SEDIMENTOLOGICAL STUDIES IN SOUTHERN JAMESON LAND, EAST GREENLAND

II. Offshore-estuarine regressive sequences in the Neill Klinter Formation (Pliensbachian-Toarcian)

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Coarsening upwards sequences 8–40 m thick are described in which four major facies can be recognised: 1. Lenticular bedded mudstone; 2. Wavy bedded fine sandstone; 3. Alternating coarse sandstone and mudstone; 4. Cross-bedded coarse sandstone. Parallel laminated sandstones also occur and at the top bioturbated muddy sandstones mark a transgressive horizon. Facies 1 and 2 are horizontally bedded whereas facies 3 and 4 form large-scale cross-sets. Palaeocurrent data suggest a WNW-ESE trending coastline, with strong bi-directional currents operating normal to it. Mud-draped foresets, bipolar cross-sets and sharp alternations between deposition by traction currents and accretion from suspension indicate a tidal environment. Both shoreface and deltaic progradation are considered unlikely, and an estuarine model similar to the Heligoland Bight of the southern North Sea is proposed. Shelf deposits pass upwards into fields of migrating dunes and megaripples which accumulated in low relief estuary channel extensions and shoals.

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The sequences to be described occur in the Neill Klinter Formation (Rosenkrantz, 1929, 1934; Surlyk, Callomon, Bromley & Birkelund, 1973, pp. 14–17; Sykes, 1974, table 1) which outcrops along Neill Klinter, a magnificent line of cliffs on the western side of Hurry Inlet (see Sykes, 1974, fig. 1). The fauna has been extensively studied by Rosenkrantz (1934, 1942), who found ammonites of Pliensbachian (*jamesoni* Zone) to Toarcian (*thouarsense* Zone) age. The formation is 213 m thick at Albuen and has been divided into three members. At the base richly fossiliferous arkoses of the Rævekløft Member (Surlyk et al., 1973, pp. 17–18) reach over 20 m in thickness at Kap Hope (Rosenkrantz, 1942, p. 22), but die out north of Hurry Inlet (Rosenkrantz, 1934, p. 88; Surlyk et al., 1973, p. 17). This is followed by the Gule Horn Member (Surlyk et al., 1973, pp. 19–22), which is described in detail in this paper. The member is 120 m thick at Albuen but has not yielded any ammonites. It is overlain by the 86 m thick Ostreaelv Member (Surlyk et al., 1973, pp. 22–24) which yields Toarcian ammonites. The member is discussed briefly at the end of the paper.

Gule Horn Member: Facies description

The Gule Horn Member was studied along Neill Klinter at Albuen and an un-named gully between Vardekløft and Astartekløft (see Sykes, 1974, fig. 1). The unit consists of a series of coarsening upwards sequences between 8 and 40 m thick. Four major facies can be recognised:

Facies 1. Lenticular bedded mudstone

This facies is dominated by grey mudstone with isolated ripples of fine sandstone (pl. 1, fig. 1) – the typical lenticular bedding of Reineck and Wunderlich (1968, p. 102). The ripples and occasional discrete bed of fine sandstone are usually internally cross-laminated. Very rarely sharp-based beds of coarse sandstone or even mudflake conglomerate are intercalated but these are always less than 5 cm thick.

There is very little bioturbation – some *Planolites* can be seen in pl. 1, fig. 1, whilst epireliefs of the trail *Gyrochorte* are common on the top surfaces of ripples. The vertical U-tube *Diplocraterion* is restricted to the coarse sandstone beds. Facies 1 marks the base of each sequence and although only 1–2 m thick, it is laterally very persistant.

Facies 2. Wavy bedded fine sandstone

Alternations of continuous beds of fine sandstone and mudstone on varying scales characterise this facies. The alternations are often on a centimetre scale and may be called wavy bedding (Reineck and Wunderlich, 1968, p. 100). Thicker beds of fine sandstone are also included in this facies (pl. 1, fig. 2; see also Surlyk et al., 1973, fig. 10). They average 5–10 cm in thickness and are ripple cross-laminated with occasional mud flasers. The top surface always shows linguoid ripples (pl. 2, fig. 1), which bear a fine *Cruziana* ichnofacies dominated by *Gyrochorte* and *Muensteria*. This is followed by a thin ($<$ 5 cm) mudstone interval which shows lenticular bedding with isolated ripples of fine sand. As in facies 1 thin sharp-based beds of coarse sandstone are occasionally developed.

