Lateral accretion features (epsilon cross-bedding) and point bars in the weichselian Køge Esker, East-Sjælland, Denmark

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Jensen, J. P.: Lateral accretion features (epsilon cross-bedding) and point bars in the weichselian Køge Esker, East-Sjælland, Denmark. *Bull. geol. Soc. Denmark.* Vol. 37, pp. 11-19, Copenhagen, October 14th, 1988. https://doi.org/10.37570/bgsd-1988-37-02

In the Køge Esker, Spanager lateral accretion features (epsilon cross-bedding) were produced by complex point bar growth. The point bar genesis is based upon the presence of epsilon cross-bedding, the channel side attached nature of the bar (inner accretionary bank) and the paleoflow pattern. The Spanager sequence is divided into three flow discharge cycles ("megavarvic" sedimentation units).

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Introduction

Recently lateral accretion features in esker deposits have been described by Terwindt and Augustinus (1985) from the Scottish Middle Mause Esker. Here they reported longitudinal as well as lateral paleoflow directions normal to the esker axis. This resulted in a talus slope model. The deposition took place in a subglacial tunnel. The sediments was induced laterally via thrustplanes.

Lateral accretions features (epsilon- cross-bedding) are also found in the Køge Esker in the Spanager gravelpit, Sjælland. However, the lateral accretion features were apparently produced by complex point bar growth. This paper describes the sedimentary structures and aspects of these pointbar sediments.

Stratigraphy and setting

The Køge Esker is situated in the eastern part of Sjælland, Denmark (fig. 1). The undulating and segmented esker ridge is approximately 20 kilometres long and is partly covered by till. The main paleocurrent directions are roughly parallel to the longitudinal trends of the local esker ridges. The main trend is more or less east-west, c.f. Andersen (1931), Jensen (1985).

The Køge Esker, described by Andersen (1931), Milthers (1948), Humlum (1976), Andreasen, Jørgensen, Miller and Nielsen (1981), Jensen (1985) was probably deposited by the Main Weichselian oscilating iceadvance from the east. North facing folds are mainly found in the southern eskerflanks. They are interpreted as being generated by an icepressure from the south, created by a later Weichselian ice, which overran the area. (Jensen, 1985). Where the folding is intense the former till cover is often incorporated within the folded esker sediments, which indicates a pre-deformation age of the till. The ice advance, which created the main part of the deformations may correspond to the Young Baltic ice advance, c.f. Houmark-Nielsen (1987).

Epsilon cross-bedding in side attached bars

Epsilon cross-bedding is defined as intrasets separated by erosional or lateral accretionary planes, which dip more or less normal to the paleocurrent direction derived from the intrasets, c.f. Allen (1982).

Apart from outwash glaciodeltas as described by Clemmesen and Houmark-Nielsen (1981) and talus slopes as described by Terwindt and Augustinus (1985) other fluvial bars may show epsilon cross-bedding. Collinson (1970) and Bluck (1979) described medial, lingoid and side attached types

