ripples in shales from a local lagoonal setting, 230 m level in Fig. 6). This easterly palaeocurrent direction is also present in the lower, more shaly units of the adjacent Sildredomen section (Fig. 6). Tangential cross-bedded, as well as trough cross-bedded units carrying convolute lamination structures, are present in some beds.

The cross-stratified and ripple-laminated coarse sandstones may locally comprise up to 6 m thick fining-upward units. The good sorting, lack of red colouration and the similar sedimentological development of this sandstone in the North Greenland localities visited, combined with well developed southerly directions of transport, suggest a shallow-marine, coastal sand of shoreface origin. Deposition was highly influenced by south-easterly coast-parallel currents. At one location, lagoonal organic-rich black shales directly overlie the cross-bedded sandstones. In this lagoonal facies, ripple laminated sandstones with easterly transportation directions possibly reflect currents away from land, striking at a right angle to the palaeo-coastline. A barrier island configuration with associated, cross-bedded, well sorted tidal inlet sands therefore cannot be excluded, even with the dominant southerly palaeocurrent directions present.

Above the Valanginian sandstones, successions of shallow-marine to non-marine shales and sandstones are present (Håkansson, Heinberg & Stemmerik 1981; Håkansson et al. 1991; Håkansson, Heinberg, Madsen et al. 1994; Heinberg & Håkansson 1994). In East Peary Land, shallow-marine Aptian to Albian shaly and sandy sediments are found locally (Fig. 3).

In the Kilen area of Kronprins Christian Land (Figs. 1-3, 8-9), the upper Mesozoic succession (>3500 m thick) has a possible Late Oxfordian/Early Kimmeridgian base, and the succession is more continuously exposed than in East Peary Land. The lowermost 350 m of the Kilen succession is made up of highly bioturbated, dark grey shales and sandstones of Kimmeridgian to Valanginian age. The marine successions contain ammonites and bivalves, and often form upward-coarsening units. Some of the coarser grained intervals contain plant fragments and glauconitic beds.

The highly bioturbated, well-bedded, poorly sorted medium-grained, belemnite sandstones of the Birkelund Fjeld Formation (Figs. 2, 8), represent shallow-marine depositional conditions.

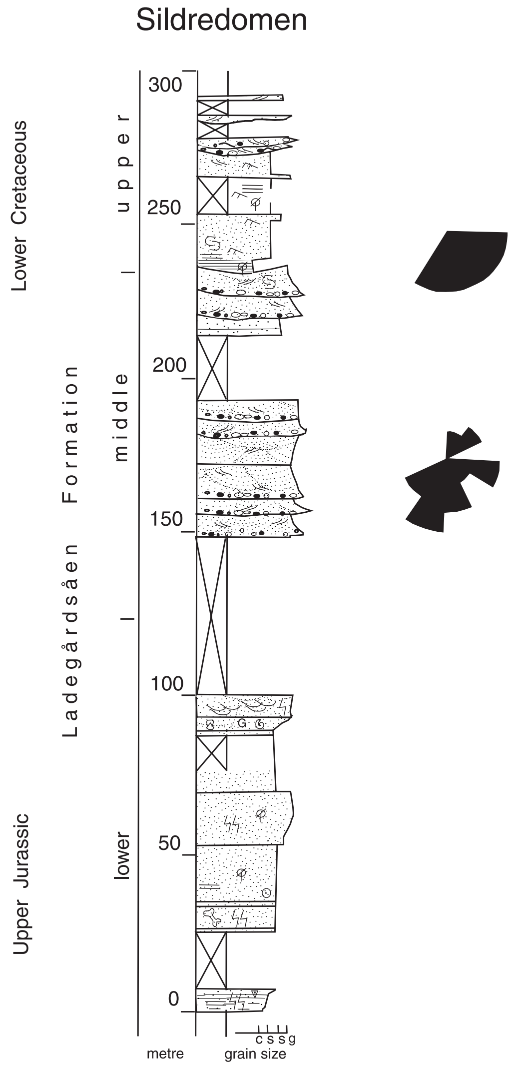


Fig. 6. Stratigraphic log from Sildredomen, East Peary Land—the Ladegårdsåen Formation of Oxfordian–Valanginian age. Rose diagram of transportation directions based on ripples and cross-bedding.

Thalassinoides, Rhizocorallium and *Planolites* ichnofossils are common in the lower parts of the succession, whereas imprints of cycad leaves and stems are present throughout the formation (Figs. 2, 8). The latter suggest a strong terrestrial influence. Well developed bioturbation gives the unit a rubbly appearance. The Splitbæk Formation (Figs. 2, 8) overlies the Birkelund Fjeld Formation and consists of 18 m of organic-rich, finely laminated black shales in its lower part, in a total thickness

