Mid-Miocene progradational barrier island and back-barrier deposits, central Jylland, Denmark

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Abstract

This paper reports on a c. 15 m thick section of marine, coastal sand, that combine a hitherto less described facies sucession transitional to the Miocene fluvio-deltaic and open marine deposits. The section is exposed in a pit located 10 km northeast of the sandy fluvio-deltaic brown coal bearing strata of the Søby-Fasterholt area, known as the Odderup Formation (Middle Miocene). The section comprises more than 6 m of trough cross-stratified, low-angle cross-stratified and parallel-laminated, sand and gravel, deposited on the foreshore and backshore of a barrier island. Locally these deposits are eroded by a steep-sided washover channel with a sandy fill. The overlying back-barrier deposits are up to 9 m thick, and are initiated by a thin bituminous mud bed with a mixture of terrigeneous and marine organic matter. Above, a series of 0.2-2 m thick beds of tangential to sigmoidal cross-stratified sand, often with well preserved topsets, are deposited. These beds are interbedded with ripple-laminated and parallel-laminated sand. Burrows of *Ophiomorpha,* possibly *Skolithos* and *Arenicolithes* occur in the back-barrier deposits and in the top of the washover channel-fill.
The succession of well-preserved coastal facies-belts indicates that the depositional area was characterized by a large sediment supply in combination with a rising sea-level. The section was probably formed fairly rapidly during a coastal progradation more or less contemporaneously with the general transgression that led to the deposition of the brackish-marine Hodde Formation and later the fully marine Gram Formation.

Introduction

Tertiary deposits in Denmark have been studied by several workers, and the investigations have provided a good understanding of the main features of the Tertiary stratigraphy and depositional environments (e.g. Sorgenfrei 1958, Larsen & Dinesen 1959, Rasmussen 1961, 1966, Kristoffersen 1972, Radwanski et al. 1975, Friis 1976, 1978, Heilmann-Clausen 1988, Koch 1989). The Miocene, sandy Ribe and Odderup Formations are interpreted as fluvio-deltaic deposits whereas the Arnum, Hodde and Gram Formations, mainly consisting of mud, are interpreted as marine. The Vejle Fjord Formation consisting of muddy and sandy deposits are interpreted as a prograding barrier island and lagoonal succession. Many details about the spatial distribution of the formations, and the transition between the marine and non-marine depositional units have yet to be resolved.
This paper presents a preliminary interpretation of a section of marine coastal sand exposed in a sand-pit situated 4 km south of Ikast at the Toftlund Møllebakke. Here an erosional remnant of Miocene sand forms a small hill surrounded by Quaternary glacio-fluvial sand and gravel (Fig. 1). The location is only 10 km northeast of the Søby-Fasterholt area with thick brown coal bearing fluvio-deltaic strata of the Odderup Formation (Koch 1989). The deposits in the Toftlund Møllebakke are found in 75 - 91 m a.s.l. which is 15 - 40 m higher than the general topographical level of the Søby-Fasterholt area. As the tectonic dip of the Neogene deposits in the area is close to zero it is suggested that the deposits studied here are relatively younger than the deposits in the Søby Fasterholt area. The locality thus shows a hitherto less described sandy coastal facies, transitional to the sandy fluvio-deltaic deposits and the muddy marine deposits. The paper is an extended version of a presentation given at "Maringeologisk Møde i Århus, 7.-8. oktober 1993" (Nielsen & Nielsen, 1993).

FACIES AND SEDIMENTARY UNITS

The investigated section consists of three sedimentary units that can be traced over a distance of more than 600 m in a northeast-southwest direction (Fig. 1). They are defined by their bounding surfaces, geometry, facies composition and genetic relations, and are subdivided into five sub-units: Unit 1A, foreshore and backshore; Unit 1B, aeolian dunes; Unit 2, washover channel-fill; Unit 3A, bituminous mud; Unit 3B, back barrier sand. They are described in ascending order.

