

ANTHERING SECTION

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Topics:

Paleocene/Eocene-boundary section in a succession of deep-water turbidites and hemipelagites

Tectonic unit:

Rhenodanubian Flysch Zone

Lithostratigraphic units:

Rhenodanubian Group, Anthering Formation

Chronostratigraphic units:

Upper Paleocene to Lower Eocene

Biostratigraphic units:

Upper part of calcareous nannoplankton Zone NP9 to upper part of Zone NP10

Location:

Outcrops in the Kohlbachgraben near Anthering

Coordinates:

E 013° 01' 17", N 47° 53' 19"

References:

Heilmann-Clausen & Egger, 1997, Egger, Heilmann-Clausen & Schmitz (2000), Crouch et al. (2001), Egger et al. (2003), Huber et al. (2003), Egger & Brückl (2006), Iakovleva & Heilmann-Clausen (2007), Egger, Heilmann-Clausen & Schmitz (2009)

From the carpark at the Reinthal inn it is an approx. 10 minutes walk on a small road to the first outcrop of the section, which is located along the course of the Kohlbach creek (no trail!). We examine the section (Fig. A1.9) walking up-stream from the lower Eocene (NP10) to the uppermost Paleocene (NP9).

The Anthering section is located about 18 km to the north of the Untersberg section as the Anthering and Untersberg sections are separated by the thrust between the Northern Calcareous Alps and the Rhenodanubian Flysch zone, the original palinspastic distance between them must have been much greater than at present. However, reliable data on this distance are lacking.

The 250 m thick upper Paleocene to lower Eocene deposits of the Anthering section, spanning calcareous nannoplankton Zones NP9 and NP10. These sediments comprise the youngest part of the Rhenodanubian Group. This group was deposited on the continental rise to the south of the European plate, which was the main source for the siliciclastic detritus entering the basin. The section is composed of calcareous mud-turbidites with intervening hemipelagic claystone indicating a deposition below the calcite compensation depth. The general sedimentary record of the Anthering-section is typical for an abyssal plain facies. Paleo-water depth estimations by Butt (1981), using foraminifera assemblages, range between 3000 to 5000 m.

In the Eocene part (Anthering Formation) of the section, the turbidite succession is characterized by the predominance of graded silty marlstone, which form about 85% of the succession (Anthering Formation). Occasionally, these turbiditic marlstone layers overlie silty to sandy beds deposited from the same turbidity current. The turbidites usually display base-truncated Bouma-sequences. Turbidites displaying complete Bouma-sequences are very rare. Single turbidite layers can reach thicknesses up to 2 m. The finegrained sand-fraction represents, on average, 5% of the sedimentary rocks and exceptionally up to 10%. The fine-grained (silty-clayey) sediment displays carbonate contents of 29% to 53%. The clay fraction is dominated by smectite.

Common intercalations of hemipelagic claystone occur between the individual mud-turbidite beds. The hemipelagic claystones prove a position of the basin-floor below the local calcite compensation depth. They are devoid of carbonate and display sharp contacts to the turbiditic marls. Usually the claystones show a greenish to greyish colour (0.15 wt% organic carbon on average) with a large number of dark spots as indications of intensive bioturbation. Only in the middle part of the section (outcrop E and one layer in outcrop D) darkgrey homogeneous claystones with abundant pyrite framboids and relatively high contents of organic carbon (0,94 wt% on average) occur. These black shales indicate an oxygen deficient environment at the basin floor. As they occur together with bentonite layers, volcanism might have led to eutrophic conditions and high plankton productivity responsible for the anoxic conditions.

