Neogene fluvial and nearshore marine deposits of the Salten section, central Jylland, Denmark

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The deposits of the Salten succession was laid down in a transgressive-regressive event during the latest Chattian (latest Oligocene) and/or the early Aquitanian (earliest Miocene). Five facies associations are recognised and interpretated as deposited in 1: High-energy fluvial, 2: Low-energy fluvial, 3: Flood plain, 4: Tidally influenced fluvial, and 5: Marginal marine/delta plain environments. The dating by biostratigraphy indicates that the Salten succession correlates with the Vejle Fjord Formation. The succession correlates with fluvial deposits outcropping in gravel pits at Addit and Voervadsbro and thus these deposits are of latest Oligocene – earliest Miocene. This is in contrast to former studies that indicate a correlation with the upper Lower – Middle Miocene Odderup Formation. The age of the Salten succession as revealed from this study indicates that the Miocene deposits in Jylland are progressively truncated towards the north and east.

Keywords: Sedimentary facies, stratigraphy, dinoflagellate cysts, Denmark, Miocene.

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The Salten succession (Figs 1–2) was first studied by Hartz in 1898 (Hartz 1909) and correlated with a Lower Miocene coal-rich succession in Schleswig-Holstein, northern Germany. The succession was well exposed in the early 20th century (Hartz 1909) but during the years increased vegetation began to cover the section and only a minor part of the outcrop could be studied (Larsen & Kronborg 1994). Resumed cultivation of the outcrop during the last decade has resulted in a better exposure of the section (Fig. 2).

Study of the Miocene succession of Denmark during the last five years has resulted in a new litho-

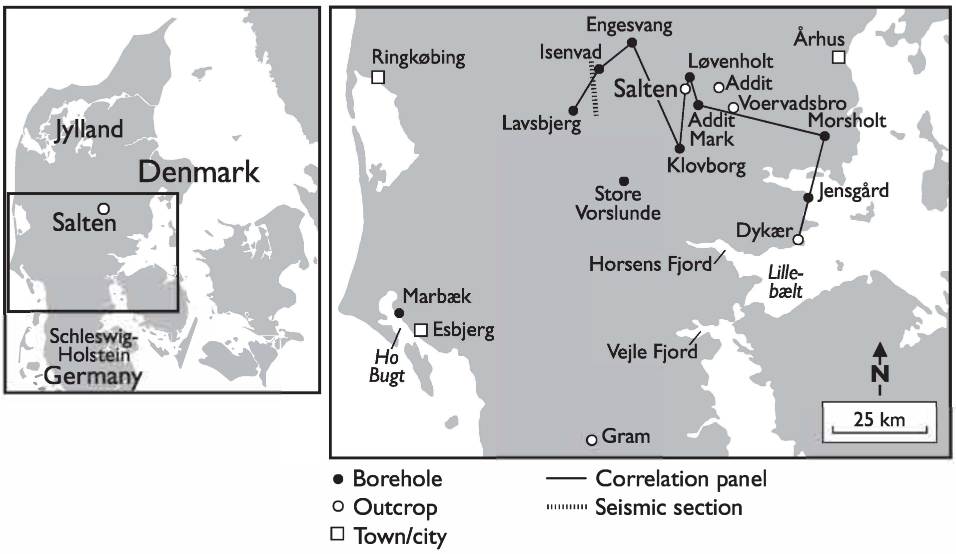


Fig. 1: Location map showing the locations of the Salten outcrop, correlation panel in Fig. 8 and seismic section in Fig. 9.

Fig. 2: Photograph of the Salten outcrop autumn 2004. The outcrop is 32 m high. Scalebar 5 m shown to the left.

and biostratigraphic framework (Dybkjær & Rasmussen 2000; Rasmussen 2004a). Recent studies of outcrops in the Vejle Fjord and Lille Bælt area has given new insights in the stratigraphy and depositional environment (Fig. 1)(Dybkjær & Rasmussen 2000; Rasmussen & Dybkjær 2005). The coastal Marbæk Klint exposure near Esbjerg has recently been re-interpreted and correlated with the Upper Miocene Gram Formation (Piasecki *et al.* 2002).

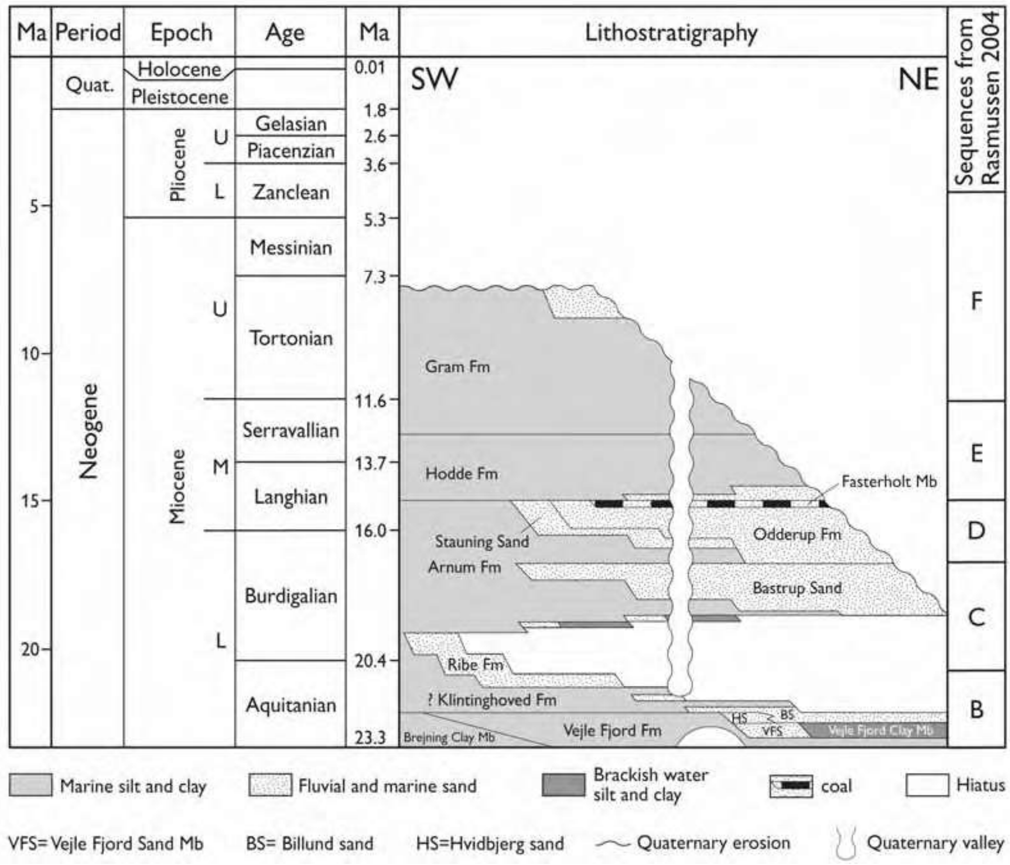
Sand-rich deposits in outcrops and browncoal- and gravel pits in central Jylland are commenly referred to the Lower – Middle Miocene Odderup Formation (Friis 1976; Koch 1989; Friis *et al.* 1998; Weibel 2003) mainly based on lithostratigraphic considerations and floristic characters. Palynologic and sequence stratigraphic analyses of Miocene strata in Denmark during the last five years has, however, given new insights in the stratigraphy in this part of Jylland (e.g. Dybkjær & Rasmussen 2000; Dybkjær 2004a; Rasmussen 2004b; Piasecki 2005; Rasmussen & Dybkjær 2005).

