Palynological and microfossil biostratigraphy and palaeoecology over the Paleocene–Eocene transition, Femern Bælt, northern Germany

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A palynological and micropalaeontological biostratigraphic and palaeoecological investigation has been carried out on the Paleocene–Eocene transition of core 10.A.057 from the Femern Bælt (Fig. 1). Initial investigations of boreholes from the Femern Bælt indicated that core 10.A.057 included a thick succession of Upper Paleocene – Lower Eocene clay (Sheldon & Nøhr Hansen 2010; Rambøll Arup JV 2011; Fig 2). Complete Paleocene–Eocene sections have been described from Jylland and the Storebælt (Heilmann-Clausen 1985, Laursen & Andersen 1997; Laursen & King 2000, Nielsen *et al.* 1986), but no detailed studies have been published on these successions from the Femern Bælt. Boreholes were drilled on Lolland in Denmark, under the Femern Bælt and on Fehmarn island, Germany from 2009 to 2011 as part of geological and geophysical investigations performed in preparation for the construction of a fixed road and rail link connecting Denmark and Germany. The boreholes penetrated Campanian – Upper Eocene strata, overlain by Quaternary deposits. Borehole 10.A.057 is located in the southern part of the Femern Bælt (Figs 1, 2).

Fig. 1. Map of Denmark and northern Germany showing the location of the planned fixed road and rail link across the Femern Bælt and the location of borehole 10.A.057 at 54°31.8′N, 11°15.9′E.

Geology and palaeoecology

The Femern Bælt is located in the German Basin south of the Ringkøbing–Fyn High. During the Late Cretaceous, the Danish area was characterised by an epicontinental sea resulting in chalk deposition. The sea became more restricted in the early–middle Paleocene and several highs bordered the marine area (Clausen & Huuse 2002). Transgression during the Selandian resulted in clastic marine sedimentation and the North Sea, Denmark and the German Basin formed a partially enclosed shelf area. During the late Paleocene and Early Eocene, sediment deposition occurred in a relatively deep marine basin, at some distance from the shore. Intense volcanic activity caused by the opening of the North Atlantic resulted in deposition of ash and tuff layers during this period. The present distribution of the upper part of the Palaeogene sediments is a result of erosion and glaciotectonic deformation during the Quaternary (Fig. 2).

In the 10.A.057 core, the very fine-grained clays of the Upper Paleocene Holmehus Formation and Østerrende Clay (informal lithostratigraphic unit of Nielsen *et al.* 1986) are overlain by the Lower Eocene Ølst Formation, which is characterised by dark grey clay with abundant layers of black volcanic ash (Heilmann-Clausen *et al.* 1985).

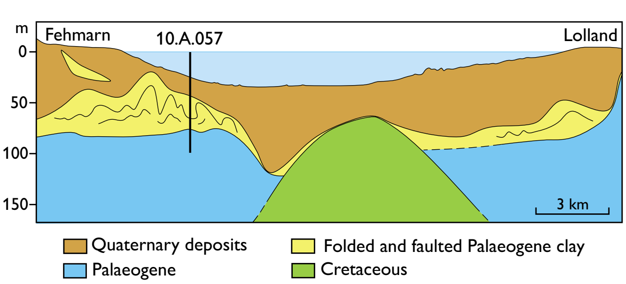

Fig. 2. Sketch south–north cross-section of the Femern Bælt area showing the location of borehole 10.A.057.

Fig. 3. Range chart showing the distribution (number of specimens) of dinocysts, diatoms, foraminifers and radiolarians from borehole 10.A.057. **P**: pyrite, **A**: ash layer.

Biostratigraphy

A total of 19 samples were analysed for dinocysts, diatoms, foraminifers and radiolarians (Figs 3, 4). The Danish Paleocene–Eocene zonation of the Viborg-1 cored borehole (Heilmann-Clausen 1985) and the North Sea zonation of Mudge & Bujak (1996) were used for the dinoflagellate cyst stratigraphy. The North Sea Cenozoic zonation of King (1989) was used for microfossils.

Dinocysts

The samples from 100.49 to 90.31 m are assigned to the *Areoligera gippingensis* Acme Subzone P5a (Mudge & Bujak 1996; Fig. 3). This subzone represents the uppermost part of zone V4 (Heilmann-Clausen 1985) and is equivalent to the uppermost part of the Holmehus Formation (Mudge & Bujak 1996). P5a is characterised by an acme of *A. gippingensis* and the presence of *Eisenackia margarita*. The top of P5a is defined by the top of the *A. gippingensis* acme. Nielsen *et al.* (1986) found low abundances of *Deflandrea oebisfeldensis* in V4 in a borehole from the Storebælt but Heilmann-Clausen (1985) did not find this species in V4. The boundary between V4 and the overlying V5 is tentatively placed, since relatively high abundances of *A. gippingensis* continue into V5.