Unit 1A: Foreshore and backshore
Description

Unit 1A consists of a fining upward succession of gravel and coarse to medium-grained sand, that makes up the lower 5.8-6.7 m of the section (Fig. 2, loc. A). The lower part consists of trough cross-stratified sets, 5-10 cm thick and 0.5-1.0 m long, of coarse-grained sand and gravel (Fig. 3). The foreset inclination is dominantly towards the southwest while the set boundaries dip 7-10° to the northeast. Upwards, the foreset dip directions change to a highly variable pattern.
These strata are overlain by a 15-20 cm thick layer of well sorted gravel with a pebble content of c. 5 % representing the coarsest grain size found in the section. The layer shows thick sets of climbing cross-stratification. It has strong yellowish-brown and black colours due to post-depositional precipitation of ferri and mangano-oxides. The sets are 5-15 cm thick and the set-boundaries dip rather steeply, 20-30° to the southwest while the concave-upward foresets dip northeastward. The set boundaries can be traced into the overlying plane laminated sand as they change from steep dip to low angle dip. At the same point the sets thin to 0,5-1,5 cm.
The upper 1.8-2.7 m are dominated by irregular parallel-stratified and low angle cross-stratified, coarse-grained sand and gravel in beds 0.2-0.4 m thick. Subtle internal discordances and small scour-fills occur.

Interpretation

The trough cross-stratified beds were formed by accretion of 3-D dunes moving towards the south-west, driven by strong mostly unidirectional currents. The dipping set-boundaries indicate a high supply of sediment and sufficient vertical accretion space.
The variable dip of the foresets in the overlying trough cross-beds indicate that the current direction changed frequently. The gravelly cross-strata that can be followed up-dip into parallel-laminated layers reflect southwestern progradation of an inclined accretion surface in a powerful depositional regime. The overlying parallel-laminated and low angle cross-stratified gravelly sand is interpreted as deposited during upper plane bed regime.
Unit 1A was thus deposited in a very energetic environment. The sequence of structures is very similar to those found on recent sandy to gravelly coasts and a detailed comparison is possible. The lower trough cross beds were probably formed by wave-generated currents in the "inner rough zone" of Clifton et al. (1971) or the "swash-trough transition zone" described by Davidson-Arnott & Greenwood (1976). The climbing, gravelly cross-strata were formed at the toe of the beach where the surf zone passes into the swash zone; the overlying parallel-stratified sand represents beach lamination formed by the swash-backwash on the berm and at the gently sloping backshore. Unit 1A, therefore, represents a progradation of an inner nearshore zone (c.f. Clifton et al. 1971) with a northwest-southeast orientation facing the sea to the southwest.

Unit 1B: Aeolian dunes
Description

The unit is poorly exposed and the original structures are masked by Quaternary cryoturbation processes that affect minimum 3 m of the section at locality A. It consists of two gently inclined trough-stratified sets of well-sorted, coarse-grained sand, 0.5-0.8 m thick, laterally passing into horizontally laminated sand. Foresets dip to the west and to the east.

Interpretation

Due to the lack of sufficient data the interpretation of the unit is uncertain. The well-sorted sand and the trough shaped and relatively low angle foresets resemble structures produced by aeolian dunes and may have been formed on the backshore of the coast. This interpretation implies a continued progradation of the shore.

Unit 2: Washover channel
Description

In the northern part of the southern pit a 0.5-3.8 m thick channel-unit of well-sorted, medium-grained sand, is exposed for more than 60 m (Fig. 4a). Only the uppermost part is exposed in the northern pit. The channel base shows a relief of 3.3 m with steep sides sloping 10-40°. At the base, scattered pebbles and a patchy silty layer, 1-2 cm thick, occur. The lowermost meter of the unit consists of medium-grained, parallel-laminated or low-angle cross-stratified sand beds, 5-15 cm thick, conformably overlying the erosional base (Fig. 5). The upper part of the channel-fill is characterized by laterally consistent sets, 10-20 cm thick, of parallel laminated sand. Eastward dipping set boundaries downlap on internal erosion surfaces. *Ophiomorpha* burrows, cemented by iron oxides, are abundant in the top part of the channel fill (Fig. 6a). The topmost 5 cm below the overlying bituminous mud bed fines upwards and possess an upward transition from flaser to lenticular bedded heterolithic sand with a slightly bio-mottled appearance (Fig. 6b).