The aim of this study is to unravel the depositional environment and to date the deposits outcropping at Salten and thus to place this part of the Neogene succession in a regional stratigraphic framework. The former interpretation of a fluvial depositional environment (Hartz 1909) was based on the content of terrestrial organic matter and the lack of marine fossils. This study applies a multidisciplinary approach by using sedimentology and palynology. Especially the new advances in biostratigraphy by using palynology have made it possible to date the Miocene marginal marine deposits that do not contain calcareous fossils. Furthermore the development of palynology has shown that even minor marine incursions in a sedimentary succession are sufficient in order to get proper datings. Recent unpublished data from boreholes in central Jylland have revealed that intervals of coarse-grained deposits in central Jylland may be of different ages than formerly assumed (Friis 1976; Koch 1989; Friis *et al.* 1998; Weibel 2003). In order to solve this problem studies of outcrops i.e. the Salten succession, which provide excellent windows into the subsurface, are important because they provide details not assessable in materials from boreholes.

Geological setting

Cenozoic sediments were deposited throughout the Danish region from the Central Graben in the west to the margin of the basin towards the east near Sweden. In the Paleogene, the North Sea Basin was generally fully marine, connected by several straits to the Atlantic Ocean (Ziegler 1990). Danian deposition of chalk and other carbonates was followed by deposition dominantly of fine-grained clastic sediments until the end of the Paleogene when most of the Danish region became emended. From this time and onwards, the North Sea basin became a large silled basin open only to the northwest between the Shetland Islands and Norway (Løseth & Henriksen 2005) and probably restricted marine in periods. A total shift of the sedimentary regime was induced at this time by uplift of the Norwegian region and coarse clastic sediments were flushed into the basin from the north

Fig. 3: Miocene lithostratigraphy of Denmark (modified from Rasmusen 2004a).



and northeast (Michelsen *et al.* 1998; Rasmussen 2004c).

The Neogene succession of the central North Sea Basin comprises complete, thick Miocene and Pliocene successions (Rasmussen *et al.* 2005). Generally, the basinal strata thin up-dip towards Jylland. The Danish onshore, mainly Miocene succession comprises uppermost Chattian (top Oligocene) to Upper Miocene (Tortonian) strata separated from the Paleogene and Pleistocene by significant unconformities. Messinian (Upper Miocene) and younger Neogene strata are missing onshore Denmark. The youngest strata were eroded during Pliocene–Pleistocene time due to major uplift of the eastern part of the North Sea Basin (Japsen 1993; Japsen et al. 2002)

A depositional system of coastal plains and deltas prograding into the North Sea Basin and interfingering with marine basinal mudstone characterised the Danish region from the beginning of Neogene. The depositional system was controlled by the interaction of significant climatic alterations (Zachos *et al.* 2001; Rasmussen 2004b) that combined with large-scale tectonic events, caused significant sea-level variations.

Three major, deltaic successions subdivide the marine, basinal succession into four distinct units (Rasmussen 2004a; Fig. 3). The marine to marginal marine Vejle Fjord Formation (Sequence B) is limited upwards by the marine Klintinghoved Formation and the mainly fluvial Ribe Formation or Billund sand (Sequence B and lower Sequence C). The following marine mudstones of the lower Arnum Formation are limited upwards by the Bastrup sand (Sequence C). Marine mudstones of the upper Arnum Formation are in the northeastern part followed by the deltaic Odderup Formation locally with brown coal beds (Sequence D). In the mid-Langhian, the sea probably totally covered the Danish region and the Hodde and Gram Formations were deposited (Sequence E and F). The youngest preserved Miocene sediments onshore Denmark is the shallow marine sand of the uppermost Gram Formation, outcropping at Gram and along Ho Bugt (Piasecki *et al.* 2002; Piasecki 2005; Rasmussen 2005). Pliocene uplift, followed by Pleistocene glacial erosion have removed Miocene strata from most of the Danish region and limited the distribution of the Miocene succession to mid- and southern Jylland.

