Tertiary fluvial deposits of Jylland, Addit area.

H.C.S. Hansen

Abstract

Sandy fluvial deposits of Tertiary age are described from three sand pits in the Addit area with up to 28 metres high outcrops. The deposits form up to 20 metres thick fining-upwards successions of mainly large-scale tabular cross-sets of medium and coarse sand interpreted as fluvial bars. Individual successions are capped by thinly interbedded sands and silts and occasionally completed with a coal bed. Concave-up bounding surfaces separate the fining-upwards successions. Channel switching, breaks in active channel aggradation, rapid scour- and filling events and chute activity created bounding surfaces described as a 4-tier hierarchy. The palaeocurrents derived from trough foresets suggest that the channel course was straight rather than sinuous. The current directions were generally to the south and southwest.

Introduction

Miocene deposits consisting of interfingering marine and non-marine sands and clays are found throughout mid and southern Jylland in Denmark. They are generally covered by a Quaternary overburden consisting of glacial outwash sands and diamictons. The Miocene deposits were grouped into formations by several authors (Sorgenfrei, 1958; Rasmussen, 1961a, 1961b, 1966; Kristoffersen, 1972). The deposits described in the present study probably belong to the non-marine Middle Miocene Odderup Formation (B.E. Koch, 1993, personal communication). This formation mainly consists of medium to coarse-grained sand with occasional silt, clay and lignite beds. The Odderup Formation was deposited in a fluvio-deltaic environment near Søby and Fasterholt, some 40 km west of the present study area (Rasmussen, 1961; Larsen and Friis, 1973; Friis, 1978; Koch, 1989). Vegetational studies around Fasterholt show (Friis, 1985), that the climate was warm, temperate to subtropical and that the plant communities corresponded to wetland communities of the Atlantic Coastal Plain of North America. Petrographic studies of heavy minerals and the presence of fossiliferous Palaeozoic chert suggest a provenance from the Scandinavian shield to the east and northeast of Denmark (Friis, 1973, 1974). The present study describes the Odderup Formation in three pits along the sides of the Gudenå valley near Addit and Voervadsbro (fig. 1). The Voervadsbro locality was previously interpreted to be of fluvial origin and tentatively referred to the Odderup Formation (Larsen and Friis, 1973; Friis, 1976). The location is only 29 km east-southeast of the locality of Toftlund Møllebakke. The latter locality is interpreted as marine, Middle Miocene sand deposited in the foreshore and backshore of a barrier island (Nielsen & Nielsen, 1993). This paper is an extended version of a presentation given on 8th October 1993 at "Maringeologisk Møde i Århus" (Hansen & Nielsen, 1993).

Facies description and interpretation

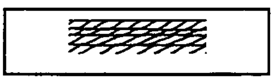
Logs were recorded in the field and later redrawn from photographs of outcrops to provide a photorealistic rendering of facies of a scale of 1:50. Symbols represent structures too small to be recorded naturalistically at 1:50. The description and interpretation of facies follow the well established lithofacies classification of Miall (1977, 1978). This facies classification is subdivided further according to the size and geometry of beds, foreset features, grain-size and coset development (McKee et al., 1953, Bridge, 1993). Bridge (1993) has pointed to the danger of oversimplifying the classification and interpretation of facies through the use of acronyms. To remedy this situation, representative sections of logs have been included in the text to provide both an enhanced legend and a visual link from facies descriptions to logs and outcrop.

Facies Sp: planar cross-bedded sand.

Planar cross-beds are predominant in most of the recorded logs (figs. 2, 4-6). The excellent lateral continuity of this facies group is shown on fig. 7. Sets comprising cosets usually maintain their thickness for some tens of metres normal to the progradation direction. The lower bounding surface eventually becomes concave-up and wedges out against the upper bounding surface of a coset or group of cosets (fig. 7). The bounding surfaces may be parallel throughout sections parallel to bedform progradation within the extent of an outcrop (100 metres). Facies Sp is arranged into three main groups according to set thickness: simple dune bedding less than one metre thick, simple dune bedding from 1 to 2 metres thick and large, composite cosets, 1 to 3 metres thick.

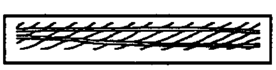
Simple dune bedding less than one m thick:

This facies is divided into three facies based on set geometry and foreset style.



Cosets of tabular cross-bedded, medium-grained sand with steep foresets with angular foreset terminations. Each set is non-erosive. Sets may stack into uniform intervals some 5 metres thick (fig. 4). This facies is interpreted as having formed by 2-dimensional dunes (Harms et al., 1982) migrating under low to intermediate flow-stage in the shallower parts of a river channel. They may be similar to transverse bedforms described by Smith, 1971.

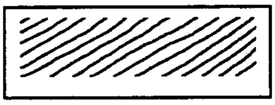
Tabular cosets composed of groups of planar, wedge-shaped sets. The individual sets are angular to tangential cross-bedded with occasional deformed foresets and composed of medium to coarse-grained sand. Set bases may be erosional in places. This facies may be associated with intervals of near-massive sand, e.g. at 2 metres on fig. 4. During high stage a high traction-transported sediment load may induce a shear stress on the bedform thereby causing it to deform (McKee et al. 1962a, 1962b, Allen & Banks, 1972). High sediment concentrations are expected in the deeper parts of a river channel during rising stage as a result of increasing competence of the river to transport sediment (McKee et al, 1967). The supply of sediment is often augmented by sediment released by riverbank collapse during rising stage. Banks tend to become unstable during rising stage because of river scouring in combination with an increased weight and decreased shear strength of bank material due to absorption of water (Laury, 1971; Wells et al. 1993). The sets are therefore interpreted as formed by 2-dimensional dunes migrating under high flow stage in the deeper part of a river channel.



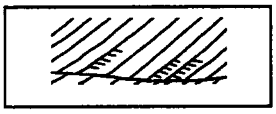
Tabular cosets of tapering sets of angular cross-bedded, medium to coarse-grained sand with distinct, massive bottomsets. Interpreted as 2-dimensional dunes transitory to 3-dimensional dunes migrating under high river flow stage promoting a high rate of suspended load versus bedload in the deeper parts of a river channel (Harms et al. 1982).

Simple dune bedding from 1 to 2 metres thick :

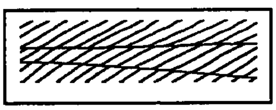
This facies is subdivided into three facies according to set geometry and the presence or absence of backflow ripples. The sets may combine to form cosets which share a constant, total thickness although some sets may increase in thickness at the expense of others. Fig. 6 and 8 show 2nd order bounding surfaces of this nature.



Tabular sets of angular cross-bedded, fine, medium or coarse sand. Interpreted as formed by 2-dimensional, simple bars migrating slowly under low to intermediate flow stage conditions in deeper parts of a river channel.



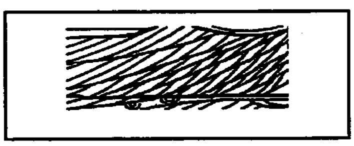
Tabular sets of angular cross-bedded, medium or coarse sand with occasional backflow ripples climbing up the lower third of the foresets. The base is often erosive. Interpreted as formed by 2-dimensional, simple bars migrating under intermediate to high stage, stable flow conditions in deeper parts of a river channel. Thicker sets are seen in the bottom half of fig. 6, thinner sets higher up in the succession.



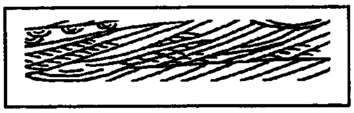
Tabular cosets composed of wedge-shaped, angular cross-bedded sets of medium sand. Interpreted as formed by 2-dimensional bars transitory to 3-dimensional bars. The bars were migrating slowly with downstream bars being frequently eroded by upstream bars. This facies was probably deposited in a shallower part of the channel than the above two facies and therefore subject to more varying flow conditions (fig.5, at 5-7 metres).

Large, composite cosets, 1 to 3 metres thick :

This facies is subdivided into two facies according to the geometry of the sets forming the cosets.



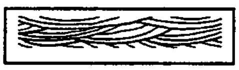
Tabular cosets constructed of wedge-shaped sets of medium to coarse sand building down large, low-angle concave-up foresets. Often with erosive top and base. Interpreted as formed by the migration of 3-dimensional bars. The large thickness of the bars is a result of their migration into the deeper parts of a channel under intermediate to high flow stage conditions. The partial erosion of the bar crest and front and the many reactivation surfaces are interpreted as a result of the 3-dimensionality of the bedform rather than numerous flow-stage variations (fig.6).



Tabular cosets made of cross-bedded sets with angular foreset terminations or foresets with asymptotic terminations. Numerous ripples are seen on the lower half of foresets and rarely on the upper half. They are interpreted as having formed by strong eddy currents in the lee of the bedform (Simons et al. 1965). Reactivation surfaces are found occasionally. Ripple lamination in the top half of cosets may display current directions normal to the direction of progradation of the large foresets. The base is strongly erosive with tangential-based foresets grading into bottomsets, that are occasionally deposited in cut- and fill structures. Interpreted as formed by the migration of 2-dimensional bars into shallower water than the above facies giving rise to strong separation eddies and cross-current phenomena in the lee side of a transverse bar (fig. 6).