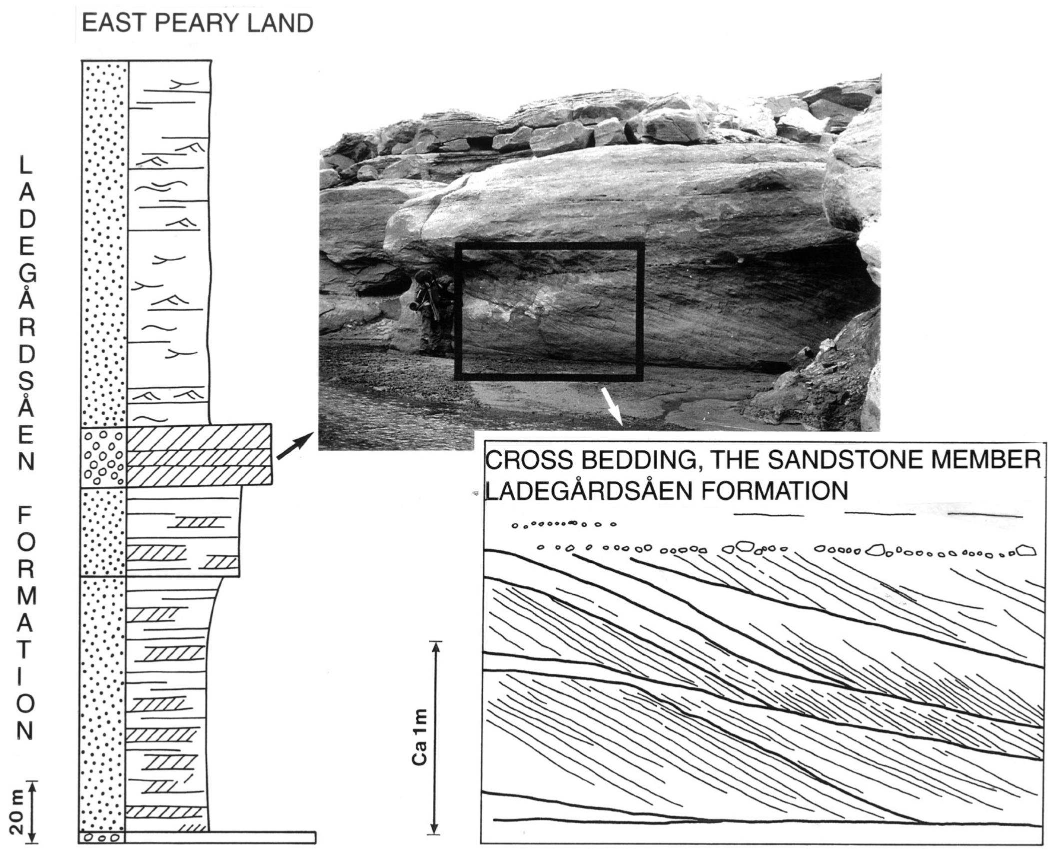


Fig. 7. Detailed logs and photograph from the Valanginian Sandstone of the Ladegårdsåen Formation, Skvatdalen, East Peary Land.

of 30 m. The uppermost 12 m consists of parallel laminated, bioturbated, fine-grained sandstones. The Splitbæk Formation is overlain by the 90 m thick, overall upward-coarsening sandstone and shale formation of the Kuglelejet Formation (Fig. 2). The formation is partly cemented sandstones and bioturbated with *Thalassinoides, Helminthoidea* and *Teichichnus.* Overall the lowermost 40 m of the Kuglelejet Formation is made up of several 5 - 20 m thick coarsening-upward successions, whereas the uppermost, more finer-grained, 50 m of the formation are composed of 1 - 2 m thick coarsening-upward intervals. In detail the lowermost 20 m are seen to be composed of 1 - 3 m thick upward-coarsening units, with a few ripples and plant fragments present. The beds contain scattered ammonites and well preserved skeletal remains probably belonging to *Plesiosaurus.* The central part of the Kuglelejet Formation (level 125 m in Fig. 8) comprises several cross-stratified, channelized beds in a 6 m thick unit, exhibiting clear south-easterly palaeocurrent directions. These units contain the ichnofossils *Skolithos* and *Diplocraterion habichi*, and cut-and-fill structures which are 30 - 60 cm deep. Their erosional bases carry grains of glauconite in lag conglomerates. The dark grey to black shales of the Dromledome Formation (Figs. 2, 8) (70 m thick) overlie the Kuglelejet Formation. These shales show only faint bioturbation, but a few traces of *Zoophycos* have been observed. The Dromledome Formation contains *Buchia* and normally comprises parallel laminated shales. The various depositional units possess dispersed 10 - 30 cm thick siderite beds, partly with nodular developments. The uppermost part of the Dromledome Formation is formed by a 2.5 m thick fine, micaceous sandstone bed with hummocky cross-stratification. The Dromledome Formation is overlain by the well sorted, medium to coarse-grained, light grey sandstones of the Lichen Ryg Formation (Figs. 2, 8).

The shallow-marine, yellowish weathering ?Valanginian sandstones of the Lichen Ryg Formation form a 30 - 50 m thick unit, creating the steepest local relief in the area. These well-cemented, cross-stratified sandstones have a similar appearance in the Kilen sections to the above-mentioned Valanginian sandstone unit in East Peary Land. In the Kilen sections, however, a greater spread of palaeocurrent directions has been measured, but a southerly direction is also documented there. The cross-strata are commonly tangential with erosional bases and conglomeratic lags, often with mud flakes in the 0.5 - 2 m thick beds; they may represent tidal inlet deposits of a barrier island dominated coast. The upward-fining sandstone beds are cross-stratified to ripple-laminated, and in some units convolute lamination has been observed. Plant fragments are common. The upper part of the Lichen Ryg sandstone unit is highly bioturbated and contains well developed *Diplocraterion* and *Thalassinoides* traces. The ?Valanginian Lichen Ryg Formation at Kilen is highly stylolitized.