Interpretation

The large relief and the pebbles occurring on the erosional base of the unit show that the process cutting the basal surface was very forceful. The fill was formed during less energetic conditions, but occurred rather quick, and shortly after the erosional event as the steep sides of the channel would have been levelled out during longer term exposure. The sets seem to follow the concave channel base but laterally accreted fill is suggeted by the dipping set boundaries. The internal discordances of the channel-fill, indicate that it was formed by multiple events. The *Ophiomorpha* burrows indicate marine conditions, and were formed before the deposition of unit 3A, because no mud has been transported down from the bituminous mud bed to unit 2 by the organisms. The lack of well developed cross-bedding probably precludes a tidal inlet or a fluvial channel origin. Instead, the unit is interpreted as a storm generated erosion of a barrier island with a subsequent fair-weather fill.

Unit 3A: Bituminous mud
Description

The back barrier sequence (units 3A and 3B) is initiated by a thin layer of bituminous mud that occur at locality B and C overlying unit 2 (Fig. 2). It varies in thickness from 10 cm in the southern pit to 2-4 cm in the northern pit. The boundary to the overlying cross bed of unit 3B is sharp and accentuated by a cemented sand layer, 1 cm thick (Fig. 6b). Where the unit is thickest, the lower 4 cm consist of sticky, bituminous, black clay with plant fragments. The upper 6 cm consist of bituminous mud with sandy lenses. A LECO-ROCK-EVAL combustion analysis from the lower 4 cm indicates a total organic carbon content of c. 25 % and a hydrogen index of 210. The main component is amorphous organic matter, with fragments of brown coal as a minor constituent. It is barren of microfossils and contains few pollen grains and dinoflagellate cysts (pers. com. D. Jutson & N.P. Poulsen). Dry samples are brown and show a very thin lamination.

Interpretation

The unit was deposited in a protected environment that received both mud and organic material. The sandy lenses show that sand was supplied occasionally. Roots have not been seen which suggests that the organic matter is allochtonous. The fairly high hydrocarbon index may suggest a marine origin of some of the organic matter. The unit overlies the channel-fill and may be restricted to the depression of the washover channel. It is thus suggested that unit 3A was deposited in a small pond formed in the residual topographical low of the washower channel on the backside of the barrier island, where organic matter (such as seaweed) accumulated.

Unit 3B: Back barrier sand
Description

This unit is exposed at locality B and C. It is up to 7,5 m thick and comprises cross-bedded and low-angle cross-bedded, medium to coarse-grained sand separated by beds of parallel-laminated and ripple-laminated fine to medium-grained sand (Fig. 2). It is coloured by oxides, especially in the upper 5 m, and the sedimentary features in the upper 2 m are intensely disturbed by Quaternary cryoturbation.
The horizontally-laminated and ripple-laminated sand exhibit weakly developed bedding recognized either by small grain size variations or by patchy lamination of black, organic detritus. The cross-stratified sand beds are mostly 0.2-0.5 m thick. Some show an overall coarsening upward, others are normal graded with tangential to sigmoidal foresets where topsets are preserved. The dip directions are uniform to the northwest or south within a single bed.
One cross-stratified set, with a thickness varying from nearly 2 meters at loc. B to 0.2 m at loc. C make up the lower part of the unit (Fig. 4b). The lower contact of the cross-bed is slightly erosive. The upper limit is arbitrary at loc. B as no distinct surface exists between the topsets and the overlying diffusely laminated sand (Fig. 7). At loc. C the upper surface is plane and erosive. The bed shows an overall fining upwards from coarse to medium-grained sand. The lowermost 0.1 m of the bed shows sub-horizontal lamination which continues upward into foresets with a thickness of 1-7 cm. Systematic variations in foreset thicknesses have not been observed. The foresets dip 20-28° to the south-southwest at loc. B and to the south at loc. C. Foresets are sigmoidal where the topsets are preserved (Fig. 8). Reactivation surfaces occur regularly at intervals of 1.0-3.0 m. The upper half of the bed contains *Ophiomorpha* burrows, c. 10 cm long and 1.0-1.5 cm thick (Fig. 6c).
The upper part of unit 3B contains muddy sand with 0.2-0.3 cm thick and 5 cm long, vertical to sub-vertical burrows that bifurcate and sometimes occur in clusters c. 5 cm wide (Fig. 6d). *Ophiomorpha* burrows, 1.0 - 1.5 cm thick and up to 8 cm long occur together with vertical burrows, up to 8 cm long and 0.4 - 1.0 cm thick, possibly of *Skolithos* or *Arenicolithes*-type.