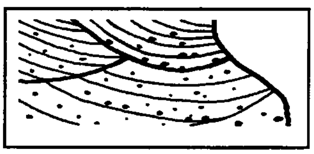
Facies St: trough cross-bedded sand.
This facies is subdivided into four facies according to the grain-size and scale of the sets. The large scale St facies are found close above the deeper parts of concave-upwards 2nd order bounding surfaces (figs 2, 4 and 5). The small scale St facies occur in a somewhat higher position (fig.2 at 17 metres, fig. 5 at 14 metres).

Small scale trough cross-bedded sand, fine-grained, occasionally medium to coarse sand. Interpreted as formed by the migration of 3-dimensional ripples in deeper parts of the river channel under high flow stage.



Medium scale trough cross-bedded medium to coarse-grained sand. Interpreted as formed by the migration of strongly 3-dimensional dunes under high flow stage in the deeper parts of river channels.

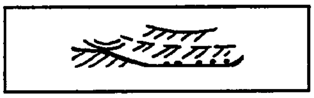
Large scale trough cross-bedded medium and coarse sand with granule and pebble lags in troughs. Interpreted as formed by the migration of strongly 3-dimensional dunes under very high flow stage in the deepest parts of river channels.



Large to giant scale trough cross-bedded coarse-grained pebbly sand fining to medium-grained sand. Interpreted as formed by the migration of strongly 3-dimensional dunes under very high and waning flow stages in the deepest parts of river channels.

Facies Ss : scour-fill sand.
This facies is subdivided into three facies according to grain-size, bed geometry., the nature and conspicuousness of laminae.

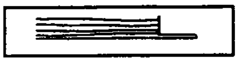
Medium to coarse, pebbly sand bedded conformably to the bottom and sides of scours several metres wide. Eroded into the top of simple, 2-dimensional bars. Interpreted as formed by chutes eroding into the top of bars situated in topographically high positions within the river channel. Chutes filled during waning flow stage (fig. 2 at 19 metres, fig. 5 at 13 metres) (McGowen and Garner, 1970).



Medium and coarse-grained sand, partly vaguely ripple laminated and partly massive, with decimeter-wide cut- and fill structures and granule lags at the base. This facies fills several meter wide, shallow scours. It is interpreted as having formed as a result of relatively rapid deposition during high flow stage in the deeper parts of the river channel (fig. 6 at 1 meter).

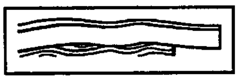
Diffusely laminated to massive, medium to coarse sand displaying shallow scour- and fill structures and deposited in 5 - 10 m wide channel features. This facies may be found immediately above a 1st order bounding surface (fig. 4 at 1 meter). It is interpreted as having formed during very high stage as a result of erosion and rapid deposition in the deepest part of the river channel.

Facies Sh : plane-bedded sand.



Plane-bed laminated, medium-grained sand with coarse sand and granules at the base (fig. 6 at 6 metres). This facies may form the top of cosets otherwise consisting of large scale Sp facies. They are grouped by 2nd order bounding surfaces. This facies is interpreted as having formed on the top of bars during a large increase in current velocity. This increase created the lag and the plane bedded facies was deposited subsequently during slightly waning flow.

Facies Sm : massive sand.

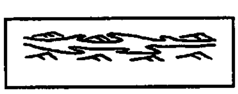


Sand, massive. Drapes existing topography, which may be erosive. Interpreted as having formed during rapid stage variations in parts of the river channel carrying a high sediment load or due to rapid deposition of surplus sediment load following a collapse of the river bank (fig. 2 at 12, 14 and 18 metres).

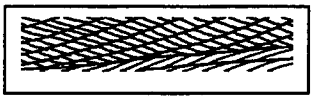
Facies Sr: ripple cross-laminated sand.

This facies is subdivided into three facies according to grain-size, the presence of interbeds of draped lamination, convoluted bedding or climbing ripple lamination. It is predominant in the upper part of fining upwards successions (fig. 4 at 12-16 metres).

Rippled sand, fine to medium, rarely coarse-grained, interbedded with thin drapes of massive sand. Interpreted as deposited by relatively slow moving water in a very shallow part of the river channel, e.g. during the formation of passive channel fill in a partly abandoned river channel.



Rippled sand, fine to medium-grained, interbedded with layers of massive, convoluted sand. Interpreted as passive channel fill that formed due to an alternation of relatively slow moving water in a shallow part of the river channel and sediment saturated pulses of water flowing into this partly abandoned river channel. The subsequent deposits of clays, silts and muds on top of this facies retarded the expelling of pore water. High pore water pressures led to convolution of the massive interbeds of sand.



Sand, medium to coarse, climbing ripple laminated. The base is erosive. Interpreted as having formed during intermediate to high stage as a result of rapid sediment deposition in depressions between large bars in the deeper parts of the river channel.

Architecture of the deposits

To fully understand the deposits, it is necessary to first consider the organization of the succession i.e. the architecture of the deposits. A hierarchy of four orders of bounding surfaces has been interpreted on figs. 2-7 according to their relative position and the hierarchy of their mutual intersection. The bounding surfaces have been described and interpreted as follows:

1st order : Low-curvature bounding surface, defining a '50 metres plus' channel width. This surface forms the base of a 10-20 metres thick fining-upwards succession. Interpreted to record channel switching. See figs. 3-6.

2nd order : Low-curvature bounding surface , defining a '50 metres plus' channel width. This surface forms the base of 2-5 metres thick successions, which may be fining upwards. Interpreted to record stages in active channel aggradation brought about by lateral movement of the channel on a more frequent basis than the 1st order surface.

3rd order : High-curvature bounding surface, defining a 5-10 metres scour/channel width. Position: lower part of a fining-upwards succession. Interpreted to record rapid scour and fill events within the lowest level of a channel during high stage flow. See figs. 5 and 7.

4th order : High-curvature bounding surface, defining 5-10 metres scour/channel width. Position: middle to upper part of a fining-upwards succession. Interpreted to record rising stage chute activity or the dissection of large bars during falling stage. See figs. 5 and 7.

Paleocurrents

Paleocurrents have been measured in outcrop on unconsolidated sediments. Trough axes and foreset dip directions are plotted on fig. 10. Separate plots were made for each of the three localities and facies groups.
Large scale Sp facies is dominant in the Sønder Vissing Sand (A) locality. The foreset dip azimuths towards the south-southeast are very consistent with a low spread (fig. 6). No St facies were available for measurement.
The Silkeborg Kvartssand (B) locality is divided into many sediment packets separated by bounding surfaces (fig. 7). Trough axis dip directions towards 210-230 degrees were measured on St facies immediately above the presumably central, planar part of the lower 1st order bounding surface shown on fig. 9. In contrast to this, directions towards 150-180 degrees were measured in large scale St facies above the slightly concave, upper 1st order bounding surface (fig. 5 and 9). It may be assumed, that the measurements above the lower 1st order bounding surface is more central to a channel axis than the measurements above the sloping, upper 1st order bounding surface and should yield a better

estimate of channel axis direction. The large scale Sp facies yield foreset azimuths towards the southeast (fig. 5) and south-southwest (fig. 2) respectively for the same two intervals. There is a tendency for the Sp foreset azimuths to diverge some 60 degrees from St trough axes dip directions measured above the same 1st order bounding surface.
At the Voervadsbro (C) locality a single, large trough axis yielded 202 degrees dip direction immediately above a more than 100 m wide 1st order bounding surface. Abundant large scale Sp facies showed consistent progradation directions towards the west and southwest (fig. 4). Accordingly, the same tendency of diverging St and Sp foreset dip directions is seen both at locality B and C.
It can be concluded, that the paleocurrent measurements are consistent between locality C and the lower 1st order succession in locality B. The difference in measurements between the upper and lower 1st order successions in locality B confirm the distinction between stacked 1st order successions.
The consistent difference in foreset dip directions between St and Sp facies support the interpretation of a type of river with complex bar forms, cross-channel bars, which may migrate at an angle to the river trend as described from the South Saskatchewan by Cant and Walker (1978) and from the Brahmaputra by Coleman (1969) and Bristow (1987).

Facies associations

One fining upwards succession has been identified in pit C (fig. 4) and three, stacked, 10 to 20 metres thick, fining-upwards facies successions have been identified in pit "B" (fig. 9). Two incomplete successions were identified on the basis of an analysis of the hierarchy of bounding surfaces in outcrop (fig. 7) and the trend of facies transitions from large scale to small scale structures and from large scale, sandy, gravelly St facies via small scale Sp facies to sandy, silty Sr facies (fig. 2 at 12 metres). A third, 15 metres thick succession was identified immediately below these in a borehole (fig. 3) on the basis of a fining upwards trend from coarse sand to silt and clay with roots (fig. 3). The facies associations comprising these successions are described and interpreted below.

