

# Palynology of the Lower Eocene deposits of northwest Jutland, Denmark

PI SUHR WILLUMSEN



Willumsen, P.S. 2004–12–15: Palynology of the Lower Eocene deposits of northwest Jutland, Denmark. *Bulletin of the Geological Society of Denmark*. Vol. 52, pp. 141–157, Copenhagen. © 2004 by Geological Society of Denmark. ISSN–6297.

Early Eocene spores and pollen assemblages from the uppermost part of the Stolle Klint Clay and the overlying Fur Formation are diverse and well preserved. The terrestrial microflora comprises 42 species of spores and 108 species of pollen and four spores and pollen zones are established i.e. *Interpollis velum-Labrapollis globosus*, *Basopollis atumenscens*, *Basopollis orthobasalis* and *Thomsonipollis magnificus* zones. The zones are directly correlated to the existing tephrochronology and stratigraphy. The dinoflagellate cysts assemblages are referred to Zones 6 and 7 of Heilmann-Clausen or the upper part of the *Apectodinium hyperacanthum* and *Glaphyrocysta ordinata* Interval Biozone of Powell. A marked shift in the terrestrial and marine palynomorph assemblages takes place at the transition between the two oldest spore and pollen zones at c. 1.2 m below ash layer –19b.

**Keywords:** Palynology, early Eocene, spores and pollen, Stolle Klint Clay, Fur Formation, tephrochronology, biostratigraphy, correlation.

*Pie Suhr Willumsen [pi.willumsen@geo.uio.no], Department of Geosciences, University of Oslo, P.O. Box 1047, Blindern, NO-0316 Oslo, Norway.*

Palynological studies in Denmark of the Upper Paleocene and Lower Eocene strata have mainly focused on organic-walled marine microplankton or dinoflagellate cysts (Hansen 1979; Heilmann-Clausen 1982, 1985, 1988, 1994). Calcareous micro- and nannofossils in the sediments from the Paleocene–Eocene transition in Northwest Europe are sparse whereas palynomorphs are frequent and palynological zonation is the prime biostratigraphical tool for dating of the Paleocene–Eocene succession (Schröder 1992; Heilmann-Clausen 1994).

The excellent preserved palynomorph assemblages and relatively high sedimentation rate during the deposition of the Lower Eocene Fur Formation provide an excellent basis for a high-resolution palynological study of this interval (Willumsen 1997, 1998). In Denmark, Krutzsch (1966) examined early Eocene spores and pollen assemblages, but the Stolle Klint Clay and Fur Formation were not studied in detail nor correlated to the existing tephrochronology established by Bøggild (1918) and Gry (1960). Krutzsch (1966) found that the Stolle Klint Clay and Fur Formation contain a low diversity microflora. This study, however, shows that spores and pollen assemblages recorded from the Stolle Klint Clay and Fur Formation are well preserved and diverse. Hence, the pur-

pose of this paper is to present the early Eocene terrestrial microflora and to establish a spores and pollen biozonation.

The spores and pollen assemblages are furthermore related to the established tephrochronology for Northwest Europe and to changes in the marine palynomorphs, mainly dinoflagellate cysts, with the aim to establish an integrated regional palynological zonation for the early Eocene in Denmark. Relation to early Eocene environmental changes is also discussed.

## Lower Eocene sediments in Denmark

In Denmark, the Lower Eocene sediments are referred to the Ølst Formation, the Stolle Klint Clay and Fur Formation. The Lower Eocene sediments are exposed as coastal cliffs and in quarries in northern Jylland, Denmark (Fig. 1A, B). The sediments accumulated in a relatively offshore position within the North Sea Basin.

The Paleocene–Eocene Series boundary is placed

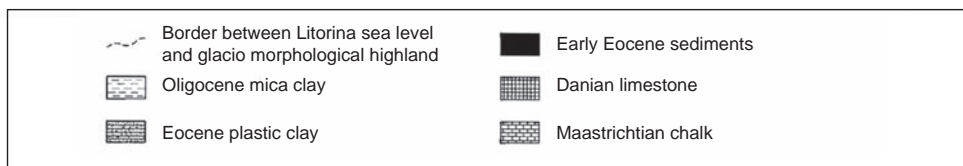
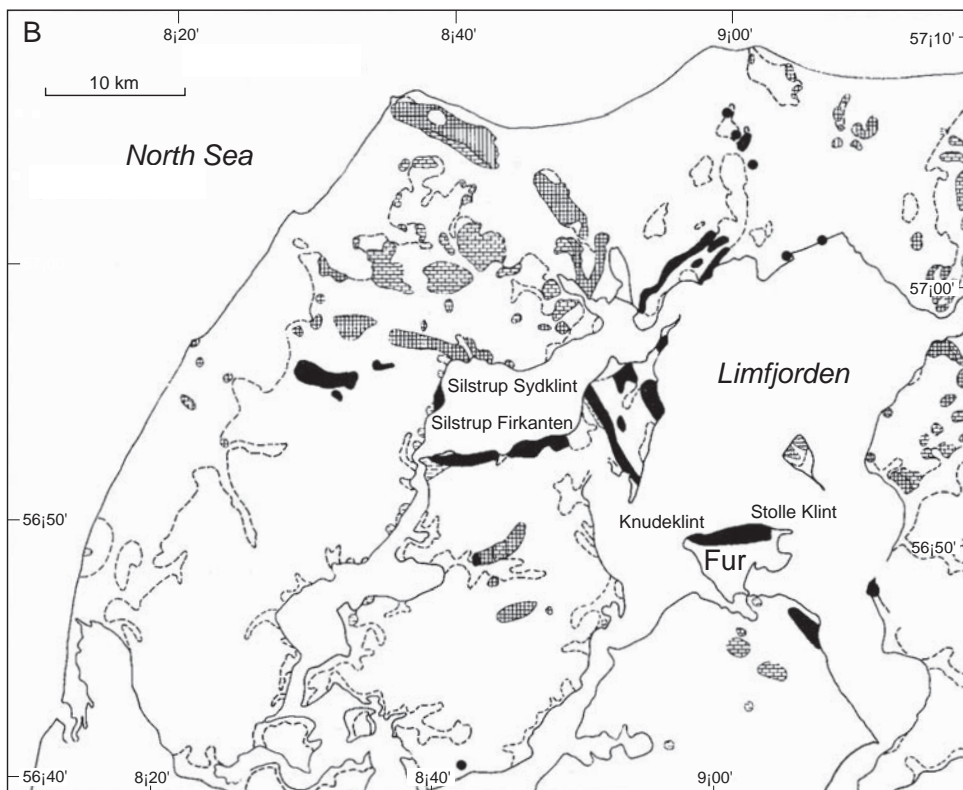


Fig. 1A. Location map showing the main localities mentioned in the text  
 Fig. 1B. Limfjorden area and the distribution of the Lower Eocene deposits. Stolle Klint, Firkanten Silstrup and Silstrup Sydclint locations are shown. The geological map is from Klint & Pedersen (1995).

Chron	Series	Stages	Nannoplankton Zones Martini 1971	Volcanic phases Knox, 1997	Ash layers Bøggild, 1918	Denmark onshore NNW Heilmann-Clausen (1995) Björkslev & Heilmann-Clausen (1986) Beyer <i>et al.</i> (2001)	Denmark onshore SEE	Central North Sea Knox and Holloway (1992)	England South-East Beyer <i>et al.</i> (2001)	Heilmann-Clausen (1985) Dinoflagellate Zones	Powell (1992) Dinoflagellate Zones	Spore and pollen Zones This study
24r	Early Eocene	Ypresian	NP11	2.2c		Knudshoved Mb						? ? ? ?
					+130							Thomsonipollis magnificus Zone
			NP10	2.2b	+118	Silstrup Mb	Vårum Mb	Balder Formation	London Clay Formation	Zone 7	Glyphyrocysta ordinata Interval Biozone (Gor)	Basopollis orthobasalis Zone
					+1	Fur Formation		Sele Formation	Harwich Formation			Basopollis atumenscens Zone
				2.2a	-19b	Knudeklint Mb						Basopollis atumenscens Zone
					-33		Haslund Mb					Interpollis velum - Labrapollis globosus Zone
			NP9	2.1	-39	Stolle Klint Clay			Woolwich & Reading beds	Zone 6	Apeccidinium agglutatum Interval Biozone (Aal)	
25n	Paleocene	Thanetian					Glaucanitic Silt		Upnor Formation	Zone 5		
25r							Østerrende Clay					
26n			NP8			Holmehus Formation		Lista Formation	Thanet Formation			

Fig. 2. Lithostratigraphic relationships and correlation of the Lower Eocene Stolle Klint Clay and the Fur Formation with other lower Eocene formations from south-eastern Denmark, Central North Sea and south-eastern England. Nannofossils are not present in the Stolle Klint Clay and Fur Formation and correlations to the nannofossil Zones of Martini (1971) are based on indirect evidence.

at the base of the late Paleocene negative carbon excursion (CIE) or below the magnetic Chron 24r (ISPS Newsletter No. 9, November 2000). In Denmark, the Upper Paleocene Glaucanitic Silt Unit was deposited during Chron 25n and the overlying Østerrende Clay during Chron 25r. Accordingly, the Paleocene–Eocene boundary in Denmark is recorded at the top of the Glaucanitic Silt Unit or at the base of the Stolle Klint Clay (Beyer *et al.* 2001) (Fig. 2).

*Stolle Klint Clay.* Stolle Klint Clay is dark-grey, fine-laminated clay with organic material; ash layers are present and the ash layers –34 to –39 occur in the Stolle Klint Clay (Bøggild 1918; Gry 1960). The Stolle Klint Clay is up to c. 15 m thick. It conformably overlies the Paleocene Østerrende Clay or unconformable the Holmehus Formation and the boundary is usually marked by the Glaucanitic Silt Unit; it is overlain by the Fur Formation. It constitutes the lower part of the Haslund Member of the Ølst Formation (Heilmann-Clausen 1995, fig. 12). The Stolle Klint Clay has also been referred to as Unfossiliferous Clay (Hansen 1979).

Pedersen & Surlyk (1983) placed the sediments of the Stolle Klint Clay in the Fur Formation, but Heilmann-Clausen *et al.* (1985) found that the sediments containing the ash layers –34 to –39 should be con-

sidered as a separate lithological unit i.e. the Stolle Klint Clay (Fig. 2).

*Fur Formation.* The type locality for the Fur Formation is Knudeklint on the western side of the Fur (Pedersen & Surlyk 1983) (Fig. 1A). The Fur Formation is c. 60 metre thick; it is a dark-grey to light-grey diatomite, which turns clayey white to light yellowish during weathering. Numerous alternating black to grey volcanic ash layers intersect the diatomite (Pedersen & Surlyk 1983). The known occurrences of the diatomite are limited to the east, north and west by structural highs (Fig. 1B).

The Fur Formation is subdivided into the lower Knudeklint Member and upper Silstrup Member (Pedersen & Surlyk 1983; Heilmann-Clausen *et al.* 1985).