Interpretation

The cross-bedding was formed by southward and northwestward migrating dunes. The uniform dip directions of the foreset and the well preserved topset indicate that the dunes were relatively straight crested, 0,5 - 2.0 m high. The burrows indicate marine conditions. The sigmoidal foresets and the reactivation surfaces may suggest a tidal origin (Kreisa & Moiola, 1986), but further support is missing. The well preserved topsets and the gradual transition to overlying plane and ripple-laminated sand indicate a large sediment supply. This, and the lack of scours, suggest that the bedforms were protected from direct influence of large waves. The ripple-laminated sand was deposited by small ripples during calm periods or between the larger bedforms. The large difference in thickness of the lower cross-bed may reflect a topographic relief of the depositional area or erosion of the bed. The unit is thus suggested to have been formed behind a barrier island protected from the North Sea waves.

WELL DATA

The regional extension of these marine deposits is not known. However, data from boreholes in the nearby Nørlund Plantage, 2.5 km south of the pit, suggest that the deposits are present here as well.

Conclusions

A barrier-coast environment is suggested for the section studied here. The deposits consist of wave-formed, trough cross-stratified, coarse-grained sand of the inner rough zone, gravel deposited at the beach toe, and parallel-laminated and low angle cross-stratified sand of the swash-backwash zone and the backshore (unit 1A) overlain by aeolian sand (unit 1B). It is erosively overlain by a sandy washover channel-fill (unit 2) formed by a storm induced break-through of the barrier, whereby the dune field and backshore were eroded. The channel-fill is overlain by back-barrier deposits initiated by a thin, bituminous mud bed (unit 3A) deposited in a pond in the residual topographical low of the washover channel on the leeward side of the barrier. The mud is overlain by the back barrier sand with an up to 2.0 m thick cross-stratified bed formed by a bedform migrating south-southwestward. The protected back-barrier environment persisted through the deposition of the overlying ripple-laminated and cross-bedded sand.
The well preserved sedimentary structures indicate that the deposits were formed in an area characterized by a high sediment influx during a period of rising sea-level. The section represents a coastal progradation during a phase of rising sea level. We suggest that it is younger than the brown coal bearing fluvio-deltaic sequence of the upper Odderup Formation in the Søby - Fasterholt area. The section may thus have formed during the general transgression that flooded the deltaic coast, leading to the deposition of the brackish-marine Hodde Formation, and the fully marine Gram Formation.