In the lowermost Eocene (Subzone NP10a) at the Anthering section, 23 layers of altered volcanic ash (bentonites)

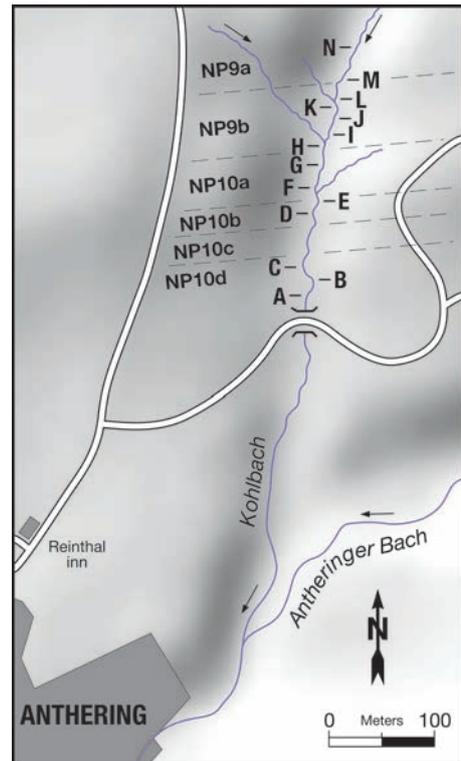


Figure A1.9 ▲
Location of outcrops and biostratigraphy of the Anthering section near Anthering