Facies 1 and 2 may be considered together to cover all gradations between

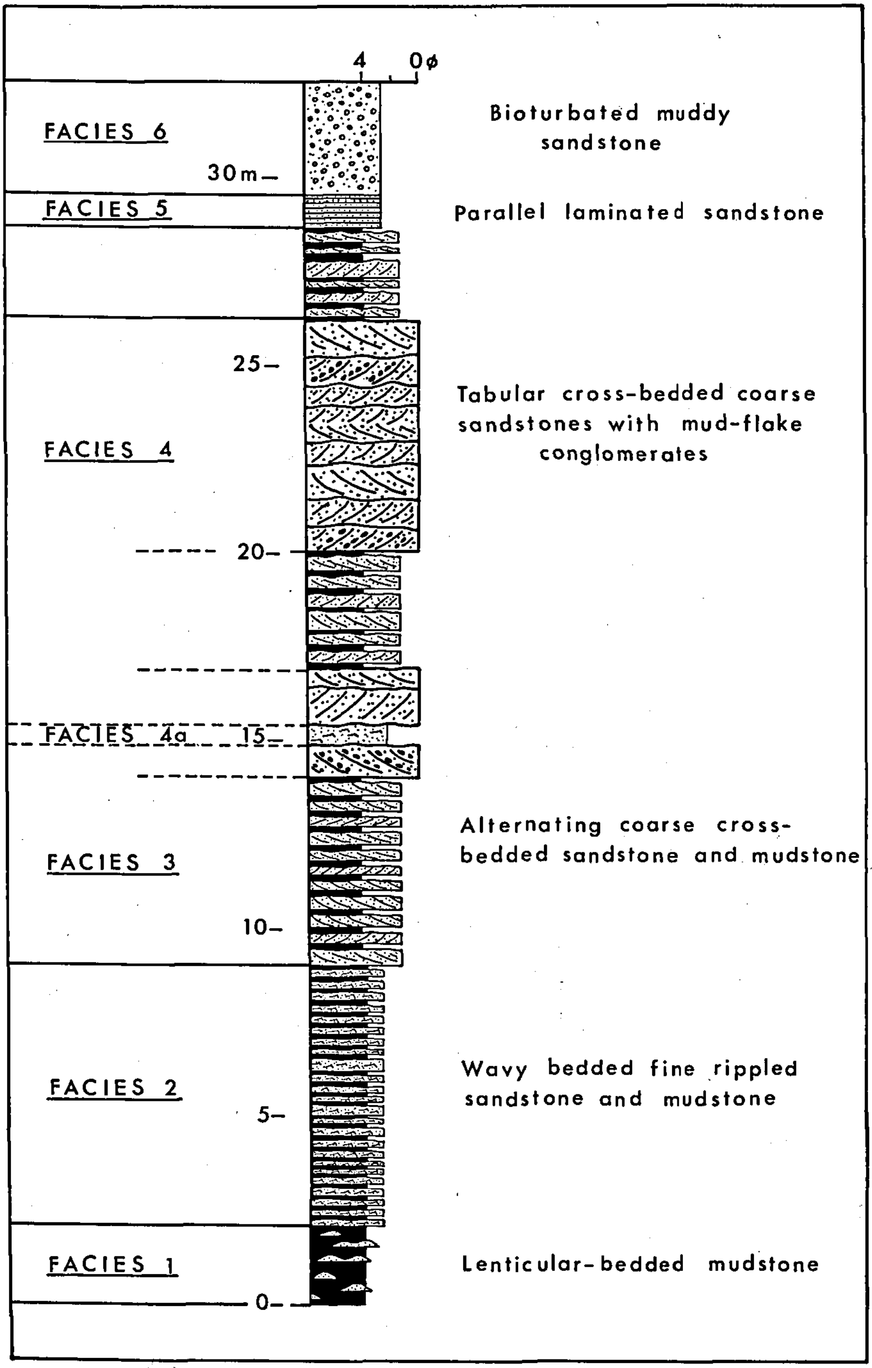

Fig. 1. A generalised coarsening upwards sequence in the Gule Horn Member at Albuen. Facies are numbered as in the text.

pure mudstone and 30 cm beds of fine sandstone with rippled tops and thin mudstone drapes. Facies 1 is mud-dominated; facies 2 is fine sand-dominated.

Facies 3. Alternating coarse sandstone and mudstone

This facies is superficially similar to the thicker alternations of fine sandstone and mudstone of facies 2, but there are fundamental differences. The sandstone beds are coarse-grained and form thicker, 10–50 cm beds. Accompanying this increase in grain size, rippled bedforms are replaced by small-scale tabular cross-bedding, often with bipolar dips in successive sets. Commonly the foresets show mud drapes, which may be in various states of fragmentation to form mudflake breccias and conglomerates (pl. 2, fig. 2). The sandstone beds often fine upwards with a rippled top to the coarse sandstone, followed by fine rippled sandstone with mud flasers and finally lenticular bedded mudstone. In other examples the mudstone directly overlies the rippled top of the coarse sandstone. This facies is characterised by the trace fossil *Monocraterion* (R. G. Bromley, personal communication, 1974).

Small-scale channels about 50 m wide and 1 m deep were observed at Harris Fjeld.