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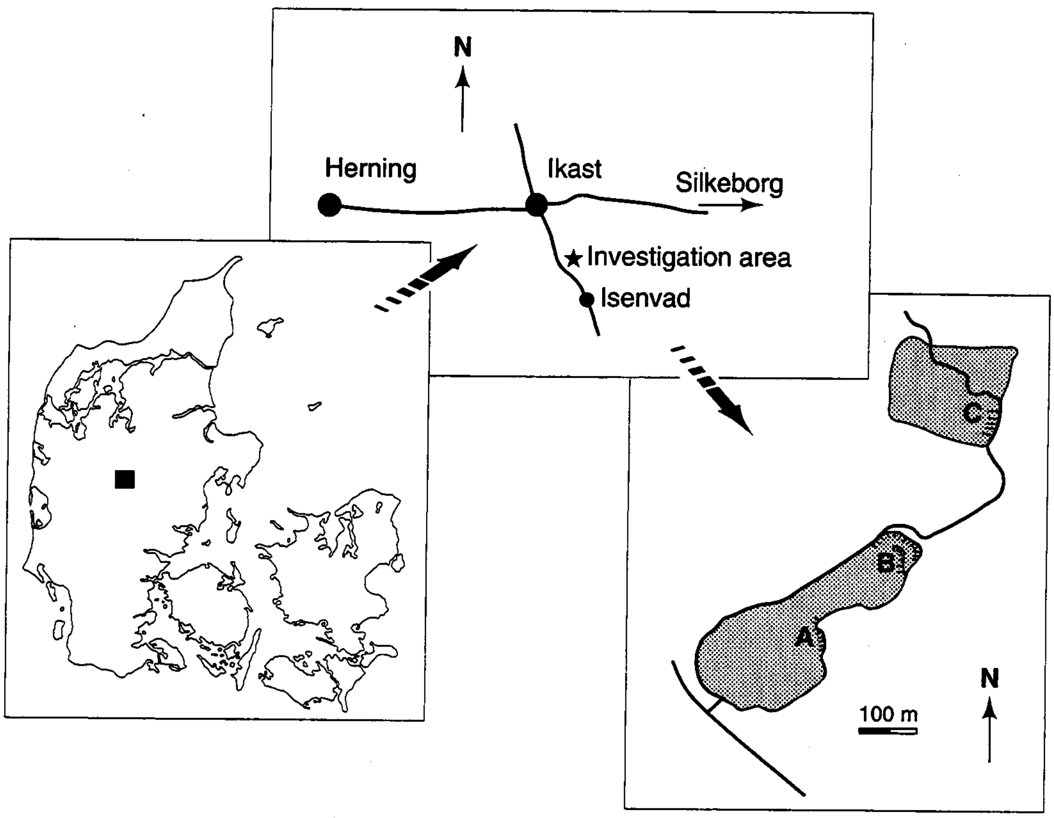

Fig. 1 Location map, localities in the sand pit are indicated by the letters A,B & C.