The open marine bioturbated shales and sandstones of the Galadriel Fjeld Formation overlie the Lichen Ryg Formation in the Kilen area, displaying open marine sedimentation. In the lowermost part of the Galadriel Fjeld Formation (Figs. 2, 8 - 9), well developed hummocky cross-stratification and cone-in-cone structures occur. Ripple crest orientations have been measured as striking east–west (level 390 m) (Fig. 8.). The overlying Upper Cretaceous formations represent several coarsening-upwards marine sequences accumulated in a pull-apart basin developed in a right-lateral strike–slip regime (Håkansson, Heinberg, Madsen et al. 1994).

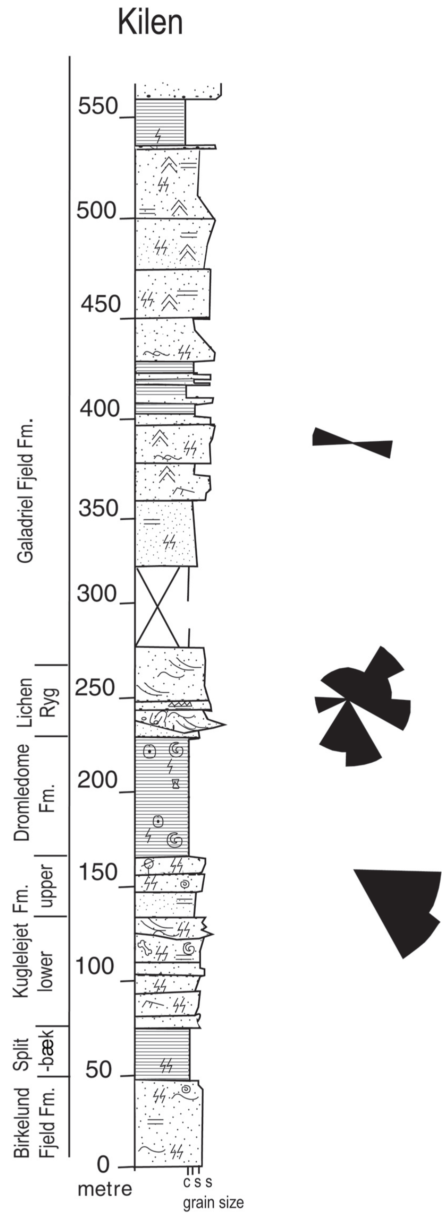


Fig. 8. A compilation of the stratigraphical succession at Dromledomen, Kilen. Rose diagram of transportation directions are measured from ripples and cross-bedding. In the Galadriel Fjeld Formation ripple crest orientation is shown.

Svalbard

The uppermost Triassic and Lower Jurassic succession of Svalbard (Wilhelmøya Subgroup) (Figs. 2, 5, 10) is dominated by shallow-marine sediments, deposited during a period characterized by reduced terrigeneous clastic influx and several stratigraphic breaks. The Wilhelmøya Subgroup is succeeded by the basal beds of the Janusfjellet Subgroup, showing initiation and advance of the major Bathonian–Callovian transgression in the area (Bäckström & Nagy 1985; Nagy et al. 1990) disrupted by a mid-Callovian regressive phase (Smelror, pers. comm. 2000). The transgressive development continued well into the Oxfordian, as seen in the transition of the phosphatic conglomerate of the Brentskardhaugen Bed up into the black, organic-rich, finely

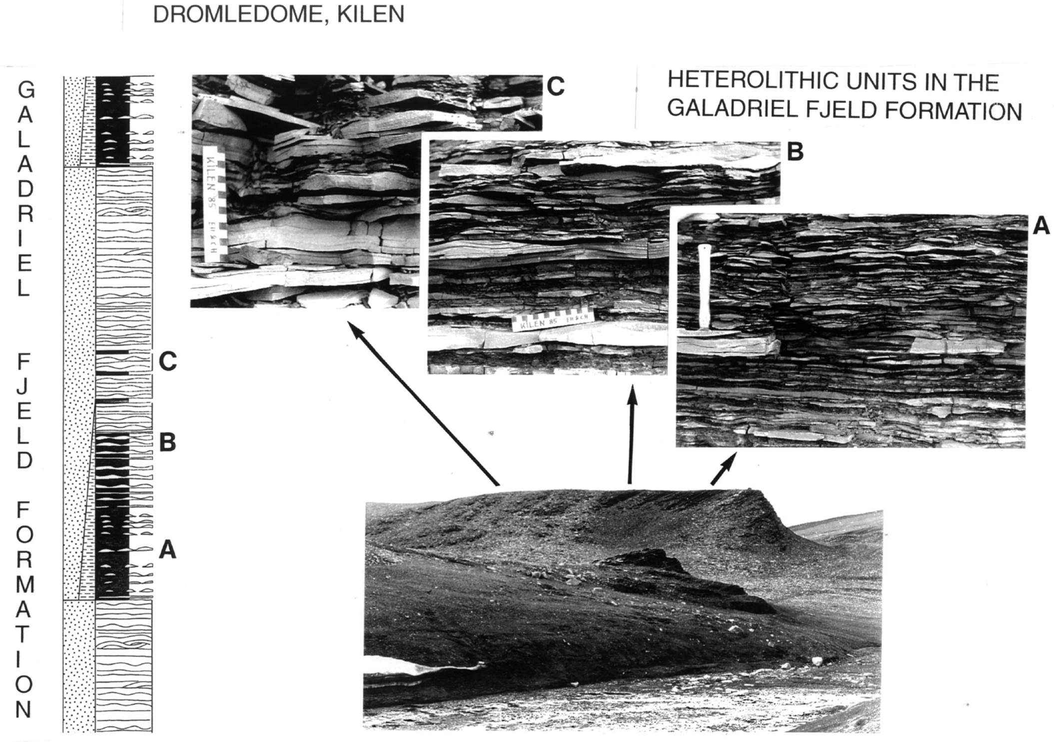


Fig. 9. A detailed lithological log and field photos of the ripple laminated heterolithic strata of coarsening-upward successions of the Galadriel Fjeld Formation near Dromledomen, Kilen.

