Tidally influenced deltaic sequences from the Kap Stewart Formation (Rhaetic-Liassic), Scoresby Land, East Greenland

LARS B. CLEMMENSEN

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Sediments from the Kap Stewart Formation in Scoresby Land are described and interpreted as tidally influenced detaic deposits. Two major types of sequences can by destinguished: (A) horizontally laminated black mudstone followed by flaser or lenticularly bedded sandy mudstone and erosively overlain by cross-bedded channel sandstone. (B) horizontally laminated black mudstone overlain by wave-ripple bedded, horizontally laminated or structureless sandstone. It is suggested that sequence A was deposited during infilling of an interdistributary bay. The mud and fine sand at the base of the sequence resulted from overbank floods; the channel sands formed when distributary channels extended into the bay under tidal influence. Sequence B is interpreted as a bay mouth sequence; laterally redistributed sand was deposited at the seaward end of open bays by wave-action. Palaeocurrent data suggest a southerly palaeoslope and an E-W trending coastline in Scoresby Land during deposition of the Kap Stewart Formation.

Lars B. Clemmensen, Geologisk Museum, Øster Voldgade 5-7. DK-1350 Copenhagen K, Denmark, May 17th, 1976.

Sediments of the Kap Stewart Formation are only known from the Jameson Land Basin in central East Greenland, where they constitute the lowermost formation of the Jameson Land Group (Surlyk et al. 1973).

In the southern part of the basin plant- and coal-bearing deposits of Rhaetic to Hettangian age have long been known (for summary of earlier work see Donovan 1957). The sediments of southern Jameson Land have recently been described as alluvial fan and low sinuosity non braided river deposits (Sykes 1974a). In the western part of the basin one section of the Kap Stewart Formation has been described by Surlyk et al. (1973) showing coal-bearing sandstones and black mudstones. In the northern part of the basin only few descriptions of this formation are available (e.g. Grasmück & Trümpy 1969; Perch-Nielsen et al. 1972), and no detailed interpretation of the depositional environment has so far been given. The exact age of the Kap Stewart Formation in Scoresby Land remains rather uncertain. The few plant remains described, however, indicate a Lower Liassic age (Harris 1946).

During the field-season of 1975 the present author had the opportunity to study sediments of the lower portion of the Kap Stewart Formation in the northern part of the depositional basin in the Scoresby Land area (fig. 1). In this region the sediments in question consist of light yellowish quartz sandstones and black mudstones which overlie reddish grey sandstones and mudstones or light-coloured limestones of the Upper Triassic (Norian? – Lower Rhaetic) Ørsted Dal Member of the Fleming Fjord Formation (Perch-Nielsen et al. 1974).

The sediments of the Kap Stewart Formation are generally poorly exposed for sedimentological studies. Only two good sections were encountered, one at Kap Biot and one at Sydkronen (figs. 1, 2 & 3). A study of sedimentary facies and sequential features undertaken here forms the main basis of the interpretation of the depositional environment in Scoresby Land.

The general trend of the shoreline and the palaeoslope of the studied part of the basin are discussed in the light of palaeocurrent measurements recorded from the sandstones.

Sedimentary facies

The term facies is here used for a group of sedimentary rocks differing from other rocks in lithology, sedimentary structures and bio-

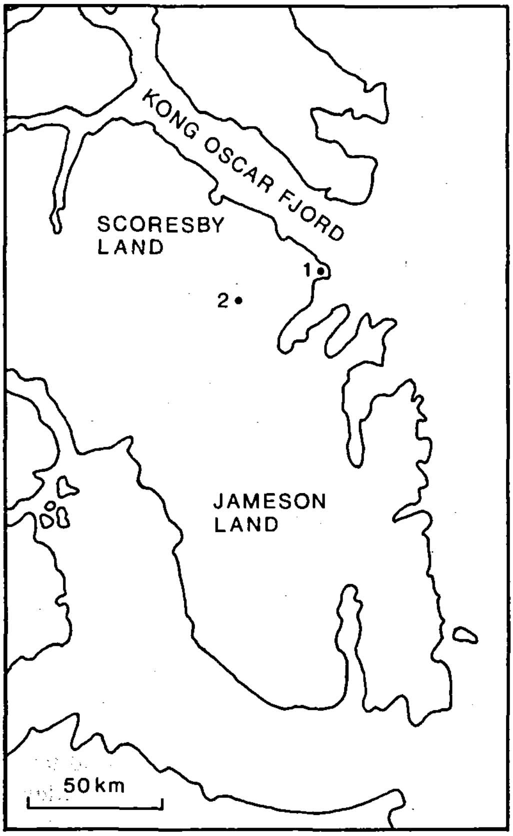

Fig. 1. Map of the investigated area showing the described localities at Kap Biot (1) and Sydkronen (2).

logical constituents. In the present case emphasis has been laid on the physical sedimentary structures as trace fossils are relatively rare in most of the facies.

It has been possible to distinguish six major facies types. The physical sedimentary structures and grain-size disclose the specific hydrodynamic conditions prevailing during the time of deposition. However, since identical hydrodynamic conditions may very well occur in different sedimentary environments, the individual facies is seldom unequivocally related to a definite depositional environment. Thus interpretation of the sedimentary environment is here mainly based on the sequential arrangement of the facies.