The characteristic diatomite and interbedded dark ash layers are glacially folded and thrust faulted and brought into their present position during the Saalian to late Weichselian ice advances (Gry 1940, 1964, 1979; Pedersen & Surlyk 1983; Klint & Pedersen 1995; Pedersen 1996). The detachment of the dislocation is situated below the base of the Fur Formation in the plastic clay at depth of 80–100 m (Pedersen 1996).

The two contemporaneous facies: the clayey diatomite (Stolle Klint Clay and Fur Formation) and mudstone (Ølst Formation) deposited in the Danish

part of the North Sea Basin (Heilmann-Clausen *et al.* 1985; Michelsen *et al.* 1998; Beyer *et al.* 2001) (Fig. 2). Beyer *et al.* (2001) showed that the Ølst Formation is equivalent to the magnetic chron C24r. This indicates that the Ølst Formation (and Stolle Klint Clay and Fur Formation) deposited in *c.* 1.1 Ma.

The Stolle Klint Clay, Fur and Ølst formations are correlated to the upper Sele and the lower Balder formations in the Central North Sea and Upnor Formation, Woolwich and Reading beds, Harwich Formation and the lower to middle part of the London Clay Formation in southeast England (Fig. 2; Knox & Harland 1979; Heilmann-Clausen *et al.* 1985; Knox & Holloway 1992; Beyer *et al.* 2001).

## The study area

Stolle Klint Clay and Fur Formation are exposed in the coastal cliffs of the Limfjorden, northwest Jutland and three of these coastal cliffs were examined in this study (Fig. 1B).

The lower boundary of the Fur Formation is exposed at the Stolle Klint. Here, the clayey white to light yellow diatomite of the Fur Formation overlies dark-grey, slightly calcareous, silty clay with few, thin ash layers of the Stolle Klint Clay. The transition from the top of the Stolle Klint Clay and into the basal part of the Fur Formation was examined at Stolle Klint in this study (Fig. 3).

## Tephrochronology

Bøggild (1918) and Gry (1960) established the high-resolution tephrochronology in the Stolle Klint Clay and Fur Formation. The ash layers are divided into a 'negative ash series' numbered -39 to -1 and a 'positive ash series' numbered +1 to +140.

The Knudeklint Member of Fur Formation includes the 'negative ash series' down to -33 and the 'positive ash series' from +1 to +140 belongs to the Silstrup Member of the Fur Formation (Pedersen & Surlyk 1983; Heilmann-Clausen *et al.* 1985). The uppermost part of the Fur Formation *i.e.* from the base of ash layer +1 to ash layer +140 is exposed at Silstrup Sydsklint in the western part of the Limfjorden area (Fig. 1B).

Four volcanic phases within the nannoplankton interval NP9–NP10 of the North Sea Basin are recognized (Knox 1997). The phases are related to regional tectonic events including regional uplift of the NE Atlantic margin accompanied by uplift of the

southern North Sea area and onset of pyroclastic activity in the Greenland-Faeroes Province (Fig. 2). The ash layers can be recognized over long distances (Knox 1989, 1992, 1996, 1997; Egger *et al.* 2000). The two distinct ash layers -17 and +19 are preserved in the borehole at the Wursterheide, North Germany. They have also been identified in the Hales and Harwich members in the lowest part of the London Clay Formation, onshore U.K., and in cores from the Deep Seas Drilling Project borehole 550 in the East Atlantic (Berggren *et al.* 1995) (Fig. 1A).

Tephrochronology is important in the dating of the sediments at the Paleocene–Eocene transition in Northwest Europe. Ash layer -17 in the Fur Formation has been traced to various locations in Northwest Europe and the North Atlantic region (Berggren *et al.* 1995) and it has been dated radiometrically to 54.5–55.0 Ma (Swisher & Knox 1991; Wing *et al.* 1991).

Correlation of the ash layers in Denmark with the ash layers in the East Atlantic DSDP 550 borehole allows for correlation of the oceanic nannoplankton biozones and the magnetic chronostratigraphy to the North Sea area (Fig. 1A). The interval from ash layer -17 to ash layer +19 has been assigned to the lower third of NP10 Zone and to the lower half of the magnetic Chron C24r (Berggren *et al.* 1995; Knox 1997).

## Palaeoenvironment

The clayey diatomite of the Stolle Klint Clay and Fur Formation accumulated below wave base and with several shifts between anaerobic and aerobic bottom conditions (Pedersen 1981; Pedersen & Surlyk 1983). The dominance of neritic benthic diatoms indicates that water depth did not exceed 50 m (Fenner 1994; Mitlehner 1996). A high number of land-derived fossils including insects, plants and birds, have been collected from the diatomite probably reflecting a relative nearshore depositional position (Larsson 1975; Pedersen & Surlyk 1983; Willmann 1990; Møller Andersen & Andersen 1996). Northerly winds probably caused upwelling in a nearly landlocked sea and the diatomite accumulated (Bonde 1974, 1979, 1987). This sea was connected to the Atlantic Ocean through a narrow seaway between Norway and Scotland. Local structures probably put a limit the lateral distribution of diatomite in the north-western part of Jutland (Pedersen & Surlyk (1983). Danielsen & Thomsen (1997) found that the regional depositional model proposed by Bonde (1974, 1979, 1987) could explain the occurrence of 1 to 15 m thick beds of diatomitic sediments in the Danish part of the North Sea Basin.

## Material and methods

80 samples collected from the three coastal outcrops, Stolle Klint, Silstrup, Firkanten and Silstrup Sydklint were examined (Figs 1B, 3). The tephrochronology and geological profiles of Bøggild (1918) and Gry (1940, 1964, 1979) were used to correlate the sample series from the three localities (Fig. 3). Samples were collected from c. 2.5 m below ash layer -34 to c. 4.2 m above ash layer +118 (Willumsen 1997, 1998). Ash layer +138 was established in the Silstrup Sydklint.

The sample spacing is 1 m and Figure 3 shows the position of the collected samples in relation to the ash layers and lithostratigraphy.

All the samples were processed for palynology following the procedure presented by Willumsen (1997). 3–4 grams of sediment were treated with cold HCL (10%) in 1 hour followed by a treatment in cold HF with a concentration of 40% for a minimum of eight days. After removal of the HF 10% cold HCL was added and the sample was left for an hour before it was centrifuged and the HCL decanted. Treat-

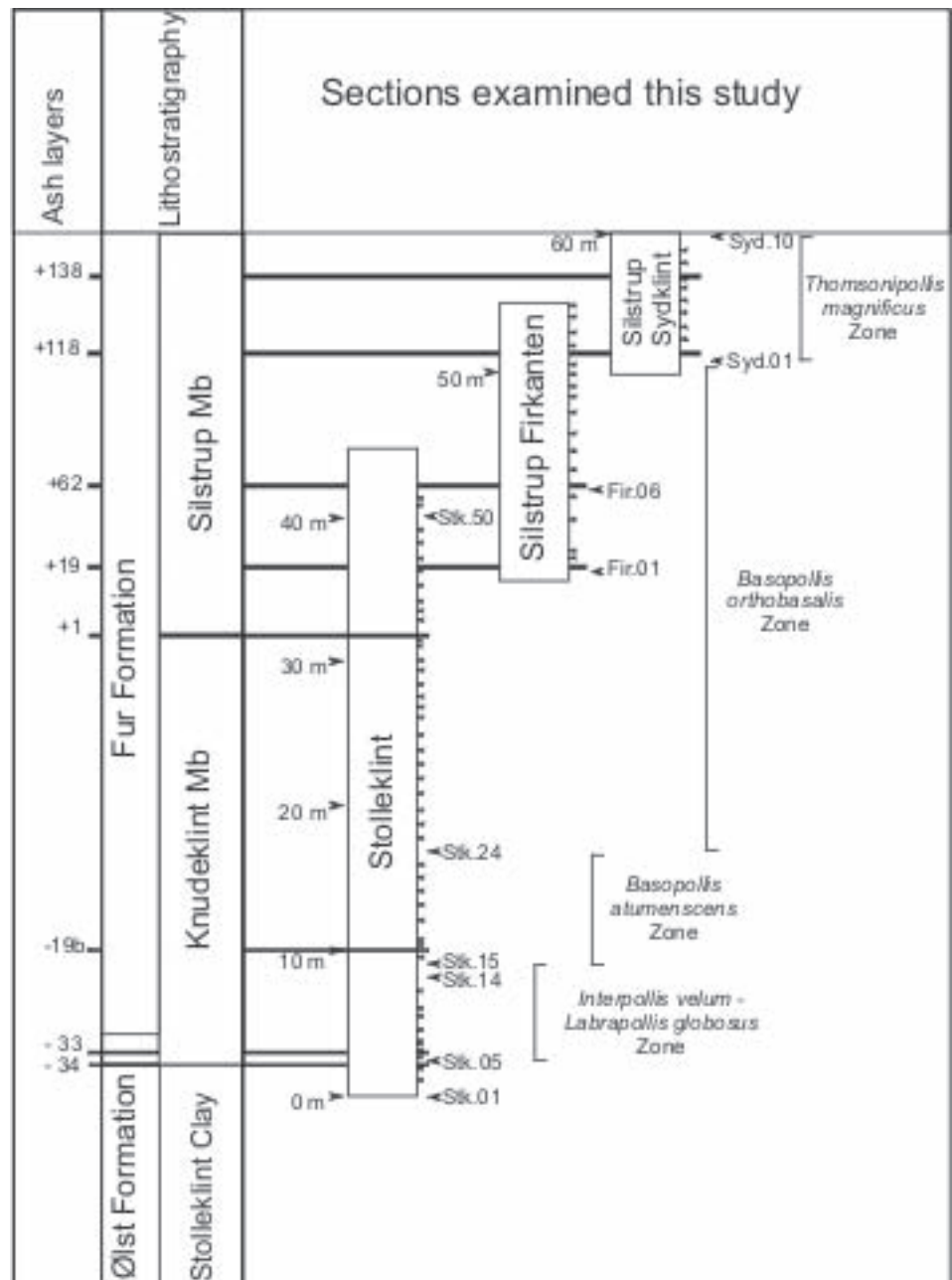


Fig. 3. Position of the 80 samples collected in the Stolle Klint, Firkanten Silstrup and Silstrup Sydklint sections. The stratigraphical oldest collected sample is Stk. 01 and is the base of this study. Six of the stratigraphical lowest samples are from the uppermost part of the Stolle Klint Clay and 74 samples are from the Fur Formation. The positions of the most distinct ash layers are indicated.

ment with 10% KOH for 1–2 minutes was carried out on all samples after the HF and HCL had been removed. Heavy liquid separation and weak oxidation in *c.* 2 minutes in a 36% nitric acid were carried out on 10 samples. The organic debris was sieved through 6 mm filters and mounted in glycerine oil on microscope slides.