laminated shales of the Lardyfjellet Member of the Agardhfjellet Formation (Figs. 2, 5). In the Late Oxfordian/Early Kimmeridgian, a transgression most likely affected the North Greenland localities, and the first Jurassic shallow-marine sands (Ladegårdsåen and Birkelund Fjeld formations) were deposited there, while black, organic-rich clays were formed on Svalbard and in the Barents Sea (Fig. 2). This configuration continued into the Kimmeridgian.

Depositional conditions were dominated by anoxic to hypoxic sedimentation during the Oxfordian and Kimmeridgian (Lardyfjellet, Oppdalsåta and Slottsmøya members) (Figs. 2, 5, 10). Periods with high wind and storm activity locally disrupted the sedimentation of organic-rich clays, with deposition of offshore sand bars (the upper Kimmeridgian–lower Volgian Oppdalsåta Member; Dypvik et al. 1991). Periods of generally north–north-westward blowing storms reworked the prodeltaic and shelf deposits which until then had been fed from the north (Dypvik et al. 1991; Dypvik et al. 1992), creating widespread offshore bars and sublittoral sheet sands at this time. The uppermost coarsening-upward intervals of the Oppdalsåta Member consist of rather homogeneous silt- and sandstones with well-oriented belemnites.

The dark grey shales of the Lardyfjellet and Slottsmøya members, separated by the sandy storm-dominated Oppdalsåta Member, span the Oxfordian to Middle Volgian (Fig. 10). They can most likely be correlated with the Birkelund Fjeld, Splitbæk and Kuglelejet formations in Kilen (Håkansson, Heinberg & Stemmerik 1981; Håkansson et al. 1991; Håkansson, Heinberg, Madsen et al. 1994; Heinberg & Håkansson 1994) (Figs. 2, 5, 8). However, only the dark shales of the Splitbæk Formation show a lithology comparable to the shales of the Agardhfjellet Formation.

The sedimentation of black, organic-rich clays continued on Svalbard throughout the Jurassic (although Smelror claims the possibility of a late Volgian hiatus; pers. comm. 2000) (Figs. 5, 10-11) under partly reducing conditions. This is reflected by dark grey shales (the paper shales of the Slottsmøya Formation), highly enriched in trace elements such as V, Ni, U and Cr (Dypvik 1980; Nagy et al. 1988, 1990). In contrast, the time-equivalent North Greenland successions display higher sand content, lighter colours and a lower organic content. The upward-coarsening development of the Slottsmøya Member culminated at the contact between the Agardhfjellet and Rurikfjellet formations, marked by the Myklegardfjellet Bed. The base of this bed represents a transgressive surface which seems to be correlative with the contact between the Kuglelejet and Dromledome formations.

After maximum transgression around the Ryazanian–Valanginian transition (Fig. 2), an upward-shallowing, regressive development took place during Valanginian and Hauterivian times. In this period shallow-marine and partly prodeltaic conditions dominated on Svalbard, in an overall southward-prograding, regressive development (Figs. 5, 10 - 11). The Ryazanian–Valanginian Wimanfjellet Member is made up mainly of very fine-grained claystones with a few dispersed sideritic beds (Fig. 10). The Wimanfjellet Member has been interpreted to represent the deepest water conditions of the Janusfjellet Subgroup (Nagy et al. 1990). These are probably correlative with the shales of the Dromledome Formation in the Kilen section. The succeeding sand-prone Ullaberget Member (mainly Hauterivian) forms a sedimentological continuation in an overall upward-coarsening development that can be subdivided into at least three small-scale coarsening-upward intervals. These intervals contain several cross-bedded and rippled units, varying from a few centimetres to more than 30 cm in thickness. In the uppermost parts, hummocky cross-stratification is common. These developments reflect storm-wave and current influenced delta-front sedimentation in a prograding shallow-marine delta complex (Dypvik et al. 1991). The southerly palaeocurrent directions (deltaic progradation) match well with the southerly ?Valanginian transport directions in the light grey, cross-bedded sandstones of the Lichen Ryg Formation in Kilen (see above).