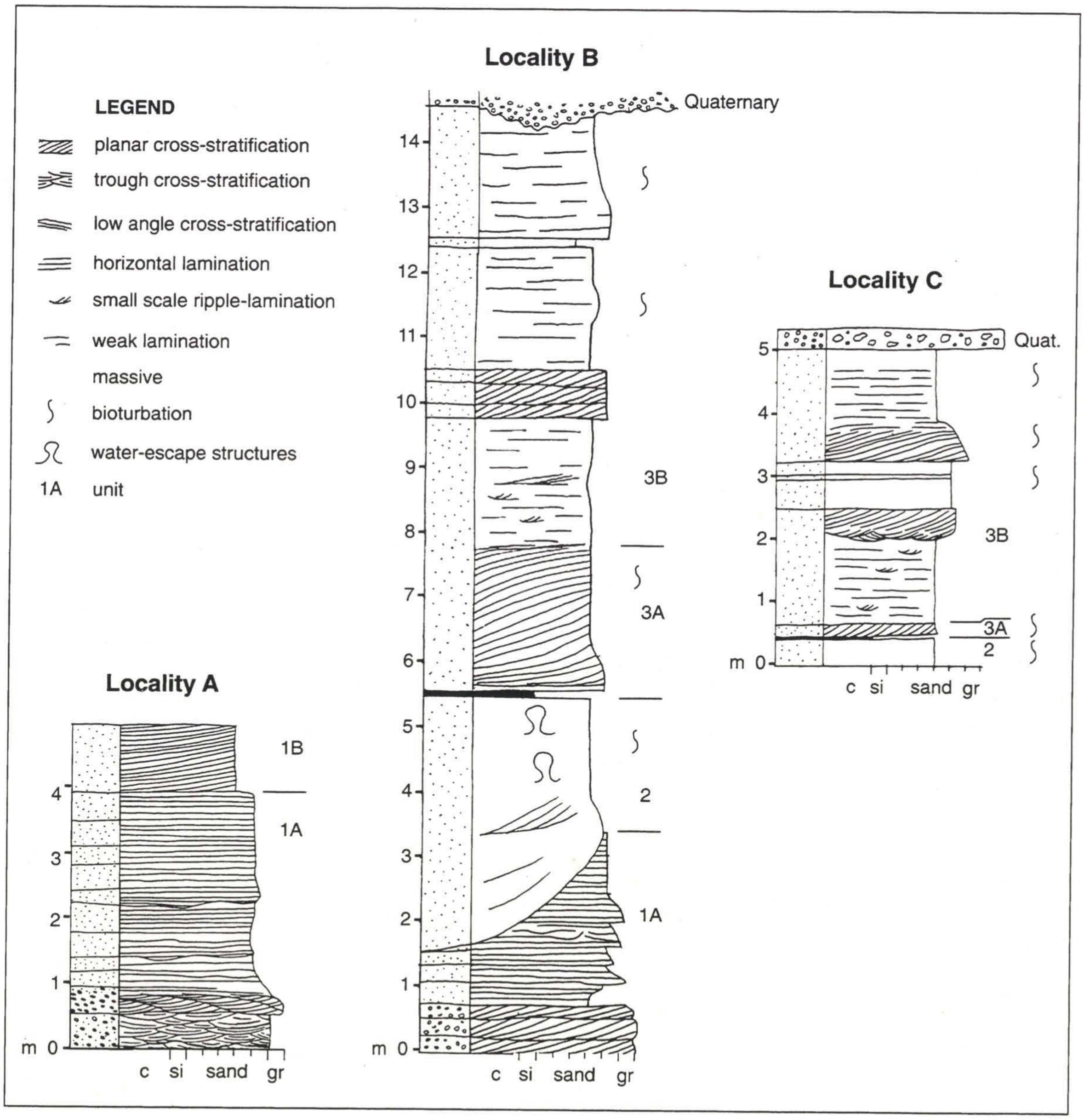

Fig. 2 Sedimentological logs from locality A, B and C.

Fig. 3 Wave-formed trough cross-bedding of the inner rough zone/swash-trough transistion zone, gravelly cross-stratification of the beach toe overlain by plane laminated and low angle cross-stratified sand of the swash-backwash zone and back shore (unit 1A). Northeast to the left. Height of the section shown is 2 m.

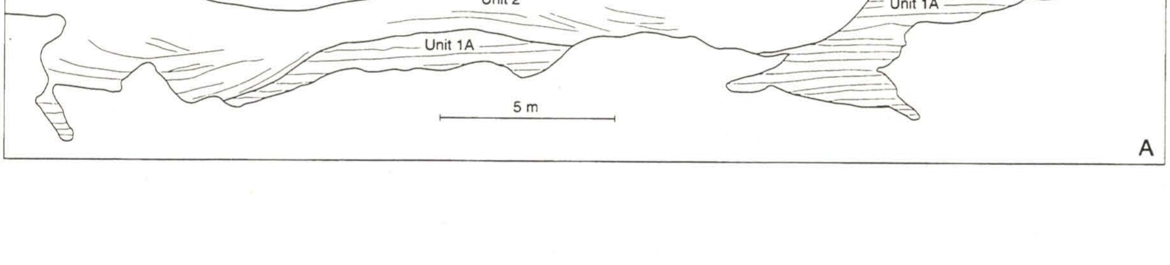

Fig. 4A Line drawing from photo mosaic of the washover channel-fill (unit 2) and underlying plane-laminated sand of unit 1A. Loc. B.

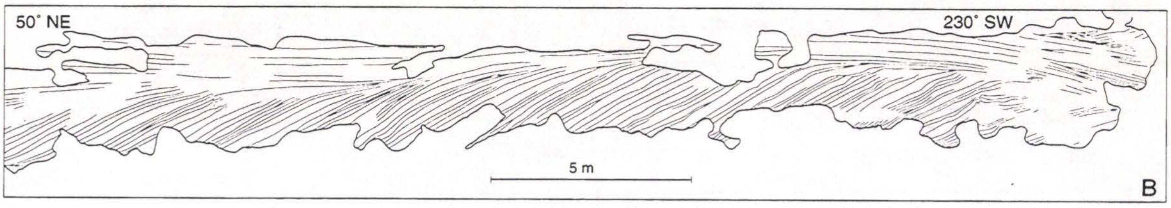

Fig. 4B Line drawing from photo mosaic of the lower cross-bed of unit 3 (Loc. B). Note the tangential to sigmoidal foresets, reactivation-surfaces and the relief of approximately 1 m over a distance of only 10 m (from 29 m to 19 m).