Horizontally laminated black mudstone (Facies 1)

Description. The facies comprises black horizontally laminated sterile mudstone. The facies varies in thickness from a few decimetres up to 10 m. The mudstones commonly disintegrate in very thin flakes ('paper shale') and the black colour is probably caused by a high content of carbonaceous matter. The laminae of the facies are frequently less than one millimetre thick, and show a lateral continuity of at least several metres. The grain-size of the facies is restricted to very fine silt and clay, but in the upper portion of the mudstone there is often an admixture of coarser silt. The facies is laterally extensive.

Interpretation. The fine grain-size of the facies and the absence of structures indicative of wave or current action suggest deposition from suspension in a low energy aquatic environment. The total absence of macrofossils and the undisturbed lamination indicate anaerobic conditions at the sediment-water interface.

Flaser and lenticularly laminated sandstone (Facies 2)

Description. This facies covers a wide range of sediment types all composed of interlaminated fine sandstone and mudstone. The thickness of the facies seldom exceeds 50 cm. One end member of the facies is made up of lenticularly bedded sediment with the sand concentrated in small lenses (Reineck & Wunderlich 1968). A study of the shape and internal structures of the sand lenses revealed that they were of both wave and current origin. The other end member of the facies is more sandy and displays thin claydrapes between horizons of small-scale cross-laminated sandstone corresponding to the flaser bedding of Reineck & Wunderlich (1968). Indistinct burrows as well as plant remains appear commonly in this facies.

Interpretation. Flaser and lenticular bedding form in an environment of alternate periods of current or wave activity and slack water (Reineck & Wunderlich 1968). As pointed out by de Raaf & Boersma (1971), flaser and lenticular bedding commonly indicate tidal action although the same sedimentary structures may

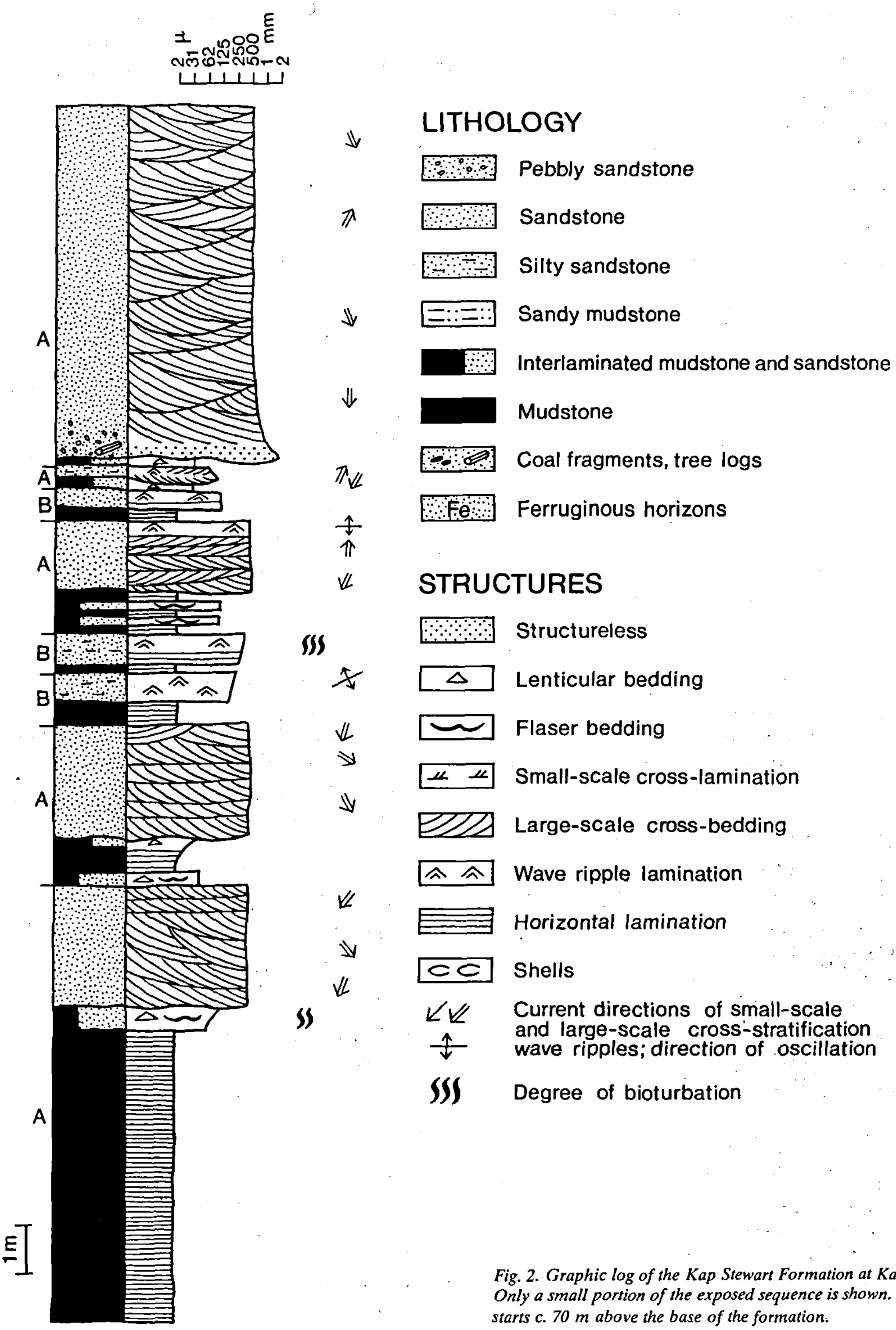

Fig. 2. Graphic log of the Kap Stewart Formation at Kap Biot. Only a small portion of the exposed sequence is shown. Profile starts c. 70 m above the base of the formation.