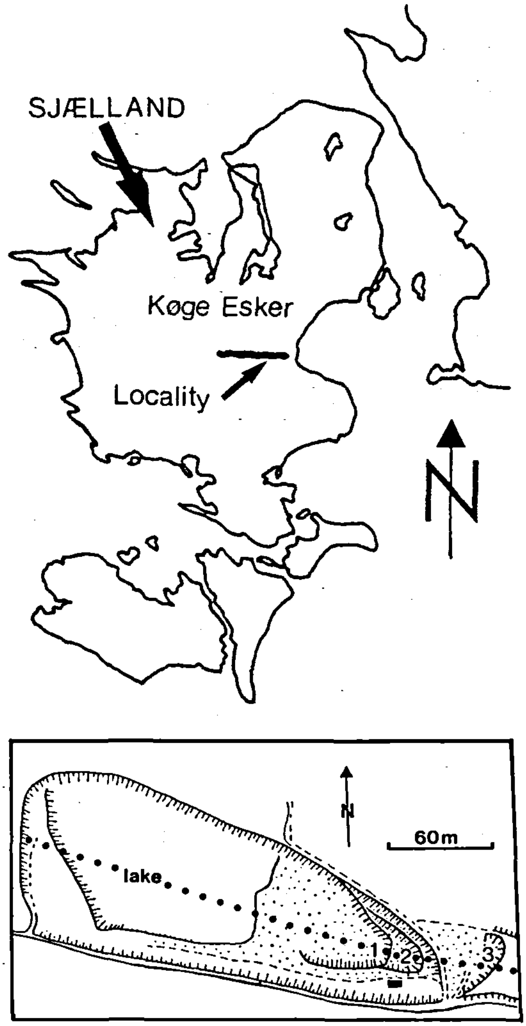

Fig. 1. The location of the Spanager gravel pit and the position of the 3 profiles, described in the text (numbers 1, 2 and 3). The dotted line marks the local esker axis.

which showed epsilon cross-bedding. Side attached bar types will be dealt with here due to the distinct channel side attachment and the paleoflow pattern in the Spanager example.

A side attached bar of a braided origin is termed a lateral bar, while in case of a meandering river genesis, a point bar is the prefered term.

In lateral bars as well as in point bars the intrasets may show paleoflows normal to the main channel flow as well as along or up the epsilon cross-bedding, c.f. Allen (1982), Bluck (1971, 1979), Cant and Walker (1978), Mossop and Flach (1983), Ori (1984) and Puigdefabregas and Van Vliet (1975).

However, Bluck (1979) argues that lateral bars are characterised by the presence of an inner slough channel or slough area, while point bars only exhibit an "inner accretionary bank". This inner accretionary bank corresponds to the upper part of an epsilon cross-bedded point bar, where it is clearly bank attached. See fig. 2.

In short, it seems appropiate to assume point bar genesis providing the bar in question shows bank attachment features (inner accretionary bank) as well as epsilon cross-bedding with intrasets climbing up and along the major planes.

Description and interpretation

The sequence, described here contains the following features which suggest deposition in a pointbar system: 1) the side attachment of the bar (inner accretionary bank), 2) the presence of the epsilon cross-bedding and 3) the paleoflow pattern.

The sequence can be divided into five (A–E) genetic sedimentary units, which are described and interpreted below.

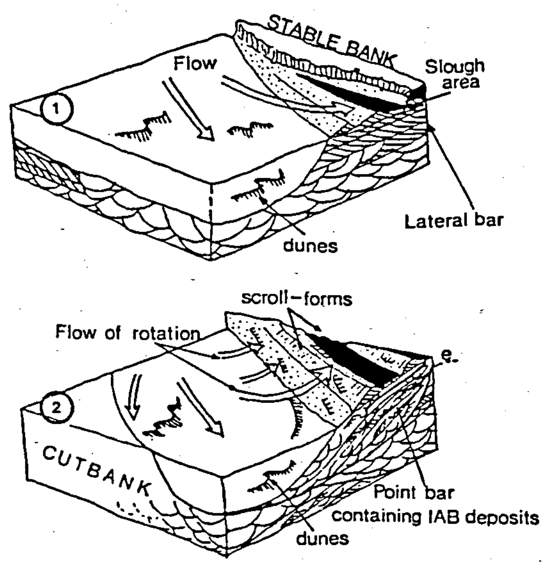

Fig. 2. Two different side attached bartypes, the lateral bar, nr. 1 and the pointbar, nr. 2. Note the epsilon cross-bedded inner accretionary bank (IAB) in the point bar and note also the slough channel area in the lateral bar of South Saskatchewan type. The point bar model is modified after Allen (1982), Bluck (1979) and Jackson (1976). The lateral bar model is modified after Cant and Walker (1978).

