Lower Cretaceous fluvial-deltaic sediments at Kûk, Nûgssuaq, West Greenland

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About 140 m of Lower Cretaceous sediments of the Kome Formation overly the gneiss basement in the Kûk, area. Three facies associations have been recognised in these sediments. Facies association A, which dominates the succession, consists essentially of trough cross-bedded coarse subarkosic sandstone alter-nating with dark laminated mudstone rich in coalified plant debris. Sedimentary structures, facies sequ-ences, and channel morphology suggest that this facies association was deposited by distributaries flowing from east-southeast across a delta plain. Facies association B occurs as coarsening-upwards mudstone – rippled fine sandstone – medium-grained sandstone sequences within the fluviatile sediments of facies association A. These sequences are regarded as the deposits of minor mouth bars and crevasse splays that prograded into interdistributary bays. Facies association C, consisting of tabular cross-bedded medium-grained sandstone, is interpreted as having been deposited from transverse bars in the distal part of a sandy braided river that flowed from south-southwest. The sub-Cretaceous surface was a deeply weathered uneven plain; the present slopes and abrupt steps in this surface are entirely the result of post-Lower Cretaceous faulting and tilting. The sediments are cut off to the east by a major fault.

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The Cretaceous-Tertiary sediments of central West Greenland, for a long time the object of much attention from palaeontologists, have in the last decade been in the limelight as never before. This is partly because they provide a record of events that took place along the western margin of Greenland during the break-up of Laurasia (Rosenkrantz & Pulvertaft 1969) and partly because of the intensified search for oil and gas in more and more remote and inhospitable regions (Henderson 1969). The amount of published sedimentological information on these sediments is however still rather meagre, being limited to a general account in Henderson, Rosenkrantz & Schiener (1976), short reports by Gry (in Rosenkrantz et al. 1941; 1942), Hansen (1976) and Schiener (1975; 1977), and a more stratigraphically biased paper by B. E. Koch (1959).

The present paper deals with the Lower Cretaceous sediments in the Kûk area which is situated on the north side of Nûgssuaq peninsula, at the present boundary of the West Greenland Cretaceous-Tertiary basin (fig. 1). In addition to the sediments themselves, the nature of the sub-Cretaceous land surface and the problem of the original eastward extent of the sedimentary basin are discussed.

The field work on which the paper is based was carried out in connection with the writer's mapping for the Geological Survey of Greenland's 1:100000 sheet 70 V2 N – Agpat. The Agpat sheet mapping project is primarily a Precambrian basement study being carried out by senior students and staff from the Institute of General Geology, Copenhagen University.

Setting and age

The Lower Cretaceous sediments of the Kûk area, often referred to as the Kome Formation (B. E. Koch 1964, p. 538), are best exposed along the coast north-west of the Kûk delta and in the valleys and gullies cut back from the shore (fig. 2). The maximum thickness, about 140 m, is seen in Majoragdlagtarfik, the largest of these gullies. The sediments lie directly on a deeply weathered Precambrian gneiss basement. Overlying the sediments unconformably, and overlapping onto gneiss, there are pillow breccias, olivine basalts and plagioclase-porphyritic basalts of the West Greenland Tertiary province.

The exact age of the Kome Formation is hard to determine because of the lack of surtable fos-

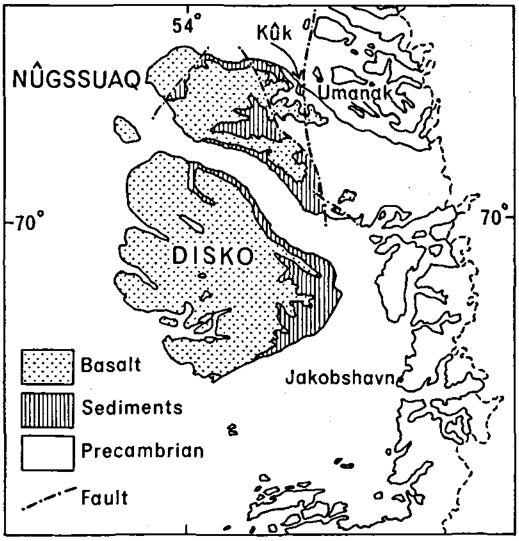

Fig. 1. Map showing the position of the Kûk area in the West Greenland Cretaceous-Tertiary basin.

sils (B. E. Koch 1964). The fossil flora in the sediments (»Kome flora«) is well known through the memoir of Heer (1883). Pedersen (1968), who supplemented Heer's results with finds of leaves of angiosperm affinity at Pátorfik, 7 km north-west of Kûk, considers the formation to be of Barremian-Aptian age, while Schiener (1977, p. 45) accepts a general Early Cretaceous age on the basis of palynological information supplied by C. A. Croxton.

Basal sediments and sub-Cretaceous regolith

The contact of the Cretaceous sediments with the underlying gneiss basement is well exposed in the coastal cliffs 1.7 km north-west of Kûk and in the Kûtsiaq stream-cut and nearby gullies. Poor exposures are seen at an altitude of about 450 m on the north-west side of Sarfâgfip kugssinerssua.

The gneiss basement shows the effect of Cretaceous weathering to a depth of at least 35 m below the sub-Cretaceous surface; the weathering front (Ollier 1969, p. 121) has not been seen. Alteration at this depth can be detected in the powdery kaolinised nature of the feldspars in the gneiss which otherwise still has its primary structural and textual characters. Approaching the sub-Cretaceous surface the degree of kaolinisation increases and biotite starts to show alteration to a chloritic mineral. Within a few metres of the surface there is a rather abrupt change from a rock which, though much altered, still has a typical gneiss aspect, to a soft mass composed almost entirely of kaolin and quartz in which a flakiness and orientation of quartz seams parallel to the structure in the underlying gneiss can just be seen. This passes up into a structureless quartz-kaolin aggregate. The point at which residual sediment gives way to the first transported sediment is impossible to fix. The first horizon that is definitely not residual is a ca. 10 cm thick dark silt – fine sand layer with a varying amount of coaly material that constitutes a useful marker when the gneiss-sediment contact is followed across the coastal cliffs.

The gneiss surface undulates gently, and the thickness of the residual sediment and intensely weathered gneiss zone varies accordingly. In a small depression there is ca. 1.5 m of diamictite overlying the weathered gneiss. In this, irregularly shaped blocks of vein quartz up to 10 cm across are supported in a sandy clay matrix. In a stream-cut east of Kûtsiaq unsorted conglomerate with poorly rounded quartz boulders and slabs of silty mudstone lies on a moderately weathered gneiss surface. The conglomerate passes up into sand with slightly inclined gravel streaks, which in turn is overlain by a silty mudstone with sand streaks. A ca. 10 cm thick dark laminated mudstone marks the boundary between the basal sediments and typical sediments of the Kome Formation.