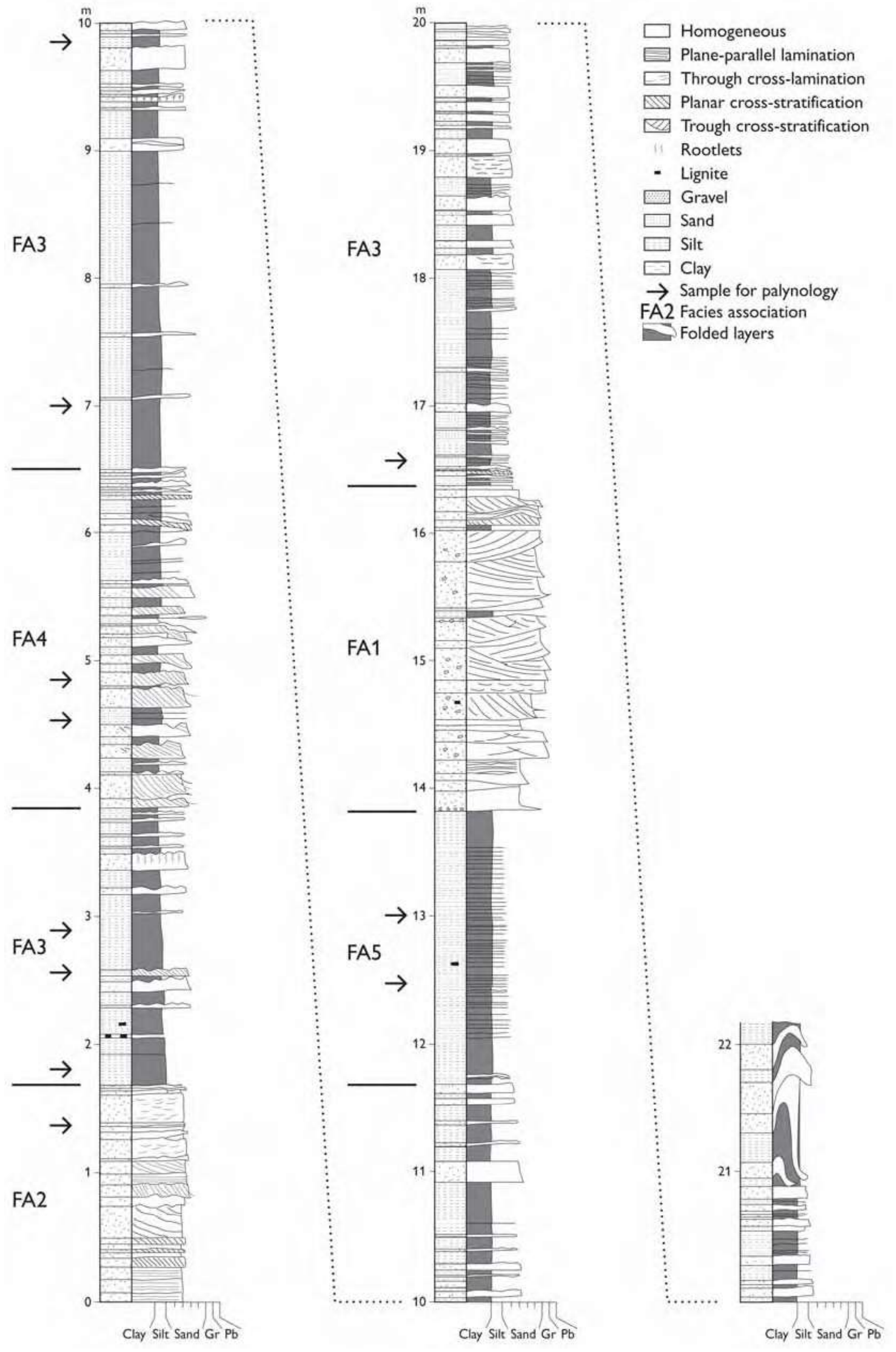


Fig. 4: Sedimentological log from Salten.

Methods

A 22 m thick succession of sand and mud was measured at the Salten outcrop (Fig. 4). Eleven samples were taken for palynological study. The samples were processed in the Palynological Laboratorium at The Geological Survey of Denmark and Greenland (GEUS) using standard techniques involving HCl and HF digestion, heavy liquid separation, brief oxidation with HNO_3 and sieving on 11 μm filters. The organic residue was incorporated in glycerine gel and at least two residue slides were prepared from each sample. The organic residue was then studied in a normal transmitted light microscope.

In order to date the succession and to correlate it to nearby boreholes and outcrops, two slides per sample were thoroughly investigated for their content of dinoflagellate cysts which were identified to species. Concurrently with this, the occurrence of all other marine algae, acritarchs and freshwater algae were registered for quantitative purposes (Fig. 5).

The composition of organic sedimentary particles (the palynofacies) was studied in order to support the interpretation of the depositional environment. A minimum of 300 organic sedimentary particles were referred to amorphous organic matter (AOM), black wood (carbonised wood fragments), brown wood, cuticles and membranes, and palynomorphs, respectively. The brownish AOM present in the studied section are possibly partly degraded vitrinite and thus of terrestrial origin. A minimum of 200 palynomorphs were referred to microspores, non-saccate pollen, saccate pollen, freshwater algae, acritarchs or dinoflagellate cysts (Fig. 6) (Table 1 and 2 in Rasmussen & Dybkjær, 2005).

Palynology

Dating and correlation

The studied succession from the Salten outcrop is dated as latest Chattian (latest Oligocene) and/or early Aquitanian (earliest Miocene), based on the dinoflagellate cyst assemblage, and correlated to the Vejle Fjord Formation. The assemblage is, in all the studied samples, dominated by *Homotryblium plectilum* (Fig. 5). *Spiniferites* spp. is common, while *Dap-*

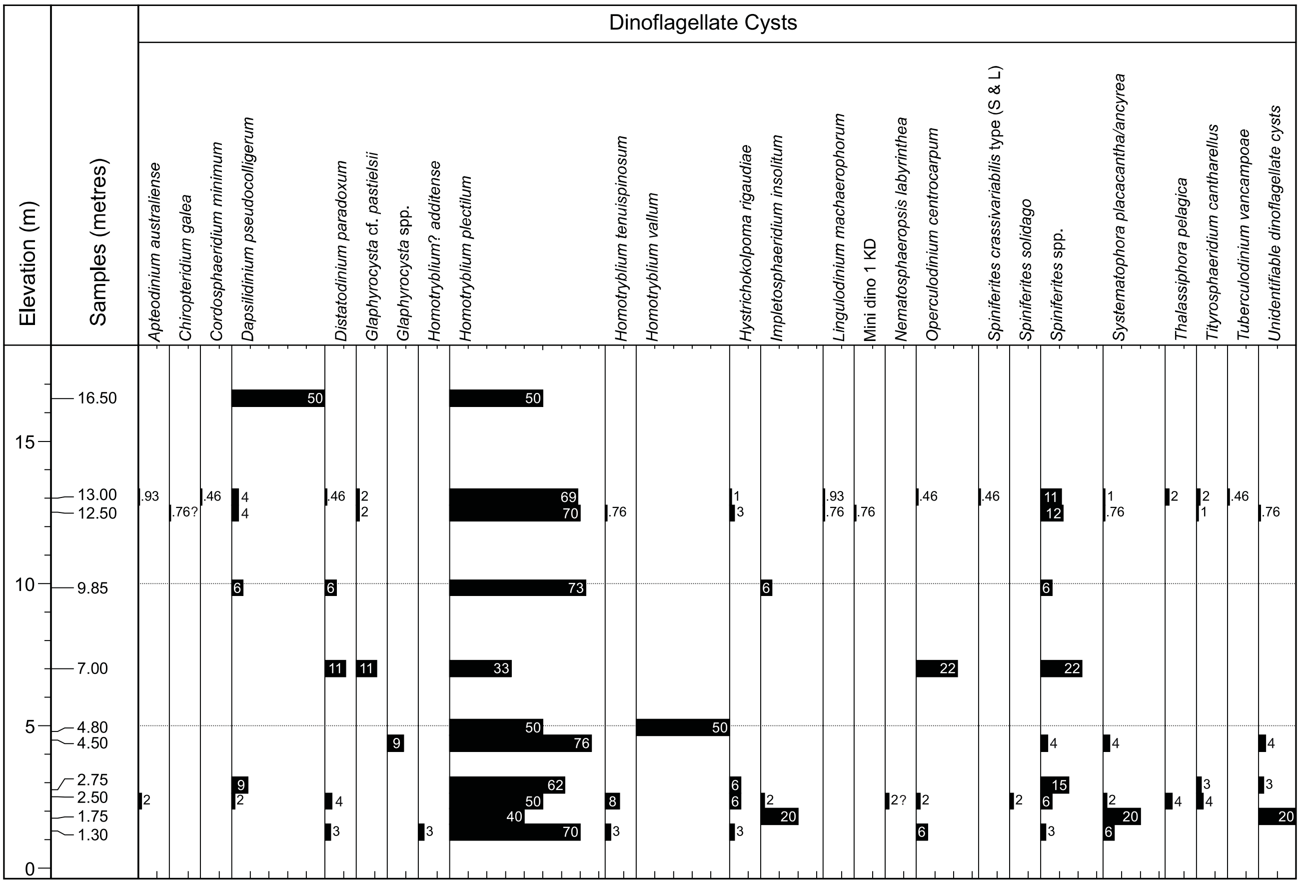


Fig. 5: Range chart of dinoflagellates in the Salten succession.

silidinium pseudocolligerum, *Distatodinium paradoxum*, *Glaphyrocysta* cf. *pastielsii*, *Homotryblium tenuispinosum*, *Hystrichokolpoma rigaudiae*, *Operculodinium centrocarpum*, *Systematophora placacantha*, *Thalassiphora pelagica* and *Tityrosphaeridium cantharellus* occur in low number, but consistently throughout the studied succession. The occurrence of a questionable *Chiropteridium galea* at 12.50 m and the sporadic occurrences of *Glaphyrocysta* spp. and *Homotryblium*? *additense* are of stratigraphic significance.