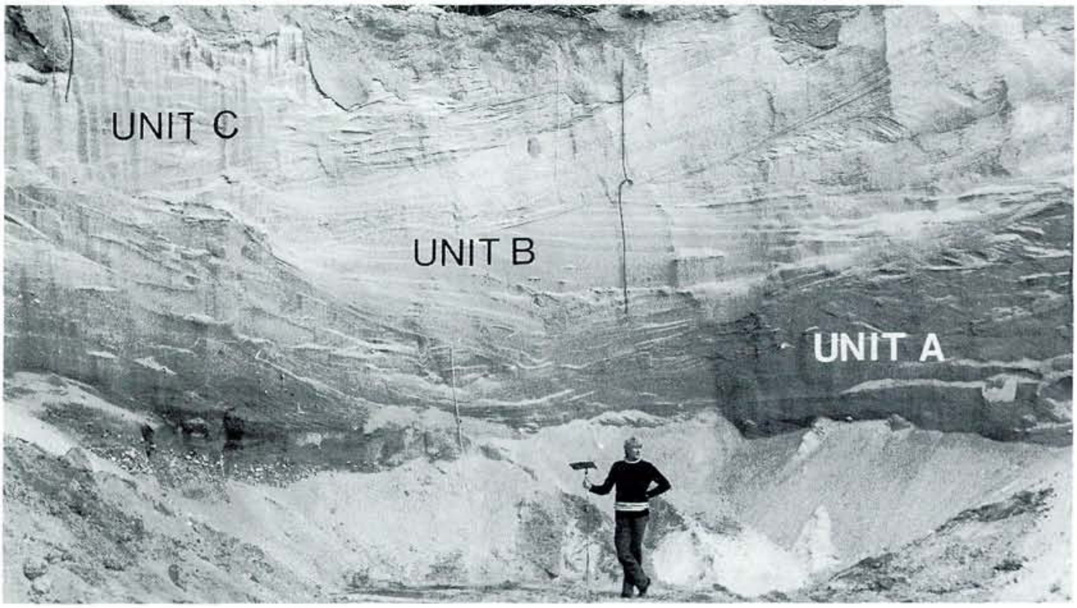

Fig. 3a. Photograph of a part of profile 1 viewed towards east. The odd features hanging down the profile are old cables from a preexisting building above the profile.

The three-dimensional geometry of the point bar system has been reconstructed on the basis of the three profiles shown in figs 3, 4, 5. The oldest profile (fig. 3) contains the channel eroded unit (unit A) and the point bar unit (unit B) and the meander channel unit (unit C). The intermediate profile (fig. 4) shows the top of the unit B and C and the reactivated channel unit (unit D). The third and youngest profile contains the assumed top of unit D and the meander belt unit (unit E), (fig. 5). The complete log of the Spanager sequence is shown in fig. 7. In this figure the sequence is divided into facies units and cycles and an interpretation of the relationship between them is given.

The facies

The facies code of Miall (1977, 1978) is adopted here, with a single addition. The additional facies is facies Fr. This facies is a fine grained ripple laminated facies.

There are three main groups of facies:

A gravelly coarse facies group with prefix G, a sandy group with prefix S and a fine end member group specified by F. A small letter after the prefix denotes whether the facies is characterized by 1) through cross-bedding (t), 2) small scale ripple lamination (r), 3) massive appearence/no sedimentary structure (m), 4) horisontally strat-

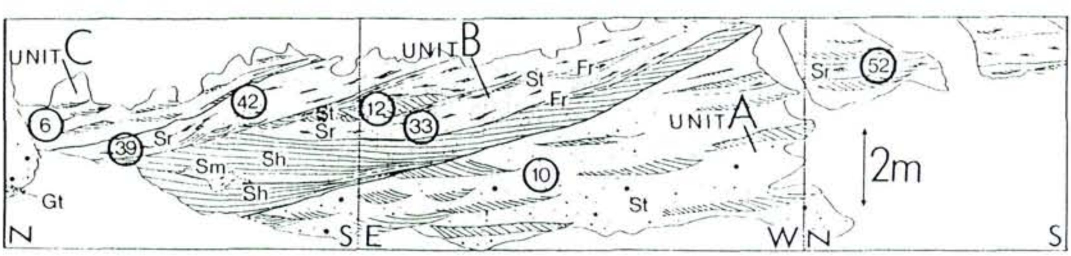

Fig. 3b. Profile 1. The encircled numbers refer to the numbers of paleocurrent meassurements and their location in the profile. The paleocurrent meassurements can be found in fig. 6. N, S, E and W refer to the orientation of the profile segments. Gt, St, Sr, Sm, Sh, Fr anf Fl are facies codes. A, B and C are sedimentary units, which are shown and interpreted in Fig. 7.
The profile shows the epsilon cross bedded upper part of unit B and its channel side attached nature. Note also how the dunes (facies St in unit C) climbing up the point bar surface. This is due to the rotationary flow in the meander channel.

ification/lamination (h in case of sand, l in case of fines), 5) low angel cross stratification (l).