In his account of the gneiss-sediment transition north-west of Kûk Schiener (1977, pp. 50–51) recorded what he thought on the basis of macroscopic observations to be an acid tuff lying between the regolith and the first coaly silty horizon. The present writer has not seen any deposit in this position that he could confidently call a tuff. A compact rock with pyrite-rich nodules that occurs below the coaly siltstone marker has been examined in thin section. More than 50% of this rock consists of angular or rarely subrounded quartz fragments up to 1.5 mm across that almost invariably show undulatory extinction. None shows crystal faces, and none shows typical resorption embayments. No shard forms and no feldspar fragments, kaolinised or otherwise, were observed. The small pyrite nodules have replaced

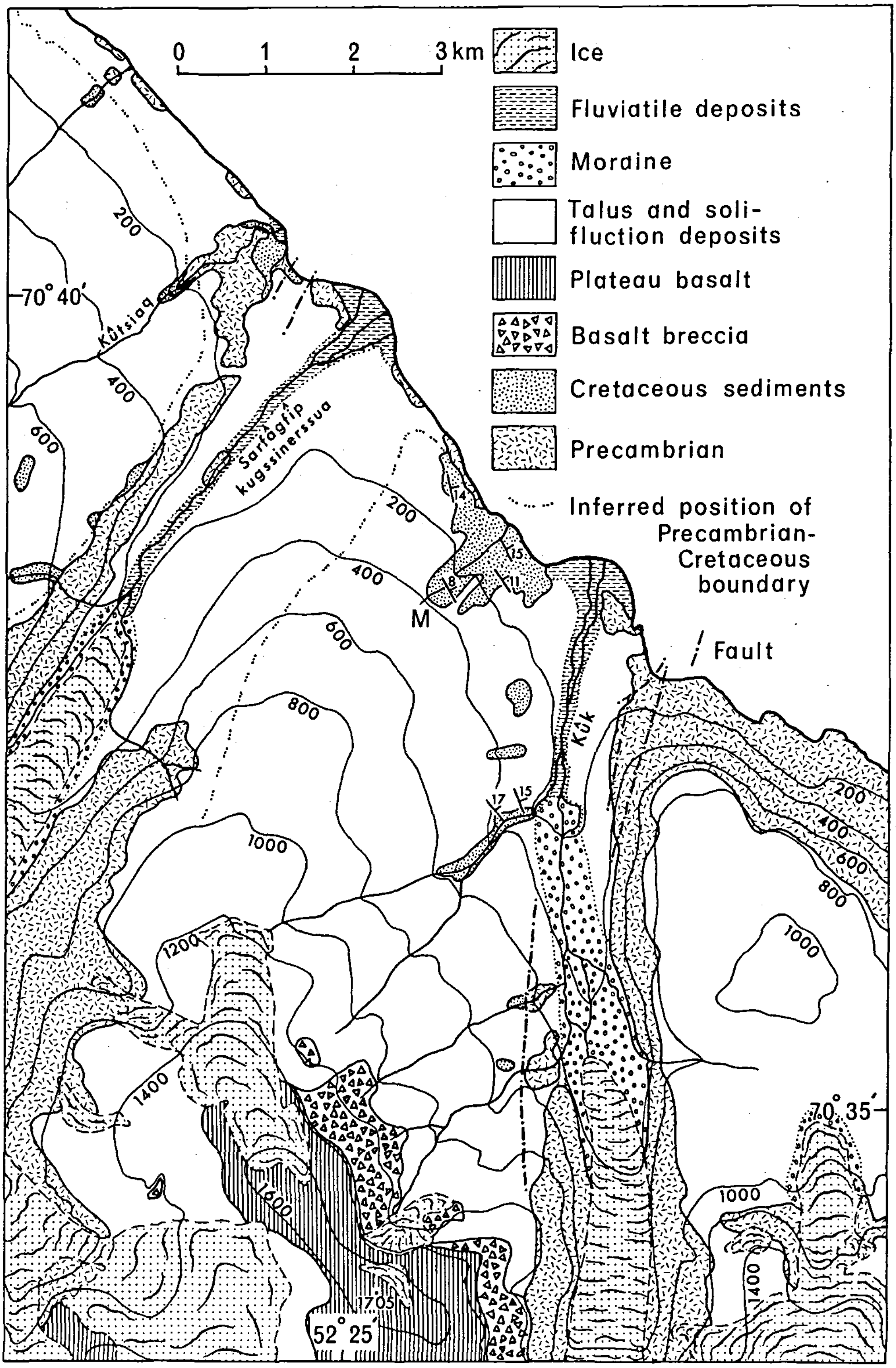

Fig. 2. Geological map of the Kûk area. »M« denotes Majoragdlagtarfik. Topography based on Geodetic Institute 1:50000 sheet 70 V.2 E.