Facies 4. Cross-bedded coarse sandstone

These coarse sandstones show high-angle, large-scale tabular cross-sets up to 1 m high (pl. 3, fig. 1). Low-angle sets with erosional discontinuities are also common, though true herring-bone sets are rare. Mudflake conglomerates (often subsequently altered to sideritic mudstone) are a prominent feature, usually seen on foresets rather than as basal lags. Rippled surfaces occur at least every metre and many have thin mudstone drapes. Usually the sandstone beds have a sheet-like geometry due to subsequent erosion, though some retain a megaripple bedform (pl. 3, fig. 2).

Within this facies there are also horizons of fine-grained often cemented sandstone (facies 4a). They are either massive or rippled and sometimes show *Diplocraterion* descending from the top surface. Many are protrusive or retrusive, whilst others are almost completely truncated, suggesting either very rapid erosion whilst the animal was still in its burrow, or late-stage erosion after its death.

Two other minor facies can be recognised:

Facies 5. Parallel laminated sandstone

This facies comprises sharp-based fine-medium sandstones with parallel or low-angle cross-lamination, indefinite rippling and primary current lineation (pl. 4, fig. 1). Its maximum thickness is only 70 cm and it may be associated with facies 2, 3, 4 or 6.

Facies 6. Bioturbated muddy sandstone

This facies is extremely limited in its development, reaching a maximum thickness of 3.5 m. Completely mottled muddy fine sandstone is the dominant lithology, though hints of rippling and sand-mud alternations indicate that the original sediment was either facies 2 or 3. Facies 6 is associated with facies 2, 3 and 5 in the upper sequences of the Gule Horn Member and becomes the dominant facies in the overlying Ostreaelv Member. It is always sharply overlain by facies 1 mudstones.

Facies relations and palaeocurrents

A generalised facies model of a coarsening upwards sequence is illustrated in fig. 1. Fig. 2 gives some indication of the vertical and lateral relationships, together with the total palaeoccurrent data for both the Gule Horn and Ostreaelv Members, with individual readings noted beside the sections at Albuen and Vardekløft. Over 90 % of all ripple marks in facies 2 were linguoid and therefore impossible to measure in vertical section – the few relatively straight-crested trains show a consistent NW-SE orientation which agrees with independent observations made by R. G. Bromley (personal communication, 1973). The primary current lineation is an average of four observations from facies 5. The cross-beds in facies 3 and 4 are more variable though upwards there is a change from N-S to NE-SW bipolar orientation.

The ripples and primary current lineation suggest a shoreline trending WNW–ESE, with strong tidal currents operating normal to it. The actual location of the shoreline is uncertain. It may have lain southwards (the source of the underlying fluviatile Kap Stewart Formation – Sykes, 1974, fig. 2), although to the south at Rævekløft the lower part of the Gule Horn Member is dominated by facies 1 muds implying a northerly derivation.

When viewing major sequences from a distance a tripartite division is apparent:

(3) An upper horizontally bedded unit formed by facies 5 and 6.
(2) A central unit of SW-dipping large-scale cross-sets formed by facies 3 and 4 (pl. 4, fig. 2). When viewed down dip these cross-sets merely appear as irregularly undulating bedding planes.
(1) A lower horizontally bedded unit formed by facies 1 and 2.

It is interesting to note that unit (2) above is often laterally persistant.

Interpretation

The abundance of mud-draped ripples and foresets, bipolar cross-sets and the sharp alternation between deposition from traction currents and accretion by suspension indicate that these sequences were formed under tidal conditions (also suggested by Surlyk et al., 1973, pp. 65, 70). With this basic premise the following interpretation is put forward.

Facies 1. Since in any marginal tidal environment sand deposition occurs near low water mark (Evans, 1965, pp. 228–231), the mud-dominated facies may represent either tidal flat or open shelf conditions. In this case the rare belemnites with a *Cruziana* ichnofacies indicate marine conditions (Seilacher, 1967, p. 414) and the lateral persistance is more typical of an open shelf than tidal flat. The absence of mudcracks (cf. Klein, 1970, p. 976), rootlets and coals (cf. Sellwood, 1972, p. 102) also makes a tidal flat environment unlikely. The low degree of bioturbation implies a rapid rate of mud sedimentation with the sea bottom just occasionally disturbed by current activity. The coarse sands are catastrophic deposits probably emplaced by storms.

Facies 2. As the shoreline progrades, so increasing tidal velocities deposit fine-grained sands – their variable thickness being a response to variation in the neap-spring tidal cycle. It should be remembered that prior to compaction the mud and sand components were probably of about equal thickness.

Facies 3. Similar conditions existed in facies 3 except that stronger tidal currents were able to move migrating dunes of coarse sand. These were subsequently reworked either by less powerful tidal currents or by wave action to produce the rippled top surface on which suspended mud fell out. These processes are well documented by recent tracer studies (Oertel, 1972, p. 6).