Description, unit A

Unit A fines upwards and consists of large scale trough cross-bedded gravel deposits, facies Gt. Above lie cosets of large scale trough cross-bedded sand, facies St (fig. 3). The total thickness is minimum 6 meters. The set thickness in both facies vary from 0,2 meters near the top of the unit to 0,8 meters in the lowest part of the unit. The sets show parallel as well as wedge shaped bounding planes and set widths from 1 to 5 meters.

Close to the top of the unit there is a wedge shaped body of ripple laminated sand, facies Sr. This sand body gets thicker towards south, up to 0,5 meters.

Paleocurrent directions in this facies were toward northwest.

Interpretation, unit A

The occurence of the large scale trough cross bedded facies are interpreted as having been produced by dunes migrating along the channel bottom. The decrease in dune height reflects a gradually decrease in paleo flow energy.

The wedge shaped body of rippled sand, facies Sr, may represent a relic of an older pointbar or may simply reflect a lowering of the flow energy level.

Description, unit B

Unit B fines upwards and cuts into unit A below. It possesses a well developed channel geometry (fig. 3). The channel width was minimum 25 meters. The lower part of unit B consists of diffusely horisontally stratified sand, facies Sh, draped with a single layer of laminated fines, facies Fl. Locally the diffusely stratified sand contains laminated silt-clay clasts. These clasts are seen to originate from one single centimeter thick draping layer of fines.

The upper part of the 6 meter thick unit B contain intrasets, which are separated by inclined major erosional planes. The planes dips vary from 25 deg. north in profile 1 (fig. 3) to 34 deg. northeast in profile 2 (fig. 4). The intrasets are defined by ripple laminated sand, facies Sr, sandy ripple laminated fines, facies Fr and single sets of large scale trough cross-bedded sand, facies St. Measurements within the intrasets show paleocurrent directions towards northwest, west and south (fig. 6). Cosets of facies St define the top of unit B. Here the paleocurrent directions was towards west-southwest, c.f. fig 4 and fig. 6.

Interpretation, unit B

Unit B is considered generated by high energy channel scouring followed by a complex filling of the channel. Pointbar growth characterises the upper part of the unit. In the lower part of the unit B the intense channel scouring and the diffuse horisontally stratification in facies Sh suggest an upper plane bed or antidune generation at the time of deposition. The fine grained drape, facies Fl, which locally drapes the channel floor and which also is found as intraclasts in facies Sh indicates deposition from suspension during a period of low energy flow in the channel.

The point bar genesis in the upper part of the unit B is shown by the presence of erosional planes as well as accretionary planes, which define epsilon cross-beds. Due to an assumed fluctuating secondary flow of rotation some intrasets show paleocurrent directions towards south, up the erosional planes. Other intrasets are less influenced by the rotationary flow and dip towards west and northwest. (Fig. 6) which is more or less normal to the dips of the erosional planes. This paleoflow pattern is in accordance with the classical point bar model of Allen (1963, 1965, 1982). Furthermore, the rather steeply dipping epsilon cross-beds of the channel side attached point bar thus contain the inner accretionary bank deposits of Bluck (1979).

Locally bedforms such as dunes (facies St) act as an obstacle to the rotationary flow. Finer grained material (facies Fr) are simultaneously deposited in lee of these bedforms. The finer grained material may be considered as an equiv-

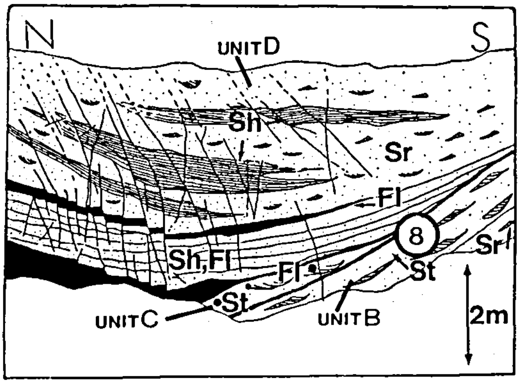

Fig. 4. Profile 2. The units B, C and D represent point bar growth, channel abandonment and following reactivation. See also fig. 6 and fig. 7.

alent to the deposits often found between scroll bar. The dunes may have acted as a sort of scroll bars, c.f. Sundborg (1956).