The samples from 90.31 to 79.42 m are assigned to the *E. margarita* Subzone P5b (V5) based on the last occurrence (LO) of *E. margarita* (Mudge & Bujak 1996). *E. margarita* has its LO in the Østerrende Clay (Nielsen *et al.* 1986).

Zone V6, which is characterised by a dominance of the warm-water genus *Apectodinium* and an acme of *Apecto-*

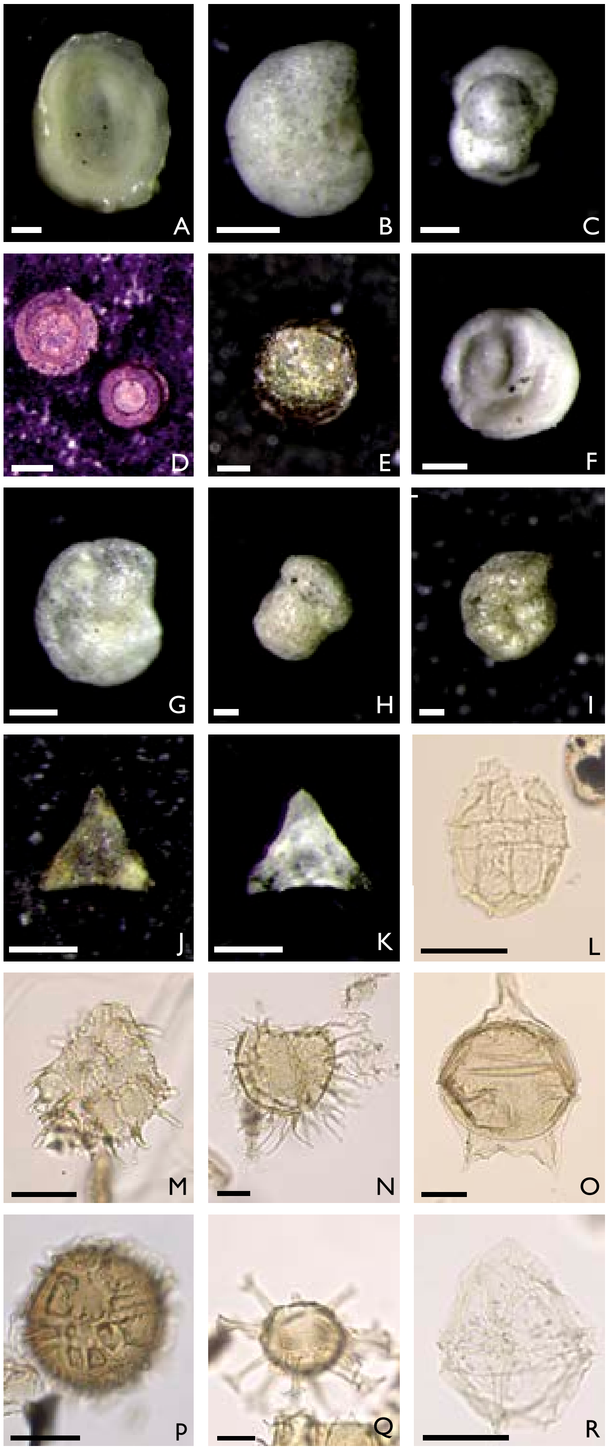

Fig. 4. Selected fossils: **A**–**C** and **F**–**I**: foraminifers, **D**, **E**, **J**, **K**: diatoms, **L**–**R**: dinocysts. **A**: *Ammodiscus cretaceous*. **B**: *Cyclammina amplectens*. **C**: *Cystammina pauciloculata*. **D**: *Coscinodiscus morsianus moelleri*. **E**: *Fenestrella antiqua*. **F**: *Glomospira charoides*. **G**: *Haplophragmoides walteri*. **H**: *Labrospira scitula* (front). **I**: *Labrospira scitula* (side). **J**: *Trinacria regina*. **K**: *Trinacria regina* (siliceous). **L**: *Microdinium* cf. *ornatum*. **M**: Piece of dinocyst. **N**: *Areoligera gippingensis*. **O**: *Deflandrea oebisfeldensis*. **P**: *Eisenackia margarita*. **Q**: *Hystrichospharidium tubiferum*. **R**: Unidentifiable peridinoid cyst. Scale bars: 100 µm (**A**–**K**), 20 µm (**L**–**R**).

dinium augustum, was not found in this study. A missing core section from 79.42 to 73.36 m could represent Zone V6, but V6 has not been observed previously in the Femern Bælt area (C. Heilmann-Clausen & H. Nøhr-Hansen, personal communication 2013). However, V6 is present in the Stolle Klint Clay, north-western Jylland. The base of the *Apectodinium* acme in the earliest Eocene is a global event and is coupled with a carbon isotope excursion denoting the start of the Paleocene–Eocene Thermal Maximum (PETM).