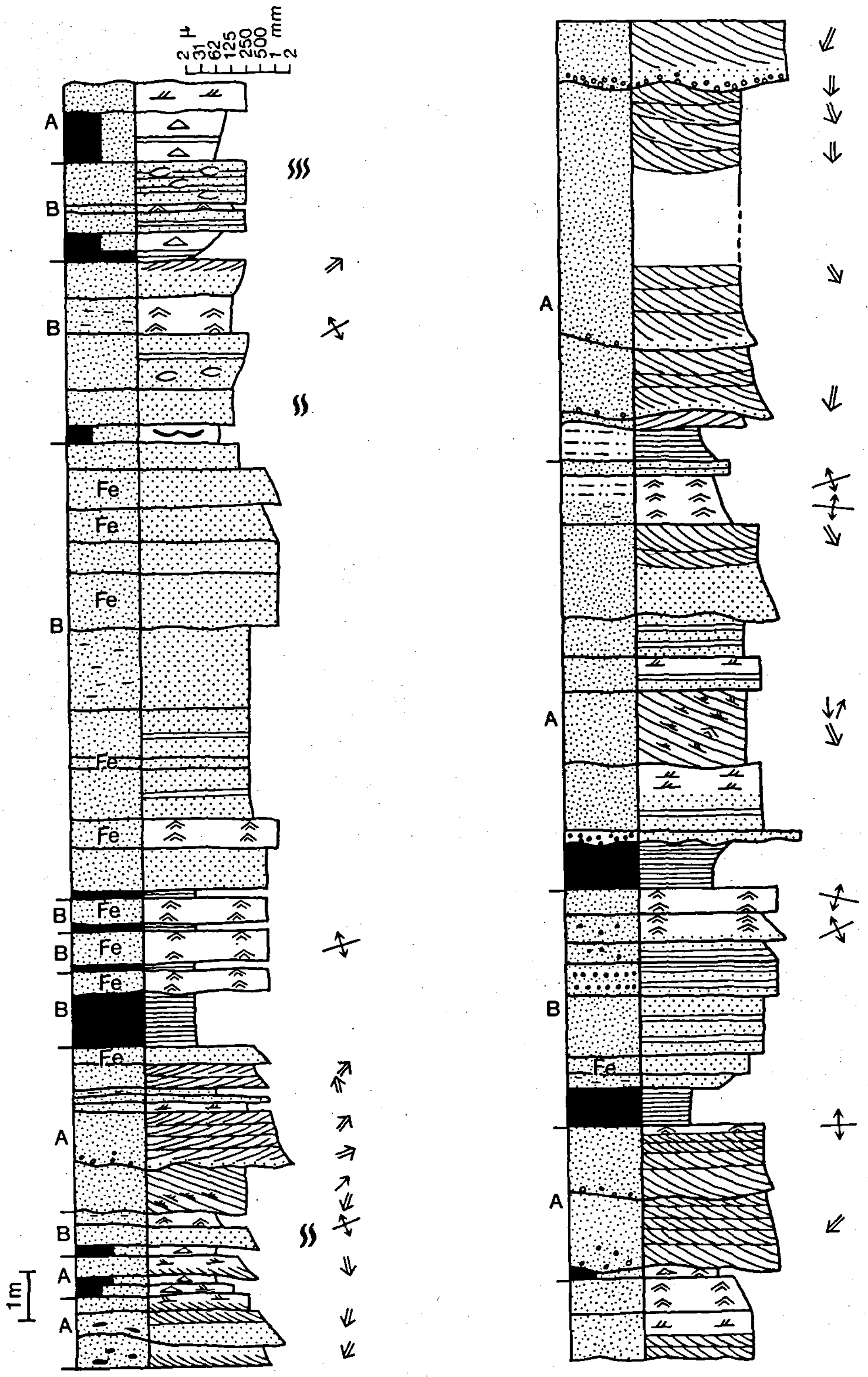

Fig. 3. Graphic log of the Kap Stewart Formation at Sydkronen. Only a small portion of the exposed sequence is shown. Profile starts c. 100 m above the base of the formation.

also occur in a large number of modern nontidal environments.

Small-scale current-ripple laminated sandstone (Facies 3)

Description. This facies is composed of fine-grained, commonly muddy sandstone showing small-scale current-ripple lamination. The thickness of the facies rarely exceeds 50 cm. Transitional types to the flaser-laminated sandstone of facies 2 are often encountered. The facies may locally display some wave-reworking of the structures. Superimposed sandstone beds of this facies commonly show opposed current directions and the overall palaeocurrent pattern is unequally bipolar (NE–SW) the strongest mode being the southern one.

Biogenic escape structures are relatively common in this facies (fig. 4).

The facies occurs either as descrete horizons or as the upper unit in a structural fining-upwards sequence initiated by large-scale cross-bedded sandstone.

Interpretation. The small-scale cross-laminated sand was deposited by currents operating in the lower part of the lower flow regime (Simons et al. 1965). The overall bipolar palaeocurent pattern of the facies may indicate deposition from tidal currents (de Raaf & Boersma 1971), and the occurrence of biogenic escape structures suggests periods with a sudden increase in sediment supply.