A dominance of *Homotryblium plectilum* is characteristic for the lower, most proximal parts of the Vejle Fjord Formation, as seen in e.g. the Addit Mark, Klovborg, Morsholt and St. Vorslunde boreholes and in the outcrop at Dykær (Dybkjær 2004b; Dybkjær & Rasmussen 2004; Rasmussen & Dybkjær 2005). In the upper, more distal part of the Vejle Fjord Formation *H. tenuispinosum* dominates the dinoflagellate cyst assemblage (Dybkjær 2004b). The correlation between the Addit and Klovborg boreholes, and the lithostratigraphic and sequence stratigraphic interpretation of the successions in these boreholes (Fig. 8), are revised compared to Dybkjær (2004a, b).

The presence of *Thalassiphora pelagica* in the samples at 2.5 m and 13 m from the Salten outcrop supports a correlation to the Vejle Fjord Formation as this species has its last occurrence in the lowermost part of the overlying Arnum Formation (Dybkjær 2004a; Rasmussen & Dybkjær 2005). Also the occurrence of a questionable *Chiropteridium galea* at 12.50 m, the consistent occurrence of *Glaphyrocysta* and the occurrence of *Homotryblium*? *additense* in the lowest sample at 1.30 m support a correlation to the Vejle Fjord Formation (Dybkjær 2004a, b; Rasmussen & Dybkjær 2005). *C. galea* has its last ocurrence within the Vejle Fjord Formation and *Glaphyrocysta* and *H.*? *additense* are also restricted to the Vejle Fjord Formation (Dybkjær 2004a; Rasmussen & Dybkjær 2005).

Dybkjær (2004a) and Rasmussen & Dybkjær (2005) suggested a latest Chattian (latest Oligocene) and/or early Aquitanian (earliest Miocene) age for the Vejle Fjord Formation, based on:

a) The absence of *Distatodinium biffi* which is a marker species for the Chattian (Upper Oligocene) and with a last occurrence in the uppermost Chattian

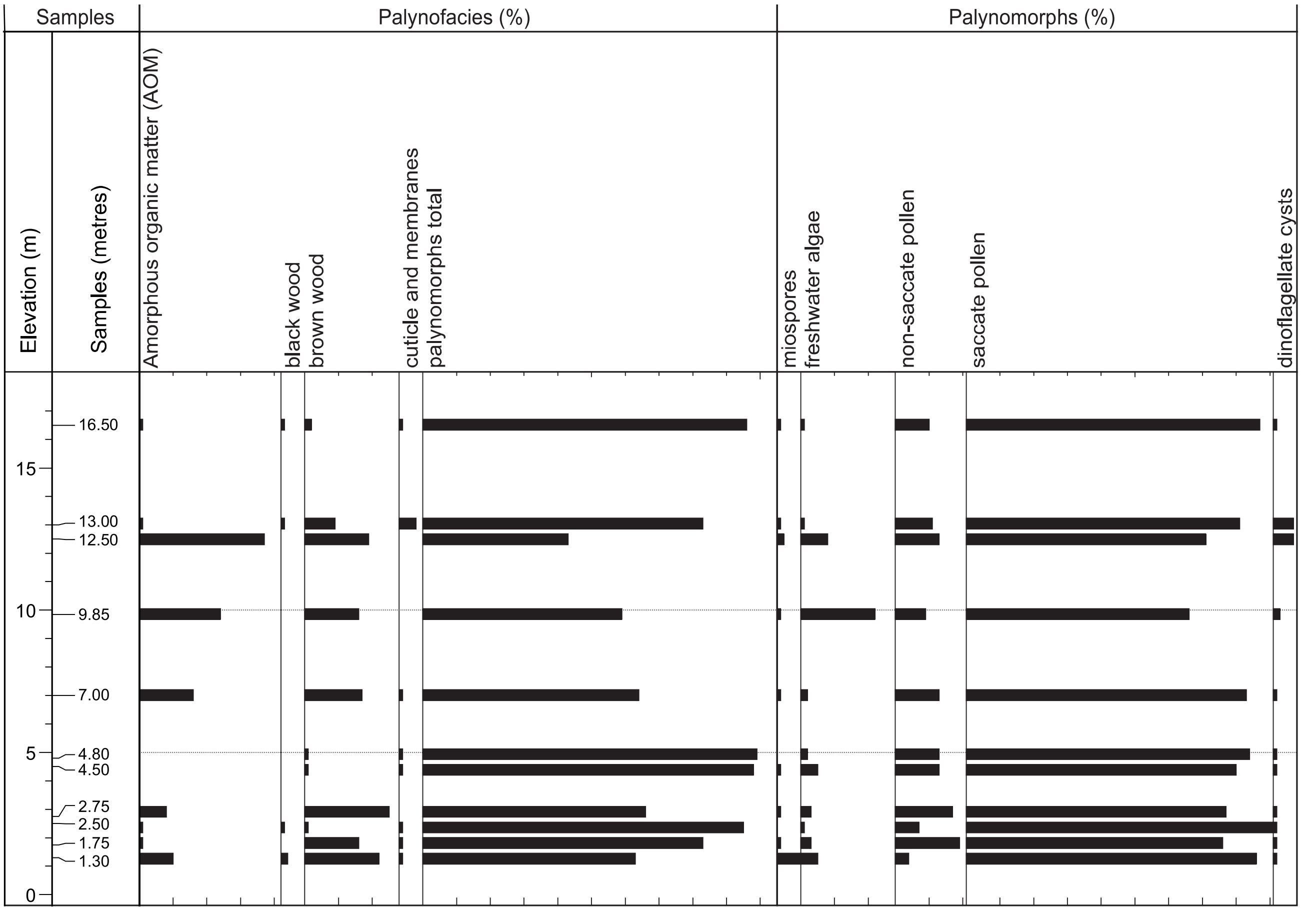


Fig. 6: Palynofacies data of the Salten succession.

in the type region for the Oligocene–Miocene boundary (Coccioni *et al.* 1997).

b) The first occurrence of *Ectosphaeropsis burdigalensis* within the formation. This species has first occurrence in the uppermost Chattien, immediately below the Oligocene–Miocene boundary, in the type region for the boundary (Coccioni *et al.* 1997).

c) The last occurrences of *Chiropteridium galea* and *Caligodinium amiculum* in the upper part of the formation, both of which has last occurrences in the Aquitanian (lowermost Miocene) (Hardenbol *et al.* 1998; Williams *et al.* 2004).

Dybkjær & Rasmussen (2003) also suggest this age of the Vejle Fjord Formation through a correlation to the stratigraphically more complete North Sea well Frida-1, including the interval with *Distatodinium biffi*.