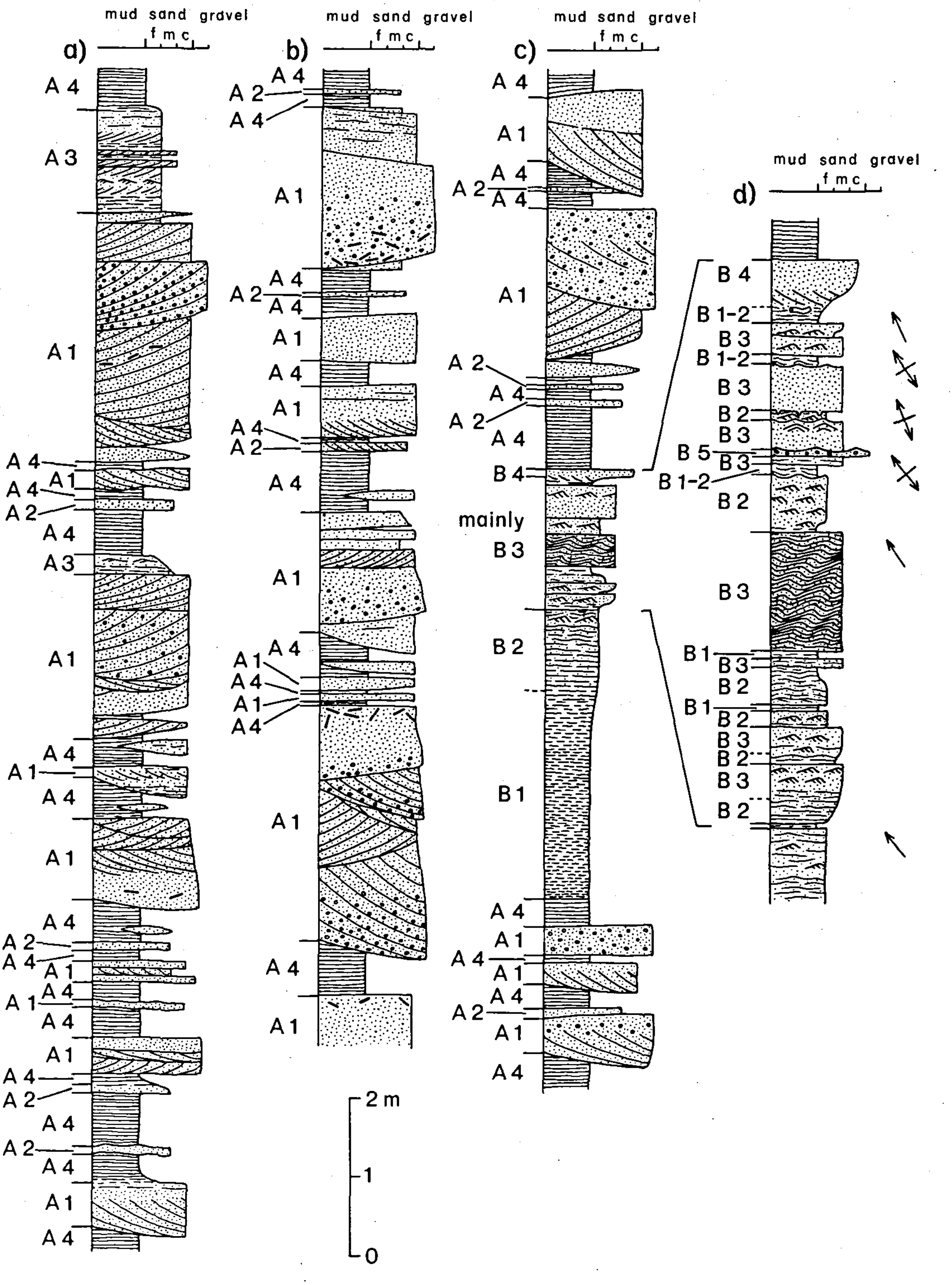

Fig. 3. a, b: Representative graphic logs of facies association A; c: Graphic log of facies association B in the lowermost of the coarsening-upwards sequences, together with the underlying and overlying sediments of facies association A; d: Detailed log of the upper part of the coarsening-upwards sequence shown in c. For legend see fig. 5.

matrix and enclose quartz grains identical to those in the surrounding rock. The matrix is largely kaolin. A similar though non-pyritic rock contains fragments that might be interpreted as collapsed pumice, but since these contain both quartz fragments with undulatory extinction and rounded zircons it is more likely that they are redeposited sediment. Rounded zircons up to 0.2 mm long are common in the surrounding matrix.

Facies associations

Three facies associations are seen in the Kome Formation in the Kûk area. Facies association A, which makes up about 85% of the total exposed section, consists mainly of coarse sandstone alternating with silty laminated mudstone containing much coalified plant debris.

Facies association B comprises mudstone and rippled fine-medium sandstone, and also a small amount of coarse sandstone, which together make up distinctive coarsening-upwards sequences. Four such sequences have been observed in the Kome Formation at Kûk.

Facies association C consists almost entirely of tabular cross-bedded medium-grained sandstone. The association occurs at two levels in the succession at Kûk.

Facies association A

Description

Both from the general appearance of sections in the field and from an examination of the graphic logs (fig. 3), it is seen that the sediments of facies association A can most conveniently be divided into four facies. These will now be described in order from the coarsest grained to the finest grained, before an interpretation of the association as a whole is attempted.

Facies A1: Cross-bedded coarse subarkosic sandstone. This facies consists of poorly consolidated coarse, often gravelly, subarkosic sandstone. Sorting is generally poor. The clasts are mainly of quartz, with subsidiary kaolinised feldspar and rare quartz-feldspar fragments; flakes of fissile siltstone are sometimes seen in the coarsest layers. Quartz clasts are angular, while feldspars are subangular-subrounded, presumably because they were partially kaolinised before being transported. Pore space is frequently occupied by kaolin. Fragments of coalified wood and finer-grained plant debris are commonly present. Rootlets have been observed at the tops of coarse sandstone bodies but are rare.

The chief structure in the coarse subarkosic sandstone is large-scale trough cross-bedding; sets can be up to more than a metre thick. Tabular tangential cross-bedding also occurs but is rare. Concentration of organic material and/or grain-size variation mark the foreset laminae. Where organic material is lacking it can be difficult to detect any internal structure because of poor sorting. Measurements on foresets are likewise difficult to obtain, but the graphic vector mean of readings taken in a sand-blasted crag carved out of a single sandstone body indicates a current direction towards 295° (all readings were corrected for tilt). Supplementary data from other, less well exposed beds also indicate a northwesterly transport. Both high-angle (25–30°) and low-angle foreset dips were observed.

In a few cross-bedded sets the cross-laminae have been contorted into upwardly-directed peaks and folds and even disrupted; the resulting patterns recall structures that have been attributed to adjustments in quicksand (Selley et al. 1963; Selley 1969).

The coarse sandstone of facies A1 occurs in bodies from a few tens of centimetres to as much as 5 m thick. The bodies have varied shapes; shoe-string geometry is most characteristic for the facies in the lower part of the Kome Formation (fig. 4) while flat prism or sheet geometry appears to dominate in the uppermost part of the formation. However, it is suspected that most units which appear as sheets within the limits of an outcrop in a ravine or small cliff would turn out to have a flat prism geometry if they could be traced over a wider area; some degree of thinning can nearly always be detected if the sheet-like bodies are followed far enough.

A few shoe-string bodies could be studied in three dimensions; these showed a direction of elongation in around 340°. The width:depth ratio for the shoe-strings can be as low as 4 in the smaller bodies, but usually the ratio is higher – around 13 being the figure given by Schiener (1977, p. 55). The lower contact of the sandstone

Fig. 4. View of facies association A of the Kome Formation on the north-west side of Majorgdlagtarfik. Note the channel sand bodies with strongly erosive lower contacts. Height of section about 17 m.

shoe-strings is erosional and can sometimes be seen cutting across bedding in the underlying sediments (fig. 4). The upper contact usually arches up somewhat, but this is due to differential compaction and thus is not a primary feature. At their edges the shoe-strings can either wedge out or feather out in dark laminated mudstone.

Facies A2: Medium-grained sandstone. This facies consists of poorly sorted medium-grained sandstone rich in coaly organic debris, and is sometimes laminated with silty laminae or, occasionally, flasers. Mica is plentiful. Small-ripple cross-lamination has been observed but is not common.

As can be seen from the representative logs in fig. 3, the medium-grained sandstone facies is only a minor component of facies association A. The facies occurs mainly in layers up to 20 cm thick which can show considerable lateral persistence, and also as thin lenses or shoe-strings. Contacts to adjacent facies can be gradational.

Facies A3: Laminated fine sandstone. This facies consists of platy fine sandstone with much plant debris and also some mica on parting planes. Both planar and low-angle cross-lamination are developed in this facies; current ripples have also been observed. Rootlets occur but are not characteristic.

Facies A4: Dark laminated silty mudstone. Fissile silty mudstone with much coalified plant debris as well as muscovite on parting planes is quantitatively the second most important facies in facies association A (see figs. 3 and 4). This mudstone is dark grey to black in colour, depending on the amount of coaly material present. The rock is not well sorted; scattered outsize quartz grains in fine or even medium sand fraction are commonly present (cf. Schiener 1977, p. 55). Thin (less than one centimetre) lenses and laminae of vitrainous coal, and occasional thin coal seams, occur within this facies.

Facies sequences: The typical sequence in facies association A is a simple alternation of facies A1 and A4. The lower contact of facies A1 is often strongly erosional, so that this facies can lie on any of the other facies. Above the erosional base of facies A1 there is sometimes a concentration of coaly wood fragments and other plant material, but no true conglomerates have been observed in this position. This may be due to a) the deeply weathered nature of the hinterland which supplied the sediments; gneiss fragments could not survive transport; b) the poorly consolidated nature of the banks at the time of channel erosion; the evidence of post-depositional differential compaction provided by the present bed forms supports this suggestion. Within facies A1 there is in general no systematic upwards change in grain-size or trough-set thickness, even though there are exceptions where a slight upwards decrease in maximum grain-size can be detected within a single set, or where cosets exhibiting a slight upwards decrease in median grain-size have been recorded. There is sometimes a lining of gravel along the base of trough sets.