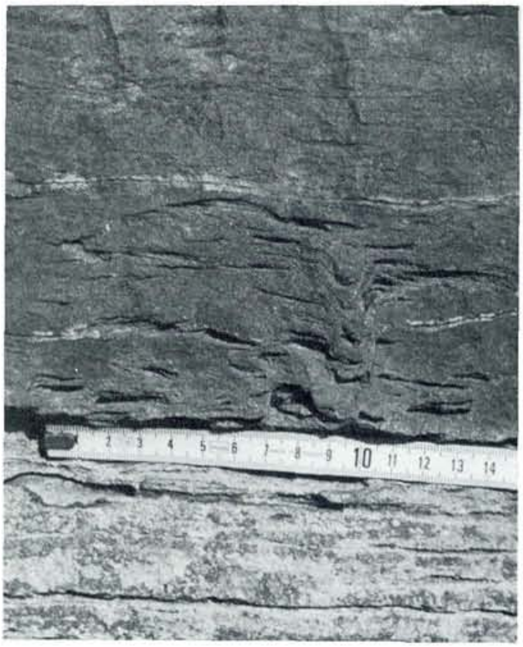

Fig. 4. Biogenic escape structure in small-scale cross-laminated sandstone (Facies 3).

Fig. 5. Large-scale trough cross-bedding in the lower part of a thick channel-sequence (Facies 4). Current flow was southwards towards the viewer. Major bounding surfaces are underlined in black ink. Length of bar 50 cm.

Large- and giant-scale cross-bedded sandstone (Facies 4)

Description. This facies makes up a large portion of the studied sequences and consists of medium to coarse normally pebbly quartz sandstone confined to large channels. The scoured base of the channel is commonly overlain by a lag-deposit of quartz pebbles and rare logs of wood or coal fragments. The

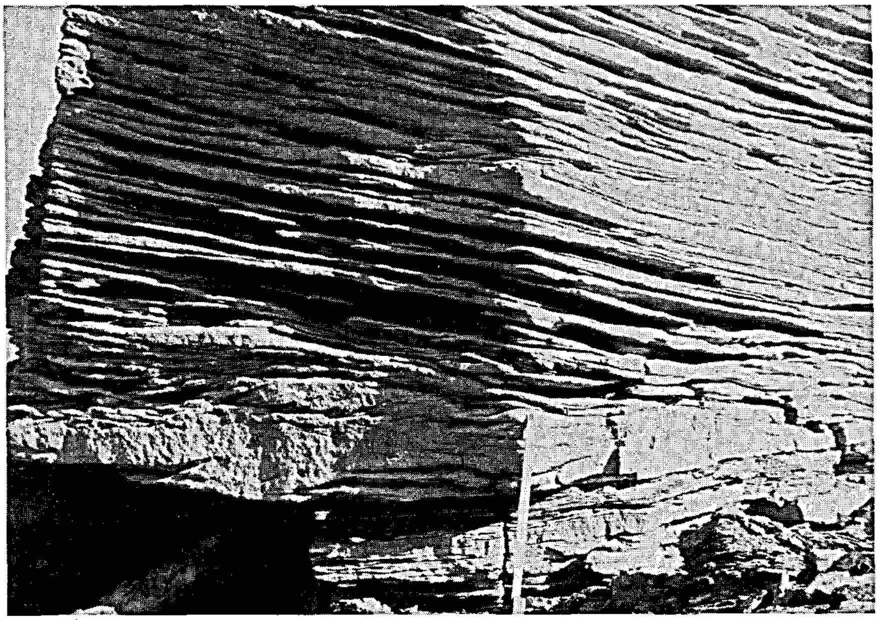

Fig. 6. Giant-scale low-angle cross-bedding with smaller intrasets climbing the foresets (Facies 4). The giant-scale set dips towards SSW. The sandstone erosively overlies silty sandstone (Facies 3). Length of bar 30 cm.

sandstone is cross-bedded apart from the lowermost part of the facies, which is mostly structureless.

Several types of cross-bedding can be recognized. The most common type constitutes planar or trough-shaped sets generally arranged in cosets of several metres thickness (fig. 5). The inclination of the foresets is normally between 25 and 30 degrees; the thickness of individual sets commonly varies from 10 cm to 1 m, but a few larger cross-bedded units have also been observed. Mud-draped foresets are locally encountered.

Another type of cross-bedding can be described as large to giant-scale planar low-angle dipping sets with small-scale intrasets (fig. 6). These intrasets (Collinson 1969) are mainly of current origin, but a few structures of wave-ripple origin have also been seen. The foresetting of the current generated intrasets is directed both upslope and downslope of the longer low-angle foresets.

Most of the cross-bedding indicates sediment transport towards the south, although northerly transport also occurred (figs. 2, 3, 7 & 8). Vectorial bimodality is rare within individual sandstone beds and true herringbone structures have not been observed. Rare, indistinct burrows appear in this facies.

Interpretation. The planar and trough-shaped high-angle cross-bedded sandstones were deposited in channels by migrating megaripples and giant ripples. Bidirectionally flowing currents presumably of tidal origin, were operating in the channels – the southerly flowing currents were by far the stronger, possibly due to a strong fluvial overprint.