Palynofacies

The sedimentary organic particles are dominated by palynomorphs (relative abundance >20%), whereas brownish amorphous organic matter (AOM) and brown wood are common (2–20%) (Fig. 6). Cuticle and membranes occur sporadically (<2%) in most samples, while black wood (carbonised wood) was found only in the lowermost and uppermost samples. The relative abundance of the brownish AOM (interpreted as partly degraded vitrinite) increases gradually from the lower part of the section up to 12.50 m, followed by a distinct decrease. In the samples at 4.5 m and 4.8 m and in the uppermost sample at 16.50 m the organic particles are completely dominated by palynomorphs.

Among the palynomorphs, saccate pollen dominate all samples, while non-saccate pollen are common (Fig. 6). Microspores occur in low numbers in all samples but show a slightly higher relative abundance in the lowermost sample. Freshwater algae, mainly *Botryococcus* and *Pseudokomewuia* aff. *granulata*, also occur in low numbers in all samples, except for the sample at 9.85 m where they are common. Marine dinoflagellate cysts were found in all samples, but occur in very low numbers in most samples and the assemblage shows a very low species diversity. In the samples at 12.50 m and 13.00 m the relative abundance of dinoflagellate cyst are distinctly higher than in the other samples. At the same time the diversity is also higher in these two samples and in the sample at 2.50 m.

The dinoflagellate cyst assemblage is dominated by *Homotryblium plectilum*, indicating a marginal marine environment with either high- or low-saline conditions (Brinkhuis 1994; Pross & Schmiedl 2002; Dybkjær 2004b). The presence of several large river systems and large deltaes imply that large amounts of freshwater were led to the depositional area (Rasmussen, 2004a), and the latest Oligocene – Early Miocene climate was generally humid, warm and temperate (Sorgenfrei 1958; Lotsch 1968; Radwanski *et al.* 1975; Buchardt 1978; Koch 1989), further implying low-saline rather than high-saline conditions.

In conclusion, the results of the palynofacies study indicate a fluvial to marginal marine environment.

Sedimentology

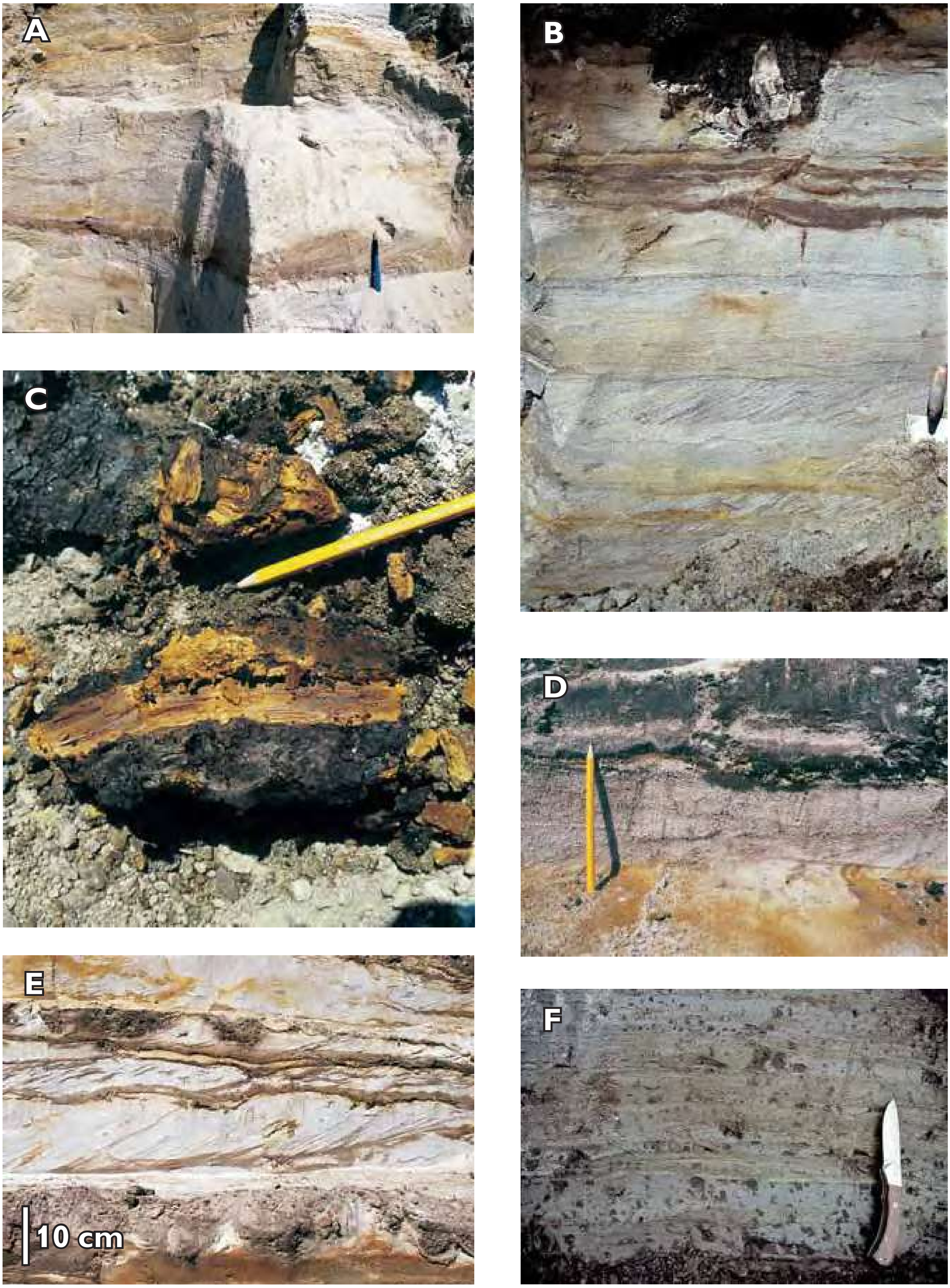
The Salten section is c. 33 m high and is composed of sand and mud capped by Pleistocene till deposits. Hartz (1909) and Larsen & Kronborg (1994) suggest that only the lower 14 m are of Miocene age, whereas an overlying 8 m of sand and mud were interpreted as Quaternary fluvial deposits. In this study the whole succession below the Pleistocene till deposits is assumed to be of Miocene age.

The succession is subdivided into five facies associations based on sedimentary structures, lithology, palaeocurrent indications and palynology (Fig. 4).

Facies Association 1: High-energy fluvial deposits

Facies association 1 is composed of white coarse-grained sand and gravel (Fig. 7A). The lower boundary of the facies association is erosional and characterised by a lithological change from clay dominated sediments to sand and gravel. Bed thickness varies between 10 cm and 25 cm. The facies is dominated by trough cross-stratified gravel, but planar cross-stratified and plane-parallel laminated sand beds are intercalated in the facies. Coal fragments occur scattered. The cross beds are characterised by alternating well-sorted, medium-grained sand and coarse-grained, pebbly sand. The latter is often wedge-shaped. Palaeocurrent measurements from planar cross-stratified beds indicate a transport direction towards SW. Due to the limited exposure of this part of the section it has not been possible to measure palaeocurrents on the trough cross-stratified sand beds.