At the upper contact of facies A1 there is usually an abrupt change or very rapid transition into facies A4. Where facies A3 has been seen, it directly overlies A1, separating it from A4; there may be a narrow transition from A1 to A3. Although facies A2-type sandstone has been seen directly overlying A1, the usual position for facies A2 is within facies A4, without contacts to the other facies.

In short, the facies sequences are A1–A4–

(A2)–A4–A1–A4 etc. (the commonent sequence), and A1–A3–A4–(A2)–A4.

Interpretation
Sedimentary structures and grain-size constitute clear evidence that the coarse sandstones of facies A1 were deposited by running water in a high energy environment, more precisely in the upper part of the lower flow regime. The frequent occurrence of units with shoe-string geometry and strongly erosive lower contacts indicates that much of the facies was deposited in narrow channels.

The angular shapes of the clasts, occurrence of slightly to moderately kaolinised feldspars, and poorly sorted texture of the sediments point to derivation directly from a weathered gneiss/granite hinterland without reworking en route, and to rapid sedimentation. The lack of marine fossils, the common occurrence of coalified wood and plant debris, the occasional rootlets, the unidirectional current pattern and the shoe-string geometry indicate a non-marine environment without tidal influence.

The above-mentioned features, together with the character of the associated facies, match the characteristics of alluvial band bodies as listed by Potter (1967. p. 344).

Trough cross-bedding in fluviatile sands has generally been explained as reflecting deposition by migrating dunes (Allen 1964, p. 175; Read & Johnson 1967, p. 249; Kelling 1968, p. 2382; Williams 1968; Leeder 1973, p. 125; Cant & Walker 1976, p. 116; Houseknecht & Ethridge 1978, p. 583 and many others). This explanation is accepted for most of the trough cross-bedding in the facies A1 sandstones. However, examples of gravel-lined sets suggests that some sets might have been formed by dunes migrating into scours unrelated to the advance of the dunes (Harms & Fahnestock 1965, p. 103). Most of the measured maximum foreset dips are in the range 25–30° which is normal for trough cross-bedding (Harms et al. 1975, p. 46); where distinctly lower maximum dips occur the sand was presumably deposited under conditions nearing the transition to the upper flow regime.

The laminated fine sandstone of facies A3, which has only been observed following immediately after facies A1, may represent the deposits of waning currents after channels became filled, with a lateral gradation into levee deposits (cf. Facies 2 of the Kap Stewart Formation of East Greenland – Sykes 1974, p. 209).

The dark mudstones of facies A4 were deposited largely from suspension in a low energy environment. They are interpreted as the overbank deposits of the flood plain. The medium-grained sandstone (facies A2) occurring mainly as thin layers within the dark mudstones represents the sporadic return of higher energy conditions when traction load was carried across the flood plain. These layers may well be crevasse-splay deposits, although they do not often show the sort of lensing and wedging-out characteristic of crevasse-splays (Allen 1965. p. 148; Read & Johnson 1967, p. 262; Kelling 1968, p. 2381). Some of the thinner sheets and shoe-strings of facies A1 could also be crevasse-splay deposits.

Facies association B

Description
The chief facies in this association are poorly laminated mudstone and small-ripple cross-laminated fine-medium sandstone. The hallmark of the facies association is however not so much the character of the individual facies but their sequence. In every case the finest facies occurs at the bottom of the sequence, and the coarser facies towards the top, so that there is a clear coarsening-upwards pattern in the sequences (figs. 3 and 5). The facies are described in order from the finest to the coarsest.

Facies B1: Poorly laminated mudstone. This sediment is very fine-grained, virtually structureless, and grey or olive grey in colour. Plant debris and mica are sparse or absent (or at least not visible to the naked eye). In the transition to the overlying coarser facies both mica and coalified plant material become more conspicuous.

Facies B2: Laminated siltstone – very fine sandstone. This facies is transitional between B1 and B3. Planar or cross-lamination are developed except where the facies is mottled due to bioturbation. Both mica and coalified plant debris occur on parting planes.