The low-angle cross-bedded sandstones with

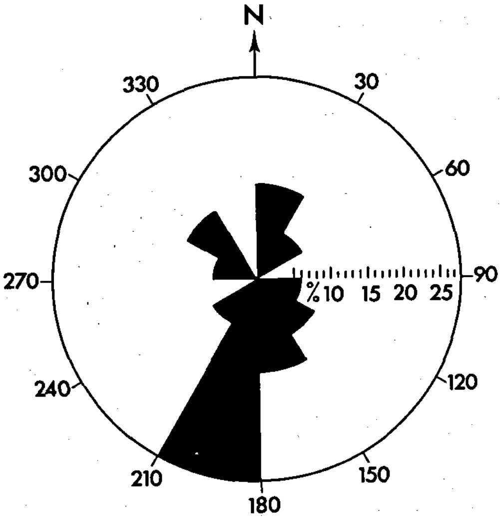

Fig. 7. Current rose of the Kap Stewart Formation at Kap Biot, based on 54 readings of large-scale cross-bedding.

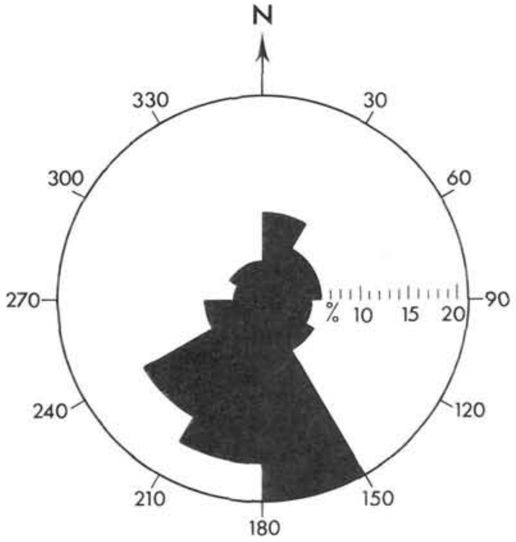

Fig. 8. Current rose of the Kap Stewart Formation at Sydkronen, based on 135 readings of large-scale cross-bedding.

small-scale intrasets are in the present case also believed to be the result of tidal activity. Ascending or descending ripple trains within larger cross-bedded units may occur both in fluvial and tidal environments as discussed by Boersma (1967). In the former case the ripples form simultaneously with the migration of the megaripple by the action of leeside eddies. The result is the formation of an "interwoven set" (Boersma et al. 1968). In the case of tidal activity the generation of the small-scale cross-lamination takes place during periods of inactivity of the megaripple front. The stronger tide forms the large-scale cross-bedding, whereas the weaker tide only can produce oppositely directed small ripples. As the present structures show an absence of features indicating simultaneous deposition and furthermore possess a few intrasets of wave-ripple origin, a tidal environment of deposition is the most likely. The wave-ripples suggest wave reworking of the low-angle bar bedform during low current activity.

Wave-ripple bedded sandstone (Facies 5)

Description. The facies forms a very characteristic part of the studied sediments. The facies is confined to beds with a thickness between 50 cm and 1 m and comprises sandstones with a grain-size ranging from fine to very coarse, in the latter examples commonly with small granules scattered throughout the sediment. Ferruginous horizons are common within this facies. The diagnostic structure of the facies is wave ripple bedding commonly having the original symmetrical ripple form preserved. In the coarse-grained end member of the facies remarkably large wave ripples (fig. 9) and associated large-scale cross-bedding appear (fig. 10). The wave ripples locally show bidirectionally dipping laminae in a symmetrical arrangement, but most wave ripples, however, display unidirectionally dipping laminae inclined towards north. The crests of the wave-ripples are usually orientated E–W, but in some cases systems with a N–S orientation interfere with the main system (figs. 11 & 12).

The facies is moderately to strongly bioturbated in contrast to the majority of the studied facies. The trace fossils constitute

Fig. 9. Large wave ripples having a ripple length reaching 90 cm and a ripple height up to 17 cm (Facies 5). Ripple crests are orientated E–W. Length of bar 30 cm.