Description, unit C

Unit C shows a fining upward trend and displays an erosional contact to the underlying unit B, fig. 3. The main part of unit C consist of cosets of large scale trough cross-bedded sand, facies St. Laterally the unit becomes more fine grained towards south. This is a gradual change. At the very top of the profile the facies St distinctively climbs and migrates upslope in relation to unit B.

The set thickness in the trough-crossbedded facies, facies St gradually diminish from 0,4 meters in north to 0,1 meter in south. The set widths of facies St vary from 1 to 3 meters. Measurements in facies St show paleocurrent directions towards west.

The top of unit C is only exposed in profile 2 (fig. 4). It consists of a complex bed of draping layers, which are made up of horisontally laminated sand, facies Sh, and laminated fines, facies Fl. The distinct and very fine lamination in facies Sh is due to clay-silt "microlayers". The lamination is centimeter-thick and is normally graded with grain sizes ranging from sand to silt-clay fraction (estimated).

The laminated layers of fines, facies Fl are up to 0,4 meters thick towards north. Towards south Fl is replaced by planes of erosion and non deposition. See fig. 4.

Interpretation, unit C

Unit C probably represents an active meander channel, filled in with sandy dunes. The dunes migrated on the channel bottom as well as on the point bar surface. Later, as the channel becomes less active suspension fines and sand settled out and draped the channel floor.

The direct influence of the rotationary flow in the channel is shown by the upward climbing character of the dunes. The dune migration toward southwest upslope in relation to the inclined pointbar surface (unit B) confirms that the local bend/point bar dominated the channel stream. Jackson (1976) characterizes such a channel zone as a "fully developed zone", where the secondary flow of rotation is fully developed and where a "classical" point bar is able to be produced. Further out in the channel the influence of the rotationary flow is reduced and here the paleoflow direction was towards west and northwest (fig. 3 and fig. 6).

The inactive channel phase is represented by the low energy/channel floor draping layers (facies Sh and facies Fl). The deposition of these layers could either be due to ice blocking the esker tunnel or may be attributed to annual low flow stage (Andersen, 1931). However, considering the local extension of the fine grained drapes necking, chute cut off or avulsion may be a more suitable solution.

Description, unit D

Unit D (fig. 4) shows ripple laminated sand, facies Sr alternating with trough shaped bodies of horisontally laminated sand, facies Sh. The troughs are up to 1 meter deep and the maximum measured width is 6 meters. Locally facies Sr climbs up the inclined channel side, as seen in the southern part of the profile.

The top of unit D is eroded but may be located in the bottom of profile 3 (fig. 5). Here it consists of a 0,5 meter thick complex layer of horisontally laminated and ripple laminated as well as massive sandy fines, facies Fl, Fr and Fm. These facies drape across the esker channel floor for a distance of at least 30 meters. The tickness of the fine drape is fairly constant.

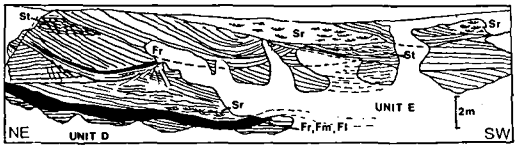

Fig. 5. Profile 3. Note the superimposed meander channels and the assymmetrical arranged foresets in the channels. Unit E is interpreted as a meander belt.

Interpretation, unit D

Unit D is interpreted as representing reactivated channel deposits. The alternation of rippled sand and scour and fill troughs was induced by fluctuating flow, which probably reflected successive floodings of the channel.