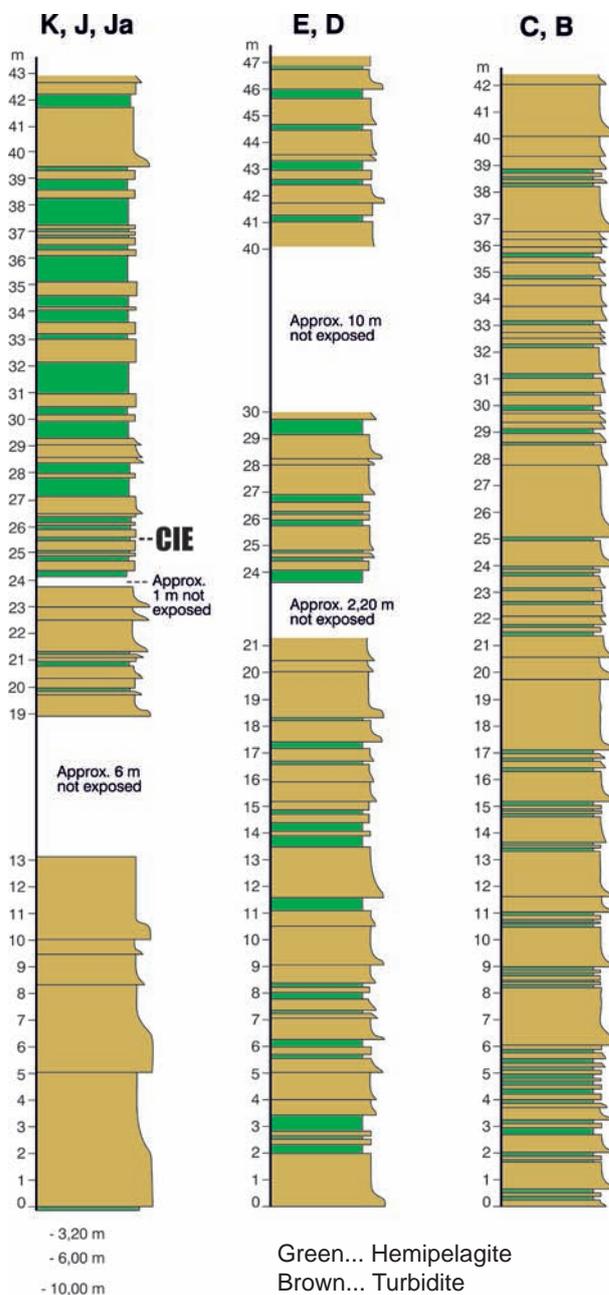
Figure A1.10 ▼
Photograph of Outcrop B





Figure A1.11 ▲
Detail outcrop B

Figure A1.12 ▼
Lithologic logs of outcrops at Anthering

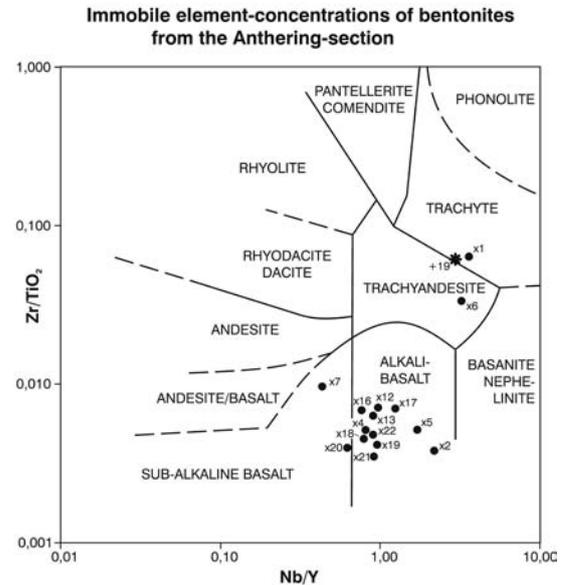
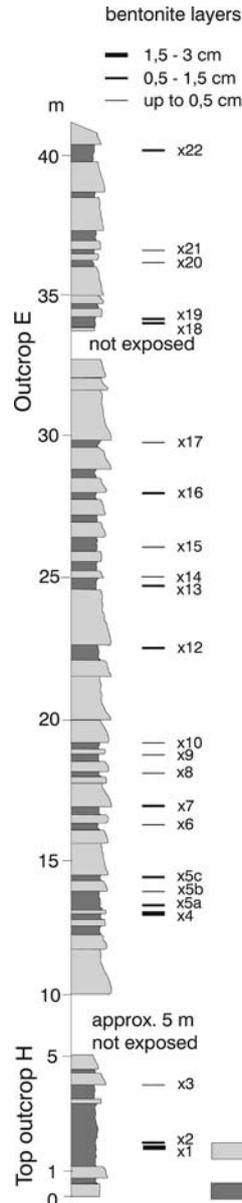


originating from the North Atlantic Igneous Province have been recorded, about 1,900 km away from the source area (Egger et al., 2000). The Austrian bentonites are between 1 mm and 30 mm thick and are considered to be distal equivalents of the “main ash-phase” in Denmark and the North Sea basin. Egger & Brückl (2006) have calculated the total eruption volume of this series as 21,000 km³, which occurred in 600,000 years. The most powerful single eruption of this series took place 54.0 million years ago (Ma) and ejected ca. 1,200 km³ of ash material which makes it one of the largest pyroclastic eruptions in geological history. The clustering of eruptions must have significantly affected the incoming solar radiation in the early Eocene by the continuous production of stratospheric dust and aerosol clouds. This hypothesis is corroborated by oxygen isotope values which indicate a global decrease of sea surface temperatures between 1–2°C during this major phase of explosive volcanism.

The Anthering section displays the global negative carbon isotope excursion (CIE) and the acme of the dinoflagellate species *Apectodinium augustum* in the upper part of zone NP9 (Heilmann-Clausen and Egger, 1997; Egger et al. 2000; Crouch et al., 2001). The onset of the CIE is characterized by the presence of the thickest hemipelagic layers of the entire Anthering Section. About 45% of the rock is claystone, whereas the average percentage of claystone in the overlying NP10 is only 14%, and even less in the lower part of NP9. The CIE-interval attains a thickness of 15 m, comprising turbidites and hemipelagites. The thickness of the turbidites varies between 0.08 m and 2.25 m, although only the thickest layer exceeds 1 m thickness. The average thickness of the turbidite beds is 0.39 m and sand-grade material, which makes up 2% of this facies, occurs only in the thickest layers. Excluding the turbidites the remaining thickness of hemipelagic claystone is 8.4 m. Using Fe- and Ca-intensity curves which probably represent precessional cycles, Röhl et al. (2000) calculated that the CIE interval lasted for 170 ky. From this, a hemipelagic sedimentation rate of 49 mmky⁻¹ has been calculated for the compacted sediment across the CIE.