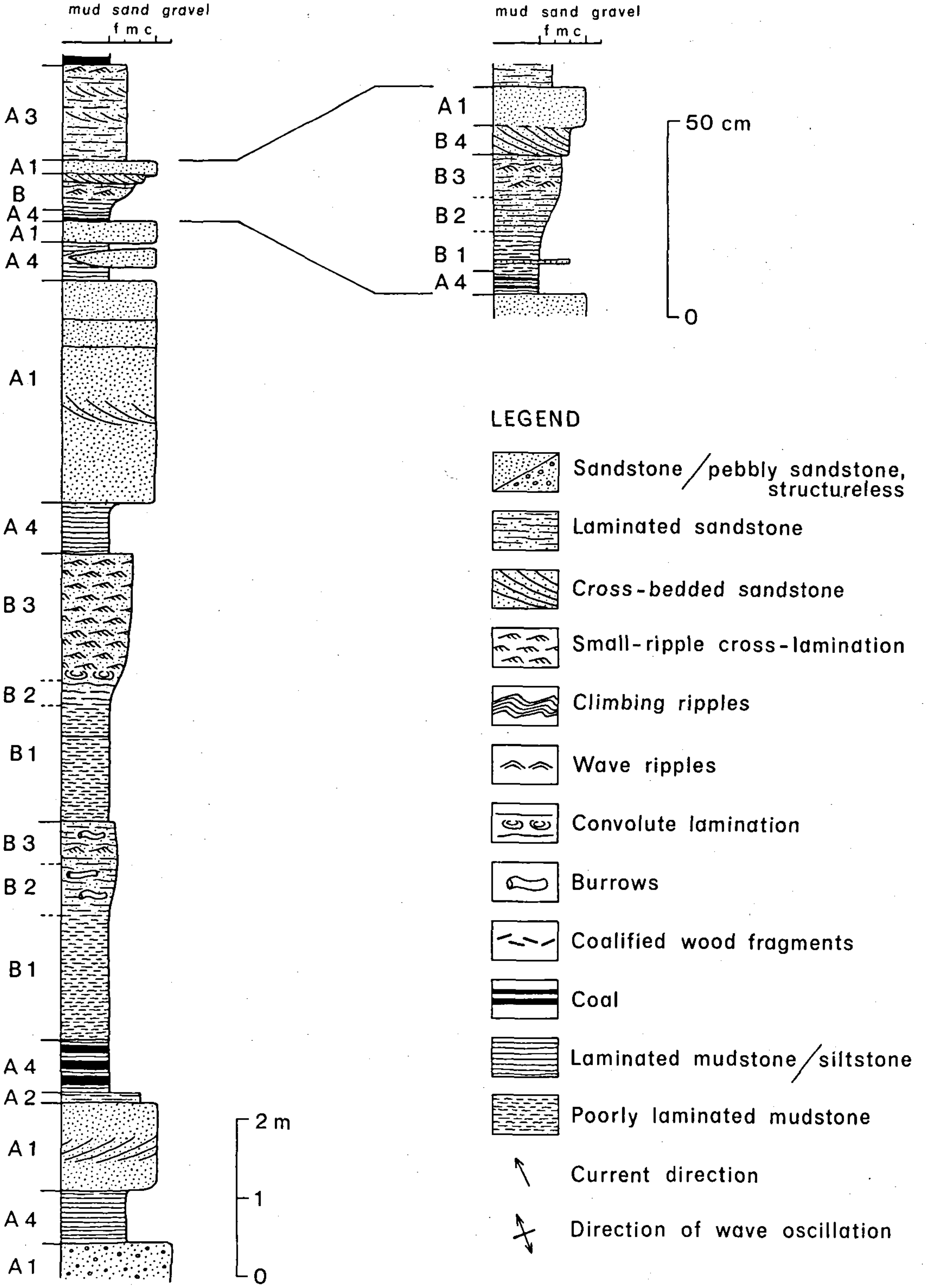

Fig. 5. Graphic log showing the upper three coarsening-upwards sequences (facies association B) and the intervening beds of facies association A.

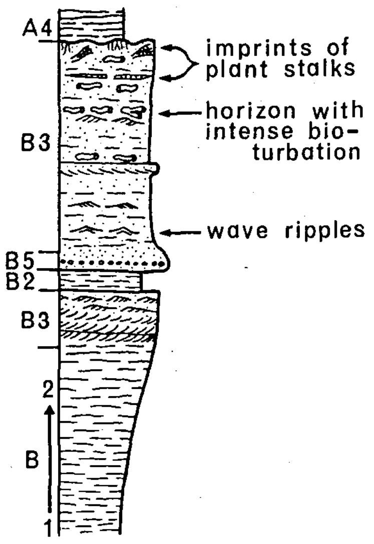

Fig. 6. Detailed graphic log of the uppermost metre of the second highest coarsening-upwards sequence as seen on the north-west side of Majoragdlagtarfik.

Facies B3: Small-ripple cross-laminated fine-medium-grained sandstone. This facies embraces sandstones with grain-size around the boundary between fine and medium sand, i.e. 0.2–0.3 mm. Individual beds usually show fairly good sorting. Mica and coalified plant remains are common and sometimes even conspicuous on parting planes.

Lamination in one form or another is characteristic of the facies. Most often the facies shows small-ripple cross-lamination, but climbing ripples, in particular the B-type of Allen (1973), convolute lamination and planar lamination also occur. Dip directions of foreset laminae indicate deposition by currents flowing towards NW-NNW.

Symmetrical oscillation ripple marks with crests oriented between 40 and 75° are seen particularly on the upper surfaces of beds where they are draped by laminated siltstone.

Biogenic structures are sporadically developed in the facies. These take the following forms: an intense network of subhorizontal branching burrows 5 mm in width; short cylindrical depressions in the upper surfaces of beds (fig. 7a); sinuous branching horizontal burrows that sometimes turn abruptly into steep burrows penetrating 2–3 cm of sediment (fig. 7b).

Facies B4: Medium-coarse sandstone. This is quantitatively a minor constituent of the facies association, and is only seen in two of the four coarsening-upwards sequences made up by the association. The sandstone is moderately sorted. Cross-bedding occurs but the medium-coarse sandstone can also be structureless.

Facies B5: Coarse, gravelly sandstone. This facies is restricted to a few less than 5 cm thick layers. The facies consists of poorly sorted material which includes quartz clasts up to 4 mm in size, and even larger shale chips. The upper surface of one gravelly sand unit shows symmetrical ripples of rather larger wave length (ca. 11 cm) than the oscillation ripples in facies B3.

Facies sequences: As already stated, facies association B makes up distinctive coarsening-upwards sequences, of which four have been observed in the Kome Formation at Kûk (figs. 3 and 5). The two lowest and the uppermost of these sequences overlie facies A4 overbank mudstones with coal, while the third sequence is stacked on top of the second (fig. 5).

The sequences begin with mudstones of facies B1, which grade up into laminated siltstone and fine sandstone of facies B2. The small-ripple cross-laminated fine-medium sandstones of facies B3 overlie facies B2, and an upwards cyclic gradation from B2 to B3 is shown in a few thin beds (fig. 3). The gravelly sandstone of facies B5 occurs as isolated layers in B3.

The lowest and highest sequences terminate with a layer of medium-coarse sandstone of facies B4, while the other two end with fine-medium sandstone. A hummocky upper surface, with impressions of plant stalks and stumps up to 2 cm wide, is seen in some exposures of the top of the third sequence (fig. 6). Within the hummocks there are rootlets.

Interpretation

The coarsening-upwards sequences made up of sediments of facies association B represent transitions from low energy conditions to higher-energy, shallower and better ventilated conditions. The sequences are interpreted as recording intervals of local inundation followed by silting up of the bodies of water.

Submergence was tranquil. The sequences be-

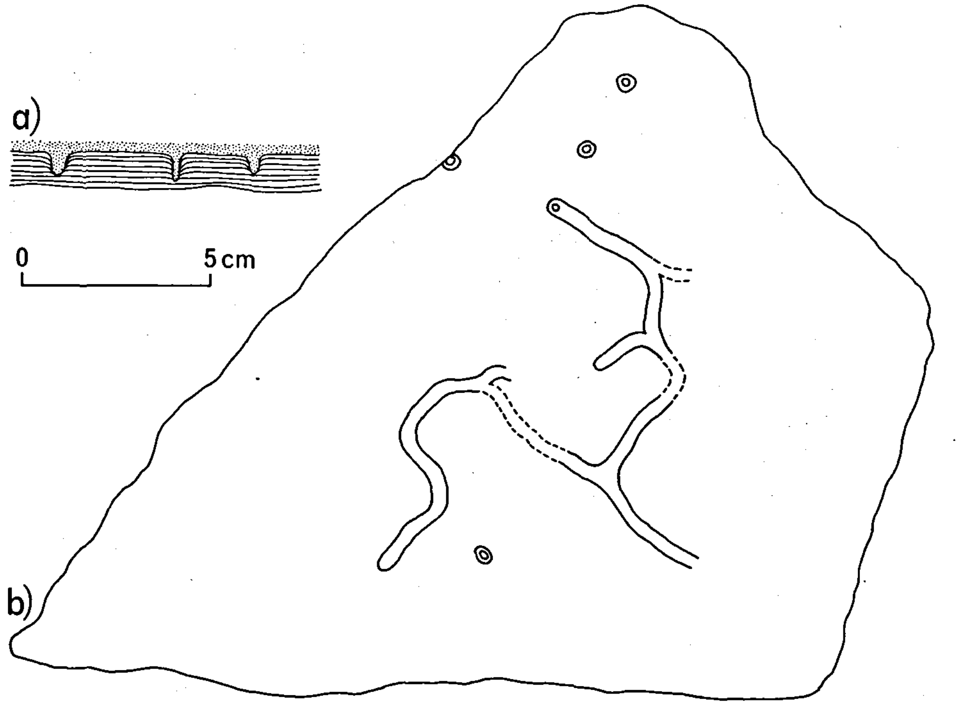

Fig. 7. Trace fossils from facies B2 in the lowermost coarsening-upwards sequence (see fig. 3, d): a) short cylindrical depressions half-a-metre from the top of the sequence, seen in cross-section; b) horizontal and vertical burrows as seen in a bedding plane just below the top of the sequence.

gin with mud deposited from suspension (facies B1); at first scarcely any plant material reached the site of sedimentation. As silting up proceeded, conditions became shallower and sedimentation became increasingly influenced by traction currents as is evidenced by small-ripple cross-lamination (facies B2 passing up into B3). The occurrence of climbing ripples indicates that the ratio of fall-out from suspension to bed load moved by traction was at times high. As silting-up proceeded, the surface of sedimentation rose above the wave base. Thin beds with larger symmetrical ripples and gravel-sized clasts (facies B5) may represent short periods of high winds.