Fig. 5 Oblique photo of the erosional contact between unit 1A and unit 2. The true maximum dip of the surface is 40°. Lamination in the plane-laminated sand is accentuated by heavy minerals. Note irregular stratification in the middle of unit 1A. Bag is 60 cm high. NNW is to the left.

Fig. 6A *Ophiomorpha* burrows cemented by iron-oxides, in the top of the channel-fill.

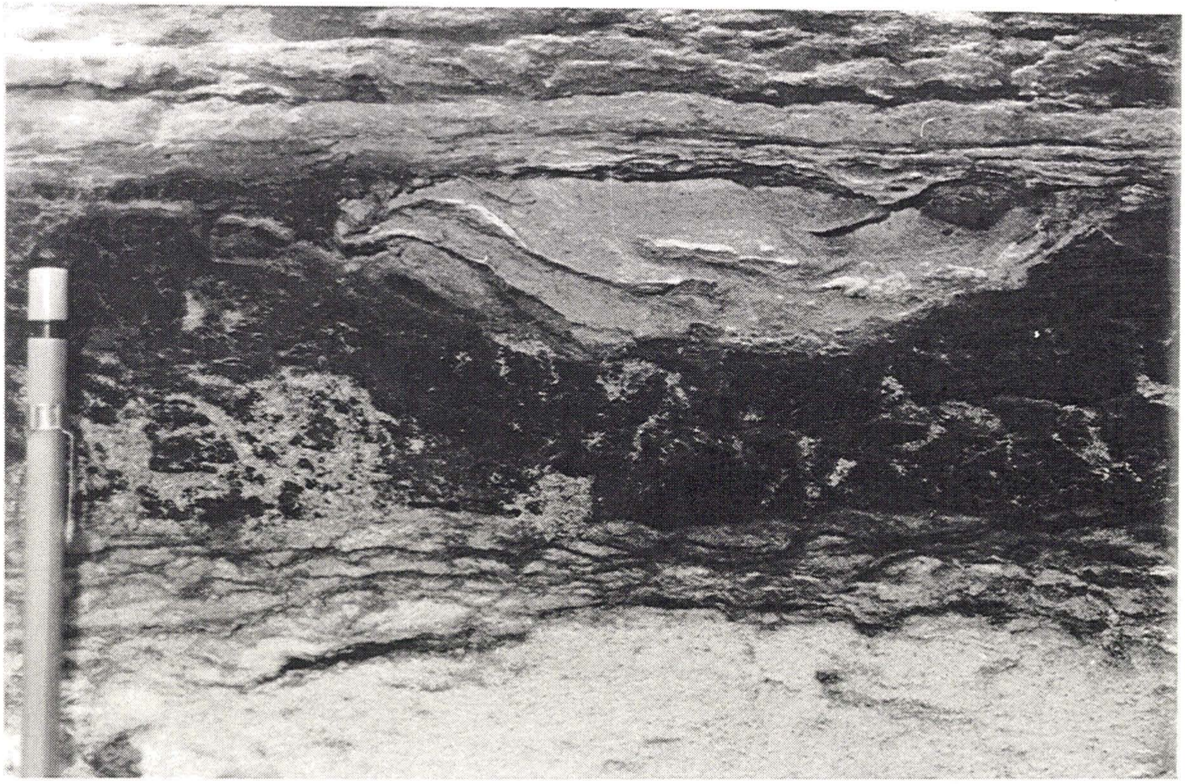

Fig. 6B Bituminous mud bed (Unit 3A, loc. B). The lower boundary is gradual and the upper is sharp to slightly erosive. A sand-filled scour is seen. Note the fining-upward of the underlying unit 2. Photo taken by H.C.S. Hansen.

Fig. 6C *Ophiomorpha* burrows, cemented by ferri-oxides penetrating the foresets of the bedform seen in fig. 9.

Fig. 6D Muddy, bioturbated sand of unit 3B (Loc. B). Vertical 2-3 mm thick burrows occurring solitary or gathered in clusters, and *Ophiomorpha* burrows. Photo taken by H.C.S. Hansen.

Fig. 7 The thick cross-bed in the lower part of unit 3B. Note the well preserved topsets and the toesets to the lower left. Foresets dip south-southwest. Southwest is to the left.