Facies 4. Finally megaripples migrated under even stronger tidal currents with velocities of 60–150 cm/sec (McCave, 1973, p. 495). Erosive events are recorded as erosional discontinuities and rippled surfaces with only thin, often carbonaceous mud partings developed. Facies 3 and 4 were probably formed in very large-scale, low-relief tidal channels, with shoals at the margins formed of finer sand (facies 4a). The association of *Diplocraterion* with this high energy shoal/bar environment is typical of the British Jurassic (F. Fürsich, personal communication, 1973). Also typical is its association with omission surfaces as indicated by truncated burrows. These powerful currents, which swept the tops of the shoals, may have also generated the parallel laminated sands of facies 5 in the surrounding deeper water. They were probable caused by storm surges superimposed on tidal currents.

Normally at the top of each sequence there is a sharp change from coarse sandstone facies 3 or 4 to mudstone of facies 1, probably due to a sharp rise in sea level. However, sometimes the rate of change of sea level seems

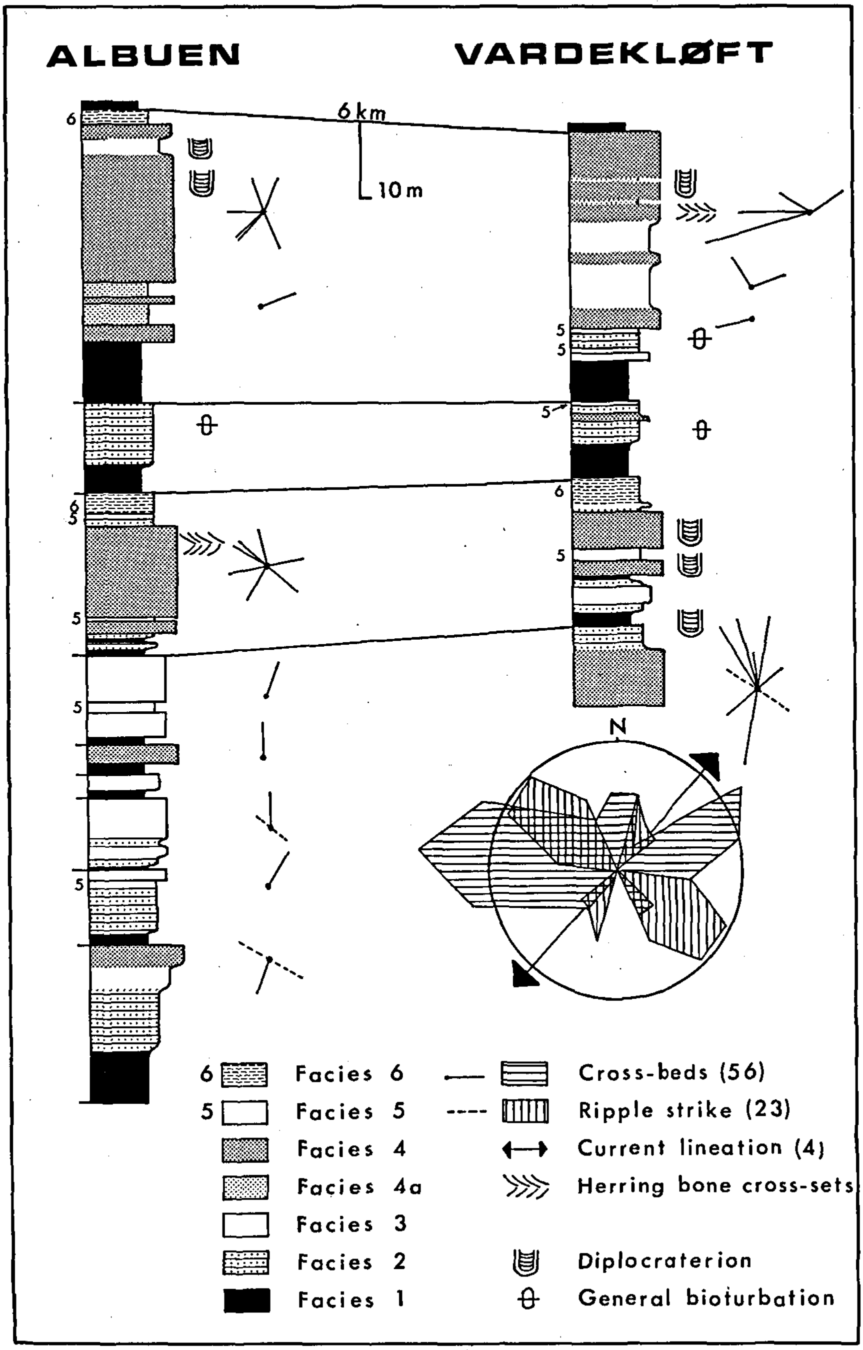

Fig. 2. Facies relations in the Gule Horn Member at Albuen and Vardekløft. Radius of the palaeocurrent circle indicates 10 measurements. Sharp profile indicates sharp facies contacts; rounded profile indicates a gradational change.

to have been quite slow. Sediment input was reduced and this allowed reworking of the top beds (usually either facies 2 or 3) by burrowing organisms to form facies 6 – a transgressive horizon.