All occurrence data are based on examination of two to three palynological slides per sample. The spore and pollen content was counted in 23 samples. The counted 23 samples were selected based on their individual stratigraphical distance of maximal 3 to 4 metres. The samples from Silstrup and Firkanten were not counted due to the overall sparse terrestrial assemblages recovered in the palynological slides from this locality. The sparse spores and pollen assemblages prohibited correlation to intervals with overlapping sample series. These intervals are from the lower and upper part of the sample series from the Silstrup, Firkanten (samples Fir.01–08 and samples Fir.15–18) to the top of the Stolle Klint (samples Stk.47–52) and the lower part of the Silstrup Sydklint (samples Syd 01–04). Figure 5 shows the interval with sparse spores and pollen assemblages (marked by an asterisk).

A minimum of 250 spores and pollen were counted on species level in 23 samples. Spores and pollen that could not be referred to a distinct species are classified as trilete spores, undetermined disaccate pollen and other pollen.

Alete azonala pollen such as *Inaperturopollenites concedipites* (Wodehouse, 1933; Krutzsch, 1971) and *Inaperturopollenites hiatus* (Potoniè, 1931; Thomson & Pflug 1953) are collected into one morphological group: *Inaperturopollenites* spp. The morphological characteristics of these pollen species are few and therefore are considered as one major group.

The marine algae including the dinoflagellate cysts were counted along with the terrestrial palynomorphs. The dinoflagellate cysts are divided into the following five groups or species: *Apectodinium* group includes all the *Apectodinium* species observed except the species *A. augustum*. The species *Apectodinium augustum* and *Deflandrea oebisfeldensis* were counted. The *Glaphyrocysta* group includes all the observed *Glaphyrocysta* and *Areoligera* species. The remaining dinoflagellate cysts are lumped into one group: other dinoflagellate cysts.

The brackish-water algae *Pediastrum* is only observed in sample Stk.01, which is the stratigraphically oldest sample investigated in this study. All other observed algae are considered to be of marine origin. The relative frequency of the marine contra terrestrial palynomorphs is estimated by adding all the palynomorphs counted in each of the 23 samples

counted. This number was then used to divide number of the spores and pollen counted in each of the 23 samples.

The palynological slides, remaining residues and samples are deposited at the Department of Geology, University of Aarhus, Denmark. The palynological slides with illustrated specimens (Plates 1 and 2) are stored at the Geological Museum, Copenhagen, Denmark (catalogue numbers MGUH 27024 to 27050).

## Biostratigraphy

The samples yield a diverse and well-preserved terrestrial flora composed of 42 species of spores and 108 species of pollen (Appendix I). Characteristic species of spores, pollen and dinoflagellate cysts are shown on Plate 1 and Plate 2. The terrestrial microflora is divided into four spores and pollen zones, which are defined below.

*Facing page:*

Plate 1.

Fig. 1. *Cicatricosisporites dorogensis*, Stk.10, slide 1-2 (H20, 2) MGUH 27024.

Fig. 2. *Verrucatosporites favus* Syd.02, slide 1-1 (J40, 4) MGUH 27034.

Fig. 3. *Podocarpidites libellus* Stk.20, slide 1-1 (E28, 1) MGUH 27047.

Fig. 4. *Zonalapollenites minimus* Syd.10, slide 1-3 (K30, 1-3) MGUH 27033.

Fig. 5. *Pitysporites labdacus* Stk.10, slide 1-2 (F33, 2; 4, E33) MGUH 27025.

Fig. 6. *Pitysporites alatus* Stk.10, slide 1-2 (E24, 3; 1, F24) MGUH 27026.

Fig. 7. *Zonalapollenites minimus* Stk.36, slide 1-1 (E28, 2) MGUH 27037.

Fig. 8. *Tricolporopollenites quercoides* Stk.05, slide 1-1 (Q20, 3) MGUH 27046.

Fig. 9. *Podocarpidites eocaenicus* Stk.39, slide 1-1 (S20, 4) MGUH 27049.

Fig. 10. *Zonalapollenites maximus* slide Stk.32, slide 1-1 (E20, 4; E21, 3) MGUH 27048.

Fig. 11. *Basopollis atumenscens* Stk.16, slide 1-1 (G22, 1) MGUH 27041.

Fig. 12. *Basopollis basalis* Stk.36, slide 1-1 (N23, 2) MGUH 27038.

Fig. 13. *Tricolporopollenites messelensis* Fir.02, slide 1-1 (L34, 1) MGUH 27050.

Fig. 14. *Basopollis orthobasalis* Stk.36, slide 1-1 (P20, 1) MGUH 27039.

Fig. 15. *Caryapollenites circulus* Stk.10, slide 1-2 (L25,4; 3, L26) MGUH 27027.

Fig. 16. *Caryapollenites triangulus* Stk.10, slide 1-1 (G26, 3) MGUH 27030.

Plate 1

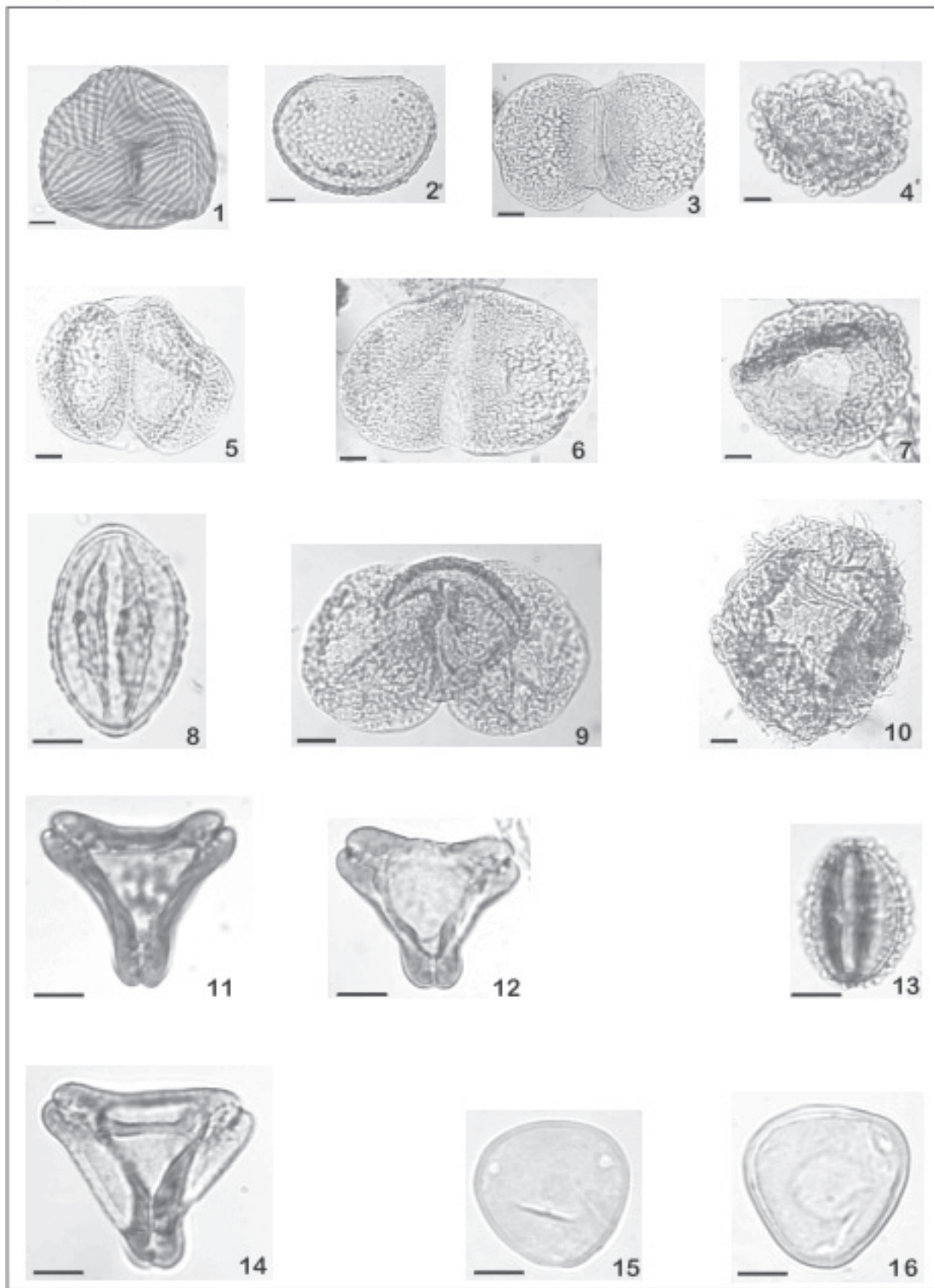
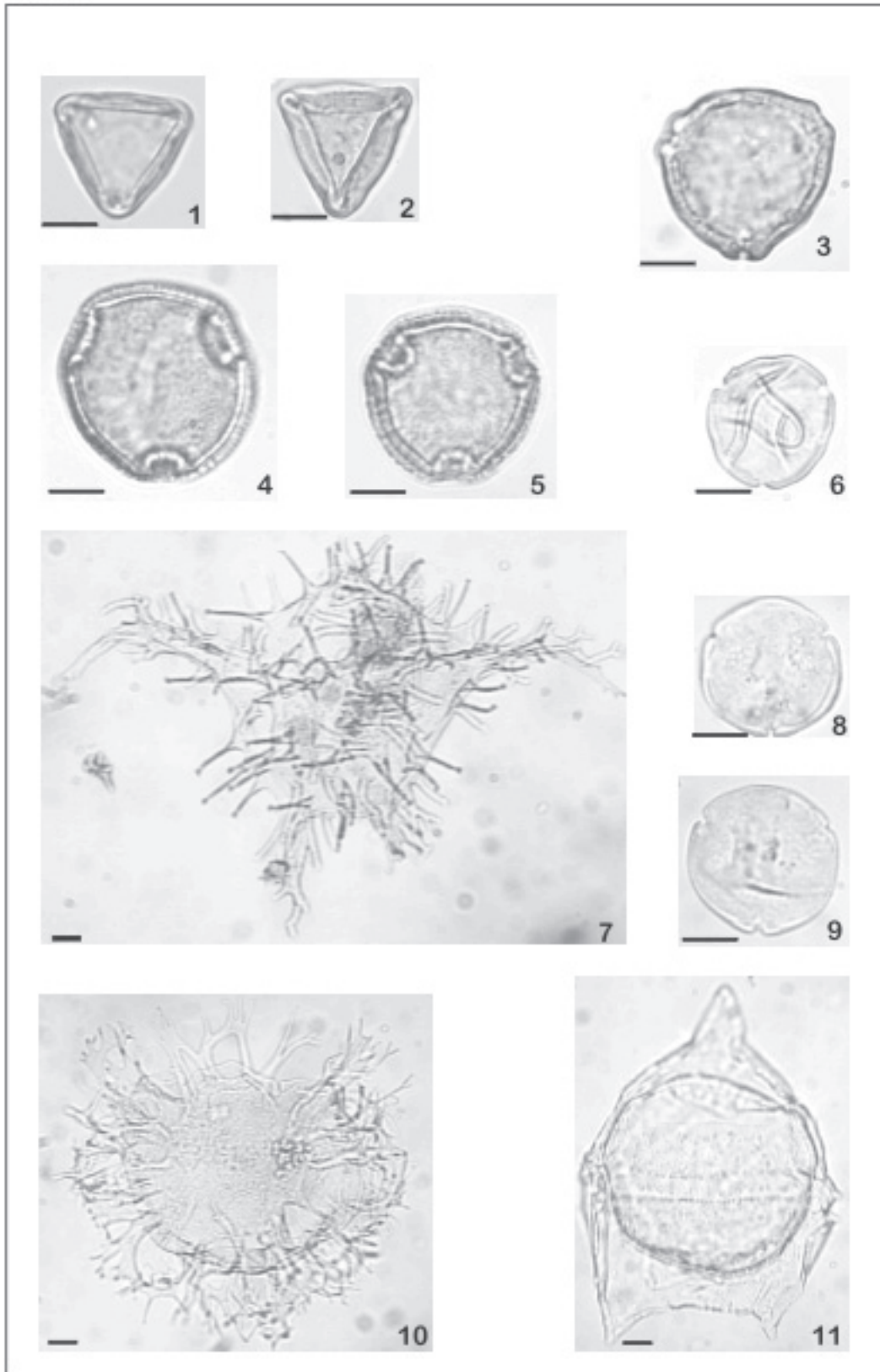