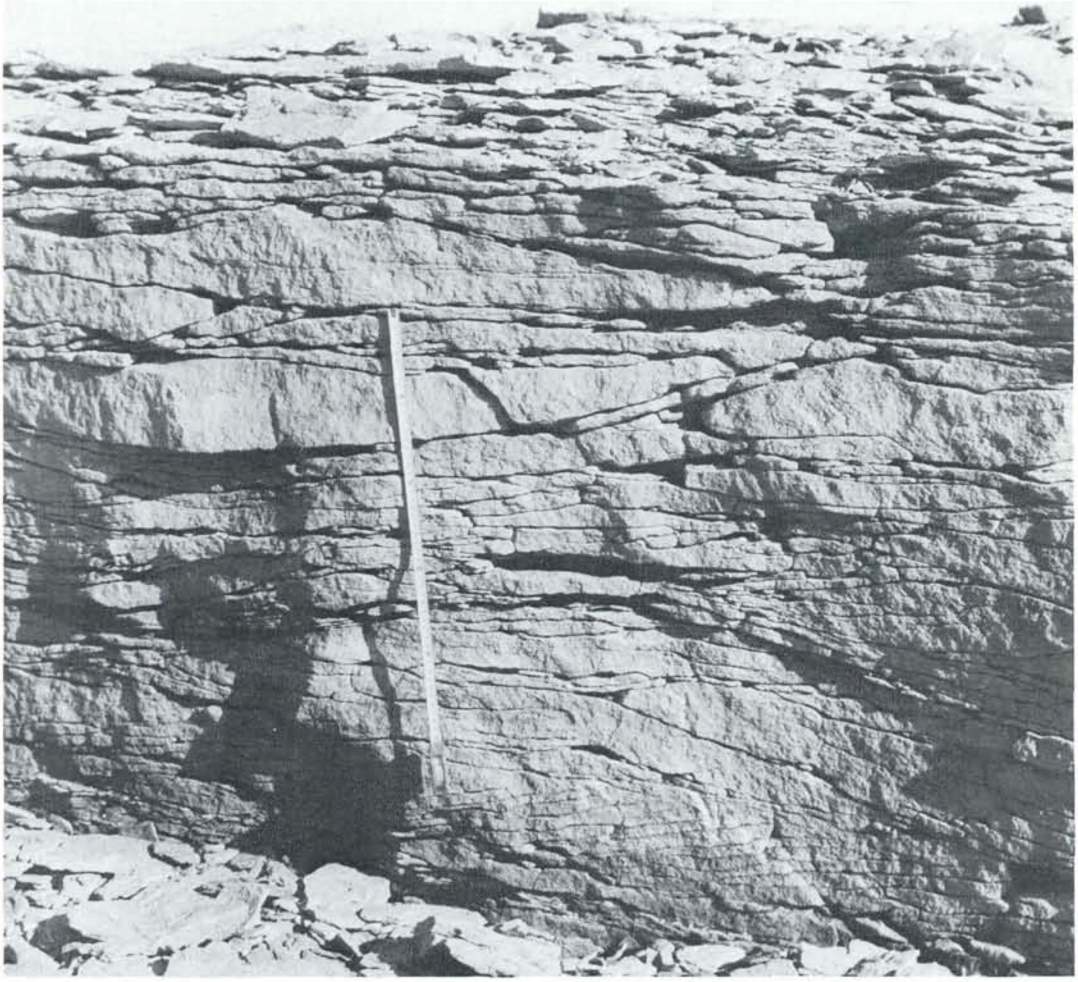

Fig. 10. Large-scale cross-bedding deposited by waves. Note that the set size decreases upwards and that most of the sets display foresets inclined towards the left (NW). Length of bar 50 cm.

winding trails seen in positive epirelief and vertical to subvertical burrow shafts with a diameter of up to 2.5 cm. In some cases the winding trails are confined to the troughs between the wave ripple crests.

Interpretation. The sedimentary structures of the facies clearly indicate that the sediment was deposited during the influence of oscillatory waves; and the observed trace fossils could indicate a marine environment of deposition. The coarse grain-size and large size of many of the ripples suggest rather strong wave action probably in a shoreface environment. The northward dipping foreset laminae of most of the ripples and the ripple orientation (figs. 11 & 12) point to an E–W trending shoreline situated to the north.

Horizontally laminated or structureless sandstone (Facies 6)

Description. This facies is especially common at Sydkronen. The facies is made up of fine to coarse sandstone with a thickness varying from less than 0.5 m to more than 7 m. The thicker units are often made up of several thinner sandstones that show slight differences in lithology and structure. Apart from intervals with horizontal lamination and rare large-

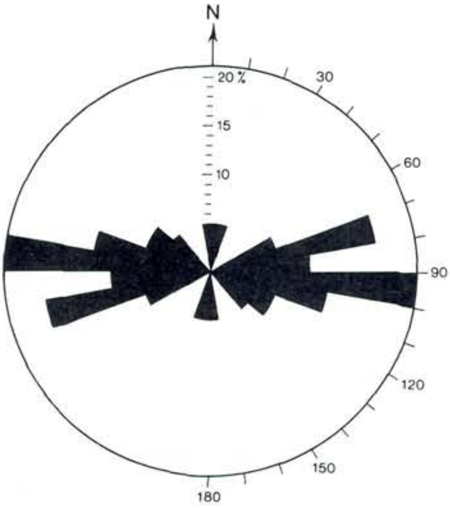

Fig. 11. Orientation of wave ripples, based on 21 readings of crest directions. Kap Stewart Formation, Kap Biot.

scale cross-bedding, the facies is apparently devoid of physical sedimentary structures. Some horizons display biogenic mottling (fig. 13). As in the former facies, brown ferruginous bands are often encountered. A special feature of this facies is the occurrence of horizontally or subhorizontally lying bivalve shells with both valves preserved (fig. 13). Unfortunately the state of preservation of these shells does not allow a closer determination.

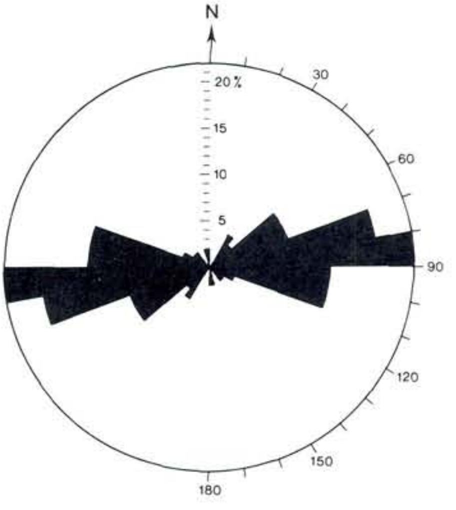

Fig. 12. Orientation of wave ripples, based on 34 readings of crest directions. Kap Stewart Formation, Sydkronen.

Fig. 13. Light-coloured structureless sheet sandstone with bivalves and biogenic mottling (Facies 6). The sandstone overlies a thin horizon with darker, silty sandstone (Facies 3).