Table 1 shows the results of sequential analysis. Although the primary trends confirm the dominantly regressive nature of the sequences, the secondary trends show strong evidence of reversals which indicate a rather fluctuating general environment.

Discussion

It is postulated that open shelf deposits are followed by a coarsening upwards regressive sequence. Therefore three prograding shoreline types are possible: 1. A simple non-deltaic shoreface away from major sediment sources; 2. A prograding delta; 3. A large estuarine embayment. The basic difference between these possibilities is the relationship between the rate of supply of sediment and the energy available for reworking it on the neighbouring shelf. Option 1 may be ruled out for although megaripples occur (Clifton, Hunter & Phillips, 1971, pp. 658–659; Howard & Reineck, 1972, p. 222), bioturbation, beach lamination and oscillation ripples are rarely present.

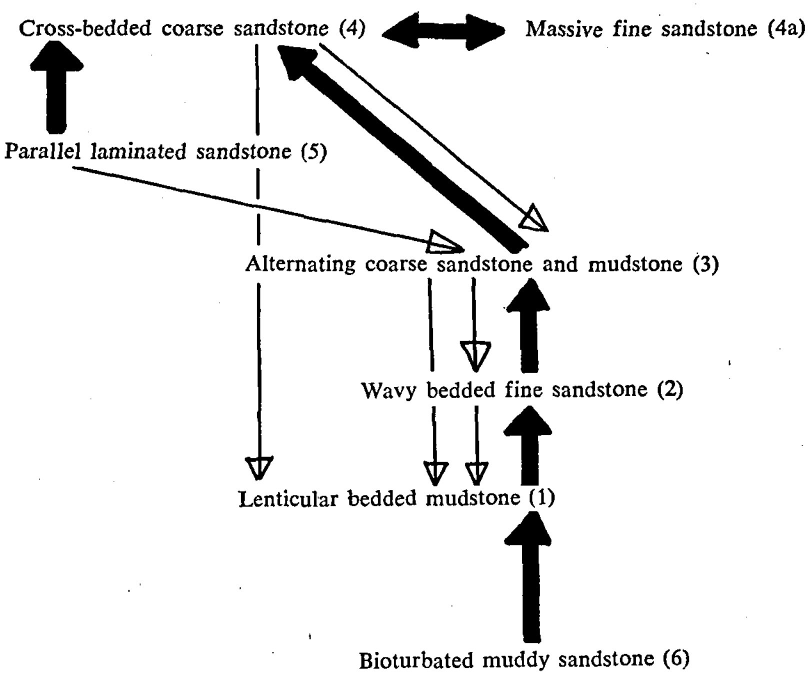

Table 1. Sequential facies analysis of coarsening upwards sequences showing primary (heavy arrow) and secondary (light arrow) trends.