Plate 2





## *Interpollis velum* - *Labrapollis globosus* Zone

**Definition.** The base of this spores and pollen zone is placed above the last occurrence of *Tricolporopollenites querciodes* at 0.4 m below ash layer -33 (sample Stk.05). The top of the zone is placed at the first occurrence of *Basopollis atumenscens* at 1.2 meters below ash layer -19b.

**Characteristics.** The *Interpollis velum* - *Labrapollis globosus* Zone ranges from above sample Stk.05 to Stk.15 (Figs 4–5). *Interpollis velum* has its last occurrence in the middle part of the zone (Stk.10) and *Labrapollis globosus* is relatively abundant in the lower part of the zone. *Interpollis microsuplicingensis* and *Platycaryapollenites platycaryoides* are also relatively common within the zone. The relative frequency of triporate pollen is high in the lower to middle part of the interval due to an increase in relative abundance of *Caryapollenites circulus* and *C. triangulus*. The *Inaperturopollenites* spp. group is also common. Disaccate pollen are very rare (<2% of the relative amount of spores and pollen).

The last occurrence of the dinoflagellate cyst species *Apectodinium augustum* is at 2.2 m below ash layer -19b (sample Stk.14), but in the lower part of this interval this species comprises between 10–20% of the total dinoflagellate cysts counted. The genus *Apectodinium* is very abundant (>30% of total amount of dinoflagellate cyst assemblage) throughout the lower to middle part of the *Interpollis velum* - *Labrapollis globosus* Zone. The *Apectodinium* spp. group comprises >40% of the total dinoflagellate cyst encountered the interval below the *Interpollis velum* -

Facing page:

Plate 2.

Fig. 1. *Interpollis microsuplicingensis* Stk.02, slide 1-1 (O29, 2; 1, O30) MGUH 27044.

Fig. 2. *Interpollis velum* Stk.02, slide 1-1 (Q22, 2; 1, Q23) MGUH 27045.

Fig. 3. *Tripoporopollenites robustus* Stk. 16, slide 1-1 (T14, 4) MGUH 27042.

Fig. 4. *Thomsonipollis magnificus* Syd.09, slide 1-2 (F28, 3) MGUH 27035.

Fig. 5. *Thomsonipollis magnificus* Syd.09, slide 1-1 (S28, 2) MGUH 27036.

Fig. 6. *Platycaryapollenites platycaryoides* Stk.10, slide 1-1 (S25, 4; S26, 3) MGUH 27031.

Fig. 7. *Apectodinium augustum* Stk.10, slide 1-1 (E24, 4) MGUH 27032.

Fig. 8. *Labrapollis globosus* Stk.10, slide 1-2 (H25, 1) MGUH 27028.

Fig. 9. *Labrapollis globosus* Stk.10, slide 1-1 (J33, 3) MGUH 27029.

Fig. 10. *Glaphyrocysta ordinata* Stk.36, slide 1-1 (N28, 3) MGUH 27040.

Fig. 11. *Deflandrea oebisfeldensis* Stk.16, slide 1-1 (F24, 1) MGUH 27043.

*Labrapollis globosus* Zone (from sample Stk.05 to Stk.01).

**Reference section.** Stolle Klint section, Fur, Denmark. Uppermost part of the Stolle Klint Clay and lower part of the Knudeklint Member of the Fur Formation.

**Correlation and age.** The spores and pollen assemblages (previously dated as late Paleocene) are earliest Eocene in age. The microflora assemblage correlates with 19.4 Subzone of Schröder (1992) and with Pg. Zone 9 of Krutzsch (1966). Krutzsch's (1966) spores and pollen Pg. Zone 9 correlates to Meyers (1988, 1989) zones SP3/Wu2 (Figs 4, 5). The last occurrence of the dinoflagellate cyst index species *A. augustum* at the top of the *I. velum* - *L. globosus* Zone also suggests equivalence to the upper NP9 to lower NP10 zones (Powell 1992; Heilmann-Clausen 1994; Egger *et al.* 2000).

## *Basopollis atumenscens* Zone

**Definition.** The base of this zone is placed at the first occurrence of *Basopollis atumenscens*. The top of the zone is defined by the first occurrence of *Basopollis orthobasalis*.

**Characteristics.** Pollen belonging to the morphological pollen group disaccates and the genus *Inaperturopollenites* are relative abundant in the lower part of this zone (Fig. 5). *Labrapollis globosus* has its last occurrence in the lower part of the zone. *Tripoporopollenites robustus* has its first constant occurrence in the lowermost part of the zone. *Podocarpidites libellus*, *Podocarpidites eocaenicus*, *Pityosporites alatus*, and *Pityosporites labdacus* have their first occurrences directly below the base of the zone within the topmost samples in the underlying *Interpollis velum*-*Labrapollis globosus* Zone (Sample Stk.12–14). Disaccate pollen is a common to abundant part of the assemblages from the *Basopollis atumenscens* Zone and this is in contrast to the underlying *L. velum*-*L. globosus* Zone. *Zonalapollenites maximus* occurs sporadically in the upper part of the *Basopollis atumenscens* Zone.

*Deflandrea oebisfeldensis* is increasingly abundant in the lower part of the zone. This acme interval of *D. oebisfeldensis* (>25% of total marine palynomorphs) is succeeded by a high relative abundance of *Glaphyrocysta* spp. (Fig. 5).

**Reference section.** The Stolle Klint section, Fur, Denmark; the lower part of the Knudeklint Member in the Fur Formation.

Series	Krutzsch 1966 Northern Middle Europe	Meyer 1988 Northwest Europe	Meyer 1989 Wursterheide North Germany	Schröder 1992 North Sea		Nannofossil zones Martini 1971	This study Denmark		
Eocene	Pg. 18 Zeitzer Bild Pg. 17 Etzdorfer Bild Pg. 16 Borklener Bild	SP5	Wu5	Zones	Subzones	NP12			
	Pg. 15 Helmstedter Bild Pg. 14 Hu-Ho Bild	SP4c	Wu4						
	Pg. 13b Bild der Helmstedter	SP4b Upper SP4b Lower	Wu3c Wu3b	20				NP10-11	Thomsonipollis magnificus Zone
	Pg. 13a Hu-Bild	SP4a	Wu3a						Basopollis orthobasalis Zone
	Pg. 12 Reistedter Bild Pg. 11 Epirolis-Bild Pg. 10 Helle-Bild								Basopollis atumenscens Zone Interpollis velum- Labrapollis gibbusus Zone
Paleocene	Pg. 9 Sangerhäuser Bild Pg. 8 Brandenburger Bild Pg. 7b Wesener Bild	SP3	Wu2	19	4 3 2 1	NP9			
	Pg. 7a Hannoversches Bild Pg. 6 Schwarze-Minna-Bild Pg. 5 Roda-C-Bild								
	Pg. 4 Roda-B-Bild Pg. 3 Roda-A-Bild Pg. 2 Eislebener Bild Pg. 1 Zahnaer Bild							SP2	Wu1

Fig. 4. Correlation of the spores and pollen assemblage zones presented herein with the European spores and pollen zonations (Krutzsch 1966; Meyer 1988, 1989) and North Sea palynological zonation (Schröder 1992).

*Correlation and age.* The spores and pollen zone is correlated to Schröder's (1992) Zone 20 and Meyer's (1988, 1989) zones SP4A/Wu3a (Figs 4–5). The first occurrence of *Basopollis atumenscens* is according to Krutzsch (1966) in the Eocene Pg. 10–11 Zone and this corresponds well with observations made in this study. The last occurrence of *A. augustum* directly below the base of the *Basopollis atumenscens* Zone indicates that this zone correlates to the lower part of the calcareous nannoplankton NP10 Zone (Powell 1992). High abundances of *Deflandrea oebisfeldensis* have been recorded elsewhere from lower Eocene sediments in the North Sea area, but it is not a regional stratigraphic event (De Coninck (1993).

### *Basopollis orthobasalis* Zone

*Definition.* The base of this zone is defined as the first occurrence of *Basopollis orthobasalis* (Fig. 5). The top of the zone is placed at the first occurrence of the index fossil *Thomsonipollis magnificus*.

*Characteristics.* *Zonalapollenites maximus* and *Z. minimus* have their first consistent occurrence in the lower part of this zone. The relative abundance of

*Inaperturopollenites* spp. and *Caryapollenites* spp. increases in the middle to upper part of the zone (Fig. 5). *Tricolporopollenites messelensis* has only been observed in the middle to lower part of the zone. The abundance of terrestrial palynomorphs decreases up through the interval from ca. 60% to <3% of the total amount of palynomorphs (Fig. 5). The uppermost part of the interval from samples Stk.50 to Syd.01 can not be characterised on the basis of spores and pollen, because dinoflagellate cysts dominate the palynological assemblages. Especially, *Glaphyrocysta* spp. dominate in the lower part of the interval, where this group comprises 25–70% of the palynomorphs. The relative abundance of *D. oebisfeldensis* is below 20% throughout this interval (Fig. 5).

*Reference section.* The Stolle Klint section, Fur, Denmark; the upper part of the Knudeklint Member and lower to middle part of the Siltrup Member.

*Correlation and age.* The first occurrence of the *Basopollis orthobasalis* is correlated to the Eocene Pg. zones 11–13a/b of Krutzsch (1966) or upper part of SP4a or SP4b lower/Wu3a-b zones of Meyer (1988, 1989). The terrestrial microflora from ash layer +62 to +118 is very sparse and shows little resemblance with the

zonations of Krutzsch (1966) and Meyer (1988, 1989). The dinoflagellate cyst assemblage is correlated to the dinoflagellate cyst Zone 7 of Heilmann-Clausen (1985) and the *G. ordinata* Interval Biozone of Powell (1992).