This value is ca. six times higher than the hemipelagic sedimentation rate in the Paleocene (Egger et al., 2009b). The increased rate of hemipelagic sedimentation at the CIE suggests a high input of siliciclastic suspension into the basin. At the level of the CIE clay mineral assemblages of hemipelagic claystone display a distinct increase of smectite and kaolinite at the expense of illite and chlorite (Egger et al., 2002). This indicates a decrease of bedrock erosion in the adjoining land areas. Well-developed smectitic soils with a mixture of kaolinite are mostly restricted to subtropical climates with a well-marked dry season (see Thiry, 2000 for a review). During the rainy season continental erosion of such areas is very pronounced (see van der Zwan, 2002, for a review) and will result in a strong increase in hemipelagic sedimentation rates (Schmitz et al., 2001).

Enhanced erosion of land areas around the CIE-interval can also be inferred from the composition of calcareous nannoplankton assemblages. Whereas, in general, reworked Cretaceous species form only 2–3% of the calcareous nannoplankton assemblages. Substantial Cretaceous admixtures are present in many samples from across the CIE (Fig. A1.15). The oldest nannoplankton assemblage showing a high percentage (>50%) of reworked specimens originates from a turbidite bed 22 m below the onset of the CIE. Three metres above the onset of this geochemical marker, the youngest assemblage with a similar percentage of reworked Cretaceous specimens has been found.



Sample (ppm)	Nb	Zr	Y	TiO ₂
x1	146.0	486.0	40.0	7673
x2	33.0	244.0	15.0	63887
x4	28.0	238.0	36.0	46700
x5a	40.0	225.0	22.0	49700
x6	154.0	490.0	45.0	14000
x7	26.0	615.0	60.0	37000
x12	27.0	254.0	28.0	35696
x13	31.0	213.0	33.0	34028
x16	30.0	222.0	39.0	32360
x17	28.0	225.0	22.0	31786
x18	36.1	258.4	44.4	34432
x19	33.8	254.4	34.5	34342
x20	33.6	252.8	51.9	39103
x21	29.9	218.8	32.8	37819
x22	35.1	308.0	40.0	39954
+19(Fur)	121.0	684.0	42.0	11300

Figure A1.13 ▲ Log of outcrop E showing positions of bentonites and immobile element-concentrations of bentonites