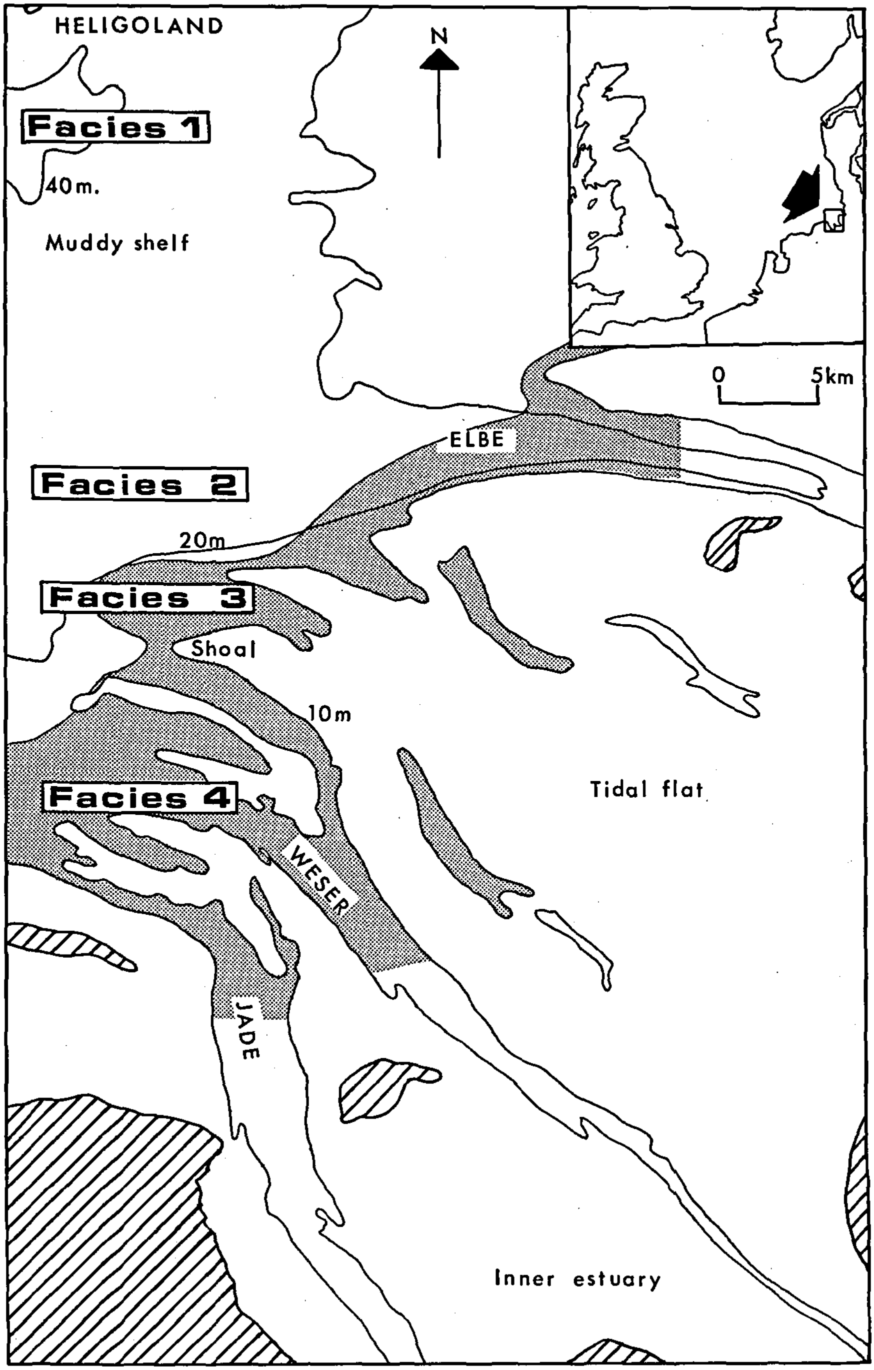

Fig. 3. Four major facies superimposed on the Heligoland Bight (after Reineck, 1963). Inclined hatching is land, stipples represent distribution of migrating coarse sand megaripples in channel extensions.

Deltas may be dominated by either fluviatile or littoral processes or form under mixed conditions (Van Andel, 1967, pp. 307–309). Since a shoreface origin has already been ruled out and there is no evidence for Mississippi-type bar finger sands, the only possibility under option 2 is a mixed fluvio-marine delta with strong tidal influence such as the Niger (Allen, 1965; Weber, 1971; E. Oomkens, 1974).

The third option is a large estuarine embayment like the Heligoland Bight of the southern North Sea (Reineck, 1963). Both sand and mud are available from fluviatile and littoral sources, and strong tidal currents are operative in tidal channel extensions and over estuary shoals.

Thus two possibilities remain – a Niger-type deltaic offlap or a Heligoland Bight-type estuarine offlap. Both of these recent analogues show a lateral facies sequence 1 - - - - - 2 - - - - - 3 in similar depths of water. It is possible that these sequences could represent a pro-delta – delta front succession with pro-delta muds overlain by river mouth bar and tidal channel sediments (Elliott, 1973, p. 24). A strong tidal influence would tend to mask their delta front origin. In contrast the scale of the sandstone-dominated facies, and the absence of pro-delta slope slump features and turbidites argue against a deltaic origin.

On the other hand Reineck and Singh (1967, p. 227), working off the Jade estuary, noted major channel features up to 5 km wide. They are separated by broad subtidal shoals and show well developed coarse sand megaripples in the centre. On a larger scale, due to lower continental shelf gradients in the past, the seaward extensions of such large estuary channels would fill with migrating megaripples and mud drapes rather than the classical fining upwards tidal channel–tidal flat sequence. The abundance of linguoid ripples is also consistent with deposition in large-scale tidal channels (Allen, 1968, p. 82; Coneybeare and Crook, 1968, p. 252).

Thus an offshore-estuarine regressive origin for these sequences is preferred. Fig. 3 is an attempt to superimpose the major facies types on the Heligoland Bight model. The remarkable similarities with this model are perhaps best understood only after detailed perusal of Reineck's (1963) maps. Similar sequences are known from the Lower Greensand of the Isle of Wight (Dike, 1972, pp. 167–172), the Middle Devonian of New York State (McCave, 1973) and the Lower Cambrian (Banks, 1973) and late Pre-Cambrian (H. D. Johnson, personal communication, 1973) of Finmark, northern Norway.

It is perhaps one of the most interesting features of the Gule Horn Member sequences that they are nearly always interrupted at facies 4 and never reveal the more marginal sedimentary environments.

Ostreaelv Member

This top subdivision of the Neill Klinter Formation consists of similar coarsening upwards sequences. The main difference is that the sequences are dominated by muddy sandstones of facies 6 due to a slower rate of sedimentation allowing bioturbation of facies 1 and 2. Also marine bivalves and belemnites occur throughout and occasional ammonites indicate a Toarcian (*bifrons – thouarsense* Zones) age. The third main contrast with sequences in the Gule Horn Member is that the trace fossil assemblage is dominated by *Rhizocorallium, Spongeliomorpha suevica* (= *Thalassinoides,* see Fürsich, 1973, p. 730) and occasional S. *nodosa* (= *Ophiomorpha,* Fürsich, 1973, p. 729). Some of the trace fossils from this member have been described recently by Bromley & Asgaard (1972a, b).