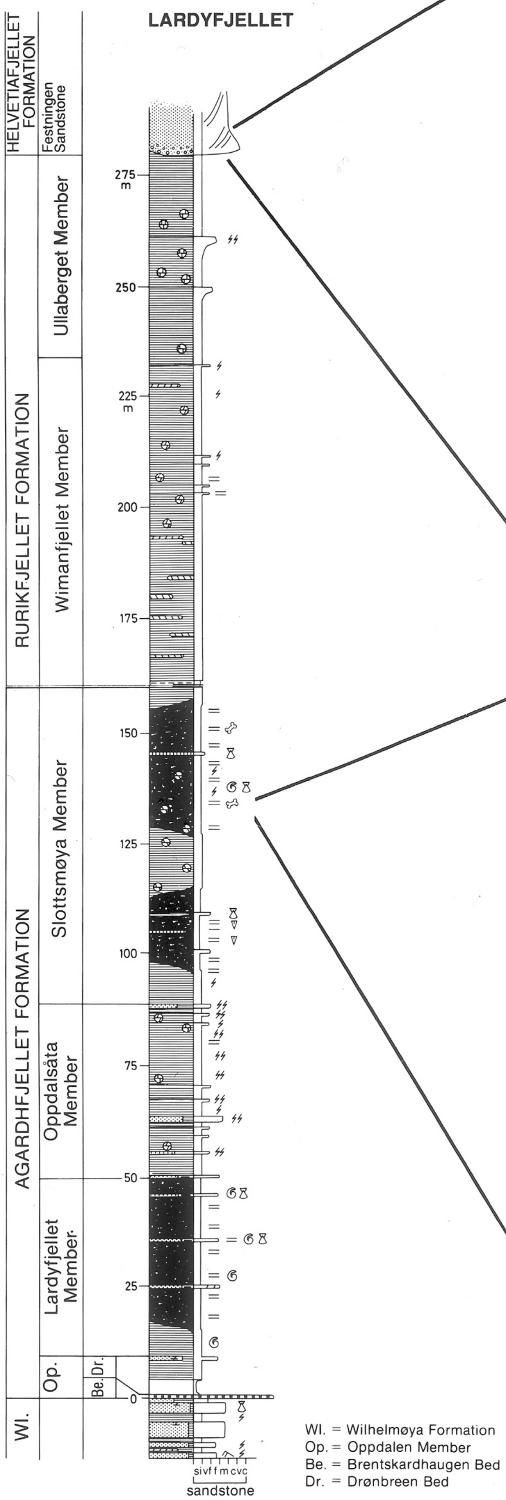
The progradational deltaic developments in the Svalbard region terminated in the Barremian, with the deposition of the up to 30 m thick, coarse-grained, fluviodeltaic Festningen Sandstone Member of the Helvetiafjellet Formation. This unit directly overlies the Janusfjellet Subgroup (Major & Nagy 1972; Edwards 1976; Steel 1977; Steel et al. 1978; Nemec et al. 1988; Grøsfjeld 1992; Nemec 1992; Gjelberg & Steel 1995). Although there is no major hiatus at the base of the Barremian section, and despite the regression seen in the Ullaberget Member, there is clear erosion and likely deep fluvial incision in places at the base of the Helvetiafjellet Formation (with fluvial deposits directly on offshore shales in places). This has been interpreted as a pronounced phase of forced regression (sea level fall) succeeding the earlier normal regression (Gjelberg & Steel 1995). The overlying plant- and coal-bearing succession of the Glitrefjellet Member displays interdistributary bay to delta top depositional conditions (Steel 1977; Gjelberg & Steel 1995), directly overlain by the shallow-marine, transgressive Carolinefjellet Formation of Aptian–Albian age (Nagy 1970; Major & Nagy 1972). The Carolinefjellet Formation is composed of prodeltaic to deeper shelf shales and sandstones. In this case, south-westward deltaic progradation occurred and depositional conditions were highly influenced by storm and wind activity. A major stratigraphic break is documented between the Albian Carolinefjellet Formation and the overlying Paleogene beds; no Upper Cretaceous sediments are recorded in Svalbard.

Compared to these published profiles from Svalbard, sections from the Barents Sea generally show more distal, open marine conditions, dominated by clastic fine-grained sedimentation through the Jurassic. The Lower Cretaceous formations of the Barents Sea are dominated by marine shales, but also contain carbonate-rich marly sediments of platform facies (Smelror et al. 1998). A thick succession of Barremian and younger sandy turbidites is predicted south to south-east of Svalbard by the sequence stratigraphic analyses of Gjelberg & Steel (1995) (Steel, pers. comm 2001).

Palaeogeography

Published offshore data presently available from the Barents Sea region are relatively sparse. In contrast, detailed sedimentological published and unpublished logs are available for more than 50 onshore Svalbard and North Greenland localities and this information is incorporated into the palaeogeographical reconstructions presented here.