The amount of undecomposed plant material preserved in the sequences indicates that the water was poorly oxygenated. However, with shallowing-up and increased agitation of the water, conditions became more congenial for bottom-dwelling organisms, though from the rather sparse trace fossil assemblages it appears that only a few species inhabited the basins.

From the general setting (see discussion later) it is most likely that the basins in question were interdistributary bays, and that the three lower coarsening-upwards sequences represent the deposits of minor mouth bars.

The uppermost coarsening-upwards sequence, which is much thinner than the lower three, terminates in coarse sand of facies A1 overlain by fine sandstone of facies A3. This thin sequence is interpreted as a small crevasse-splay deposit topped by channel-fill or levee deposits of facies association A.

Facies association C

Description

This facies association outcrops in the main tributary valley to Kûk where it forms a unit 3–6 m thick overlying thinly bedded sediments of facies association A on a weakly erosive base (fig. 8). Another poorly exposed unit occurs in the uppermost part of the Kome Formation in Majoragdlagtarfik. Only two facies have been recognised in the association; the siltstones that overlie the units are regarded as transitional to

Fig. 8. Sediments of facies association A overlain by tabular cross-bedded medium-grained sandstone of facies association C, main tributary vally to Kûk. Height of section about 18 m.

facies A4 rather than belonging to facies association C.

Facies C1: Tabular cross-bedded medium-grained sandstone. This facies dominates the association. It consists of medium-grained subarkosic sandstone which is moderately well sorted though quartz grains in coarse sand fraction and isolated pebbles do occur. There are also concentrations of pebbles along boundaries between cross-bedded sets. The pebbles, which are mainly of quartz but also of a fine cherty rock, are up to 1.5 cm long, poorly spherical, but have well rounded and polished surfaces. There is a fairly high content of comminuted coalified plant debris which together with mica tends to be concentrated towards the toes of foresets. The sandstone is locally hardened and well cemented in lenses and irregular layers that show a buff-orange weathering surface in contrast to the pale colour of the poorly consolidated sandstone.

In thin section it can been seen that quartz clasts dominate the sand fraction. These are mostly single crystals, but composite grains also occur. The feldspars are, in order of decreasing abundance, microcline, perthite and plagioclase; no orthoclase was observed (contrast with Schiener 1975, pp. 35–37). The feldspar grains vary from fresh to highly altered. Mica is common; both muscovite and bleached biotite have been observed. Flakes are often buckled and wrapped around quartz clasts as a result of compaction. A few small garnet fragments and rare rounded hornblende and zircon grains are among the heavy minerals present. Intergranular space is occupied by a carbonate-impregnated fine matrix (only the hardened sandstone was sectioned). Regarding grain shape, most of the sand-sized clasts are roughly equant, but surfaces vary from rounded to angular; there is a reasonable correlation between degree of rounding and degree of alteration of the feldspars, but no correlation could be detected between roundness and size of the quartz grains, suggesting a diversity in the provenance of the grains.

The main sedimentary structure in the facies is tabular-tangential or tabular-planar cross-bedding in sets up to 40 cm thick, with foreset dips in the range 22–28°. Boundary surfaces between the tabular-planar sets can be rather irregular (fig. 9). In the unit exposed in the tributary valley to Kûk current direction indicated by foreset dips (corrected for tilt) is towards north-northeast, with a spread of dip directions between 312° and 50°.

Distortion of laminae is common in the facies. This has given rise to convolutions, peaks and overturned folds up to 30 cm in amplitude. These structures resemble closely structures illustrated by Selley et al. (1963, p. 229 and plate XV, fig. 2) and attributed by these authors to adjustments in quicksands.

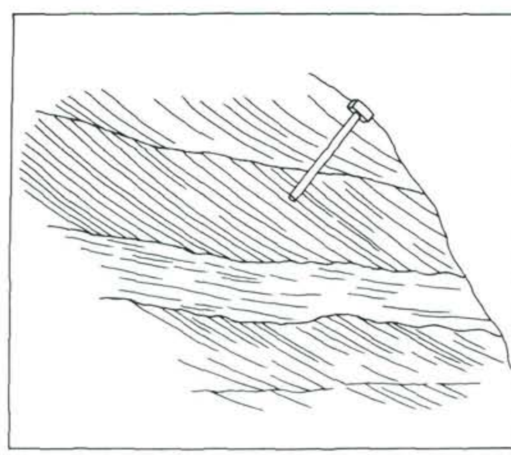

Fig. 9. Cross-bedding in the tabular cross-bedded medium-grained sandstone of facies association C. Drawn from a photograph.

Facies C2: Small-ripple cross-laminated fine sandstone. This facies has only been seen in situ overlying facies C1. The facies consists of fine (sometime almost medium) sandstone with small-ripple cross lamination. Where whole current ripples are preserved, the rock may have a flaser-like structure due to concentration of organic material in troughs between ripples.

Interpretation
Facies C1, with its medium sand grain size, degree of sorting, roundness of pebbles, tabular cross-bedding, and foreset dips towards NNE, stands in striking contrast to the sandstones of facies association A.

No marine body fossils or trace fossils have been found in the sandstone, but there is quite a lot of comminuted plant debris. No indications of strong wave action or tidal influence (herring-bone cross-bedding) have been seen. This suggests a non-marine environment. This environment is most likely to have been fluviatile rather than lacustrine. Silting-up of a lake would have given rise to a coarsening-upwards sequence dominated by low-energy sediments (Selley 1970, pp. 70–71).

Tabular cross-bedding in fluviatile sands has been shown in present-day rivers to have resulted from deposition in shifting transverse bars, particularly in the distal parts of sandy braided rivers (Harms & Fahnestock 1965, pp. 95–96 and 103–104; Smith 1970, 1972; Cant & Walker 1978, p. 630). Tabular cross-bedding in ancient fluviatile deposits has also been interpreted in this manner (e.g. Kelling 1969, p. 859; Asquith & Cramer 1975; Cant & Walker 1976, pp. 107 and 117; Houseknecht & Ethridge 1978, p. 583). The tabular cross-bedding in the medium-grained sandstone under discussion resembles that described by these authors, and it is therefore concluded that the facies was deposited from shifting transverse bars in the distal part of a sandy braided river.