The draping top layer of unit D represents a low flow stage, where only fine grained sand and fines are deposited. The uniform thickness, the complexity and the large extension of the fine grained top layer suggest an even larger extension across the esker. Similar complex layers of fines, arranged as topbeds in fining upwards cycles are found elsewhere draping across the entire esker, c.f. Andersen (1931) and Jensen (1985). This points to a mechanism involving ice blocking the tunnel or (annual) low flow stage affecting the whole tunnel.

Description, unit E

Unit E shows a fining upward trend and consists of several sub units (fig. 5). Each sub unit is defined by a large, single, but complex channel scour and fill. The channel scour depth varies from 1 to 4 meters and the width is up to at least 15 meters. Each sub unit cuts down into the underlying sediments and reveals a chaotic system of superimposed channel fills, which display foresets, planes of discontinuity and intrasets. In some places facies Sr are seen to climb along the major foresets.

Close to the top of the profile there is a large, almost tabular sub unit consisting of a body of facies Sr. This sub unit is intercut by a single foreset body.

A 5 centimeter thick drape consisting of rippled layer of sandy fines, facies Fr, is seen within a single scour and fill in the northeastern part of the profile.

Interpretation, unit E

Unit E is interpreted as channel scour and fills deposited in a meanderbelt. Within the belt point bar growth caused the formation of foresets, intrasets and planes of discontinuity. These features and the fine grained interlayer simply reflect fluctuating flow in each channel. In the upper part of the profile the rippled sand becomes more dominant, probably due to a diminishing flow energy in a late stage of the esker formation.

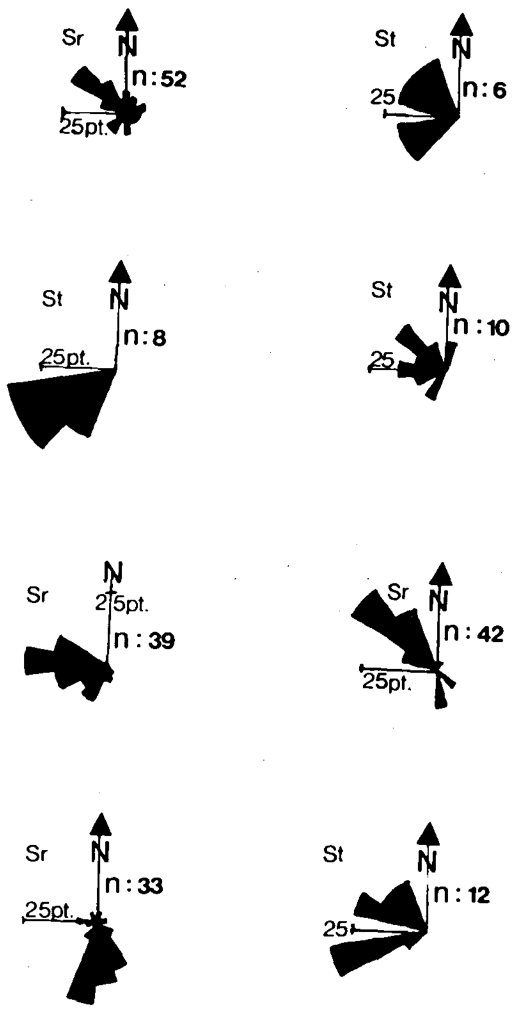

Fig. 6. Paleocurrent data. n = 52 e.q. refers to the number of observations. Facies code symbols are used to denote in which facies measurements have been made.