The Jurassic part of the Svalbard succession



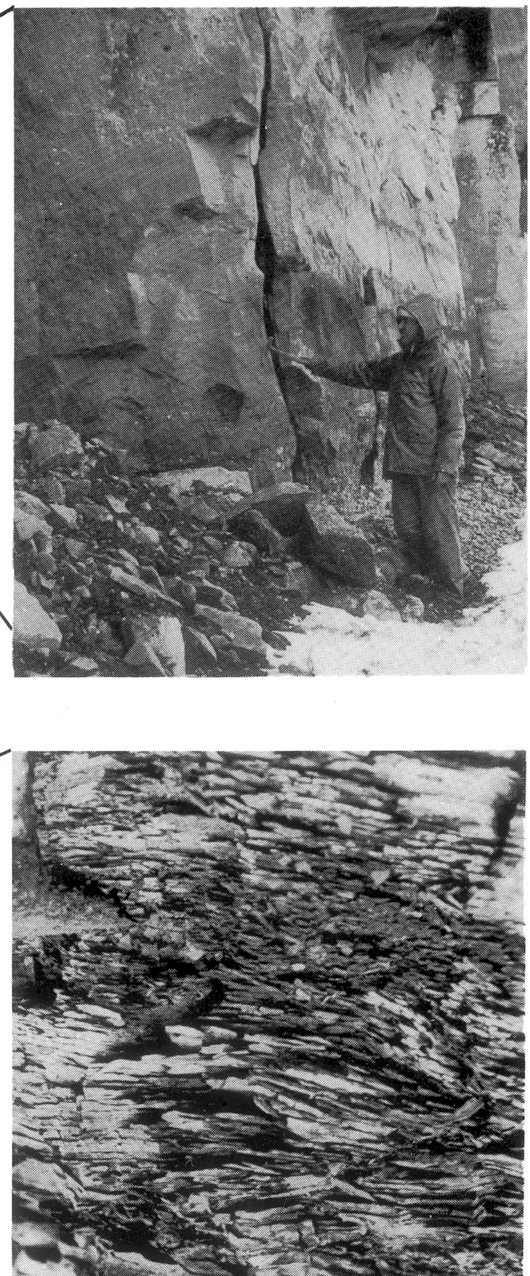


Fig. 10. Stratigraphic log of the Janusfjellet Subgroup at Lardyfjellet, Svalbard. The lower photograph shows the paper shales of the Slottsmøya Member and the upper photo shows the well developed boundary between the silty shales of the Ullaberget Member and the coarse grained Festningen Sandstone Member.

clearly reflects a more basin central position dominated by shales compared to the sandy, time-equivalent marginal marine North Greenland successions. Both the Svalbard and North Greenland sections comprise more shallow-marine depositional conditions in the Lower Cretaceous (regressive developments) than the Jurassic sections. However, the Lower Cretaceous Svalbard succession is less sandy than the North Greenland ones. In the North Greenland sections, marine Upper Cretaceous deposits are also present.

The geological analyses which have been carried out in both regions display related sedimentological developments. In the Jurassic successions, typically coarsening-upward developments are observed with no clear-cut signals of global sequentiality (Milankovitch cycles). These have, most likely, been overprinted by a combination of tectonic, local climatic and diagenetic factors.

The Callovian paleogeographic reconstruction (Fig. 12a) displays "palaeo-North Greenland" as a land area, where erosion was active, while shallow-marine depositional conditions dominated on Svalbard (Oppdalen Member). A narrow seaway existed towards the Sverdrup Basin (McConnell Island Formation) to the west with a possible "Crockerland" (Embry 1991) north of Svalbard. In the western parts of the Barents Sea, marine shelf conditions dominated (Fuglen Formation) (Worsley et al. 1988).

In Late Oxfordian times (Fig. 12b) the regional transgression that initiated in the Bathonian (the so-called Callovian transgression), developed further and shallow-marine sands, silts and clays were deposited in North Greenland and open marine conditions prevailed on Svalbard. Maximum expansion of offshore shelf conditions took place during deposition of the Lardyfjellet, Oppdalsåta and Lower Slottsmøya members (Svalbard) and the Splitbæk Formation of North Greenland. The coarsening-upward intervals of the Lardyfjellet and Oppdalsåta members reflect coastal sand bodies building up as shallow-marine bars, partly climatically controlled (Dypvik 1992; Dypvik et al. 1992). The seaway connection towards the Sverdrup Basin in the west probably widened due to a coeval size reduction of land to the north ("Crockerland" of Embry 1991). In contrast to the single major transgressive development in the Svalbard–North Greenland region, two large-scale T–R sequences (one Callovian and one Oxfordian) have been described from the Sverdrup basin (Embry 1991). The appearance of Upper Oxfordian paper shales on Svalbard and the transgressive development in East Peary Land could be distal reflections of this second phase, the Oxfordian T–R sequence of the Sverdrup Basin and the Canadian Arctic (the Ringnes Formation).

During the Late Oxfordian and Kimmeridgian (Fig. 12b, c), the Svalbard and North Greenland region was covered by a shallow epicontinental sea. Fine-grained sediments were deposited, only interrupted by shifting fluxes of sands, most likely due to wind- and storm-generated currents. Some of these sands were deposited on topographic highs, with a possible tectonic origin (Haremo et al. 1993). Similar sand ridges have been described from the Sverdrup Basin (Awingak Formation), as four poorly defined T–R sequences. Each cycle was initiated by a relative sea level rise, which was followed by basinward progradation of shallow shelf sands, in combination with a gradual decline in the sediment supply toward the end of the Jurassic (Embry 1991). In comparison, the uppermost Kimmeridgian and Volgian units of the Svalbard succession show a similar faint transgressive development (Nagy et al. 1990). The Late Jurassic (Late Oxfordian to Volgian) of the Barents Sea was dominated by deposition of fine-grained, commonly organic-rich clays in shallow to deep shelf environments, with partly anoxic bottom conditions (Worsley et al. 1988).

The Lower Cretaceous beds of this study show related sequential developments in the North Greenland and Svalbard sections. In both places, the units are dominated by minor fining-upward units and homogeneous beds (about 0.5 m in average thickness), reflecting deposition from suspension and turbidity currents. The successions are interpreted to represent parts of a southerly prograding deltaic/prodeltaic facies. Faint sequenciality can be recognized, but they clearly have been overshadowed by the regional sedimentological imprint of the northerly Early Cretaceous uplift (Faleide et al. 1993).