Interpretation. Horizontal lamination may be produced in several ways, e. g. by fast moving currents operating in the upper flow regime (Simons et al. 1965), or be the result of severe wave-action (Allen 1970). The large-scale cross-bedding denotes the migration of megaripples. The sequential arrangement of the present facies as discussed later suggests that the horizontally laminated sand of this facies was deposited in a wave-agitated nearshore marine environment. The structureless sandstone may originally have had a horizontal lamination but owing to weathering or biogenic reworking this does not show up in the field.

Sedimentary sequences and depositional environment

A study of the spatial arrangement of the sedimentary facies reveals that two main types of sedimentary sequences can be distinguished (figs. 2 & 3). One of these (sequence A) constitutes, in the ideal case, black mudstones of facies 1 at the base followed by flaser or lenticularly bedded sediments of facies 2 abruptly overlain by cross-bedded channel sandstone of facies 4 and locally small-scale cross-laminated sandstone of facies 3. The upper part of the sequence may be composed of one or several cross-bedded sand units, each possessing a channelled base. In some cases the uppermost part of this sequence displays wave ripple bedded sandstone (facies 5).

The other type (sequence B) is also initiated by black mudstone of facies 1, or sandy mudstone of facies 2, but is overlain by one or several sheet-like horizons of wave ripple bedded sandstone (facies 5) or by horizontally laminated to structureless sandstone, locally with large-scale cross-bedding (facies 6).

Sequence A constitutes a combined coarsening-upwards and fining-upwards sequence, where the upper fining-upwards sequence is made up of the channel sandstone. Sequence B constitutes in the ideal case a simple coarsening-upwards sequence.

Sequence A most likely represents the infilling of an interdistributary bay. Similar small-scale coarsening-upwards sequences topped by channel sand have recently been described by Elliott (1974) as a result of flood-generated incursions into interdistributary bays. The sterile character of the black mudstone also appears to be consistent with deposition in a sheltered environment characterized by a salinity strongly reduced by fresh-water influx. Thus it is suggested that deposition of clay took place in the central part of the bay, whereas deposition of silt and sand occurred in the marginal part of the bay. It is likely that the bays in periods were open to the sea and that the silts and sands were redistributed by weak tides and intermittent wave action. The final stage of the sequence constitutes an erosive phase during which cross-bedded sand was deposited. The unimodal southerly to unequally N–S bipolar current-pattern in the channels suggests that most of the cross-bedded sand was deposited at the mouth of southward facing tidally influenced distributary channels, which extended into the interdistributary bays.

Sequence B is interpreted as a bay mouth sequence as described by Elliott (1974). Comparison with the high-energy coastal environment at Oregon (Clifton et al. 1971) suggests that deposition of the wave-ripple bedded sandstone took place in an inner offshore or outer nearshore zone, whereas the horizontally laminated or structureless sandstone was deposited closer to land in the higher energy nearshore zone. The sand topping the sequence was probably redistributed laterally from adjacent river distributaries and finally deposited at the mouth of muddy bays during high-energy wave-action.

In view of the preferred model of deposition for the Kap Stewart Formation in Scoresby Land the apparent absence of coal seams and rootlet horizons in the studied area is surprising. Only a few transported coal fragments and some large logs of wood were observed. This is perhaps a reflection of a high subsidence rate and a high sediment supply in the northern part of the depositional basin.

In a vertical profile (figs. 2 & 3) sequences A and B alternate repeatedly. This is what one would expect in a large delta complex where extensive interdistributary bays are cut by tidally influenced distributary channels and where longshore drift and wave action form coastal sheet sand in front of many of the bays.

Conclusions

The recognition of tidally influenced deltaic deposits in the Kap Stewart Formation of Scoresby Land makes it possible to widen considerably the palaeogeographical picture of the Jameson Land Basin in Rhaetic–Lower Liassic time.

In southern Jameson Land the Kap Stewart Formation (Rhaetic-Hettangian) is composed of conglomeratic sandstones of alluvial fan origin overlain by fluviatile conglomerates,