Figure A1.14 ► Two bentonite layers at outcrop E

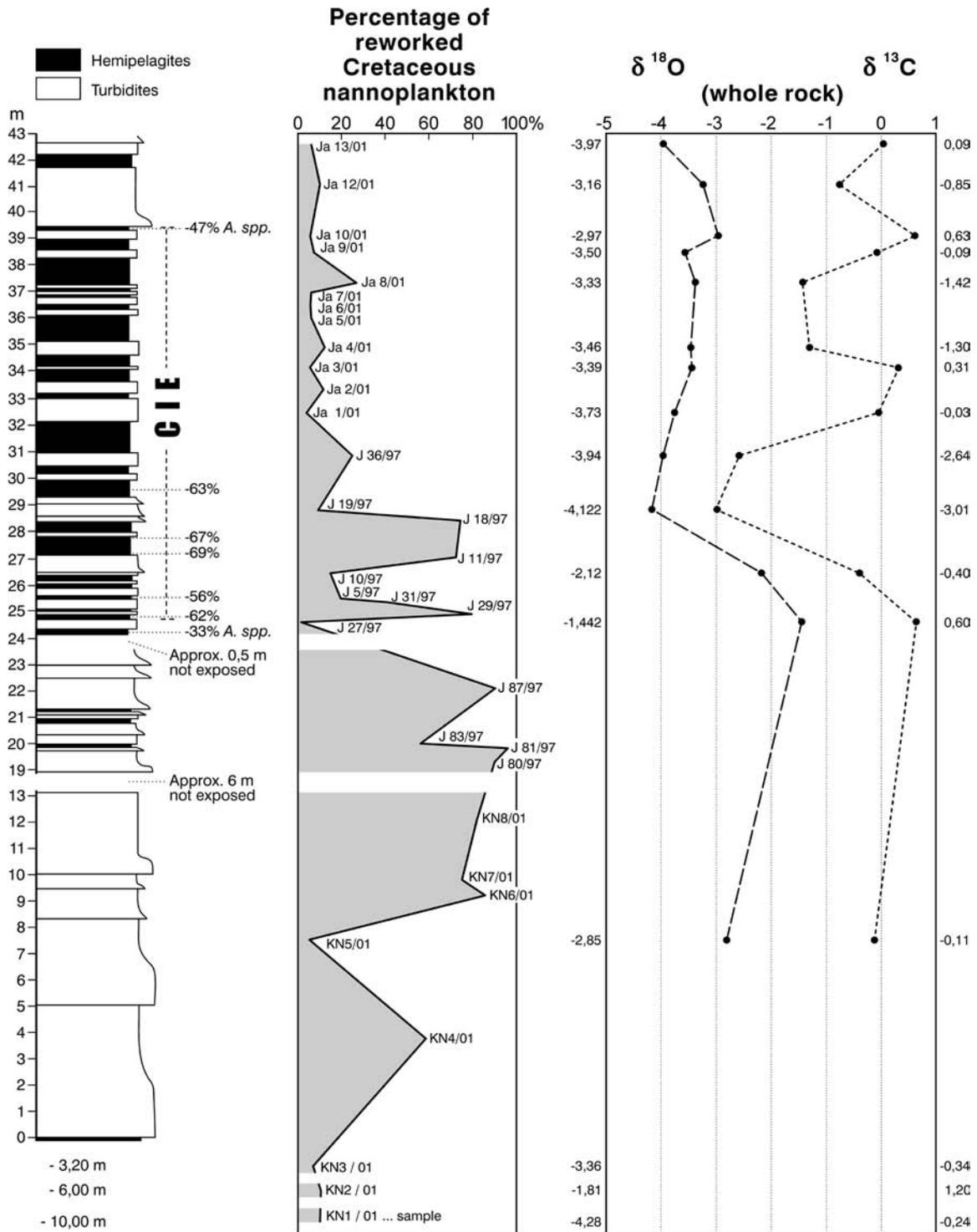


Figure A1.15 ▲

Lithostratigraphy percentages of redeposited Cretaceous nannoplankton and stable isotope record of oxygen and carbon across the CIE interval at Anthering. A. spp. percentages of the genus *Apectodinium* in the dinoflagellate assemblages (Egger et al. 2009b)

Most of the reworked specimens consist of species with a long stratigraphic ranges (*Watznaueria barnesae*, *Micula staurophora*, *Retecapsa crenulata*, *Cribrosphaerella ehrenbergii*, *Eiffellithus turriseiffelii*). Biostratigraphically important species that were found in all of the counted samples include *Bronsonia parca*, *Arkhangeltskiella cymbiformis* (small specimens), *Calculites obscurus*, *Lucianorhabdus cayeuxii* and *Eiffellithus eximius* whilst *Marthasterites furcatus*, *Eprolithus floralis* and *Lithastrinus grillii* were found only occasionally. This assemblage suggests that predominantly lower to middle Campanian

deposits were reworked at the end of the Paleocene. Probably, the erosional area was the North-Helvetic shelf at the southern European Plate where the Middle Eocene is resting with an erosional unconformity on the Upper Cretaceous.