The rippled fine sandstone of facies C2 represents deposition by waning currents before the return of flood plain conditions represented by the overlying siltstones and silty mudstones that are referred to facies A4.

It might be argued against the above interpretation of facies C1 that trough cross-bedding was not observed in the sandstone (the thickest part of the unit is however not accessible – see fig. 8), while in both Smith's (1970) and Cant & Walker's (1978) models for sandy braided rivers, tabular cross-bedded transverse bar sands should overlie trough cross-bedded channel sands. This objection is not crucial; trough cross-bedding is not obligatory in the inventory of characters of sandy braided rivers. The profile of Platte-type braided river deposits drawn by Miall (1977, p. 47) shows tabular cross-bedded sand directly overlying overbank deposits at two levels, and 9 m of section with no trough cross-bedding at all.

Discussion: the general depositional environment of the Kome Formation

The interpretation of the bulk of the Kome Formation as being of fluviatile origin is in accordance with general statements by earlier workers (Gry in Rosenkrantz et al. 1941; Schiener 1977). The interpretation will now be taken a step further to incorporate the deltaic deposits of facies association B and discuss the type of fluviatile environment involved.

Recent alluvial deposits are usually grouped into two categories: deposits of high-sinuosity meandering rivers, and deposits of low-sinuosity braided rivers (Selley 1970; Walker 1976). The alluvial deposits of facies association A of the Kome Formation cannot be matched with current models for either of these fluvial systems.

The deposits of meandering rivers are characterised by blanket geometry of the sandstone bodies (Visher 1965, p. 132; Moody-Stuart 1966, p. 1102) and rhythmic repetition of fining-upwards sequences (Allen 1964). Neither of these features can be said to characterise facies association A. Lateral accretion on point bars has played no part in the formation of the narrow shoe-string sand bodies in this facies association.

Braided river sequences are dominated by coarse sands and gravels, with fine-grained overbank deposits confined to cut-off branches and sloughs (Allen 1965, p. 163; Selley 1969, pp. 331, 338; Miall 1977, pp. 37, 46–47). In contrast, fine-grained overbank deposits constitute between a quarter and a third of facies association A. Furthermore, the sands of facies A1 appear to have been deposited largely from migrating dunes; there is no indication that transverse or longitudinal bars have played a significant part in their sedimentation (cf. Miall 1977, p. 33).

Moody-Stuart (1966, p. 1104) has suggested that there is a third type of river, one with low sinuosity and low braiding index, that should be taken into account when interpreting ancient fluviatile sequences. This idea has been taken up by Leeder (1973, pp. 124–126), Sykes (1974, p. 210) and Nami & Leeder (1978, p. 435).

Every relevant character of the deposits of low-sinuosity streams listed by Moody-Stuart (1966) can be matched in facies association A of the Kome Formation, with one important exception: the width: depth ratio of the channels. This is more than 40 in the low-sinuosity stream deposits described by Moody-Stuart, but often less than 15 in facies association A. Facies association A of the Kome Formation also has important similarities with facies association 2 of Leeder (1973) as regards facies sequences, and with the ribbon sandstones described by Nami & Leeder (1978, p. 435) as regards geometry and internal structures of the sand bodies. Both these occurrences have been interpreted by the respective authors as deposits of low-sinuosity streams, but the authors have not discussed the problem of channel morphology.

Schumm (1977) has discussed the effects of hydraulic variables on river channel morphology. Among the most important variables are the type of sediment load and the gradient. A high proportion of bed load relative to suspended load favours low sinuosity and high width:depth ratios, whereas streams carrying a high proportion of suspended material have high sinuosity and low width:depth ratios. Relatively high gradients and extremely low gradients favour low sinuosity, while moderately low gradients favour high sinuosity.

The sediments of facies association A were deposited on a plain very close to the base level; the coarsening-upwards sequences of facies association B indicate that on occasions parts of the plain actually lay below the base level and were submerged. Thus the plain probably had a very low gradient which would favour low sinuosity.

The streams that deposited the coarse sands of facies association A derived their sediment from a deeply weathered and kaolinised hinterland and are likely therefore to have been muddy; the amount of kaolin in the matrix of the sandstones suggests a relatively high content of suspended sediment in the load (even though some of this kaolin probably originated from the breakdown of feldspars in situ). This factor would have decreased the width:depth ratio of the channels, but should at the same time have lead to high sinuosity. It is concluded therefore that the Early Cretaceous streams at Kûk cannot have been stable, and hence that relationships established by Schumm for stable rivers cannot be applied in the present instance.

The depositional environment for facies association A which best satisfies the evidence and the results of flume experiments (Schumm & Khan 1972) is a delta plain, particularly if the delta was separated from the provenance area by a relatively narrow alluvial plain. The streams that deposited facies association A were therefore not rivers in the strict sense but delta distributaries. According to Elliott (1978), delta distributary channels may have high or low sinuosity. Channel switching or avulsion is a common feature of distributary channels whose fining-upwards sequences result from channel abandonment, with the fine member representing infilling of the channel by diminishing flow. As a consequence of their switching behaviour, fluvial distributary channels tend to be short-lived relative to upstream equivalents, causing the sand bodies to have low width:depth ratios (Elliott op. cit., pp. 103–104).

It has been argued that the coarsening-upwards sequences of facies association B represent silting up of basins that had developed where the delta plain had become submerged. In the wider context of regional palaeogeography it would be useful to know whether these coarsening-upwards sequences developed in a marine or lacustrine environment. The evidence from the coarsening-upwards sequences alone suggests no more than that conditions were non-tidal and rather unattractive for aquatic faunas. These conditions could equally well have arisen in a lake, a brackish lagoon, or a secluded interdistributary bay. Similar sequences in the Rhondda Beds in Wales have been interpreted by Kelling (1968, p. 2382) as lacustrine deltaic, but there the general environment was a meander belt. The general environment in the Lower Cretaceous at Kûk was a delta plain, so that the coarsening-upwards sequences are more likely to have de-

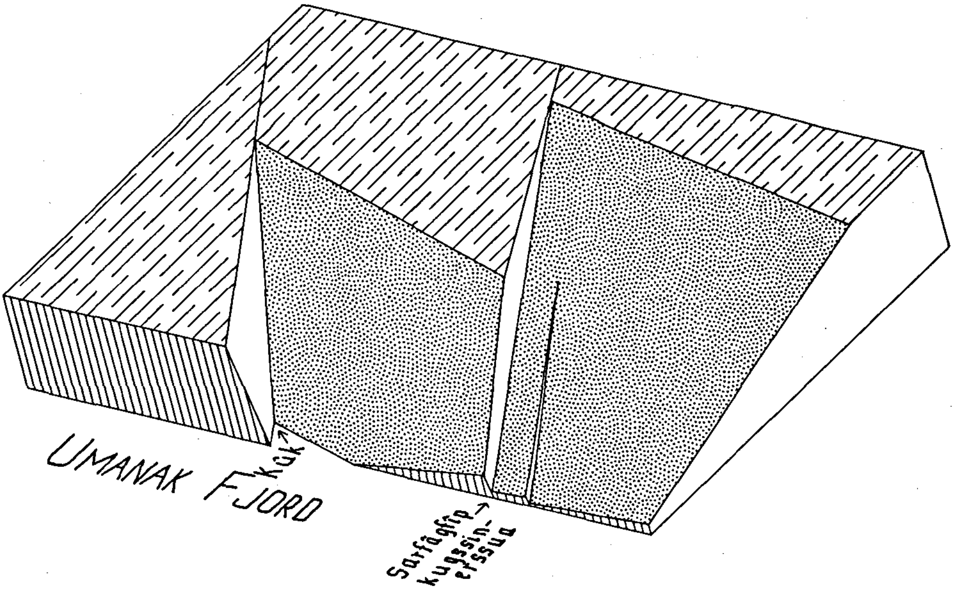

Fig. 10. Schematic block diagram illustrating post-Early Cretaceous faulting and tilting of the basement at Kûk. Sub-Cretaceous surface stippled.