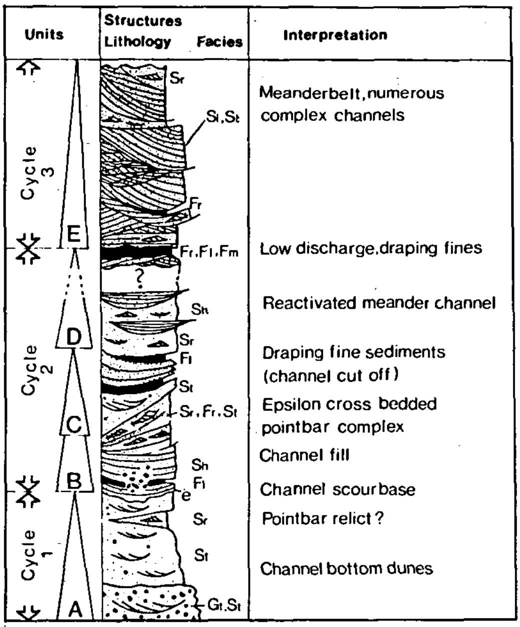

Fig. 7. Vertical profile of the Spanager sequence. Note the three "flow discharge cycles" and the units A, B, C, D and E. The facies' in the Spanager sequence: Gt (trough cross bedded gravel), St (trough cross bedded sand), Sr (ripple cross bedded sand), Sm ("massive" sand), Sh (horisontally bedded sand), Fr (ripple cross bedded sand and fines), Fm ("massive" fines), Fl (laminated fines). The total thickness of the sequence is approximately 18 meters.

Discussion

The glaciofluvial point bar model of the Spanager sequence is based upon the presence of 1) the well developed epsilon cross bedding, 2) the distinct channel side attachment (inner accretionary bank) and 3) the paleoflow pattern in the point bar intrasets and in the channel bottom dunes. All these features fit well with the classical point bar model of Allen (1963, 1965, 1982).

There is no evidence of a talus slope model as described from the Middel Mause Esker, Scotland by Terwindt and Augustinus (1985). No subaerial features such as sheet flow, scour and fill, mud or ice cracks and mudflakes have been identified. A glaciodelta model, as described from the outwash area at Kyndby, Denmark (Clemmesen and Houmark-Nielsen, 1981) is rejected as there is no sign of a prograding delta.

The sediments may have been deposited in a closed esker tunnel. It is most likely that the tunnel was not water filled during flow as there is no evidence of sliding bed facies. This facies is diagnostic for closed conduit condition in a proximal environment, c.f. Saunderson (1977). It is possible that the coarse horisontally imperfect stratified sand, facies Sh in the channel (lower unit B) were created by water surface gravity waves, which produce antidunes.

If this is so then it seems appropriate to assume a submerged glaciofluvial depositional environment, where a free water surface prevailed.

The general fining upward trends of the genetic sedimentary units may be due to 1) discharge fluctuations in the esker tunnel (Andreasen et al., 1981). These may be seasonally controled (Andersen, 1931) or may be attributed to ice blocking the tunnel or 2) lateral shifts of the channel course in relation to necking, chute cut offs and avulsion. The thick fine grained drape which is found at top of unit D presumably reflects (annual?) low flow discharge affecting the whole esker tunnel. This can be corroborated by the fact that the fine grained layer is fairly thick, complex and drapes across a large part of the esker. These features have also been recognised in fine grained layers elsewhere in the Køge Esker, where they define the topbeds in cycles that have been traced across large parts of the esker (Jensen, 1985). Furthermore, it is suggested that 3 major fining upward "flow discharge cycles" may be recognised in the Spanager sequence. The first, and oldest is unit A, the second "cycle" is composed of the units B, C and D, and the third "cycle" is unit E. Individually units B, C and D reflect changes in the local channel environment such as lateral growth of the point bar, channel zone filling and reactivation. The "cycles", on the other hand, reflect events affecting the whole esker tunnel. This is shown in the vertical profile in fig. 7.

These events are most likely governed by annual or repeated discharge fluctuations rather than by repeated ice blocks fall from a presumed ice roof. The idea of an annual control of discharge, originally put forward by Andersen (1931), therefore seems sound. This is not inconsistent with the observations from the Windsor Esker. Banerjee and McDonald (1975) identified 4 upward fining cyclic sedimentation units within the Windsor Esker.

In short, both local lateral channel events as well as annual esker tunnel discharge fluctuations presumably governed the sedimentation pattern seen in the Køge Esker.