The samples from 73.36 to 51.81 m are referred to Early Eocene *D. oebisfeldensis* Acme Subzone E1b (upper V7; Bujak & Mudge 1994). The interval from 66.18 to 51.81 m is characterised by a minor acme of *Glaphyrocysta divaricata* and a high abundance of *Microdinium* cf. *ornatum* (Fig. 3). Zone V7 is found in the upper part of the Ølst Formation (Heilmann-Clausen 1985).

Foraminifers and diatoms

The assemblages mainly consist of poorly preserved agglutinating benthic foraminifers and diatoms. Samples from 100.49 to 79.42 m are assigned to zone NSA1b. Most samples only contain few foraminifers, but two samples from the upper *c.* 2 m contain rich faunas with *Spiroplectammina spectabilis*, *Labrospira scitula*, *Ammodiscus cretaceus*, *Glomospira charoides*, *Marsonella oxycona*, *Cystammina pauciloculata*, *Recurvoides* spp., *Hormosina* spp., *Rhabdammina robusta*, *Cyclammina rotundidorsata*, *Haplophragmoides walteri*, *Bathysiphon* spp. and *Cyclammina amplectens*. This assemblage is known as the '*Rhabdammina* biofacies'. The shift from low to higher diversity benthic assemblages in NSA1b was also noted in the Bovlstrup borehole, eastern Jylland (Laursen & Andersen 1997) and was interpreted as a shift from very poor to slightly improved life conditions on the sea floor. A low-diversity diatom flora with pyritised *Fenestrella antiqua* (var. small) and *Diatom* spp. (flat) is also present, in addition to sponge debris and radiolarians (*Cenodiscus* spp.). NSA1 is assigned to the Holmehus Formation in Denmark (King 1989).

Samples from 73.36 to 51.81 m are assigned to zone NSP4. The assemblages are dominated by resting spores of centric diatoms, comprising *Coscinodiscus morsianus moelleri*, *Fenestrella antiqua*, *Diatom* spp. (flat), *Thalassiophora wittiana*, *Trinacria regina*, *Aulacodiscus allorgei* and *Hemiaulus* spp. From 66.18 to 56.87 m pyritised and translucent diatoms occur in equal numbers; above and below this level only pyritised specimens occur. This difference in preservation is probably due to variations in the oxygen level in the water column and the amount of sulphide present in the sediment (De Jonghe *et al.* 2011). Zone NSP4 also includes bryozoan fragments, fish teeth, *Inoceramus* fragments, sponge spicules and rare agglutinating foraminifers. NSP4 is assigned to the Early Eocene Ølst Formation (King 1989).

Discussion and conclusions

A dominance of agglutinating foraminifers of the '*Rhabdammina* biofacies' in subzone NSA1b suggests a middle to lower bathyal palaeoenvironment characterised by restricted water circulation, with low oxygen levels and a reducing environment at the sea floor (Jones & Charnock 1985; King 1989). The low oxygen level may have led to decreasing degradation of organic matter by bacteria and benthic organisms, giving rise to the dark grey colour of the Holmehus Formation compared with those described by Heilmann-Clausen *et al.* (1985).

A relatively high abundance of the supposed heterotrophic dinoflagellate *Deflandrea oebisfeldensis* and the rich diatom flora in the Ølst Formation may be due to increased productivity in the surface layers perhaps due to enhanced upwelling in coastal areas. The rich diatom flora, preserved as resting spores, also suggests stressed sea-surface and seabed conditions, perhaps due to volcanic ash falls and periods of anoxia (Bidgood *et al.* 1999). The scarcity of agglutinating foraminifers is probably due to reducing conditions at the sea floor. Schiøler *et al.* (2007) suggested that the Balder Formation (the North Sea equivalent of the Ølst Formation) was deposited in a restricted marine environment at upper bathyal depths with dysoxic to anoxic bottom conditions.

In core 10.A.057, palynological biostratigraphy indicates that Zone V6 is absent, either due to erosion or non-deposition, therefore the Paleocene–Eocene Thermal Maximum is not preserved at this location. A hiatus with V6 missing was noted in the Lillebælt area (Heilmann-Clausen *et al.* 1985), supporting the Femern Bælt data. However it is possible that Zone V6 is found in the missing core interval between 79.42 and 73.36 m.

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