veloped in barrier-confined lagoons or interdistributary bays (Elliott 1976, p. 122). Since there is no evidence of barrier-related facies in the Kome Formation, the coarsening-upwards sequences of facies association B are believed to represent three minor mouth bars and a small crevasse-splay lobe that grew into interdistributary bays. Hansen (1976) has recorded similar coarsening-upwards sequences throughout 330 m of Upper Cretaceous sediments on the south side of Nûgssuaq, which suggests that a deltaic environment with interdistributary bays became firmly established in the inner part of Nûgssuaq in later Cretaceous times.

The interpretation of the tabular cross-bedded medium-grained sandstone of facies C1 as deposited from transverse bars in a sandy braided river flowing from south-southwest is consistent with the regional setting of the Kome Formation. Smith (1970) has shown that transverse bars with tabular cross-bedding are characteristic of the distal parts of a braided river system, where gradients are lowest. A river flowing from south-southwest would have flowed across an alluvial plain for at least 200 km before reaching Kûk (see the generalised facies map of Henderson et al. 1976, p. 359), which is in accordance with what is predicted from Smith's model.

Faulting, tilting, and sub-Cretaceous relief

The sub-Cretaceous gneiss surface rises from just below sea level at the Kûk delta to about 1300 m in the south-west corner of the area shown in fig. 2. This is not an expression of Cretaceous relief as previously supposed (Rosenkrantz & Pulvertaft 1969, p. 884; Henderson et al. 1976, p. 341), but the result of post-Cretaceous tilting. If the area between Kûk and Sarfâgfîp kugssinerssua is tilted so that the Cretaceous beds are returned to their original more or less horizontal position, the slope of the sub-Cretaceous gneiss surface disappears and the surface assumes the form of a uneven plain. A deep regolith is much more likely to have developed on this sort of surface than on the mountainous slopes implied by previous accounts (Ollier 1965, p. 301). Furthermore, it has been shown that the tabular cross-bedded medium-grained sandstone of facies C1 was deposited on a surface of low gradient by currents flowing from south-southwest. There cannot have been a gneiss ridge just to the south at the time when this sandstone was deposited.

Although the sub-Cretaceous surface at Kûk was probably a rolling plain, it is not denied that there may have been stronger Cretaceous relief in other areas, for example south-east of Ikorfat and on Disko island.

There is a ca. 350 m drop in the level of the sub-Cretaceous surface as one crosses the Sarfâgfîp kugssinerssua valley, and correlation of marble horizons in the basement on either side of the valley also requires a downthrow to the west of this order. Thus a major fault system is believed to exist in the Sarfâgfîp kugssinerssua valley (fig. 10). Faults belonging to this system are exposed on the shore between Sarfâgfîp kugssinerssua and Kûtsiaq.

The present eastern margin of the Cretaceous-Tertiary sediments in central West Greenland has been variously attributed to a Cretaceous coastal cliff (L. Koch 1928, p. 300), post-Cretaceous faulting (Rosenkrantz et al. 1942, p. 69), pencontemporaneous faulting (Rosenkrantz & Pulvertaft 1969, p. 896), and faulting after sedimentation (Henderson et al. 1976, p. 342). In none of these accounts, however, is there any specific reference to the sediments at Kûk, in spite of their critical position at this margin. In 1978 an excellent exposure of the faulted easterly margin of the Kome Formation was found in one of the tributary valleys to Kûk. The sediments here are of facies association A and like those shown in fig. 8. There is no change whatsoever in the character of the sediments approaching the fault, and there is no more than 10 cm of crushed sedimentary material along the fault plane which dips west at 55°. Drag is negligible. In contrast, the gneiss on the footwall is intensely crushed for up to 40 m from the fault, and reddened for an even greater distance away. This crushing must have taken place as the gneiss underlying the sediments on the hanging wall moved past the footwall.

It is clear from the lack of any coarsening of the sediments towards the fault plane that faulting was not penecontemporaneous as far as the Kome Formation is concerned, but entirely later. Sediments of facies association A must originally have extended well to the east of the present faulted boundary of the Cretaceous-Tertiary basin in West Greenland.

Conclusions

1) The greater part of the Lower Cretaceous Kome Formation exposed at Kûk was deposited by low-sinuosity distributaries flowing from east-southeast across a delta plain. At intervals tranquil inundation of parts of this plain led to the development of interdistributary bays. Sedimentation at minor mouth bars and crevassing into these bays gave rise to coarsening-upwards sequences in the otherwise fluvial-dominated Kome Formation. At least once during deposition of the Kome Formation a sandy braided river flowing from south-southwest encroached for a short time across the delta plain.

2) The sub-Cretaceous surface at Kûk was a rolling landscape, perhaps with occasional inselbergs rising above areas of deep regolith. The present rise of the sub-Cretaceous gneiss surface south-west of Kûk is entirely due to later tilting of fault blocks.

3) Lower Cretaceous sediments originally extended some way east of the present, fault-controlled easterly margin of Cretaceous outcrops.

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Dansk sammendrag

En ca. 140 m tyk serie Nedre Kridt sedimenter tilhørende Kome-formationen ligger ovenpå det prækambriske grundfjeld i Kûk-området. Tre facies associationer kan skelnes i disse sedimenter. Facies association A, som er den dominerende, består næsten udelukkende af trug-krydslejret grov subarkosisk sandsten vekslende med mørk lamineret muddersten med en del karboniserede planterester (fig. 3 og 4). Sedimentære strukturer, facies sekvenser og kanal morfologi tyder på, at denne facies association blev aflejret af flodarme, der strømmede fra ØSØ over en deltaslette. Facies association B forekommer i opefter-grovere sekvenser, der består af muddersten – små-skala krydslejret finsandsten – mellemkornet sandsten i denne rækkefølge (fig. 3, 5 og 6). Disse sekvenser tolkes som aflejret i små deltaer, der voksede ud i »interdistributary bays« (lavvandede bugter mellem flodarme). Facies association C, der hovedsageligt består af tabular krydslejret mellemkornet sandsten, menes at have været aflejret i transverse barrer i den distale del af en sandet braideret flod, der strømmede fra SSV. Den subkretasiske overflade var en dybt-forvitret ujævn slette; dens nuværende hældning og stejle skrænter skyldes udelukkende blokforkastning og -kipning efter tidlig Kridt. Sedimenterne afgrænses mod øst af en stor forkastning.

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