Substantial reworking of the Cretaceous started already in the latest Paleocene. At Anthering, the uppermost 20 m of the Paleocene succession are formed by the thickest turbidites (up to 5 m) of the entire section. The siliciclastic sand-fraction in the turbidites forms around 30% of the rocks in this part of the section (Aitlengbach Formation). This suggests that a sea-level drop took place shortly before the onset of the CIE. This is consistent with data from the Atlantic region (Heilmann-Clausen, 1995; Knox, 1998; Steurbaut et al., 2003; Pujalte and Schmitz, 2006; Schmitz and Pujalte, 2007). The synchronicity of this sea-level drop in the Atlantic and Tethys regions indicates a eustatic fluctuation. Starting with the onset of the CIE, mainly fine-grained suspended material came into the basin and caused an increase in hemipelagic sedimentation rates by a factor of 5 or 6. Such an increase associated with decreasing grain-sizes has already been reported from P/E-boundary sections elsewhere and interpreted as an effect of a climate change at the level of the CIE, affecting the hydrological cycle and erosion (Schmitz et al., 2001).

DINOFLAGELLATE CYSTS

General characteristics

Dinoflagellate cysts are present in all samples from the Anthering section. Preservation varies from good to moderate. There is a tendency to better preservation in samples from turbidites than in hemipelagic samples, perhaps due to sea-floor oxidation during slow, hemipelagic sedimentation.

Common genera and species occurring throughout the section are *Apectodinium* spp., *Spiniferites* spp., *Areoligera* spp. + *Glaphyrocysta* spp. (generally 2–15%), *Polyspaeridium zoharyi* (usually 1–5%), *Homotryblium tenuispinosum* (usually 1–5%), *Operculodinium* cf. *centrocarpum* (mostly 4–12%), and *Phthanoperidinium crenulatum* (mostly 1–3%). *Lingulodinium machaerophorum* occurs sporadically and

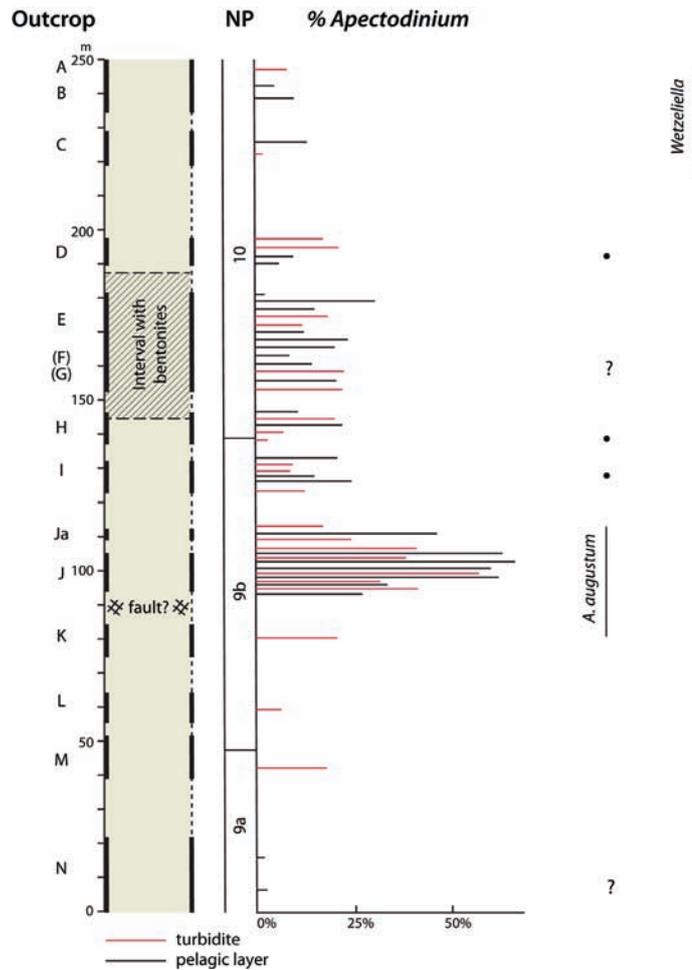


Figure A1.16 ▲

Distribution of the genera *Apectodinium* and *Wetzeliella* at Anthering. *Apectodinium* is shown as percentage of organic-walled microplankton. One fragmentary, possible specimen of *A. augustum* was recorded in outcrop N.