A. Massive and weakly laminated sand association

A typical succession may start with a several metres thick set of massive to weakly laminated, medium to coarse-grained sand immediately overlying the first order bounding surface. The massive aspect is interpreted to be the result of a very high rate of deposition. Deformed and transported megaripple sets are interpreted as caused by shear exerted by high sediment loads, perhaps induced by bank collapse (McKee et al., 1962a, 1962b, Allen and Banks, 1972; Wells et al., 1993). Large scour and fill structures (on bounding surface # 3) are due to erosion in the lowest part of a channel during high stage.

B. Tabular sand association

Large tabular sets occur on top of or laterally to facies association A, and constitute most of the active channel fill. The sets are 1 to 3 metres thick and are often capped by several, smaller sets. Sp facies are dominant with large scale St facies occurring at the base of fining-upwards successions. This structure represents sinuous crested dunes (Harms et al., 1982). Backflow ripples up to 10 cm thick are commonly associated with solitary, large scale Sp facies. Backflow ripples were formed by strong separation currents developed in front of the large bar slipfaces (Jopling, 1965, Boersma et al., 1968). Palaeocurrent measurements show that some of the ripples migrated at right angles to the progradation direction of the Sp facies foresets indicating that flow was diverted around bars. These facies are grouped into 2-5 metres thick, fining-upwards successions and separated by second order bounding surfaces. The Sp facies association is interpreted to represent straight to sinuous crested bars. The migration of the bars was frequently interrupted by flow stage variations as shown by numerous reactivation surfaces and the almost complete erosion of bars in places (fig. 8). The bars were capped by megaripples. The bars migrated oblique to the channel trend as defined by St facies progradation directions. The migration of slip faces of bar complexes obliquely to channel trend was documented by Coleman (1969) and Bristow (1987) from the braided reach of the Brahmaputra, Smith (1970, 1971) from the Platte River and Cant and Walker (1978) from the South Saskatchewan River.

C. Rippled and draped sand, clay and coal association

The top of the fining-upwards succession is formed by 1-2 metres of cosets of fine to medium-grained, rippled sand interbedded with thin drapes of massive, fine-grained sand and grading up into silty sand, silt and a metre of clay, occasionally with coal. The clay in the borehole contained roots in the clay interval (fig.3). The facies association is interpreted as a vertical-accretion deposit passing gradually into floodplain clays and swamp coals. Similar deposits are described from the Mississippi by Farrell (1987).

Depositional environments

The complete fining-upwards succession within associations A+B is interpreted to represent the establishment of a fluvial channel in a new position on the floodplain, thereby eroding 10-20 metres into the previous, mainly sandy succession and obliterating the overbank silt, clay and coal deposits. The slight decrease in set thickness and grain size upwards within associations A+B is interpreted to be due to the gradual infilling of an active channel. The topmost, fine-grained facies association C is interpreted as passive channel fill or overbank deposits, occasionally punctuated by pulses of sand deposited in massive, later convoluted, beds. The 1st order and 2nd order bounding surfaces (fig. 9) are interpreted as the result of channel switching on different time scales resulting in a nesting of channels within channels as described by Bristow (1987) from the Brahmaputra. According to Bristow, the movement of his 1st order channels, which encompass the entire river, determines the geometry of the entire sand body, whereas the movement of 2nd and 3rd order channels rework any structures left by 1st order channel movements and determines the internal structure of the preserved sand body. First order channel movements are by avulsion. Second order channels migrate laterally and third order channels dissect bars during falling stage and are subject to sudden and irregular switching. If an analogy is drawn to the present study area, the 1st and 2nd order bounding surfaces would probably correspond to the 2nd and 3rd order channels of the Brahmaputra. The 2nd order channels form 40 m thick sand bodies in the Brahmaputra. This corresponds to the 20 metres thick fining upwards succession deposited on a 1st order bounding surface in the present study area.

Conclusions

The following conclusions are based on both the geometry of bounding surfaces and the facies :

1. The dominance of sandy, active channel fill over passive channel fill and the confinement of possible lateral accretion surfaces to fronts of large, composite bars suggest that this succession does not represent a meandering river.

2. The uniform azimuth directions of trough sets towards the south and southwest indicate that the channel course was straight rather than sinuous. The azimuth directions may vary, if a different 1st order sand body is considered.

3. The foreset dip directions of tabular sets interpreted as 2-D and 3-D bars are often at a steep angle to the azimuths of immediately associated trough sets, indicating that bars migrated at an angle to the general direction of the river.

4. A possible interpretation of river style would be that of a very slightly sinuous river with bars migrating across the river channel in the style of lateral bars. Such fluvial systems are typical of the upper delta plain suggesting that the fluvial system described here might be related to a deltaic system to the south or west, where it was described by previous authors (Sorgenfrei, 1958; Rasmussen, 1961a, 1961b; Koch, 1989).

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References

Allen, J.R.L & Banks, N.L., 1972 : An interpretation and analysis of recumbent-folded deformed cross-bedding. Sedimentology, 19, p. 257-283.

Bluck, B. J., 1980 : Structure, generation and preservation of upward fining, braided stream cycles in the Old Red Sandstone of Scotland. Trans R. Soc. Edinburgh, v. 71, p. 29-46.

Boersma, J. R., Van de Meene, E. A. and Tjalsma, R.C., 1968 : Intricated Cross-Stratification due to interactions of a Mega Ripple with its Lee-Side System of Backflow Ripples (Upper Point Bar Deposits, Lower Rhine). Sedimentology, 11, p. 147-162.

Boothroyd, Jon C. and Ashley, Gail M., 1975 : Process, Bar Morphology, and Sedimentary Structures on Braided Outwash Fans, Northeastern Gulf of Alaska; in A.V. Jopling and B.C. McDonald, eds., Glaciofluvial and Glaciolacustrine Sedimentation: Soc. Econ. Paleont. Mineral. Spec. Pub. 23, p. 193-222.

Bristow, C.S., 1987 : Brahmaputra River: channel migration and deposition. In: F.G. Ethridge, R.M. Flores and M.D. Harvey (Editors), Recent Developments in Fluvial Sedimentology. Soc. Econ. Paleont. Mineral. Spec. Pub. 39, p.63-74.

Cant, D.J. and Walker, R.G., 1978 : Fluvial processes and facies sequences in the sandy braided South Saskatchewan River, Canada. Sedimentology, 25, p. 625-648.

Coleman, J.M., 1969 : Brahmaputra River, channel processes and sedimentation. Sedimentary Geology, v. 3, p.131-239.

Collinson, J.D., 1970 : Bedforms of the Tana River, Norway. Geogr. Ann. 52A, 31-56.

Farrell, K.M., 1987 : Sedimentology and facies architecture of overbank deposits of the Mississippi River, False River region, Louisiana. In: F.G. Ethridge, R.M. Flores and M.D. Harvey (Editors), Recent Developments in Fluvial Sedimentology. Soc. Econ. Paleont. Mineral. Spec. Pub. 39, p.111-120..

Friis, E. M., 1985 : Angiosperm Fruits and Seeds from the Middle Miocene of Jutland (Denmark). Det Kongelige Danske Videnskaberne Selskab Biologiske Skrifter. 24:3, 102 pp.

Friis, H., 1973 : Om silicifikater i danske ung-Tertiære aflejringer. Dansk Geol. Foren. Årsskrift for 1972. p.85-86..

Friis, H., 1974 : Weathered heavy-mineral associations from the Young-Tertiary deposits of Jutland, Denmark. Sedimentary Geology, v.12, p.199-213.

Friis, H., 1976 : Weathering of a Neogene fluviatile fining-upwards sequence at Voervadsbro, Denmark. Bull. Geol. Soc. Denmark, v. 25, p.99-105.

Friis, H., 1978 : Heavy mineral variability in Miocene marine sediments in Denmark: a combined effect of weathering and reworking. Sedim. Geol., v.21, p.169-188.

Hansen, H.C. Steen and Nielsen, Lars H., 1993 : Tertiary Fluvial Deposits of Jylland, Addit area. In: Abstract Volume, Maringeologisk Møde: Nordsøens og Skagerraks geologi. Geologisk Institut, Århus Universitet, 7.-8. oktober 1993.

Harms, J.C., Southard, J.B. and Walker, R.G., 1982 : Structures and Sequences in Clastic Rocks : Soc. of Econ. Paleo and Mineral. Short Course No. 9, 249 pp.

Haszeldine, R.S., 1983 : Fluvial bars reconstructed from a deep, straight channel, Upper Carboniferous coalfield of northeast England. Journal of Sedimentary Petrology, v. 53, p. 1233-1248.