**Remarks.** Roche (1983) used the last occurrence of *B. autumescens*, *B. basalis* and *B. orthobasalis* to define subzones within the Paleocene–Eocene transition in Belgium. *Basopollis autumescens* and *B. basalis* have their last occurrence at the top of lower Landénian (NP9) and *B. orthobasalis* has last occurrence at the top of upper Landénian (NP10) (Roche 1983).

### Thomsonipollis magnificus Zone

**Definition.** The base of this zone is defined by the first occurrence of *Thomsonipollis magnificus*. The top of this zone was not observed in this study, but is tentatively placed at the last occurrences of *Thomsonipollis magnificus*.

**Characteristics.** Spores are relatively abundant, especially *Cicatricosisporites dorogensis*. *Inaperturopollenites* spp. is also abundant in this interval.

*Deflandrea oebisfeldensis* is very abundant (>20% of the total marine flora) (Fig. 5). *Apectodinium parvum* and *A. quinquelatum* reappear in the *T. magnificus* Zone, but are a relatively rare part of the total marine microflora (0.5–1.5%) compared with the underlying *Apectodinium* acme interval within the *Interpollis velum* - *Labrapollis globosus* spores and pollen Zone. The marine microflora from the Silstrup Member has been correlated to the dinoflagellate cyst Zone 7 of Heilmann-Clausen (1985, 1994) and the *G. ordinata* Interval Biozone of Powell (1992).

**Reference section.** Silstrup Sydklint locality, Fur, Denmark; the uppermost part of the Silstrup Member. This spores and pollen zone may reach into overlying stratigraphically younger deposits and the top of the zone is only tentatively defined.

**Correlation and age.** The first occurrence of *T. magnificus* is used to define the base of Subzone Wu3b

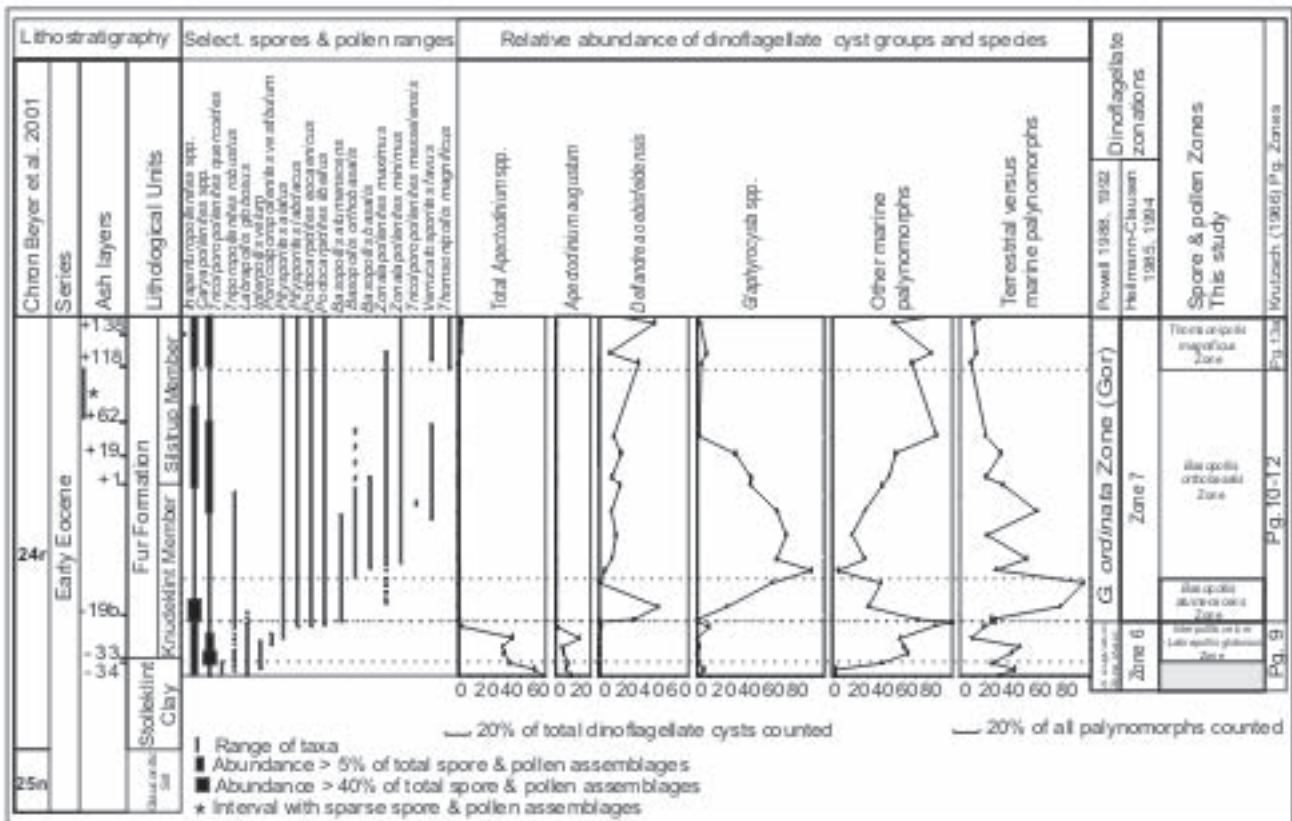


Fig. 5. Stratigraphic range of selected spores and pollen species from the three Danish localities. The relative frequency of selected dinoflagellate cyst is shown as the relative abundance of the total number of marine algae counted. The position of the most distinct ash layers are indicated and the absolute thickness of the individual ash layer are schematic.

in Meyer's (1989) threefold subdivision of the Eocene Wu3 pollen Zone from the Wursterheide borehole, NW Germany (Figs 1, 4). Furthermore, Krutzsch (1966) states that the genus *Thomsonipollis* is the most important index fossil in his Pg. 13a spores and pollen Zone. *Thomsonipollis magnificus* is a relatively rare part of the spores and pollen assemblage. In contrast, it is relative abundant in Krutzsch's overlying Pg. 13b spores and pollen Zone.

In the Fur Formation *T. magnificus* is a relative very rare part of the spores and pollen assemblage (>2%) and this interval directly below ash layer +118 to above +138 is correlated to Krutzsch's Pg. 13a Zone. The *T. magnificus* zone has also been correlated to SP4b Zone of Meyers (1988) and Wu3b Zone in the Wursterheide borehole (Meyer 1989). In the Wursterheide borehole the SP4b Zone/Wu3b zones have been correlated to the nannoplankton zones NP12 (Meyers 1988, 1989).

## Flora patterns

The species *Basopollis atumenscens*, *Basopollis orthobasalis* and *Thomsonipollis magnificus* in the Normapolles group are biostratigraphic significant in the spores and pollen assemblages from lower Eocene sediments in Denmark. This result corresponds to previous observations from NW Europe and the United States of America (Krutzsch 1960; Tschudy 1973, 1981; Frederiksen 1979; Roche 1983; Meyer 1988, 1989). The first occurrence of *Thomsonipollis magnificus* in the Danish area is in the early Eocene. Previously, *T. magnificus* has been recorded in contemporaneous deposits from Northwest Germany; Central Europe and United States (Krutzsch 1960; Tschudy 1973; Meyer 1989) (Fig. 1a). The genus *Thomsonipollis* is typical of the Eocene Pg. 13a pollen Zone (Krutzsch 1966) (Fig. 4). *Thomsonipollis magnificus* is also widely spread in Upper Cretaceous – Eocene sedimentary rocks of the Mississippi embayment region, southern Colorado and northern New Mexico and the United States of America (Tschudy 1981; Frederiksen 1979). Tschudy (1981) suggested that *T. magnificus* originated in North America in the Upper Cretaceous and then migrated to Europe by a North Atlantic or an arctic migration route during the Paleocene (Tschudy 1981).

## Changes in the marine palynomorphs assemblages

The dinoflagellate genus *Apectodinium* is very abundant from the top of the Stolle Klint Clay to the lowermost part of the Fur Formation i.e. the Knudeklint Member (samples Stk.01 to Stk.14) (Fig. 5). The last occurrence of the index fossil *Apectodinium augustum* is c. 0.5 m below ash layer –19b in the Fur Formation. This stratigraphic event coincides with a prominent drop in the abundance of *Apectodinium* spp.

The abundances of *Apectodinium quinquelatum* and *A. pavum* are relatively low in the Silstrup Member i.e. upper part of the Fur Formation (from above ash layer +114; sample Fir.15 to Fir.18 and sample Syd. 01 to Syd.10). Heilmann-Clausen (1982) did the same observation. Collinson *et al.* (2003) recorded abundance intervals of the genus *Apectodinium* in lower Eocene strata from the southern England. Crouch *et al.* (2001) also reported two intervals with relative high abundance *Apectodinium* spp. in the lower Eocene sediments from New Zealand. Furthermore, the decrease in relative abundance of *Apectodinium* spp. and concurrent increase in *Glaphyrocysta* spp. in the interval around ash layer –19b is succeeded relatively abrupt by *D. oebisfeldensis*. This change in the marine palynomorph assemblage takes place within a succession of 6 m in the Stolle Klint section (samples Stk.15 to Stk.24; Figs 3, 5). The relative abundance of *D. oebisfeldensis* varies and two intervals with dominance of *D. oebisfeldensis* are separated by an acme interval of *Glaphyrocysta* spp. (Fig. 5).

The most pronounced change in the marine microflora occurs around ash layer –19b, where the observed decrease in *Apectodinium* spp. and the concurrent increase in *D. oebisfeldensis* are distinct. Egger *et al.* (2000) recorded a similar Eocene acme interval of *Apectodinium* spp. from the Rhenodanubian Flysch at Anthering, near Salzburg, Austria. In the Rhenodanubian Flysch, as well as in the present study, the relative abundance of *Apectodinium* exceeds 60% of the total amount of dinoflagellate cysts. Regular occurrence of the species *Apectodinium augustum* is also restricted to the same interval as the acme of the genus *Apectodinium*. In the Fur Formation, the interval with abundant *Apectodinium* spp. is located below ash layer –19b, which is within the Knudeklint Member. The interval corresponds to the onset of the global dinoflagellate cyst event that has been observed at the Paleocene–Eocene thermal maximum (PETM) (Bujak & Brinkhuis 1998; Crouch *et al.* 2001, 2003).

In lower Eocene sediments from Denmark the bloom of *Apectodinium* spp. is succeeded by an interval with abundant *Glaphyrocysta* spp., which is in contrast to the observations of Tawanui, New Zealand,

where a peak of *Glaphyrocysta* spp. precedes the first bloom of *Apectodinium* spp. at the Paleocene–Eocene thermal maximum (Crouch *et al.* 2001, 2003). Intervals with high relative abundance of *Apectodinium* spp. have been related to periods of lowered sea level by Thomas (1996), but Crouch *et al.* (2001, 2003) interpreted the bloom of dinoflagellate cyst assemblage in New Zealand as indication for a sea-level rise occurring at the Paleocene–Eocene thermal maximum (PETM). In the Fur Formation intervals of high relative abundance of the genus *Apectodinium* is not related to periods with relative higher abundance of terrestrial *versus* marine palynomorphs or changes in lithology.