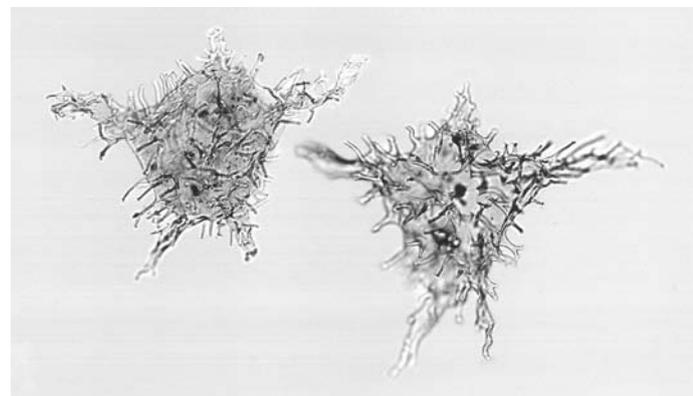


Figure A1.17 ▲

Apectodinium augustum. Left: specimen from Anthering, Outcrop J. Right: specimen from the CIE interval in Denmark (lowermost Ølst Formation, Viborg-1 borehole).

usually amounts to less than 1%. The overall composition of the dinoflagellate assemblages allows a simple subdivision of the section into three parts: The lower and upper intervals are characterized by a generally low dominance and relatively high species richness. These two intervals are separated by a middle interval coinciding with the CIE (outcrops J and JA). There the genus *Apectodinium* is dominant and reaches abundances up to 69% in hemipelagic samples (Fig. A1.16). Below and above this interval *Apectodinium* usually accounts for 5–20% of the dinoflagellate assemblages. The genus *Apectodinium* includes several intergrading species, the *Apectodinium*-plexus of Harland (1979). In spite of the strong dominance, the species richness remains relatively high within the CIE interval.

Quantitative dinoflagellate cyst data from hemipelagic layers of outcrop J reveal a 10-fold to 40-fold increase in the total number of cysts within the CIE interval (where *Apectodinium* dominates) (up to ca. 40.000 cysts/g) relative to pre-CIE samples. Above the CIE, counts reveal fluctuations in cyst numbers, but with a general trend towards smaller numbers of cysts.

Paleoecology

Relying on information from modern cyst production (e.g., Dale, 1996), the Anthering section must have been deposited below neritic waters, or waters that originated in the neritic zone. The genus *Impagidinium*, which today is purely oceanic, is present in several samples (especially in outcrop N), but usually rarer than 1–2%. Such low occurrences indicate the neritic/oceanic boundary zone (Dale, 1996). Neritic cysts are today transported over long distances with currents, and are deposited in various basinal parts of the Atlantic Ocean (e.g., Dale, 1996). The continuous presence of *Polysphaeridium zoharyi* and *Homotryblium tenuispinosum* is evidence of a rather constant, and significant, mixing of the water masses at Anthering. *Polysphaeridium zoharyi* today mainly characterizes equatorial lagoons (Dale, 1996), and the extinct *Homotryblium* is a dominant form in several well-documented inner neritic, probably lagoonal settings of various ages (e.g., Köthe, 1990; Sluijs et al., 2005).