Laury, R.L., 1971 : Stream Bank Failure and Rotational Slumping: Preservation and Significance in the Geological Record. Geological Society of America Bulletin, v. 82, p. 1251-1266.

Jopling, A.V., 1965 : Hydraulic factors controlling the shape of laminae in laboratory deltas. Journal of Sedimentary Petrology, v. 35, p. 777-791.

Koch, B.E., 1989 : Geology of the Søby-Fasterholt area. Danm. Geol. Unders. Ser. A, 22. 167 pp.

Kristoffersen, F. N., 1972 : Foraminiferzonering i det jyske Miocæn. Dansk Geol. Foren. Årsskrift for 1971. p.79-85.

Larsen, G. & Friis, H., 1973 : Sedimentologiske undersøgelser af det jyske ung-Tertiær. Dansk Geol. Foren. Årsskrift for 1972. p.119-128.

McGowen, J.H. and Garner, L.E., 1970 : Physiographic features and stratification types in coarse-grained point bars : modern and ancient examples. Sedimentology, v.14, p.77-111.

McKee, E.D. and Weir, G.W., 1953 : Terminology for stratification and cross-stratification of sedimentary rocks. Bull. Geol. Soc. Am., 64, 381-390.

McKee, E.D., Reynolds, M.A. and Baker, C.H., 1962a. Laboratory studies on deformation in unconsolidated sediment. U.S. Geol. Surv., Profess. Pap.,450D, p.151-155.

McKee, E.D., Reynolds, M.A. and Baker, C.H., 1962b. Experiments on intraformational recumbent folds in cross-bedded sand. U.S. Geol. Surv., Profess. Pap.,450D, p.155-160.

McKee, E.D.,Crosby, E.J. and Berryhill, Jr., 1967 : Flood Deposits, Bijou Creek, Colorado, June 1965. Journal of Sedimentary Petrology, v. 37, p. 829-851.

Miall, A.D., 1977 : A Review of the Braided-River Depositional Environment. Earth Sci. Rev., v.13, p.1-62.

Miall, A.D., 1978, ed., Fluvial Sedimentology : Calgary, Canadian Society of Petroleum Geologists, Memoir 5, 859 pp.

Miall, A.D., 1985 : Architectural-Element Analysis: A new Method of Facies Analysis applied to Fluvial Deposits, in : Flores, R.M., Ethridge, F.G., Miall, A.D., Galloway, W.E. & Fouch, T.D., eds., Recognition of Fluvial Depositional Systems and their Resource Potential. Soc. Econ. Paleo and Mineral. Short Course No. 19, p. 33-81.

Nielsen, Søren A.V. and Nielsen, Lars H., 1993 : A Mid-Miocene progradational, sandy barrier island and backbarrier section, central Jylland, Denmark. Geological Survey of Denmark, Ser. C. "in press."

Rasmussen, L.B., 1961a : De miocæne Formationer i Danmark. Danm. Geol. Unders. IV.rk., 4, p.1-45.

Rasmussen, L.B., 1961b : Mittel- und Ober-Miozän von Dänemark. Meyniana, 10, p.59-62.

Rasmussen, L.B., 1966 : Molluscan Faunas and Biostratigraphy of the Marine Younger Miocene Formations in Denmark. Part I: Geology and Biostratigraphy. Danm. Geol. Unders. II.rk.,88, p.1-358.

Simons, D.B., Richardson, E.V. and Nordin, C.F., 1965 : Sedimentary Structures generated by flow in alluvial channels. In: Middleton, G.V., ed., Primary sedimentary structures and their hydrodynamic interpretation. Soc. Econ. Paleo and Mineral., Spec. Publ. 12, 34-52.

Smith, Norman D., 1970 : The Braided Stream Depositional Environment: Comparison of the Platte River with Some Silurian Clastic Rocks, North-Central Appalachians. Geological Society of America Bulletin, v. 81, p. 2993-3014.

Smith, Norman D., 1971 : Transverse Bars and Braiding in the Lower Platte River, Nebraska. Geological Society of America Bulletin, v. 82, p. 3407-3420.

Smith, Norman D., 1972 : Some Sedimentological Aspects of Planar Cross-Stratification in a Sandy Braided River. Journal of Sedimentary Petrology, v. 42, p. 624-634.

Sorgenfrei, T., 1958 : Molluscan assemblages from the marine Middle Miocene of South Jutland and their environments. Dan. Geol. Unders., rk. 2, 79, 503 pp.

Wells, N.A, Richards, S.S., Peng, S., Keattch, S.E., Hudson, J.A. and Copsey, C.J., 1993 : Fluvial processes and recumbently folded crossbeds in the Pennsylvanian Sharon Conglomerate in Summit County, Ohio, U.S.A. Sedimentary Geology, v. 85, p. 63-83.

Williams, G.E., 1966 : Planar Cross-Stratification formed by the Lateral Migration of Shallow Streams. Journal of Sedimentary Petrology, v. 36, p. 742-746.

Williams, G.E., 1971 : Flood Deposits of the Sand-Bed Ephemeral Streams of Central Australia. Sedimentology, v. 17, p. 1-40.

Williams, Peter F. and Rust, Brian R., 1969 : The Sedimentology of a Braided River. Journal of Sedimentary Petrology, v. 39, p. 649-679.

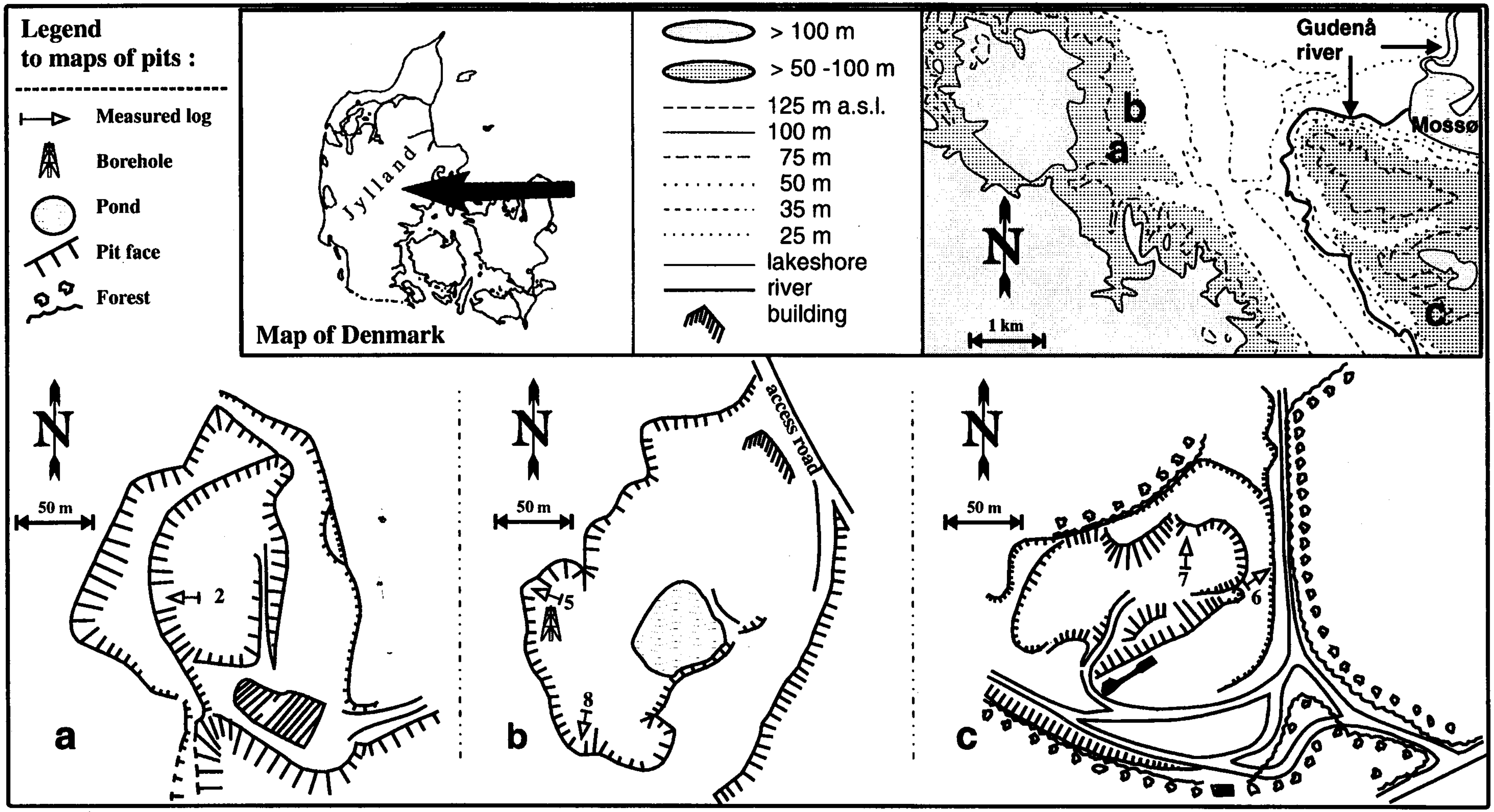


Fig.1 : Maps of quartz-sand pits in the the Addit - Voervadsbro area in central Jylland :
a: Sønder Vissing Sand A/S; b: Silkeborg Kvartssand A/S; c: pit north of Voervadsbro.