Changes in the relative abundance of the species *Deflandrea oebisfeldensis* are related to local changes in the palaeogeography and palaeohydrography of the North Sea (de Coninck 1993). Furthermore, Bujak & Brinkhuis (1998) interpreted the shift in the North Sea from the dominating *Apectodinium* spp. assemblage to the assemblage dominated by *D. oebisfeldensis* as a change from warmer to cooler surface water. Data from the diatoms assemblages in the Fur Formation suggest that an environmental shift takes place at ash layer –20 and that the diatoms flora indicate relatively more shallow water conditions followed by a transgression in the upper part of the negative ash series (Mitlehner 1996).

## Summary

The study of terrestrial microflora from the lower Eocene sediments in Denmark is based on 80 samples collected from the uppermost part of the Stolle Klint Clay and the Fur Formation. The examined samples come from three different coastal outcrops in the Limfjorden area i.e. Stolle Klint, Silstrup Firkanten and Silstrup Sydklint. The samples yield a record of excellent preserved early Eocene palynological assemblages. Several changes in both the terrestrial and marine microflora are used to subdivide the lower Eocene sediments into four spores and pollen zones: *Interpollis velum* - *Labrapollis globosus*, *Basopollis atumenscens*, *Basopollis orthobasalis* and *Thomsonipollis magnificus* zones. The zones are correlated directly with the established tephrochronology and lithostratigraphy (Bøggild 1918); Gry 1940, 1965, 1979; Pedersen & Surlyk 1983; Heilmann-Clausen 1985, 1995; Nielsen & Heilmann-Clausen 1986; Beyer *et al.* 2001).

Figure 4 shows correlation of the four spores and pollen zones to the Palaeogene spores and pollen zonations in Europe. The range and relative abun-

dance of key species of spores, pollen and dinoflagellate cysts are related to the tephrochronology, lithostratigraphy and other palynological zonations (Fig. 5).

The two stratigraphically oldest spores and pollen zones, *Interpollis velum*-*Labrapollis globosus* and *Basopollis atumenscens* Zones, comprise the top of the Stolle Klint Clay and the lower part of the Knudeklint Member in the Fur Formation. The overlying *Basopollis orthobasalis* Zone spans the upper part of the Knudeklint Member and the lower part of the Silstrup Member in the Fur Formation. The base of the youngest *Thomsonipollis magnificus* Zone comprises the upper part of the Silstrup Member of the Fur Formation.

The most pronounced changes in both the terrestrial and marine microflora occurs in the interval around –19b or at the top of the *Interpollis velum*-*Labrapollis globosus* Zone. This spores and pollen zone corresponds to the upper part of the dinoflagellate Zone 6 of Heilmann-Clausen (1985, 1994) or the *A. augustum* Interval Biozone of Powell (1992).

The terrestrial microflora from the *Interpollis velum*-*Labrapollis globosus* Zone is correlated to Zone 19.4 of Schröder (1992), Pg. Zone 9 of Krutzsch (1966) and the uppermost part of Meyers (1988, 1989) SP3/Wu2 zones (Figs. 4, 5). The stratigraphically youngest spores and pollen zones, *Basopollis atumenscens*, *Basopollis orthobasalis* and *Thomsonipollis magnificus* zones corresponds to the dinoflagellate cyst zone *G. ordinata* Zone of Powell (1992) or Zone 7 of Heilmann-Clausen (1985, 1994). The microflora assemblages from the top of the *B. orthobasalis* Zone contain very few spores and pollen in relation to marine palynomorphs and this interval could therefore not be correlated to any of the established spores and pollen zonations shown in Figure 4. The top of the *B. orthobasalis* Zone is placed at the first occurrence of the index fossil *T. magnificus*. The *Basopollis atumenscens* and *Basopollis orthobasalis* zones are correlated to the following spores and pollen zones Pg. 10–12 of Krutzsch's (1966) and SP4a/Wu3a zones of Meyers (1988, 1989) (Fig. 4). The youngest spores and pollen zone the *Thomsonipollis magnificus* Zone, is correlated to Zone Pg. 13a of Krutzsch (1966) and SP4b/Wu36b/SP4b zones of Meyers (1989). The pollen *Thomsonipollis magnificus* is recorded within the upper part of the dinoflagellate cyst Zone 7 of Heilmann-Clausen (1985, 1994) or *G. ordinata* Interval Biozone of Powell (1992).

The first occurrence of the pollen species *Zonala-pollenites minimus* and *Z. maximus* is in the early Eocene. In North Europe the first occurrence of *Zonala-pollenites minimus* and *Z. maximus* has previously been considered to be from the upper Eocene to Oligocene (Krutzsch 1966; Hochuli 1984).

The last occurrence of *Apectodinium augustum* has in the past been used to define the Paleocene–Eocene boundary in the North Sea Basin (Schröder 1992; Heilmann-Clausen 1994; Mudge & Bujak 1996). In the present study the last occurrence of *A. augustum* is ca. 5.2 meters above ash layer –33 (sample Stk.14) and according to the new definition of the Paleocene–Eocene boundary the last occurrence of *A. augustum* is now in the earliest Eocene (Beyer *et al.* 2001).

This study shows that species belonging to the pollen genus *Basopollis* are stratigraphically useful in the Danish lower Eocene sediments. This observation corresponds well with the Paleocene and Eocene strata from Belgium (Roche's 1983), where the Normapolles group such as *Basopollis basalis*, *B. atumescens*, *B. orthobasalis*, *Interpollis supplingensis*, *Nudopollis endangulatus*, *Plicapollis pseudoexelsus* contribute to determine the precise position of the Paleocene–Eocene boundary.

## Acknowledgements

I am grateful to Kaj Raunsgaard Pedersen, University of Aarhus (AU), for his supervision of this M. Sc. Project. Claus Heilmann-Clausen (AU) is thanked for many enlightening discussions of the Paleocene–Eocene transition. Bitten Larsen (AU) is thanked for her assistance with the laboratory and fieldwork. Karen Dybkjær from the Geological Survey of Denmark and Greenland is thanked for her comments to an early version of this paper. The bulletin referees Gunver Krarup Pedersen, University of Copenhagen and Jonathan Bujak, Lexis Group, are thanked for their careful reviews of this paper.

## Appendix I

(Species are listed alphabetically)

*Abiespollenites latisaccatus* (Trevisan 1967) Krutzsch 1971  
*Anacolosidites efflatus* (Potonié 1934) Cookson & Pike 1954  
*Arecipites eopapillosus* Krutzsch 1977  
*Baculatisporites nanus* subsp. *robustoides* Krutzsch 1967  
*Baculatisporites primarius* (Wolff 1934) Thomson & Pflug 1953  
*Baculatisporites quintus* (Thomson & Pflug 1953) Krutzsch 1967  
*Basopollis atumescens* (Pflug 1953)  
*Basopollis basalis* Pflug 1953  
*Basopollis orthobasalis* (Pflug 1953) Pflug 1953  
*Bombacacidites reticulatus* Krutzsch 1961  
*Brosipollis striatobrosus* (Krutzsch 1961) Krutzsch 1968  
*Camarozonosporites camarozonosporites* subsp. *decorus* (Wolff 1934) Krutzsch 1959

*Camarozonosporites hamulatisporites* subsp. *rarus* (Doktorowicz-Hrebnnicka 1960) Krutzsch 1963  
*Caryapollenites circulus* (Pflug 1953) Krutzsch 1961  
*Caryapollenites simplex* (Potonié 1931) Potonié 1960  
*Caryapollenites triangulus* (Pflug 1953) Krutzsch 1961  
*Cedripites lusaticus* Krutzsch 1971  
*Celtipollenites intrastructurus* (Krutzsch & Vanhoorne 1977)  
*Compositoipollenites medius* Krutzsch & Vanhoorne 1977  
*Compositiopollenites rhizophorus* (Potonié 1934) Potonié 1960  
*Conbaculatisporites trichopunctatus* (Thiergart 1949) Klaus 1960  
*Cicatricosisporites dorogensis* Potonié & Gelletich 1933  
*Cicatricosisporites* sp. 1  
*Cicatricosisporites* sp. 2  
*Cycadopites microfollicularis* Krutzsch 1970  
*Emmapollis pseudoemmaensis* Krutzsch 1970  
*Ephedripites* spp.  
*Ericipites callidus* (Potonié 1931) Krutzsch 1970  
*Extrapunctatosporites microalveolatus* Krutzsch 1967  
*Foveotriletes triangulus* Krutzsch 1962  
*Hydrosporites levis* Krutzsch 1962  
*Illexpollenites iliacus* (Thiergart 1937) Potonié 1960  
*Illexpollenites margaritus* (Potonié 1931) Thiergart 1937 ex.  
*Inaperturopollenites concedipites* (Wodehouse 1933) Krutzsch 1971  
*Inaperturopollenites hiatus* (Potonié 1931) Thomson & Pflug 1953  
*Interpolis microsuplicingensis* (Pflug 1953) Krutzsch 1961  
*Interpollis velum* Krutzsch 1960  
*Intratrirporopollenites microreticulatus* Mai 1961  
*Intratrirporopollenites minimus* Mai 1961  
*Intratrirporopollenites pseudoinstructus* Mai 1961  
*Ischyosporites fovearis* Krutzsch 1967  
*Ischyosporites microfovearis* Krutzsch & Vanhoorne 1977  
*Labrapollis globosus* (Pflug 1953) Krutzsch 1968  
*Laevigatosporites discordatus* Pflug 1953  
*Laevigatosporites gracilis* Wilson & Webster 1946  
*Laevigatosporites haardti* subsp. *haardti* Krutzsch 1967  
*Laevigatosporites haardti* subsp. *haardtoides* Krutzsch 1967  
*Laevigatosporites nutidus* subsp. *nutidus* (Mameza 1969) Krutzsch 1967  
*Leiotriletes maxoides* subsp. *maxoides* Krutzsch 1962  
*Leiotriletes maxoides* subsp. *minoris* Krutzsch 1962  
*Leiotriletes sinuosoides* Krutzsch 1959  
*Leiotriletes triangulatoides* Krutzsch 1962  
*Leiotriletes triangulus* Krutzsch 1962  
*Leiotriletes wolffi* subsp. *wolffi* Krutzsch 1962  
*Liriodendropollis semiverrucatus* subsp. *minor* Krutzsch 1970  
*Magnolipollis neogenicus* subsp. *minor* Krutzsch 1970  
*Magnolipollis neogenicus* subsp. *neogenicus* Krutzsch 1970  
*Mikrofoveolatosporites neogranuloides* Krutzsch 1967  
*Milfordia hungaricus* (Kedves 1965) Krutzsch & Vanhoorne 1977  
*Monocolpopollenites tranquillus* (Potonié) Thomson & Pflug 1953  
*Neogenisporites neogenicus* Krutzsch 1962  
*Neogenisporites plicatooides* Krutzsch 1962  
*Neogenisporites pseudoneddeni* Krutzsch 1962  
*Nudopollis endangulatus* Pflug 1953  
*Nudopollis terminalis* subsp. *hastatifformis* Pflug 1953  
*Nupharipollenites* sp. 1 Mohr 1984  
*Nupharipollenites* sp. 2 Potonié 1934  
*Nyssapollenites kruschi* subsp. *accessorius* (Potonié 1934) Potonié, Thomson & Thiergart 1950 ex. Simoncsics 1969  
*Nyssapollenites kruschi* subsp. *analepticus* (Potonié 1934) Nagy 1969  
*Pentapollenites pentangulus* (Pflug 1953) Krutzsch 1958