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Dansk sammendrag

I den beskrevne 8–40 m tykke lagfølge, der bliver mere grovkornet opefter, kan udskilles 4 facies. 1: "Lenticular-bedded" slamsten; 2: "Wavy-bedded" finkornet sandsten; 3: Skiftende grovkornede sansten og slamsten; 4: "Cross-bedded" grovkornet sandsten. Parallelt laminerede sandsten findes også, ligesom der i toppen af lagserien findes bioturberede, lerede sandsten, der markerer en transgressiv horisont. Facies 1 og 2 viser horisontal lagdeling, medens facies 3 og 4 danner store "cross-sets". Strømretnings undersøgelser antyder en kystlinie med NNV-ØSØ retning og kraftige ind- og udgående strømme vinkelret på kysten. "Mud-draped foresets", bipolære "cross-sets" og markante skift mellem strømaflejringer og aflejringer af suspenderet materiale indicerer tidevandsmiljø. Som recent analog til den beskrevne udvikling foreslås de estuarine forhold i Tyske Bugt i den sydlige del af Nordsøen. Shelf aflejringer går opefter gradvis over i områder med sandbanker og megaripler dannet mellem og i estuarine kanaludløbere.

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Plate 1

Fig. 1. Lenticular bedded mudstone, with ripples and burrows of fine sand (facies 1). Length of the marker pen 14 cm.

Fig. 2. Wavy bedded and alternating fine sandstone and mudstone (facies 2). Length of hammer 33 cm.

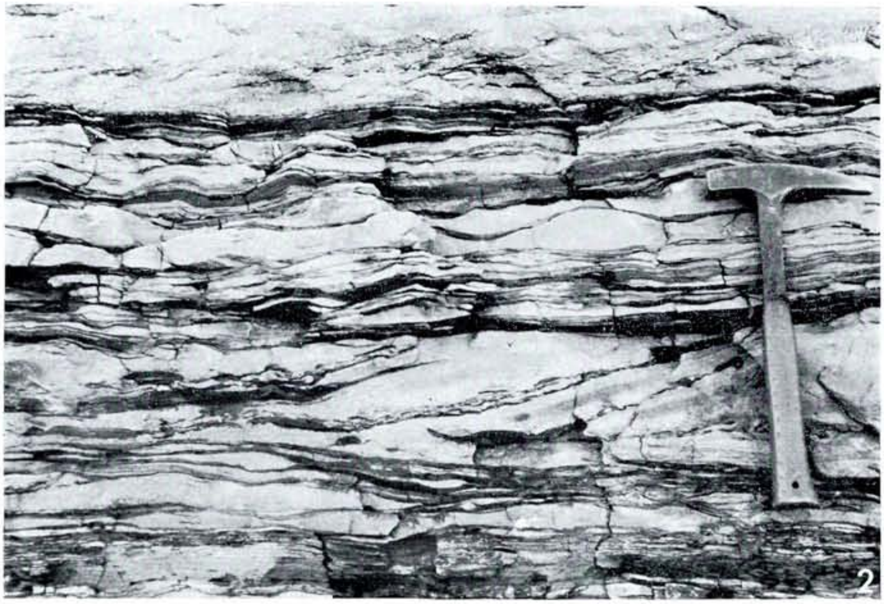
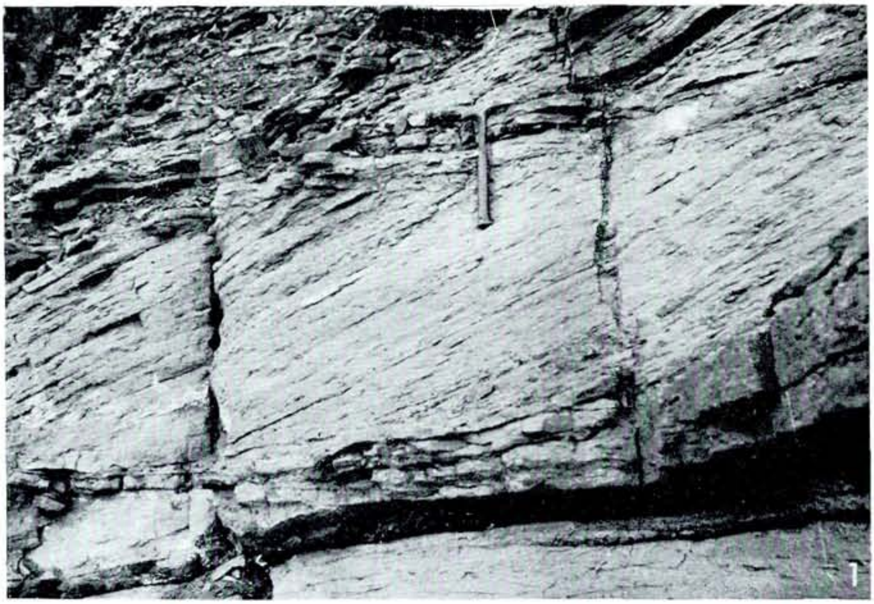


Plate 2

Fig. 1. Linguoid ripples on top of a fine sandstone bed in facies 2. Hammer point directed to 30°.