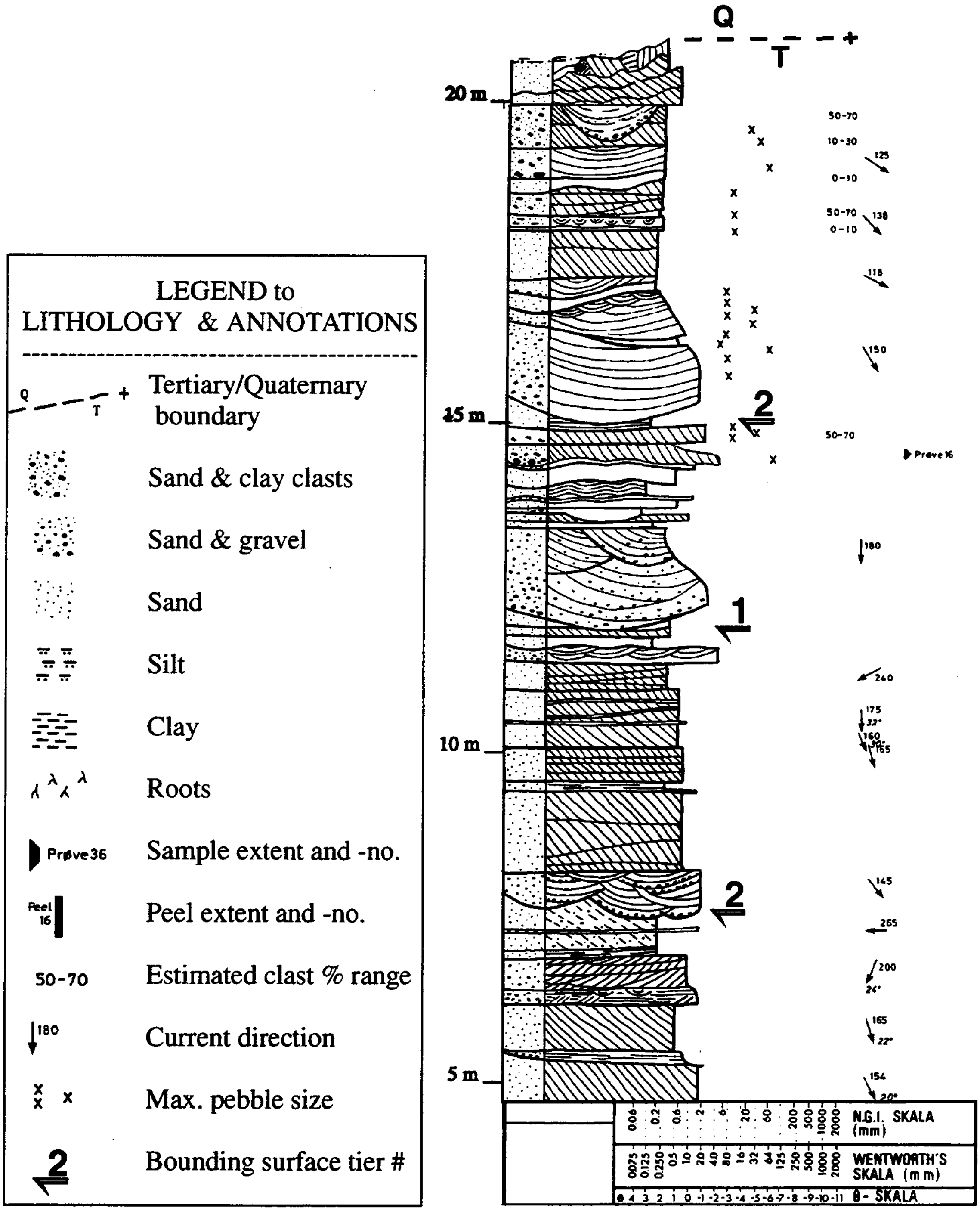
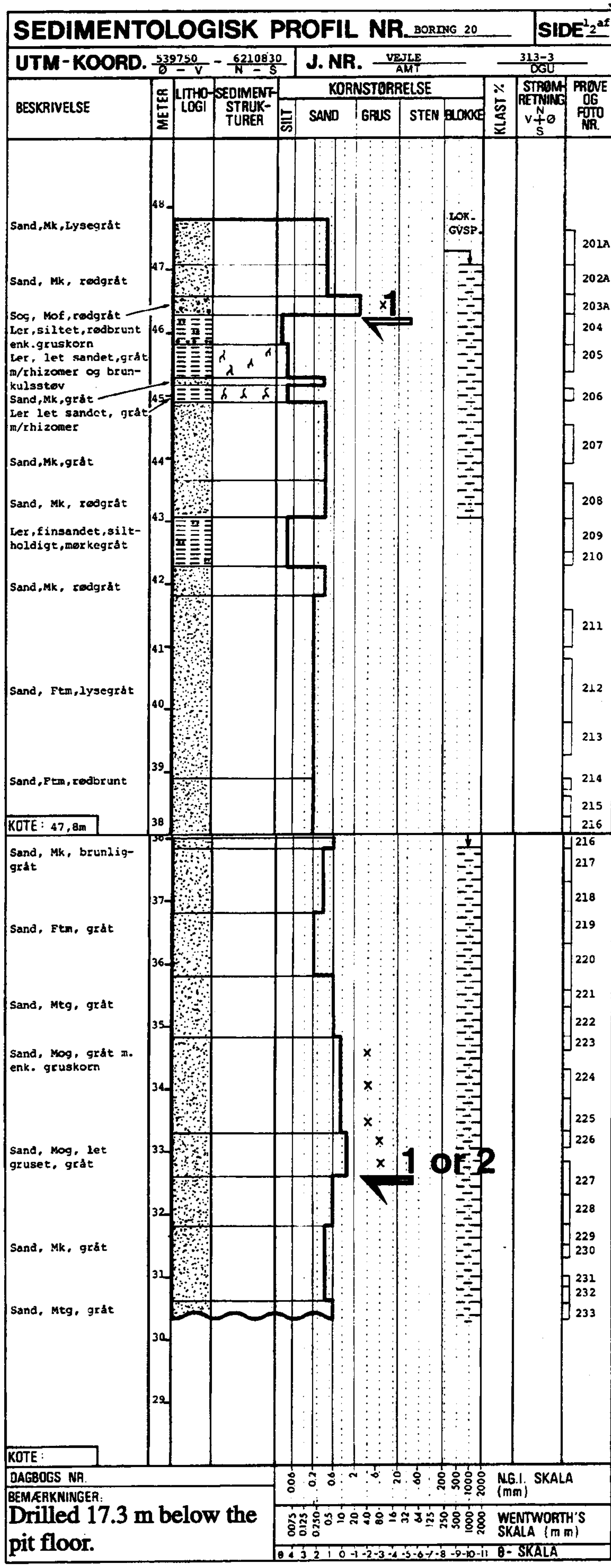


Fig. 2 :
Log no. 5 recorded at pit "b", Silkeborg Kvartssand A/S.
Several fining-upwards successions are seen. Each succession starts with a gravel lag, massive beds and St-type facies, e.g. at 7.5m, 12m and 15m. They are separated by level # 1 and 2 bounding surfaces as indicated. The interval 5-12m is the incomplete, upper part of one level # 1 fining upwards succession. The level #1 succession above 12m is truncated by quaternary erosion in this log, but fines into silty sand Sr facies elsewhere in pit "b".

Fig 3:
Borehole drilled 17 m below the pit floor near log no. 5 in the sand pit "b" of Silkeborg Kvartssand A/S. The borehole was drilled with steel casing driven in front of the auger and the sand -filled casing was bailed out successively.
A 1st order fining upwards succession begins at 46.2m with a gravel lag and extends up into log no. 5, fig. 2
A local groundwater table is found at 47m and it is concluded that the clays underneath and at 42.2-43m therefore possess a significant lateral extension and are floodplain deposits. Roots found in the top clay interval indicate the floodplain was vegetated. These clays form the top of another 1st order succession which displays a 1st or 2nd order bounding surface at 32.5m.