*Periporopollenites stigmus* (Potonié 1931) Thomson & Pflug 1953  
*Pityosporites alatus* (Potonié 1931) Thomson & Pflug 1953  
*Pityosporites labdacus* (Potonié 1931) Thomson & Pflug 1953  
*Pityosporites miroinsignis* Krutzsch 1971  
*Pityosporites microalatus* (Potonié 1931) Thomson & Pflug 1953  
*Platycaryapollenites miocaenicus* Nagy 1969  
*Platycaryapollenites platycaryoides* (Roche 1969) Kedves 1982  
*Platycaryapollenites semicyclus* Krutzsch & Vanhoorne 1977  
*Plicapollis pseudoexcelsus* (Krutzsch 1958) Krutzsch 1961  
*Plicatopollis plicatus* (Potonié 1934) Krutzsch 1962  
*Pompeckjoidaepollenites subhercynicus* (Krutzsch 1954) Krutzsch 1967  
*Polypodiidites secundus* subsp. *parasecondus* (Potonié 1934) Krutzsch 1963  
*Podocarpidites eocaenicus* Krutzsch 1971  
*Podocarpidites libellus* (Potonié 1931) Krutzsch 1971  
*Polyporopollenites undulosus* (Wolff 1934) Thomson & Pflug 1953  
*Polyvestibulopollenites versus* (Potonié 1931) Thomson & Pflug 1953  
*Porocolpopollenites rarobaculatus* Thiele-Pfeiffer 1980  
*Porocolpopollenites vestibulum* (Potonié 1931) Thomson & Pflug 1953  
*Pistillipollenites laevigatus* Krutzsch & Vanhoorne 1977  
*Radialisporites radiatus* (Krutzsch 1959) Krutzsch 1967  
*Retitriletes altranftensis* Krutzsch 1963  
*Retitriletes pseudoclavatus* Krutzsch 1963  
*Retitriletes robustoides* Krutzsch 1963  
*Retitriletes rueterbergensis* subsp. *rueterbergensis* Krutzsch 1963  
*Rousea monilifera* Fredriksen 1980A  
*Sciadopityspollenites serratus* (Potonié & Venitz 1934) Raatz 1937  
*Sequoiapollenites largus* (Kemp 1949) Manum 1962  
*Sparganiaceapollenites cuvillieri* (Gruas-Cavagnetto 1966)  
*Sparganiaceapollenites reticulatus* Krutzsch & Vanhoorne 1977  
*Stereisporites strictus* subsp. *woelfersheimensis* (Krutzsch 1959) Krutzsch 1963  
*Subtriporopollenites anulatus* subsp. *nanus* Pflug & Thomson 1953  
*Subtriporopollenites constans* subsp. *constans* Pflug 1953  
*Subtriporopollenites constans* subsp. *magnus* Krutzsch 1961  
*Subtriporopollenites constans* subsp. *medius* Krutzsch & Vanhoorne 1977  
*Subtriporopollenites magnoporatus* (Thomson & Pflug 1953) Krutzsch 1961  
*Subtriporopollenites subporatus* Krutzsch 1961  
*Tetracolporopollenites manifestus* subsp. *contractus* Pflug 1953  
*Tetracolporopollenites occultus* Thomson & Pflug 1953  
*Tetracolporopollenites sapotoides* Thomson & Pflug 1953  
*Tetracolporopollenites* sp. 1 Thiele-Pfeiffer 1988  
*Thomsonipollis magnificus* (Thomson & Pflug 1953) Krutzsch 1960 emend. Christopher 1980  
*Toroisporis toroisporis* subsp. *neddeni* (Potonié 1931) Krutzsch 1959  
*Toroisporites toroisporis* subsp. *teupitzensis* Krutzsch 1962  
*Toroisporites toroisporis* subsp. *pessinensis* Krutzsch 1962  
*Triatriopollenites roboratus* Pflug 1953  
*Triatriopollenites rurensis* Thomson & Pflug 1953  
*Triatriopollenites subtriangulus* (Stantley) Fredriksen 1979  
*Triplanosporites microsinosus* Thomson & Pflug 1953  
*Triplanosporites sinomaxoides* Krutzsch 1962  
*Triletes multivallatus* (Pflug 1953) Krutzsch 1959  
*Tricolpopollenites liblarensis* (Thomson in Potonié, Thomson & Thiergart 1950) Thomson & Pflug 1953  
*Tricolpopollenites retiformis* Thomson & Pflug 1953

*Tricolpopollenites vegetus* (Potonié 1934) Krutzsch 1959  
*Tricolporopollenites cingulum* Thomson & Pflug 1953  
*Tricolporopollenites europaeus* Krutzsch & Vanhoorne 1977  
*Tricolporopollenites megareticulatus* Krutzsch & Vanhoorne 1977  
*Tricolporopollenites messelensis* Thiele-Pfeiffer 1988  
*Tricolporopollenites microreticingulum* Krutzsch & Vanhoorne 1977  
*Tricolporopollenites parmularius* (Potonié 1934) Krutzsch 1960  
*Tricolporopollenites querciodes* Krutzsch & Vanhoorne 1977  
*Tripoporopollenites palaeobetuloides* Krutzsch & Vanhoorne 1977  
*Tripoporopollenites rhenarus* (Thomson in Potonié, Thomson & Thiergart 1950) Thomson & Pflug 1953  
*Tripoporopollenites robustus* (Mörriger & Pflug, 1951) Thomson & Pflug 1953  
*Tripoporollentes* spp.  
*Trudopollis varioreticulatus* (Stelmak 1960) Zaklinskaya 1963 Thiele-Pfeiffer 1980  
*Verrucatosporites balticus* subsp. *major* Krutzsch 1967  
*Verrucatosporites favus* (Potonié 1931) Thomson & Pflug 1953  
*Zonalapollenites gracilis* Krutzsch 1971  
*Zonalapollenites maximus* (Raatz 1937) Krutzsch 1971  
*Zonalapollenites minimus* Krutzsch 1971

## References

- Berggren, W.A., Kent, D.V., Swisher, C.C. & Aubry, M-P. 1995: A revised Cenozoic geochronology and chronostratigraphy. In: Berggren, W.A., Kent, D.V., Swisher, C.C., Aubry, M-P. & Hardenbol, J. (eds): Geochronology Time Scales and Global Stratigraphic Correlation. Society of Economic Paleontologists and Mineralogist Special Publication 54, 129–212.
- Beyer, C., Heilmann-Clausen, C. & Abrahamsen, N. 2001: Magnetostratigraphy of the Upper Paleocene – Lower Eocene deposits in Denmark. Newsletter of Stratigraphy 39, 1–19.
- Bonde, N. 1974: Palaeoenvironment as indicated by the Mo-clay Formation (Lowermost Eocene of Denmark). Tertiary Times 2, 29–36.
- Bonde, N. 1979: Palaeoenvironment of the North Sea as indicated by the fish bearing Mo-clay deposit (Paleocene/Eocene) Denmark. Mededelingen van de Werkgroep voor Tertiaire en Kwartaire Geologie 16, 1–16.
- Bonde, N. 1987: Moler og fossiler – især fisk. Skamol, Nykøbing Mors, 52 pp.
- Bujak, P.B. & Brinkhuis, H. 1998: Global warming and dinocyst changes across the Paleocene/Eocene epoch boundary, 277–295. In: Aubry, M.-P., Lucas, P. & Berggren, W.A. (eds): Late Paleocene – Early Eocene climatic and biotic events in the marine/terrestrial records. Columbia University Press, New York.
- Bøggild, O.B. 1918: Den vulkanske Aske i Moleret. Danmarks Geologiske Undersøgelse II Række 33, 84 pp.
- Cepek, P. 1989: Das kalzitische Nannoplankton des Tertiär und der Keide aus der Forschungsbohrung Wursterheide (NW Deutschland). Geologisch Jahrbuch A 111, 403–430.
- Collinson, M.E., Hooker, J.J. & Gröcke, D.R. 2003: Cobham Lignite Bed and pene-contemporaneous macrofloras of southern England: A record of vegetation and fire across the Paleocene–Eocene Thermal Maximum. Geological Society of America Special Paper 369, 333–349.