The Valanginian stage (Fig. 12d) is regionally characterized as a regressive phase. The uplift of Svalbard and areas north of Svalbard initiated the southward advance of a major, northerly located clastic shoreline depositional system. The southerly transportation directions measured in the cross-bedding of the Hauterivian Ullaberget Member from Svalbard support this interpretation. There was also Valanginian shallow-

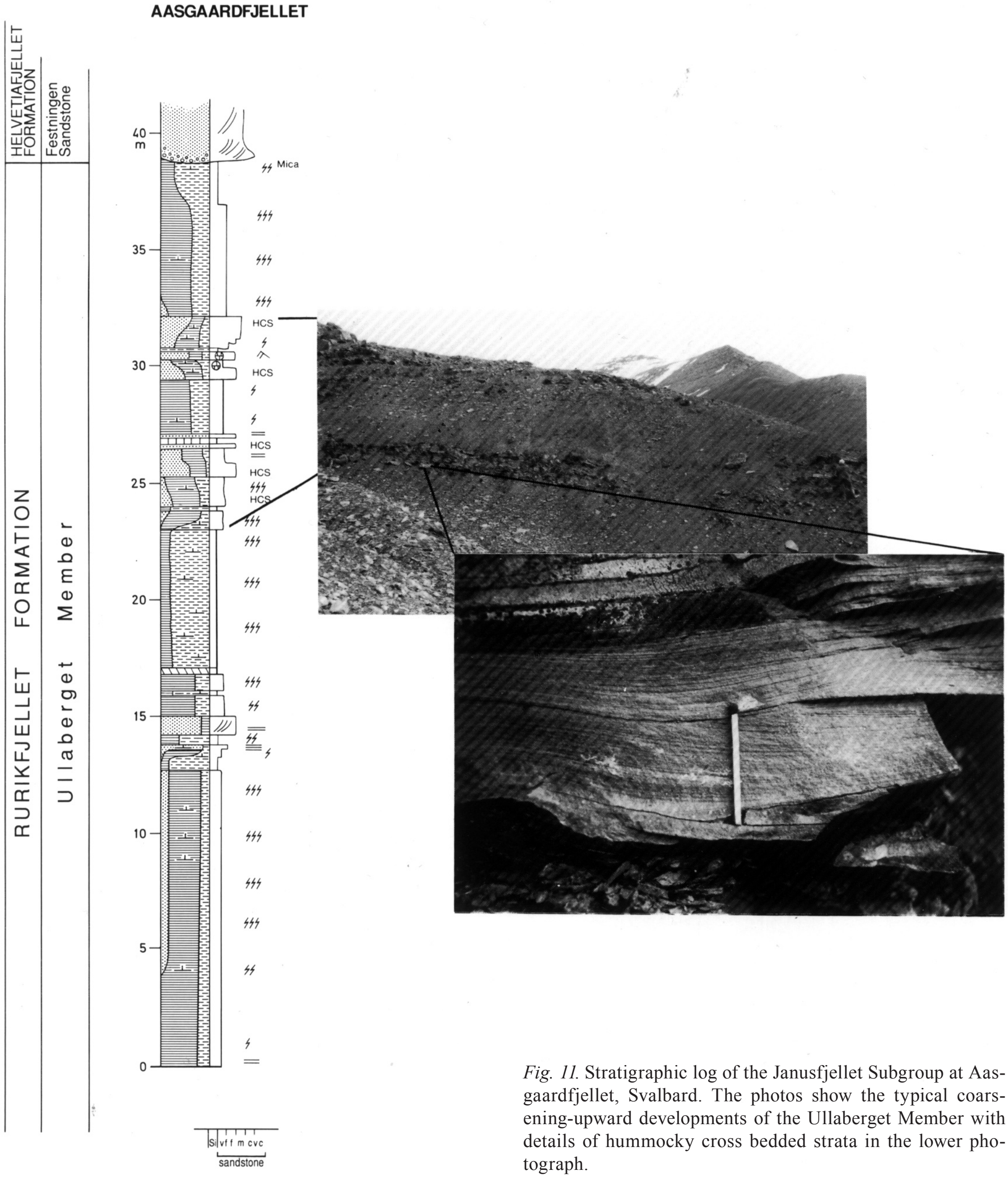
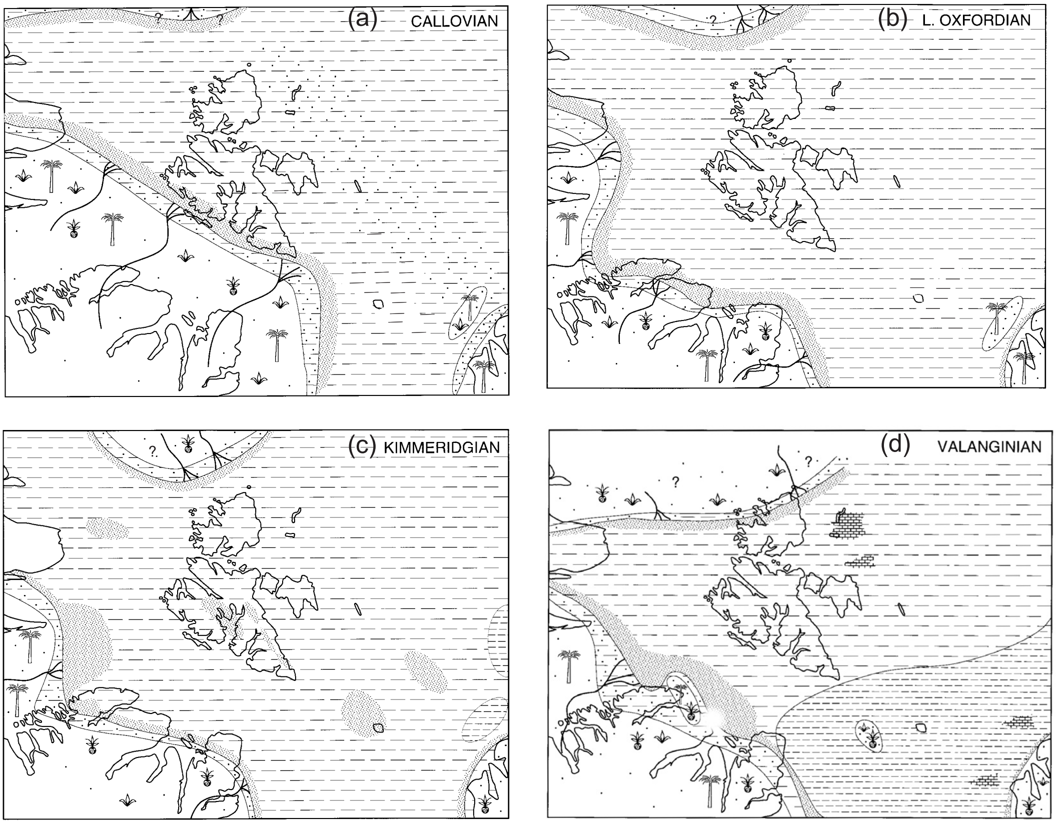