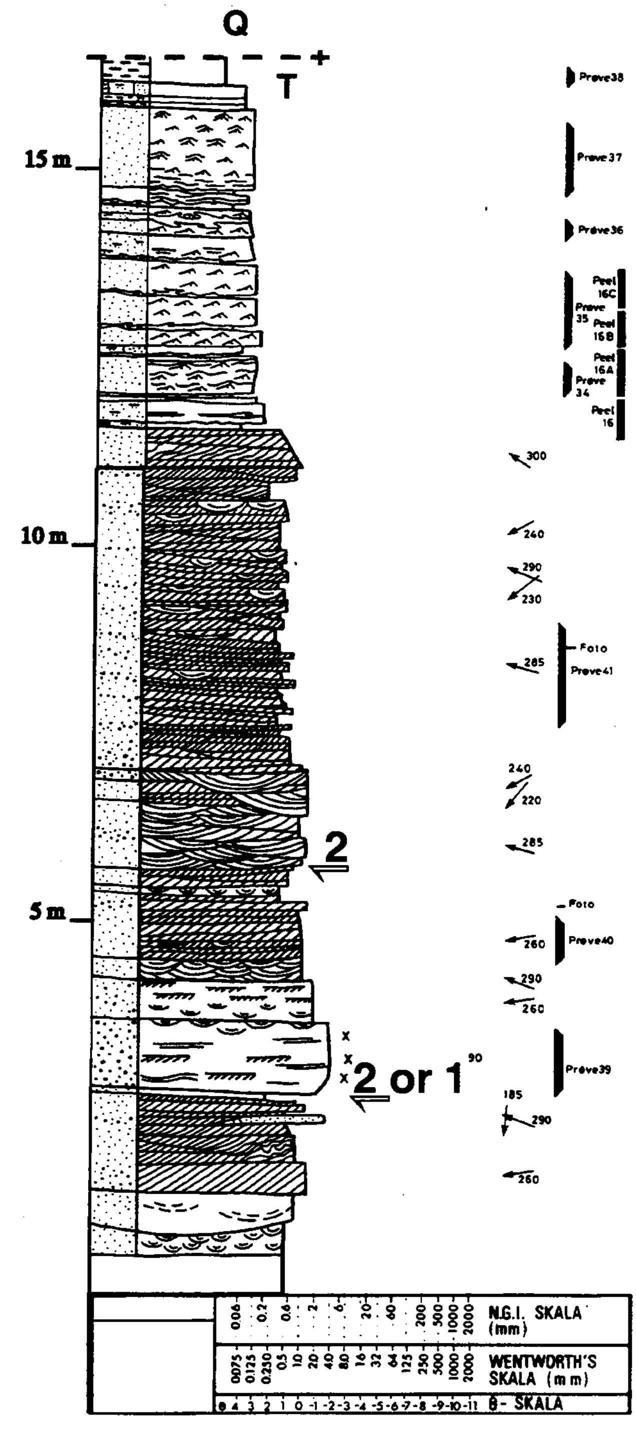


Fig. 4:
Logs no. 6 and 7 combined from pit "c", Voervadsbro. Logs were recorded below and above a terrace at 11m. A fining upwards succession begins at 2.5m, marked "2 or 1" on the log, i.e., this may be a 1st or 2nd order bounding surface. This typical succession begins with massive to wispy laminated sand with pebbles and extends through St and Sp facies to Sr facies and finally clay. Further excavations have demonstrated the presence of coal at a level corresponding to approximately 18 m on the log. Another 2nd order bounding surface is found at 6m, where the St facies reappears.

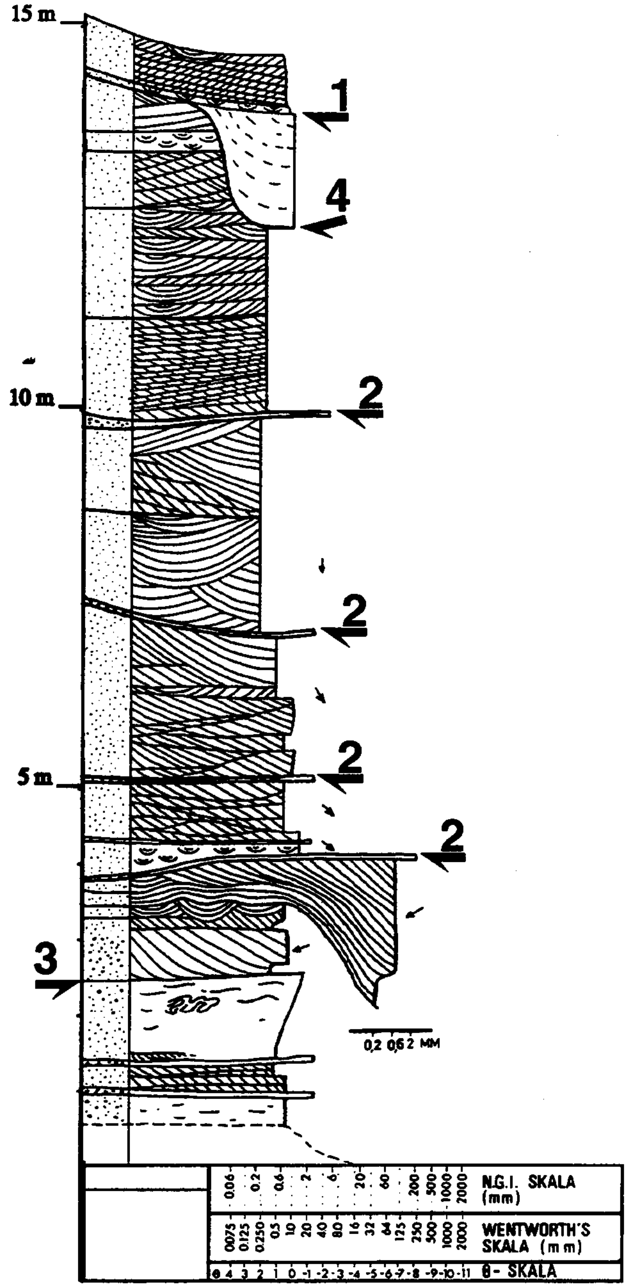


Fig. 5 :
Log no. 8 from pit "b", Silkeborg Kvartssand A/S. 1st, 2nd and 3rd order bounding surfaces correspond to bounding surfaces on fig. 7 recorded from the same pit outcrop. A several m wide scour and fill structure above surface 2b is a chute. Another scour, 20m wide, is interpreted to have formed in a deeper part of the river channel. It is found at 4m on the log. A massive to wispy laminated facies with deformed, transported megaripples is found below the set boundary at "3". It formed during very high stage flow and rapid deposition, perhaps as a result of sediment oversaturated flow after a bank collapse.

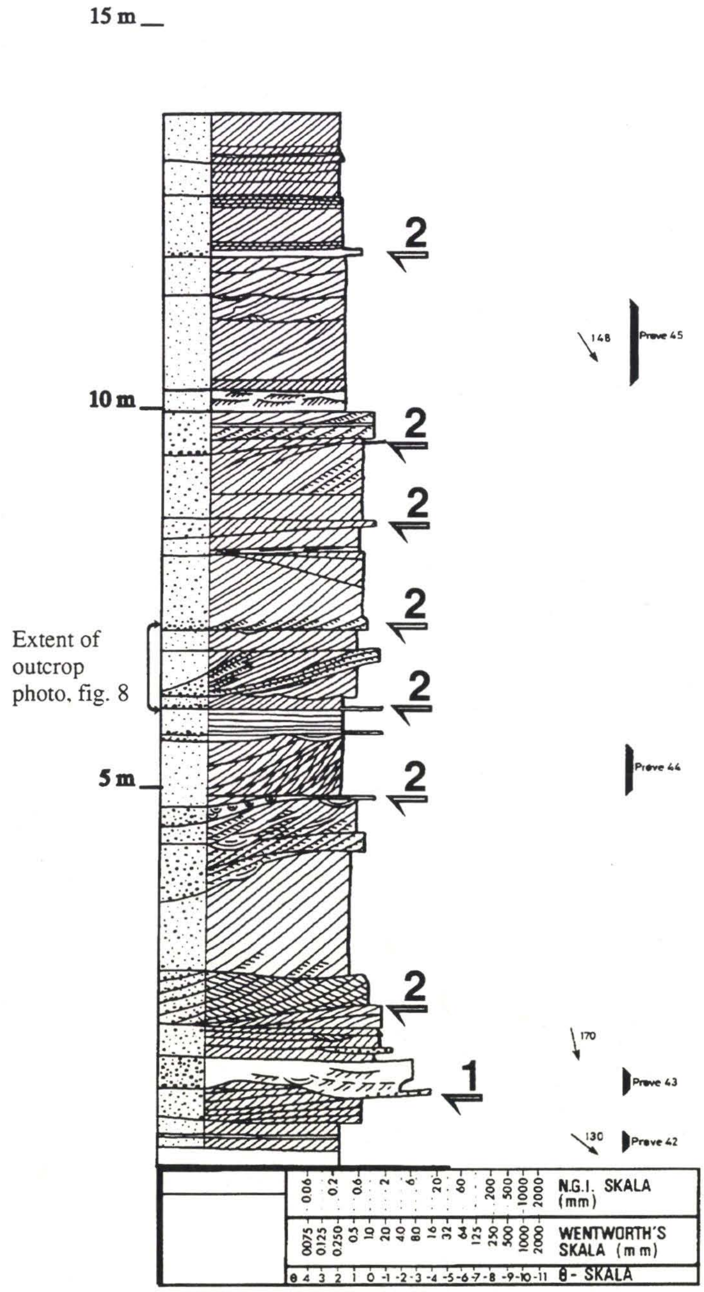


Fig. 6 :
Log no. 2 from pit "a" of Sønder Vissing Sand A/S. The base of an incomplete 1st order succession or another amalgamated 2nd order association is seen at 1m. Amalgamated Sp facies association bar deposits are found above several 2nd order bounding surfaces. The level of detail available for analysis is demonstrated by the detailed photo on fig. 8.