Fig. 2. Alternating coarse sandstone and mudstone, with tabular cross-bedding, mud drapes and mudflake breccias (facies 3).



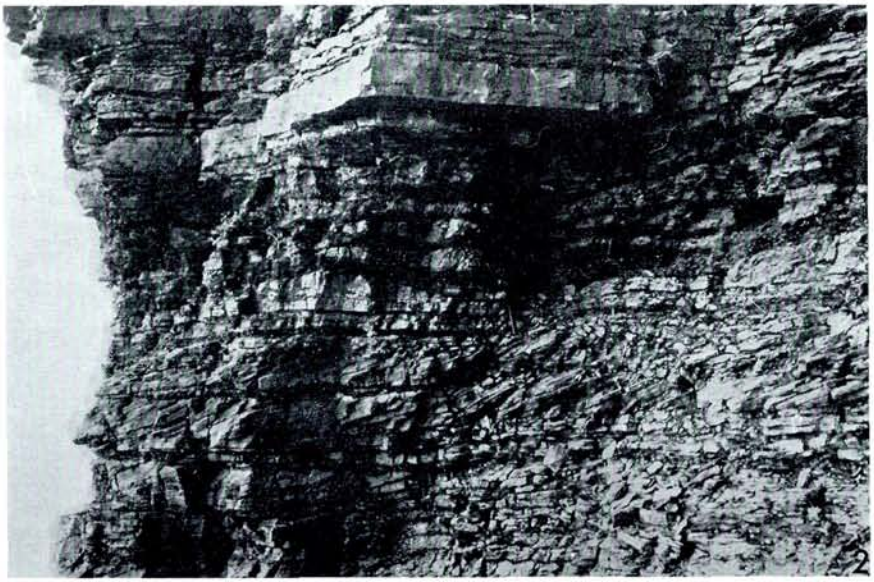


Plate 3

Fig. 1. Large-scale tabular cross-bedding in coarse sandstone (facies 4). Note rippled partings bounding the cross sets.

Fig. 2. Migrating megaripples of facies 4, separated by rippled surfaces and mud partings, followed by alternating coarse sandstones and mudstones of facies 3. Hammer is just discernable in the middle of the picture.

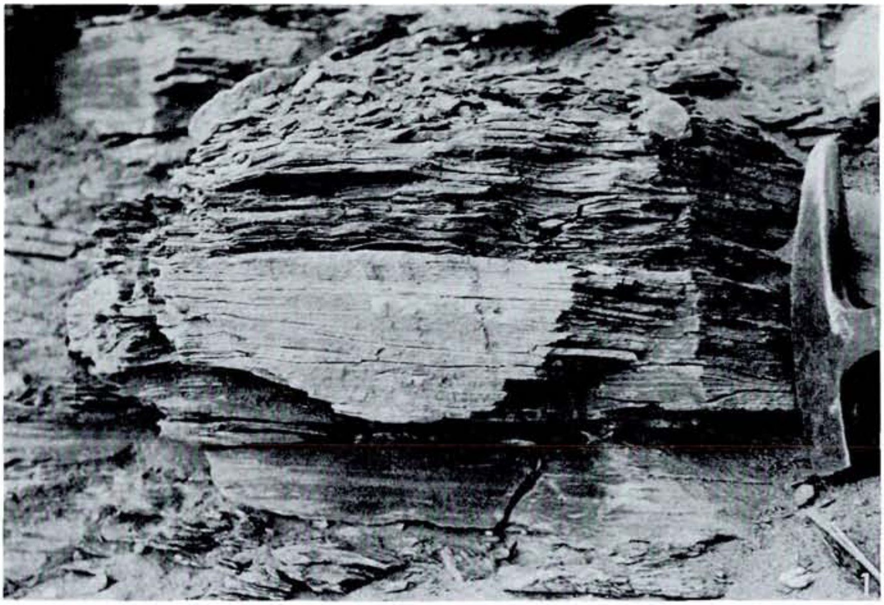


Plate 4

Fig. 1. Parallel and low-angle cross-laminated fine sandstone with some rippling (facies 5). Hammer head is 15 cm long.

Fig. 2. Horizontally bedded facies 1 mudstones overlain by mega cross-sets which pass laterally from facies 4 to facies 3 downdip. Facies 5 and 6 form the upper horizontally bedded unit. Locality – Harris Fjeld. Thickness of sequence about 40 m.