The dominance of gravel and coarse-grained sand indicate a high-energy environment. The unidirectional cross-stratification towards SW, wood fragments, and lack of marine trace fossils suggest deposition in a fluvial environment. The trough cross-


A
B
C
D
E
F
10 cm

stratified gravel beds were formed by migrating 3-D dunes in a high-energy environment. The laminae were deposited as grainfall and grainflow (Jordan & Pryor 1992). Planar cross-stratified sand was deposited by 2D dunes. The plane-parallel laminated sand was formed as upper flow-regime plane beds. The limited exposure of this facies hinders a precise interpretation, but a correlation to nearby outcrops and boreholes (see below), indicates that Facies association 1 correlates with thick sand- and gravel-rich sediments interpreted as braided fluvial deposits (Hansen 1985; Jesse 1995; Christensen 2004). No samples for palynology were taken in this coarse grained part of the studied succession.

The erosional base of the association indicates a marked change in the depositional environment from the substratum.

Facies Association 2: Low-energy fluvial deposits

Facies association 2 consists of white, medium to coarse-grained sand (Fig. 7B). The lower part is characterised by co-sets of planar cross-stratified sand with an irregular top and wavy-bedded homogeneous sand alternating with trough cross-laminated sand. The cross-bed thickness is 5 to 10 cm. The cross bedding is composed of alternating medium-grained sand and coarse-grained sand. Upwards the succession becomes dominated by plane-parallel laminated sand and planar cross-stratified sand alternating with grey to brownish clay (Fig. 7B). Measurements of the cross-stratified sand indicate a transport-direction towards the SW. Wood fragments are common in the sand beds. The lower boundary is not exposed at the section.

The organic particles in the sample at 1.30 m are dominated by terrestrial palynomorphs, especially saccate pollen (Fig. 6). Brown wood and brownish AOM are common, while black wood and cuticles and membranes occur in low numbers. However, the relative abundance of black wood is slightly higher than in the samples above. Among the palynomorphs saccate pollen is strongly dominating. Microspores occur commonly and the relative abundance is distinctly higher than in the other samples. Freshwater algae occur commonly. Dinoflagellate cysts, mainly *Homotryblium plectilum*, occur in very low numbers and show a very low diversity.

The medium to coarse-grained sand, the unidirectional cross-stratification towards SW, wood fragments, and palynomorphs indicate deposition in a fluvial environment. The plane parallel-laminated sand and planar cross-stratified sand are interpreted as deposition in the upper flow-regime and by migrating 2D dunes, respectively. The alternating medium- and coarse-grained sand reflects deposition by grainfall and grainflow respectively (Jordan & Pryor 1992). The trough cross-laminated sand was laid down under low energy conditions. The increase of mud in the upper part of the facies association may indicate deposition during low river levels where muddy water are trapped locally and mud sheets are formed or a result in flow separation and variation in flow regime in the river (Jordan & Pryor 1992). The lack of lateral accretion surfaces as well as the consistent palaeocurrent direction indicate a low-sinuosity fluvial channel.

The strong dominance of terrestrial palynomorphs and the occurrence of freshwater algae and cuticle support the interpretation of a fluvial depositional environment. The slightly higher relative abundance of black wood, compared to the other facies associations, probably reflects the coarser sediment as black wood is more resistant to oxidation and thus has a higher preservation potential in coarse-grained deposits (Tyson 1995). Additionally, the higher relative abundance of microspores indicates the nearby presence of a local spore-producing flora as spores are generally not transported far away from their parent plants (Tyson 1995). The occurrence of dinocysts in the sample representing this facies association and in all the other studied samples, indicates periodically marine influence and thus a short distance to the sea.

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Fig. 7: Representative photographs of the facies associations found at Salten. (A) Trough – and planar cross-stratified sand and gravel of facies association FA1. Pencil for scale. (B) Planar cross-stratified and laminated sand with few clay layers of facies association FA2. Trowel for scale. (C) Lignite of facies association FA3. Pencil for scale. (D) Massive rooted sand of facies association FA3. Pencil for scale. (E) Cross-stratified sand and clay of facies association FA4. Scale inserted on photo. (F) Sand-streaked clay of facies association FA5. Knife for scale.

Facies Association 3: Flood plain deposits

Facies association 3 is composed of dark brown, organic-rich, clayey silt with thin, grey sand beds and a thin coal layer in the lower part of the succession (Fig. 7C). Lignite is commonly found throughout the facies. The sand beds are 2 cm to 10 cm thick and massive with a wavy top. Rootlets may occur (Fig. 7D). The lower boundary of Facies association 3 is characterised by a distinct change in lithology from