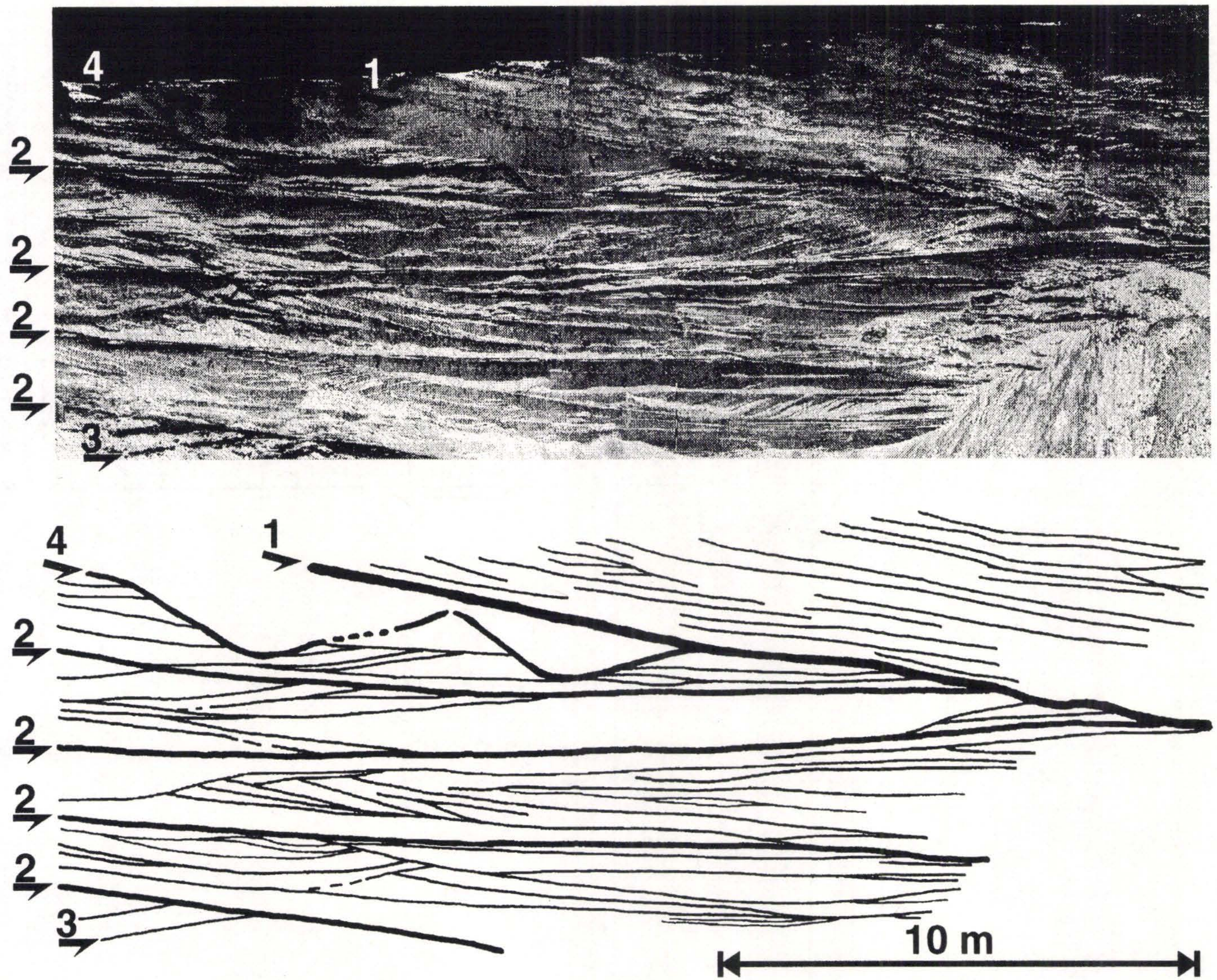
Fig.7 :
The sand pit "b" of Silkeborg Kvartssand A/S at the site of log no. 8. Bounding surfaces have been interpreted in the following hierarchy :

1) Major channel scour level, base of 1st order fining upwards successions.

2) Coset boundaries, , base of 2nd order successions, entirely Sp-facies types on this exposure. Other exposures display St-facies types at the base of 2nd order successions (fig. 2 and 5).

3) Major scour, about 20m wide. Positioned very low in a river channel.

4) Minor scour, usually 3 or 5 m wide. Interpreted as chutes.



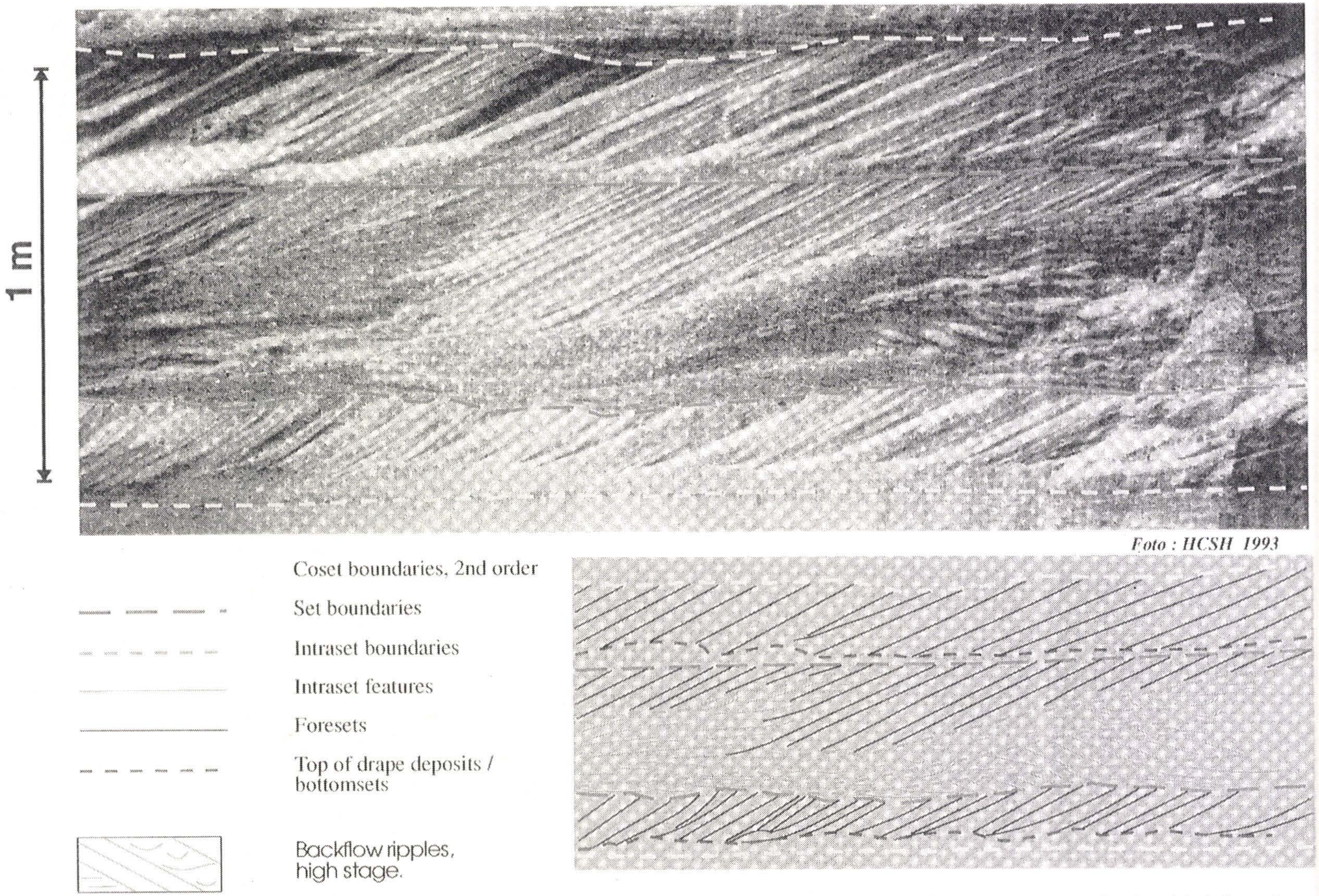


Fig. 8 : Pit "a": 3 Sp bar facies associations separated by green set boundaries: The lowest unit is a remnant of a 1m high bar. It was eroded by the passage of no. 2. The progradation of no. 2 was punctuated by development of bar lee intraset features, including backflow ripples..