Conclusions

The sandy Spanager esker sequence is divided into five sedimentary units, unit A, B, C, D and E. Each unit shows a fining upward trend and a general change from high energy flow level forms to low energy flow level forms. The units A, B, C and D represent stages in complex esker sediment deposition. Unit A is regarded as the channel eroded medium. Unit B reflects the erosive large channel scour and high energy fill at the basis and point bar growth in the upper parts. Unit C is interpreted as having been deposited in the meander channel by migrating dunes. As the channel becomes partly inactive sand and fines settled out and draped across the channel floor and point bar. Unit D is regarded generated due to later reactivation of the channel. Unit E probably represents a meander belt, where successive minor channel erosion and lateral point bar growth has created numerous superimposed scour and fills.

A division of the Spanager sequence into 3 "flow discharge cycles" is attempted. The "cycles" are 1) unit A, 2) unit B, C and D and 3) unit E.

Units B, C and D represent local channel environments. The "flow discharge cycles" are believed to reflect annual discharge variations affecting the whole esker tunnel. The "cycles" support the winter layer ideas of Andersen (1931) and are regarded as some sort of "megavarvic" cycles.

Furthermore it is suggested that sedimentation took place in a submerged tunnel (where a free water surface prevailed) rather than in a subaerial exposed tunnel.

Acknowledgements. The present paper results from a part of an unpublished thesis at the University of Copenhagen. I wish to thank Lars Clemmesen for supervising my thesis and for reading several earlier versions of the manuscript. Gyrite Brandt kindly improved the English manuscript.

Dansk sammendrag

Den sandede sekvens fra Spanager, Køge Ås er inddelt i 5 sedimentære opad finende enheder, enhederne A, B, C, D og E.

Enhed A er dannet af migrerende megaribber og småribber. Enheden er endvidere det medium enhed B eroderer i.

Enhed B anses dannet i forbindelse med kanalnedskæring og kompleks sedimentation. I den nedre del er kanalen udfyldt med diffus horisontalt lamineret sand, som anses afsat i øvre strømregimes planbundsfase eller antidune fase. Den øvre del af enheden karakteriseres af epsilon krydslejrede ribbe- og megaribbe- krydslejrede intrasæt. Paleostrømmålinger i disse intrasæt viser, at bundformerne migrerede langs, men også opad de *stejlt* hældende pålejrings/erosionsflader, der definerer epsilon krydslejringen. Selve den epsilon krydslejrede del af enhed B er tydeligvis aflejret opad den ene kanalside og indeholder derfor "inner accretionary bank"-aflejringerne. Selve den stejle epsilon krydslejring, paleostrømmønstret og kanalside-påhæftningen indikerer en pointbarre genese frem for en lateralbarre dannelse.

Enhed C består af megaribbe krydslejrede sæt, der delvist har udfyldt meanderkanalen. Megaribberne ses at klatre og flade ud opad pointbarrens på lejringsflade. Dette viser den sekundære rotationsstrøms markante indvirkning på aflejringen.

Øverst i enhed C findes draperende finkornede indslag, som antyder en delvis afsnøring af kanalen.

Enhed D består af ribbe krydslejret sand med indslag af meterbrede småkanaler, der er udfyldt med horisontalt lamineret sand. Enhed D er tolket afsat i en reaktiveret meanderkanal, hvor kanaler har skåret sig ned i det ribbe krydslejrede sand under perioder med høj strømningsenergi og evt. lav vandstand. Toppen af enhed D er eroderet, men består sandsynligvis af en 0,5 meter tyk finkornet bænk, der kan spores mindst 30 meter tværs af åsen.

Enhed E består af gentagne indslag af op til 15 meter brede kanaler, som er domineret af asymmetriske forsæt, diskontinuitets-flader og ribbe krydslejrede intrasæt. Enhed E betragtes genereret i et meanderbælte, med lateral pointbarre vækst i mindre kanaler.

Enhed C, B og Ds individuelle opad finende tendens afspejler meanderkanalens lokale variationer, f. eks. lateral pointbarre vækst, delvis meander afsnøring og reaktivering. Enhederne C, B og D, som helhed, og enheden A samt enheden E anses som 3 "cycliske" stor-enheder, hvis dannelse tilskrives variationer i åstunnelens vandføring. Ændringerne kan skyldes blokerende, nedstyrtet is eller – bedre endnu – være sæsonbestemte, hvilket er i overensstemmelse med Andersen (1931)s idé om finkornede vinteraflejringer i Køge Ås.

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