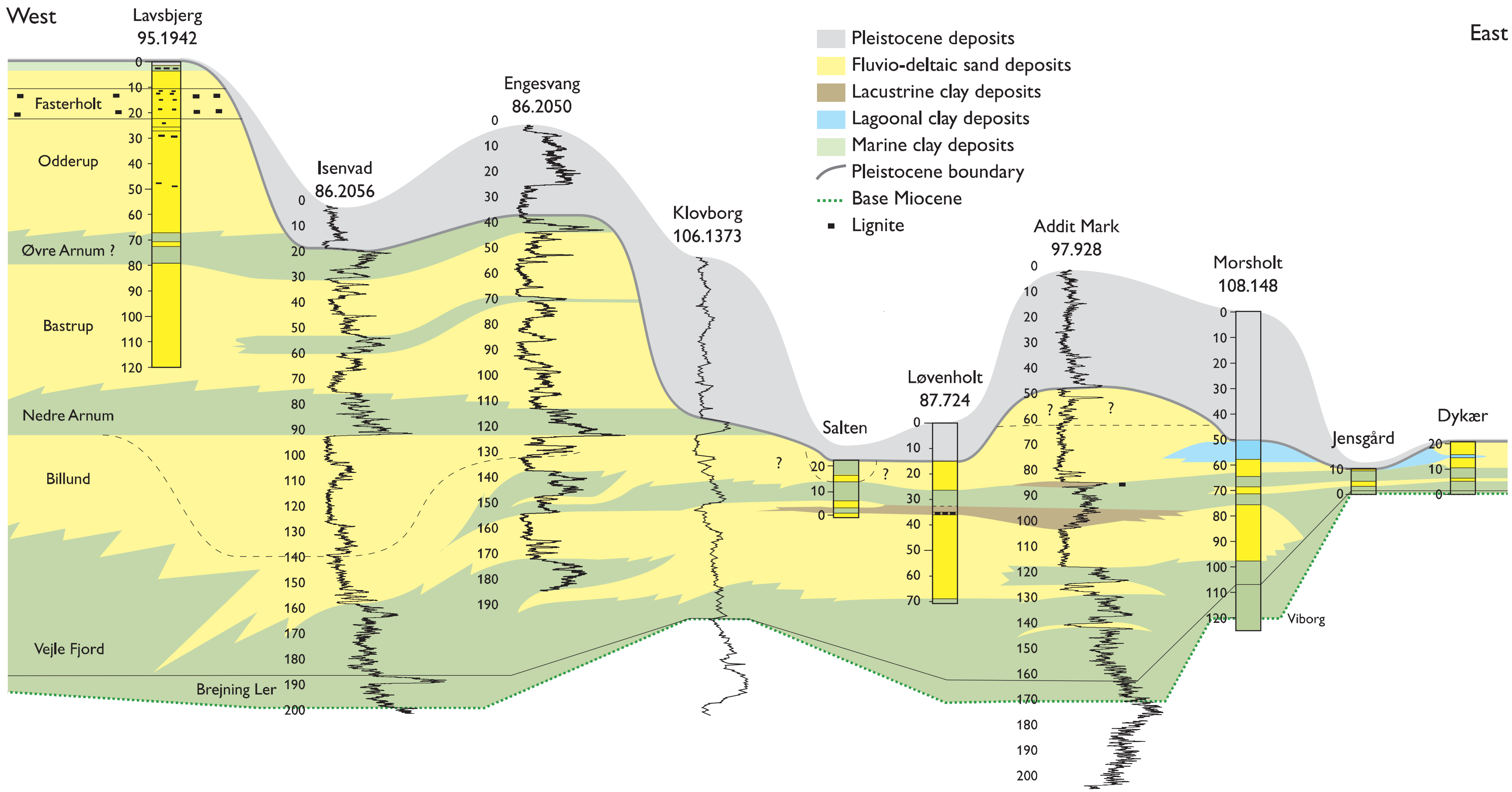

Fig. 8: Correlation panel of boreholes and outcrops including the Salten outcrop.

sand-dominated to clay-dominated deposits with few intercalations of sand beds.

The organic particles in samples 1.75 m, 2.50 m, 2.75 m, 7.00 m, 9.85 m and 16.50 m are generally dominated by palynomorphs. Brownish AOM occur commonly, with the highest relative abundances in the sample at 9.85 m, only sample 12.50 m, from Facies association 5 contains more AOM. Brown wood is common, while cuticles and membranes occur in low numbers. Saccate pollen dominates among the palynomorphs, while non-saccate pollen occurs commonly. Freshwater algae also are common in the sample at 9.85 m. Dinocysts, mainly *Homotryblium plectilum*, occur in very low numbers and show a very low diversity.

The dominance of organic-rich, fine-grained sediments indicate deposition in a low energy environment. The association with the fluvial deposits of Facies association 2 and mud with coal indicate deposition in floodplains. The thin massive sand beds with rootlets are interpreted as crevasse deposition in the flood plain environment which subsequently became vegetated (Elliot 1974).

The high relative abundances of terrestrial palynomorphs and AOM support a low energy, fluvial depositional environment with oxygen deficiency. The sporadic occurrences of dinocysts indicate, however, periodic marine influence.

Facies Association 4: Tidally-influenced fluvial deposits

This facies association is composed of alternating layers of white, medium-grained sand and dark brown clayey silt (Fig. 7E). A few lenses of grey gravel also occur. The sand is planar cross-stratified and the foreset azimuth are SW. Clay drapes and brown clay clasts up to 2 cm are common within the sand beds. The top of discrete sand beds is commonly irregular or wavy. Clay layers up to 2 cm are often capping discrete sand beds. The lower boundary of this facies association is placed at the first significant cross-bedded sand, with clay drapes in places.

The sedimentary organic particles in the samples at 4.50 m and 4.80 m are strongly dominated by terrestrial palynomorphs (Fig. 6). Brown wood and cuticle and membranes occur in low numbers where as AOM and black wood was not recorded. Among the palynomorphs the saccate pollen dominates, whereas non-saccate pollen are common. Freshwater algae occur in low numbers and dinocysts (mainly *Homotryblium plectilum*) are recorded in very low numbers.

The regular alternation of clay – and sand beds and common clay drapes on foresets indicate rapid or rhythmic changes of energy in the depositional environment. The planar cross-stratified sand was formed by migration of 2D dunes in the lower flow regime. The unidirectional orientation of paleocurrent of 2D dunes is suggestive of a dominance of fluvial processes, but the clay drapes may indicate a tidal influence on the sedimentation (Nio & Yang 1991; Plint & Wadsworth 2003). Alternatively, the planar cross-stratified sands separated by clay layers represent chute deposition on top of a point bar (Jordan & Pryor 1992). The clay clasts interbedded in the sands indicate erosion of mud, which may represent flood plain areas eroded during fluvial avulsion.

The high relative abundances of terrestrial palynomorphs combined with sporadic occurrences of dinocysts indicate a mainly fluvial depositional environment with periodic marine influence. The absence of AOM indicates a well-oxygenated environment, supporting the interpretation as a tidally influenced environment with frequent exchange of watermasses.

Facies Association 5: Marginal marine/delta plain deposits

This facies association consists of dark-brown clay with thin fine-grained sand layers. The sand layers are laminated (Fig. 7F). The spacing between the laminated sand layers is ca. 5 cm. The lower boundary of the facies association is placed at a change from homogeneous clay to clay with intercalated thin laminated, fine-grained sand.

The organic sedimentary particles in the samples at 12.50 m and 13.00 m are dominated by palynomorphs and (for 12.50 m) AOM, while brown wood is common (Fig. 6). Black wood, cuticles and membranes are not recorded. The relative abundance of brownish AOM increases up through the succession from the lowermost sample at 1.30 m and culminates in the sample at 12.50 m in which the relative abundance of AOM reaches 37% followed by a decrease to 0.7% in the sample at 13.00 m. Among the palynomorphs the saccate pollen dominates, while non-saccate pollen, freshwater algae and dinocysts are common. Microspores occur sporadically.

The dominantly fine-grained deposits indicate a quiet depositional environment. The dominance of terrestrial palynomorphs and brownish AOM strongly indicates a mainly fluvially-influenced depositional environment. However, the marked increase in the relative abundance of dinocysts compared to the samples below, indicate a stronger marine influence in this part of the succession. The influxes of fine-grained sands possibly reflect deposition during storms, which was very common during the deposition of the Vejle Fjord Formation (Rasmussen & Dybkjær 2005). Facies association 5 is thus interpreted as deposited in a marginal marine setting possibly on a lower delta plain.

Regional correlation

Figure 8 shows the correlation of boreholes from Lavsbjerg towards the west through the Salten and Addit area and further south-eastwards towards Horsens Fjord where the Vejle Fjord Formation is outcropping at Jensgård and Dykær.

The sand-rich lower part of the Salten succession can be correlated with a 35 m thick sand layer in the nearby Løvenholt boring (offset 2.5 km). A coal layer is found immediately above the sand layer at both localities. The overall fining-upward trend above the basal sand in the Salten section from 0 m to 13.85 m and the marine influence in the fine-grained interval (at 12.5–13 m) is also similar to the evolution of the section penetrated in the Addit Mark borehole. Here fluvial deposits are separated from overlying marine deposits by a likely flooding surface (Dybkjær *et al.* 2001).