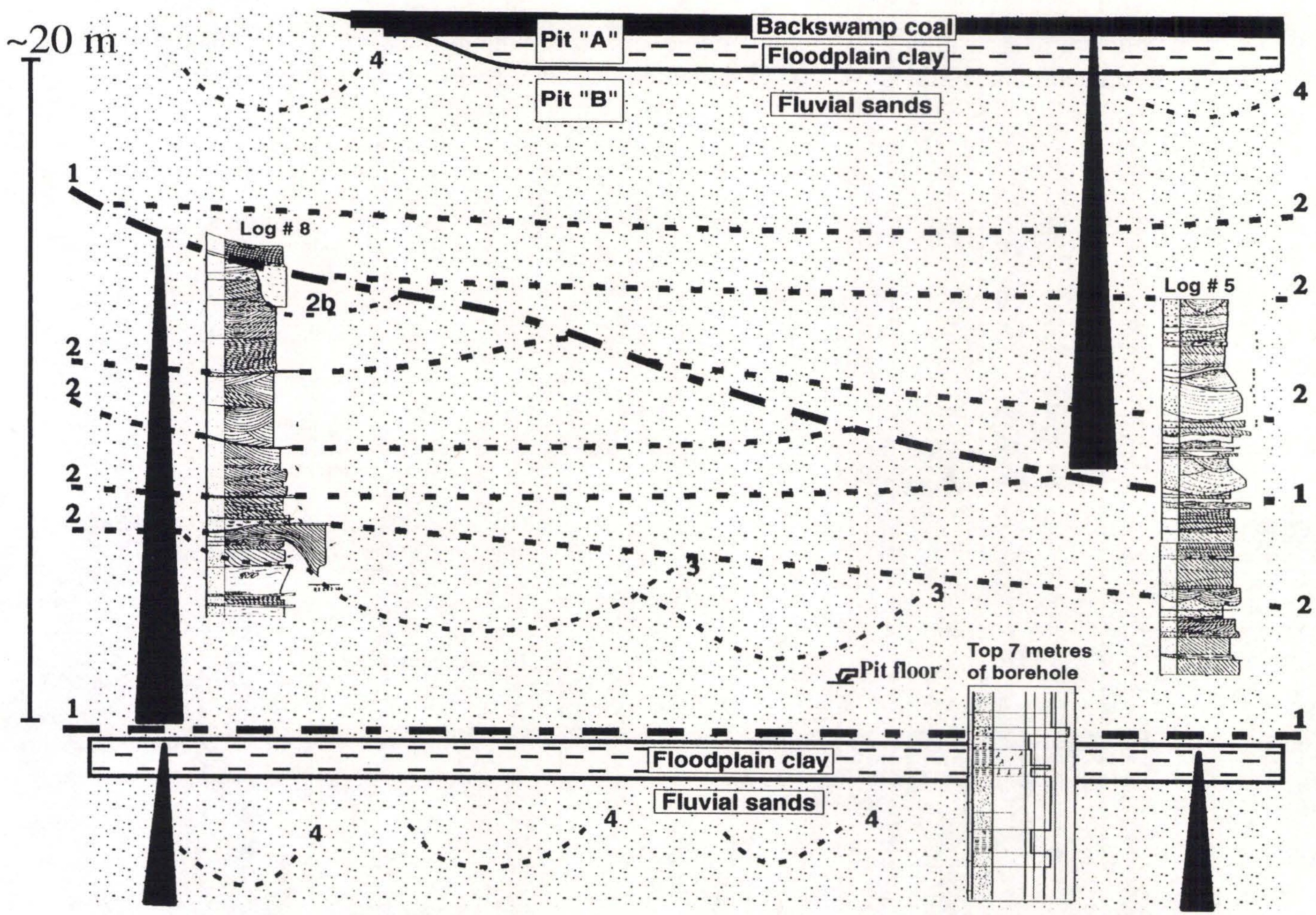


Fig. 9: Model of fluvial architecture, pit "B", Silkeborg Kvartssand. The model is based on logs, a borehole and the outcrop sketch in fig. 7. Two fining-upward successions are identified in outcrop and a third, lower one in a borehole (fig. 3). The lower succession is 13.5 metres thick and fines from coarse sand with granules (not shown) to clay with roots. The middle succession is represented by 9 metres of slightly fining coarse- to medium-grained sand (log # 8).The base of log # 8 is not recorded due to talus. The top is missing due to erosion. The third and top succession is also incomplete, lacking the lowermost, channel-bottom facies. The floodplain silt, clay and coal were recorded from pit "A", 500 metres distant.

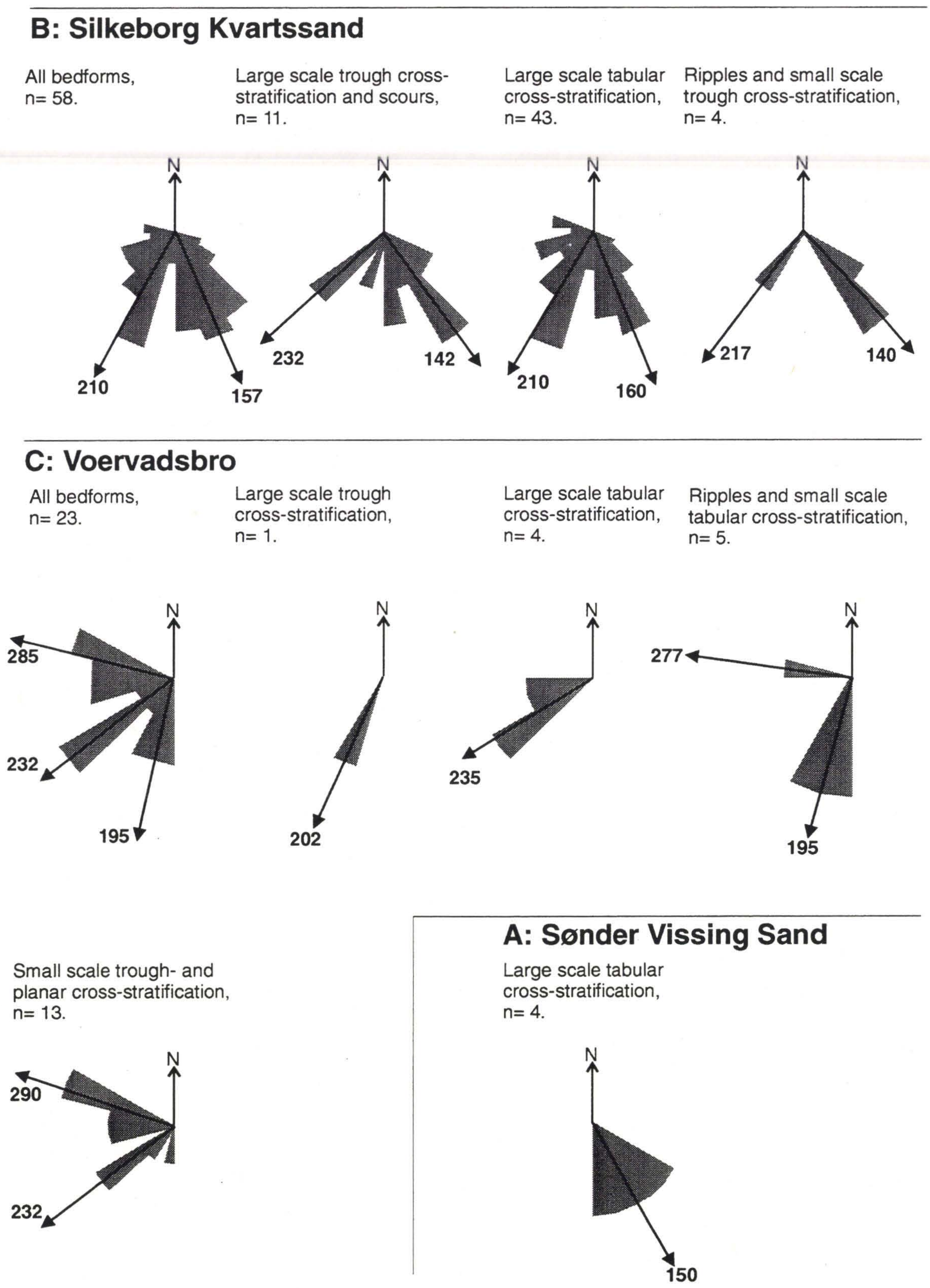


Fig. 10: Estimated mean progradation directions of bedforms in 3 sand pits: Silkeborg Kvartssand, Voervadsbro and Sønder Vissing Sand. Classification ntervals are 15 degrees.