Fig. 11. Stratigraphic log of the Janusfjellet Subgroup at Aasgaardfjellet, Svalbard. The photos show the typical coarsening-upward developments of the Ullaberget Member with details of hummocky cross bedded strata in the lower photograph.

marine and lagoonal sedimentation in North Greenland (East Peary Land), a response to the Late Jurassic to Early Cretaceous levelling of the landscape. The so-called Valanginian Sandstones of Peary Land and the Lichen Ryg Formation of Kilen both display dominant southerly directions of possible coast-parallel transport. Some deviations in the directions have been found in the Lichen Ryg Formation, possibly reflecting additional mechanisms of coastal marine deposition (e.g. rip currents and tidal inlets) in parts of these shallow-marine sandstones. Mainly clays were deposited on Svalbard, except for local carbonate banks in the eastern regions of Kong Karls Land. Sediments of the Valanginian sea, dominated by platform deposition of a condensed sequence



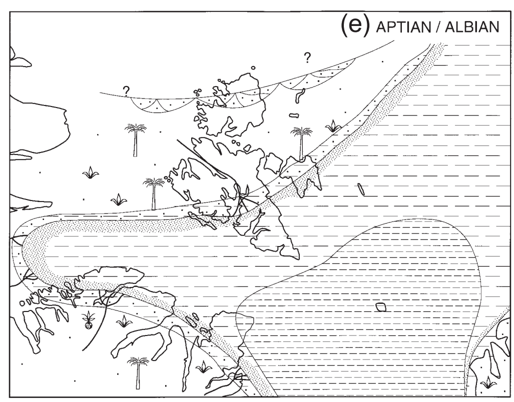


Fig. 12. Palaeogeographic reconstructions, based on the plate tectonics of Lawver et al. (1999): (a) Callovian; (b) Late Oxfordian; (c) Kimmeridgian; (d) Valanginian; (e) Aptian/Albian.

of marly sediments in the western Barents Sea (Klippfisk Formation) pass laterally southward into open marine shales of the Knurr Formation (Worsley et al. 1988; Århus et al. 1990; Århus 1991b; Smelror et al. 1998). Northerly uplift/doming started in Valanginian times and continued through the Early Cretaceous (Fig. 12d). This uplift represents the first geological signals of the Barremian rifting, which started about 10 My later along the Gakkel Ridge, north of Svalbard (Fig. 1) (Lawver et al. 1990; Faleide et al. 1993).

Valanginian to Hauterivian regressive, coarsening-upward sequences are also well developed in the Sverdrup Basin (Isachsen Formation) where they terminate in the early Barremian (Embry 1991). In Svalbard, Barremian coastal progradation is marked by the erosive forced regression base of the prominent Festningen Sandstone Member of the Helvetiafjellet Formation. The Helvetiafjellet Formation itself shows an overall transgressive trend (Gjelberg & Steel, 1995), but contains numerous punctuated regressive pulses within the general back-stepping transgression.

The Barremian transgression sediments in Svalbard continued in a punctuated manner into the Aptian, which is also evident in the Sverdrup Basin (Fig. 12e) (Embry 1991). In the post-Aptian/pre-Paleocene period, northern Svalbard was uplifted and severely eroded (Nagy 1970; Major & Nagy 1972) and no sedimentary units are present from this time interval, though the products of all this erosion should have accumulated on the Barents Shelf farther south. In contrast, marine to terrestrial Cretaceous sedimentation continued in the Sverdrup Basin and in pull-apart basins of North Greenland. Århus (1991a) compared the palynological composition of Aptian to Albian floras of Svalbard, the Barents Sea and North Greenland, and demonstrated great similarities and open marine connections between the regions and equivalent strata in Arctic Canada. In his palaeogeographical map (Århus 1991a; see also Owen 1988), an island is indicated just east of Svalbard.

Conclusion

Based on these stratigraphical comparisons and analyses, it is difficult to correlate between Svalbard and North Greenland in great detail. Comparable sedimentary developments have been observed, however: Jurassic beds dominated by coarsening-upward developments in contrast to the Cretaceous successions which typically consist of homogeneous and fining-upward units. The two shale-dominated Splitbæk and Dromeldome formations seem to be correlative with transgressive segments of the Svalbard succession, namely the middle part of the Agardhfjellet Formation and lower parts of the Rurikfjellet Formation.

This paper represents a first approach, based on local field data, to establish a regional Greenland–Svalbard palaeogeographical framework. Compilation studies will continue, and more detailed stratigraphical and petrographical comparisons related to provenance discussions are underway.

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