The lithostratigraphic correlation of the Salten outcrop with the Vejle Fjord Formation in the Engesvang and Isenvad boreholes to the west of the Salten section and in the Morsholt borehole and the two outcrops at Jensgård and Dykær to the east is consistent with the biostratigraphic data (Dybkjær & Rasmussen 2003, 2004, 2005; Rasmussen & Dybkjær 2005). The palynomorphs in the interval referred to the Vejle Fjord Formation in these boreholes and outcrops are dominated by *Homotryblium plectilum*, whereas this species is virtually absent in the interval above, referred to the Arnum and Odderup Formations. *Glaphyrocysta* spp. and *Chiropteridium galea* both occur sporadically in the Vejle Fjord Formation in these boreholes and outcrops as they do within the Salten outcrop (the recorded specimen of *C. galea* from Salten is, however, questionable). *Thalassiphora pelagica* has its last occurrence above the interval correlated with the Salten outcrop in the Isenvad and Engesvang boreholes. The presence of this species in the sample at 13.00 m within the Salten outcroop thus further supports the suggested correlation.

The upper sand layer in the Salten outcrop (13,85 m – 22,10 m) is correlated with sand recognised in all boreholes in the area and with the sand outcropping in the Addit gravel pit (Fig. 8). In the lower part of the pit a coal layer is occasionally exposed, probably corresponding to the coal layer recognised in the Addit Mark borehole around 84 m.

A single specimen of *H. plectilum* was recorded in the sample at 16.50 m from Salten. This occurrence

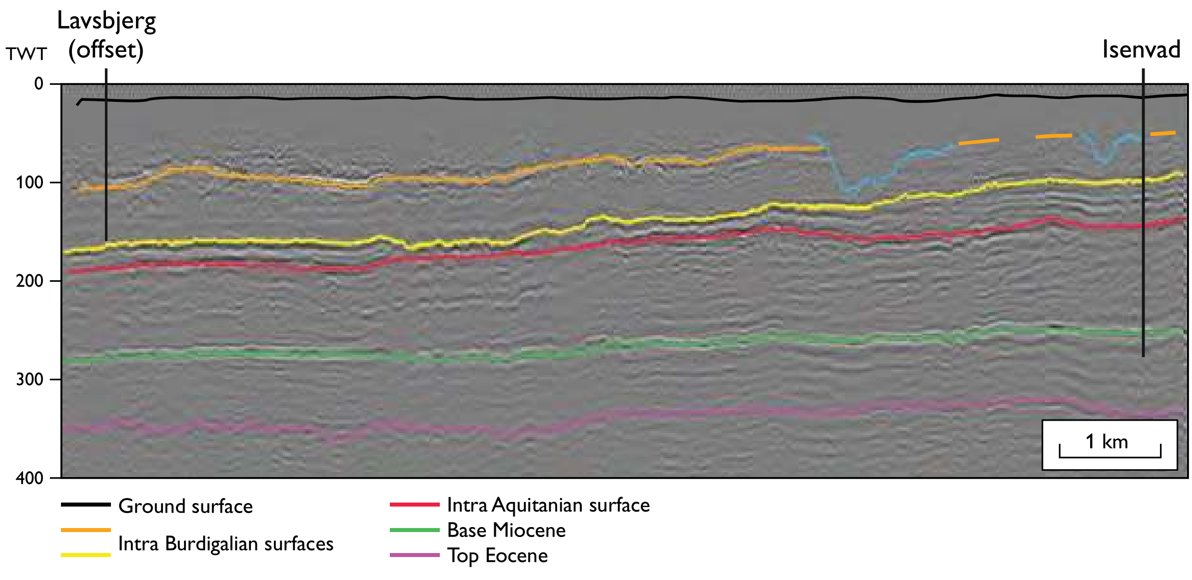

Fig. 9. N–S striking Seismic section from Isenvad showing the truncation of the Miocene succession towards the North. Seismic data courtesy COWI A/S.

indicates an age not younger than Early Miocene for the upper sand interval (cf. Manum *et al.* 1989; Williams *et al.* 1993). There is no palynological indications of the presence of younger deposits (as e.g. Pleistocene) in the measured section and no indications of reworking of palynomorphs as otherwise characteristic for Pleistocene deposits were found. Consequently, this study indicate a latest Late Oligocene – Early Miocene age for the whole section below the Pleistocene till deposits. This contradicts the earlier interpretation of the upper 8 metres of sand and mud as fluvial deposits (Hartz 1909).

Discussion and conclusion

Hartz (1909) indicate an Early Miocene age for the deposits at the Salten outcrop, which is consistent with the indication of a latest Chattian (latest Oligocene) and/or early Aquitanian (earliest Miocene) age similar to the marine Vejle Fjord Formation (Larsen & Dinesen 1959; Friis *et al.* 1998; Rasmussen & Dybkjær 2005). The regional correlation and dating indicate that the succession at Salten could be correlated with the sands outcropping in the gravel pit of Addit and possibly Voervadsbro. These two gravel pits have previously been referred to the upper Lower – Middle Miocene Odderup Formation known from brown coal pits southwest of the study area (Friis 1976; Hansen 1985; Jesse 1995; Weibel 2003). A correlation of the boreholes Lavsbjerg, Isenvad and Engesvang shows that the Gram, Hodde, and Odderup Formations are progressively truncated towards the NNE (Fig. 8). This is also consistent with seismic data that indicate truncation of the succession towards the north and east (Fig. 9). A major tilting of the eastern North Sea area took place in the late Neogene resulting in erosion along the Tornquist Zone and adjacent areas of up to 1200 m (Japsen 1993; Japsen *et al.* 2002). Therefore a marked truncation of Pliocene and older strata towards the Fennoscandian Shield characterised the eastern part of the North Sea area. This study strongly support this pattern by indicating older deposits than the upper Lower - Middle Miocene Odderup Formation at the location of the Salten outcrop.

The sedimentological interpretation of a dominantly fluvial environment is in line with the interpretation of Hartz (1909) except for the recognition of the minor marine influence in the upper part of the clay-rich succession. This is revealed by the tidal indications recognised in the sediments and the palynogical data, especially in the clay-rich part of the succession. The Salten outcrop may represent the early part of the so-called Billund delta of Early Miocene (Aquitanian) age (Rasmussen *et al.* 2004; Hansen & Rasmussen 2004). The marine influence may represent a minor flooding event during overall regression, which terminated in the Early Miocene (Burdigalian) with deposition of deltaic sediments south of the study area.

The limited extent of the outcrop does not permit a precise interpretation of the fluvial system. Studies of outcrops in nearby gravel pits at Addit and Voervadsbro indicate that these Miocene deposits were formed in a braided river system (Hansen 1985; Jesse 1995; Christensen 2004). The lower part of the Salten outcrop is interpreted as deposited in a floodplain with peat swamps and crevasse splays. These deposits are commonly associated with meandering river systems in particular on a delta plain (Miall 1996). This part of the succession was possibly deposited during an overall transgression as indicated by the increase in marine palynomorphs and may record a gradual drowning of the braided river system. The upper part of the succession, which is characterised by coarse-grained cross-bedded sand and gravel, fit better into a braided river system as described from Addit and Voervadsbro gravel pits (Hansen 1985; Hansen 1995; Jesse 1995).

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