- Crouch, E.M., Heilmann-Clausen, C., Brinkhuis, H., Morgans, H.E.G., Rogers, K.M., Egger, H. & Schmitz, B. 2001: Global dinoflagellate event associated with late Paleocene thermal maximum. *Geology* 29, 315–318.
- Crouch, E.M., Dickens, G.R., Brinkhuis, H., Aubry, A-P, Hollis, C.J., Rogers, K.M. & Visscher, H. 2003: The *Apectodinium* acme and terrestrial discharge during the Paleocene–Eocene Thermal maximum: new palynological, geochemical and calcareous nannoplankton observations at Tawanui, New Zealand. *Palaeogeography, Palaeoclimatology, Palaeoecology* 194, 387–403.
- Danielsen, M. & Thomsen, E. 1997: Paleocene/Eocene diatomite in wells in the eastern North Sea. In: Thomsen, E. & Schack Pedersen, S.A. (eds): *Geology and Palaeontology of the Mo-clay*. Geologisk Institut Aarhus University, Aarhus Geoscience 6, 19–24.
- De Coninck, J. 1993: Diachronism of the *Deflandrea Oebisfeldensis* acme towards the southern margin of the Belgian basin. *Bulletin de la Société belge de Géologie* 102, 105–115.
- Egger, H., Heilmann-Clausen, C. & Schmitz, B. 2000: The Paleocene/Eocene boundary interval of a Tethyan deep-sea section (Austria) and its correlation with the North Sea basin. *Bulletin Society Géologie du France* 171, 207–216. Séance spécialisée: SGF-APF-CFS, La limite Paleocene – Eocene en Europe, Paris, 19–20 janvier 1998.
- Fenner, J. 1994: Diatoms of the Fur Formation, their taxonomy and biostratigraphic interpretation. In: Nielsen, O.B. (ed.): *Lithostratigraphy and biostratigraphy of the Tertiary sequence from the Harre borehole, Denmark*, Aarhus Geoscience 1, 99–104.
- Frederiksen, N.O. 1979: Paleogene sporomorph biostratigraphy, northeastern Virginia. *Palynology* 3, 129–167.
- Gry, H. 1940: De Istektoniske Forhold i Moleret. *Meddelelser fra Dansk Geologisk Forening* 9, 586–627.
- Gry, H. 1964: Furs geologi. *Dansk Natur - Dansk Skole. Årskrift* 1964, 45–55.
- Gry, H. 1979: Beskrivelse til Geologisk Kort over Danmark. Kortbladet Løgstør. *Danmarks Geologiske Undersøgelser I Række* 26, 58 pp.
- Hansen, M. 1979: Age of the Mo-Clay Formation. *Bulletin of the Geological Society of Denmark* 27, 89–91.
- Heilmann-Clausen, C. 1982: The Paleocene–Eocene boundary in Denmark. *Newsletter of Stratigraphy* 11, 55–63.
- Heilmann-Clausen, C. 1985: Dinoflagellate stratigraphy of the uppermost Danian to Ypresian in the Viborg 1 borehole, central Jylland, Denmark. *Danmarks Geologiske Undersøgelser, Serie A* 7, 39 pp.
- Heilmann-Clausen, C. 1988: The Danish Subbasin. Palaeogene dinoflagellates. *A* 100, 339–43. In: Vinken, R. *et al.* (eds): *Northwest European Tertiary Basin. Results of the IGCP Project No. 124*. *Geologisch Jahrbuch*.
- Heilmann-Clausen, C. 1994: Review of Paleocene dinoflagellates from the North Sea Region. *GFF* 116, 51–53.
- Heilmann-Clausen, C. 1995: Palaeogene aflejring over danskekalken. In: Nielsen, O.B. (ed.): *Danmarks geologi fra kridt til i dag*. Aarhus Geoscience 1, 70–113.
- Heilmann-Clausen, C., Nielsen, O.B. & Gersner, F. 1985: Lithostratigraphy and depositional environments in the Upper Paleocene and Eocene of Denmark. *Bulletin of the Geological Society of Denmark* 33, 287–323.
- Hochuli, P.A. 1984: Correlation of middle and late Tertiary sporomorph assemblages. *Paléobiologie continentale, Montpellier* 14, 301–314.
- Klint, K.E & Pedersen, S.A.S. 1995: The Hanklit Glaciotectonic Thrust Fault Complex, Mors, Denmark. *Danmarks Geologiske Undersøgelse Serie A* 35, 30 pp.
- Knox, R.W.O'B. 1989: Mineralogy and stratigraphy of volcanic ash layers in Lower Palaeogene beds of the Wursterheide borehole, northern Germany. *Geologisch Jahrbuch A* 111, 217–231.
- Knox, R.W.O'B. 1992: Tephra layers as precise chronostratigraphical markers. In: Hailwood, E.A. & Kidd, R.B. (eds): *High resolution stratigraphy*. Geological Society of London, Special Publication 70, 169–186.
- Knox, R.W.O'B. 1996: Tectonic controls on sequence development in the Paleocene and Earliest Eocene of SE England: implications for North Sea stratigraphy. In: Hesselbo, S.P. & Parkinson, N.D. (eds): *Sequence stratigraphy in British Geology*, Geological Society of London, Special Publication 103, 209–230.
- Knox, R.W.O'B. 1997: The Late Paleocene to Early Eocene Ash layers of the Danish Mo-Clay (Fur Formation): stratigraphic and tectonic significance. *Aarhus Geoscience* 6, 7–11.
- Knox, R.W.O'B. & Harland, R. 1979: Stratigraphical relationships of the early Paleogene ash-Series of NW Europe. *Journal of Geological Society of London* 136, 463–470.
- Knox, R.W.O'B & Holloway, S. 1992: Palaeogene of the Central and Northern North Sea. Published by the British Geological Survey on behalf of the UK Offshore Operators Association. In: Knox, R.W.O'B & Cordey W.G. (eds): *Lithostratigraphic nomenclature of the UK North Sea, A1–A5*.
- Krutzsch, W. 1960: Über *Thomsonipollis magnificus* (Th. & Pf. 1953) n.fgen.n.comb. und Bemerkungen zur regionalen Verbreitung einiger Pollengruppen im älteren Paläogen. *Freiberger Forschungshefte* C86, Berlin, 54–65.
- Krutzsch, W. 1966: Die sporenstratigraphische Gliederung des Älteren Tertiär in nördlichen Mitteleuropa (Paläozän–Mittelo-oligozän). *Methodische Grundlagen und gegenwärtiger stand der untersuchungen. Abhandlungen des Zentralen Geologischen Institut* 8, 112–149.
- Krutzsch, W. 1971: Atlas der mittel- und jungtertiären dispersen Sporen- und Pollen – sowie er Mikroplanktonformen des nördlichen Mitteleuropas. Lieferung VI. *Deutscher Verlag der Wiss* 234 pp.
- Larsson, S.G. 1975: Palaeobiology and mode of burial of the insects of the Lower Eocene Mo-clay of Denmark. *Bulletin of the Geological Society of Denmark* 24, 193–209.
- Martini, E. 1971: Standard Tertiary and Quaternary calcareous nannoplankton Zonation. In: Farinacci, A. (ed.): *Proceedings of II Planktonic Conference, Roma 1970*. Volume II, Edizioni Tecnoscienza, 739–785.
- Meyer, K.J. 1988: Pollen und Spores. In: Vinken, R., Von Daniels, C.H., Gramann, F., Köthe, A., Knox, R.W.O'B., Kockel, F., Meyer, K.J. & Weiss, W. (eds): *The Northwest European Tertiary Basin: Results of the IGCP Project No.124*, *Geologisch Jahrbuch A* 100, 88–294.
- Meyer, K.J. 1989: Pollen und Sporen des Tertiär aus der Forschungsbohrung Wusterheide, NW-Deutschland. *Geologisch Jahrbuch A* 111, 523–539.
- Michelsen, O., Thomsen, E., Danielsen, M., Heilmann-Clausen, C., Jordt, H. & Laursen, G.V. 1998: Cenozoic sequence stratigraphy in the eastern North Sea. In: de Graciansky, P-C., Hardenbol, J., Jacquin, T. & Vail, P.R. (eds): *Mesozoic and Cenozoic sequence stratigraphy of European Basins*, Society of Economic Paleontologists and Mineralogist Special Publication 60, 91–118.



- Mithlener, A.G. 1996: Paleoenvironments in the North Sea Basin around the Paleocene–Eocene boundary: evidence from diatoms and other siliceous microfossils. In: Knox, R.W.O'B, Corfield, R.C., & Dunay, R.E. (eds): Correlation of the Early Paleogene in Northwest Europe, Geological Society Special Publication 101, 255–308.
- Mudge, D.C. & Bujak, J.P. 1996: An integrated stratigraphy for the Paleocene and Eocene of the North Sea. In: Knox, R.W.O'B, Corfield, R.C., & Dunay, R.E. (eds): Correlation of the Early Palaeogene in Northwest Europe, Geological Society Special Publication 101, 91–114.
- Møller Andersen, N. & Andersen, S. 1996: Kæmpemyre og andre danekræ fra Limfjordens askeserie. Studiet af en uddød insektfauna fra Danmarks Palæogen. *Naturens verden* 11/12, 417–432.
- Nielsen, O.B., Baumann, J., Deyu, Z., Heilmann-Clausen, C. & Larsen, G. 1986: The Tertiary section of borehole D. G. I. 83101, Østerrenden, Store Bælt, Denmark. In: Tyge Møller, J. (ed.): Twentyfive years of geology in Aarhus. *Geoskrifter* 24, 235–253.
- Pedersen, G.K. 1981: Anoxic events during sedimentation of a Palaeogene diatomite in Denmark. *Sedimentology* 28, 487–504.
- Pedersen, G.K. & Surlyk, F. 1983: The Fur Formation, a late Paleocene ash-bearing diatomite from northern Denmark. *Bulletin of the Geological Society of Denmark* 32, 43–65.
- Pedersen, S.A.S. 1996: Progressive glaciotectonic deformation in Weichselian and Palaeogene deposits at Feggeklit, northern Denmark. *Bulletin of the Geological Society of Denmark* 42, 153–174.
- Powell, A.J. 1988: A modified dinoflagellate cyst zonation for latest Paleocene and earliest Eocene sediments from the central North Sea. *Review of Palaeobotany and Palynology* 56, 327–344.
- Powell, A.J. 1992: Dinoflagellate cysts of the Tertiary System, 155–251. In: A. J. Powell (eds): A stratigraphic index of dinoflagellate cysts. Chapman & Hall, London.
- Roche, E. 1983: Les Normapolles du Paleocene et de L'eocone de Belgique stratigraphie et paleoecologie. *Physio-Géo* 6, 13–26.
- Schröder, T. 1992: A Palynological Zonation for the Paleocene of the North Sea Basin. *Journal of Micropalaeontology* 2, 113–126.
- Swisher, C.C. & Knox, R.W O'B. 1991: The age of Paleocene/Eocene boundary:  $^{40}\text{Ar}/^{39}\text{Ar}$  dating of the lower part of NP10, North Sea Basin and Danmark. IGCP Project 308 (Paleocene/Eocene boundary events), International Annual Meeting and Field Conference, 2–6 December 1991, Brussels, Abstracts with Program, 16.
- Thomas, J.E. 1996: The occurrence of the dinoflagellate cyst *Apectodinium* (Costa & Downie, 1976) Lentin & Williams 1977 in the Moray and Montrose Groups (Danian to Thanetian) of the UK central North Sea. In: Knox, R.W.O'B, Corfield, R.C., & Dunay, R.E. (eds): Correlation of the early Palaeogene in Northwest Europe. Special Publication of the Geological Society 101, 115–120.
- Tschudy, R.H. 1973: Stratigraphic distribution of significant Eocene palynomorphs of the Mississippi Embayment. U. S. Geological Survey Professional Paper 743-B, B1–B24.
- Tschudy, R.H. 1981: Geographic distribution and dispersal of Normapolles genera in North America. *Review of Palaeobotany & Palynology* 35, 283–314.
- Wing, S.L., Bown, T.M. & Obradovich, J.D. 1991: Early Eocene biotoc and climatic change in interior western North America. *Geology* 19, 1189–1192.
- Willmann, R. 1990: Insekten aus der Fur-Formation von Dänemark (Moler, ob. Paleozän/ unt. Eozän?). 1 Allgemeines. *Meyniana* 42, 14 pp.
- Willumsen, P.S. 1997: En palynologisk undersøgelse af den askeførende Fur Formation. Unpublished Cand. Scient. Thesis. Aarhus University, Denmark. 147 pp.
- Willumsen, P.S. 1998: Terrestrial and marine palynomorph assemblages from the Danish Fur Formation, at the Paleocene/Eocene transition. In: Rey, J. & Rochini, F. (eds): La limite Paléocène–Éocène en Europe: Événements et Corrélations. Séance spécialisée. Université Paul-Sabatier – Toulouse III, Laboratoire de Géologie sédimentaire et Paléontologie. *Strata Série* 1(9) 130–133.