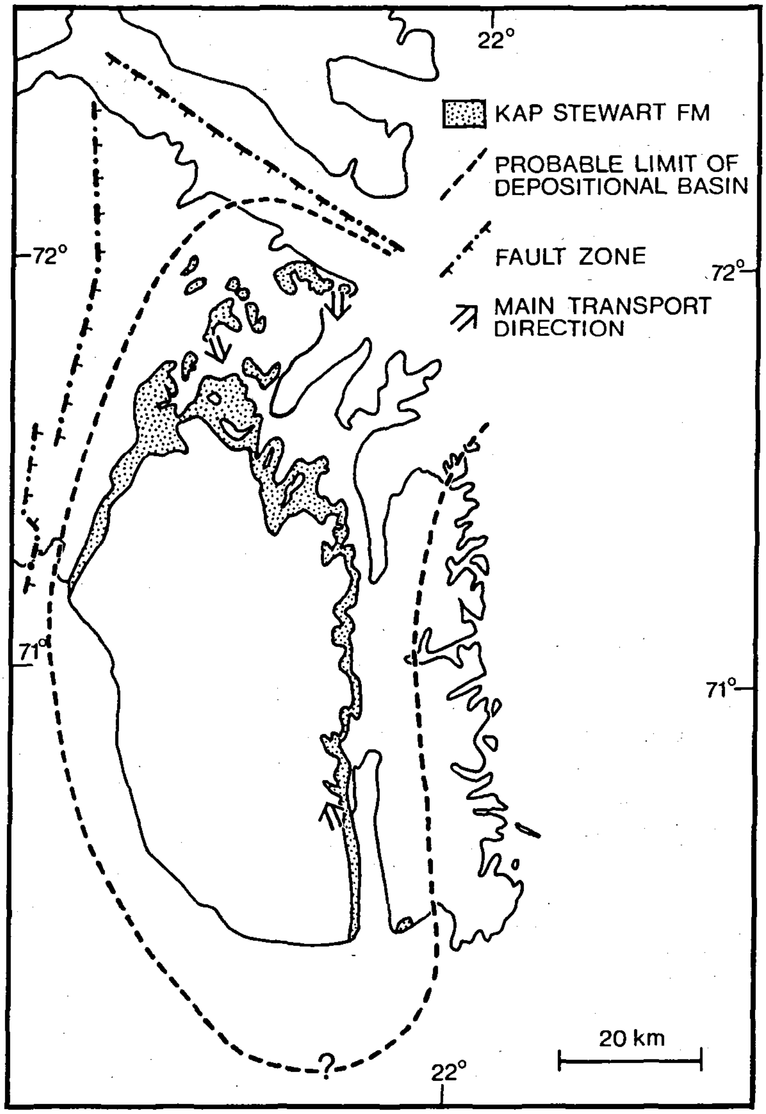

Fig. 14. Map showing probable limit of and rough transport pattern within the sedimentary basin during deposition of the Kap Stewart Formation. The map should be viewed when bearing in mind that the exact age of the studied sequences of the Kap Stewart Formation in Scoresby Land remains rather uncertain. Accordingly the shown transport directions from the southern (Sykes 1974a) and the northern part of the basin may well belong to different time-stratigraphic levels within the formation. The distribution of the outcropping sediments from the Kap Stewart Formation is after Surlyk et al. (1973).

rippled sandstones and variegated siltstones with plant remains and occasional coal seams (Sykes 1974a).

As shown in the present paper the facies of the Kap Stewart Formation in Scoresby Land are quite different from those encountered in the type area in southern Jameson Land. Some of the facies here described even show similarities to those of the overlying Neill Klinter Formation (Pliensbachian-Toarcian) in southern Jameson Land (Sykes 1974b). Whereas the age of the Kap Stewart Formation is well established in the type area, the precise age of the formation in Scoresby Land is problematic. Mapping of the Jurassic sediments (Surlyk et al. 1973) has shown, however, that the Kap Stewart Formation forms a thick sheet of clastic deposits in the whole basin and can be traced from the type area in the south to the northern part of the basin, where the formation is topped by a relatively thick sequence of black sterile mudstones. The Kap Stewart Formation is furthermore overlain by the Upper Liassic Neill Klinter Formation in the whole area. It is suggested, therefore, that the Kap Stewart Formation can be regarded as a fairly well-defined time-stratigraphic unit of Rhaetic-Lower Liassic age in the whole basin and that the facies shifts merely reflect a change towards more marine conditions in the northern part of the basin. The few age-diagnostic plant fossils from the Kap Stewart Formation in Scoresby Land (Harris 1946) are in agreement with these considerations as they give a Lower Liassic age.

In contrast to the unimodal northward current pattern in southern Jameson Land (Sykes 1974a), the palaeocurrent data from the Kap Stewart Formation in the northern region show an unequally bipolar current-pattern with the strongest mode towards south. This pattern has already been suggested to indicate tidal activity with the strong southward mode caused by fluvial overprint. If this interpretations holds true, the palaeocurrent data in Scoresby Land invariably point to a northerly source area. Looking for a possible northerly source area one is struck by the fact that deposits of the Kap Stewart Formation or equivalents seem to be lacking north of Kong Oscar Fjord (Donovan 1957). In this connection it is interesting to note that Bütler (1948) postulated the existence of transverse fault lines in the Kong Oscar Fjord and that Surlyk et al. (1973) have suggested tectonic disturbance of the Kong Oscar Fjord region in early Jurassic time.

In light of the new palaeocurrent data discussed above it can be concluded that the northern part of the Jameson Land Basin was characterized by a southward palaeoslope and an E–W trending coastline during deposition of the Kap Stewart Formation. Furthermore it seems reasonable to conclude that the area north of Kong Oscar Fjord was a land-area of non-deposition in this period and formed the source area of the sediments here described. Finally it is suggested that this Rhaetic-Lower Liassic palaeogeographical picture (fig. 14) could reflect tectonic uplift to the north along fault lines in the Kong Oscar Fjord region.

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Dansk sammendrag

Sedimenter fra Kap Stewart Formationen i Scoresby Land beskrives og tolkes som tidevandsprægede deltaiske aflejringer. Sedimenterne forekommer i to forskellige sekvenser. (A) Horisontalt laminerede sorte muddersten efterfulgt af flaser eller linselaminerede sandede muddersten og erosivt overlejret af krydslejrede sandsten, som er begrænset til kanaler. (B) Horisontalt laminerede sorte muddersten overlejret af bølgeribbe laminerede, horisontalt laminerede eller strukturløse sandsten. Sekvens A tænkes at beskrive et deltamiljø med udstrakte bugter, der langsomt blev fyldt op med ler og fint sand for til sidst at blive gennemskåret af deltakanaler. Sekvens B blev sandsynligvis dannet, når strømme og bølger førte det sandede sediment langs kysten og aflejrede det foran de åbne bugter. Palæostrøm data tyder på, at vi havde en sydlig palæogradient og en Ø-V orienteret kystlinje i det nordlige Scoresby Land under aflejringen af Kap Stewart Formationen.

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