The acme of *Apectodinium* at the PETM is globally widespread (Crouch et al., 2001), however, the beginning of the acme in some sections precedes the global warming indicated by the CIE (Sluijs et

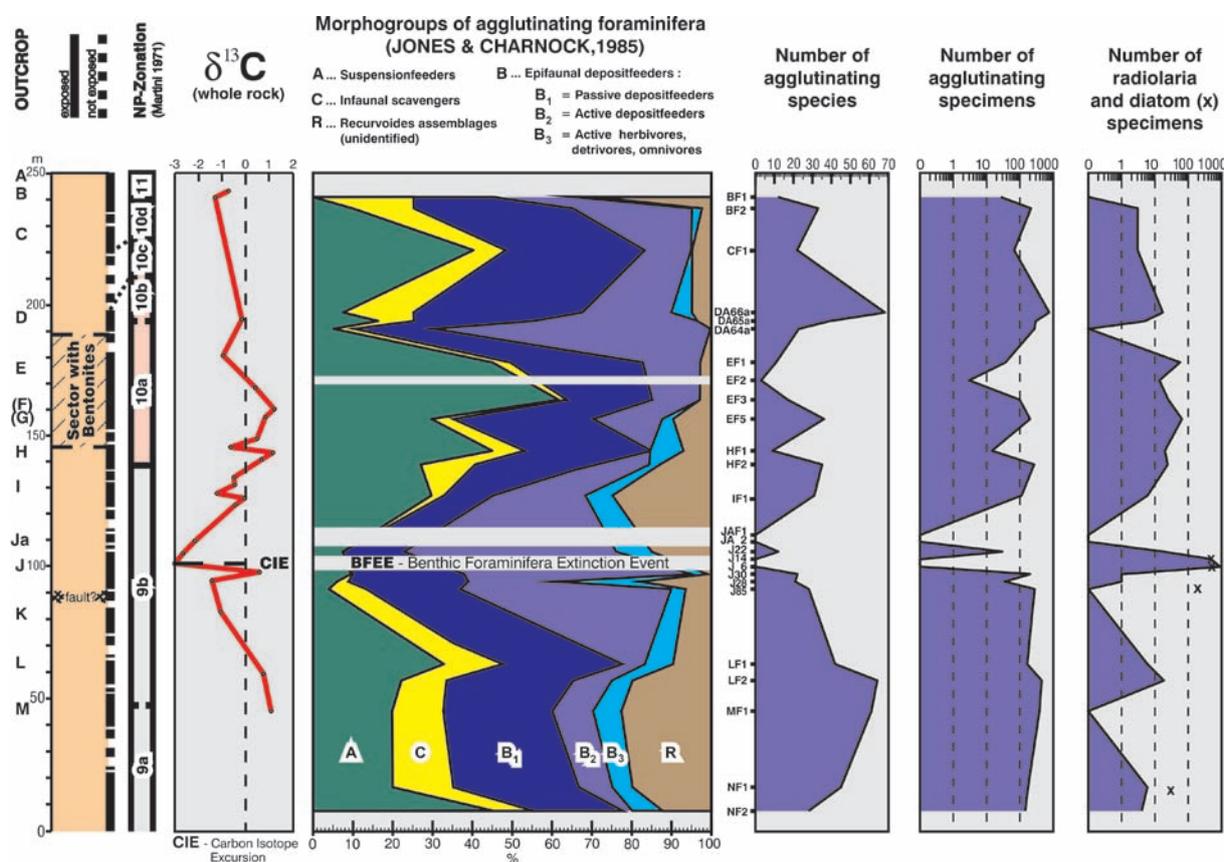


Figure A1.18 ▲ Distribution of agglutinating foraminifera and siliceous plankton in the Anthering section (modified from Egger et al. 2003)

al., 2007; 2011). The geographic and temporal distribution of *Apectodinium* shows that the genus was favoured by warm waters (Bujak & Brinkhuis, 1998), but the onset of the *Apectodinium* acme before the CIE in some areas shows that it was dependant on some other environmental factors too. Observations from the North Sea Basin clearly show that *Apectodinium* bloomed strongest in some marginal marine settings, where nearly monotypic assemblages may occur, e.g., in the Sparnacian facies of NW France. Observations from Anthering indicate that *Apectodinium* was associated with eutrophic waters (Egger et al., 2003).

Apectodinium augustum

The morphologically most extreme species of the *Apectodinium*-plexus is *A. augustum*. Typical specimens (Fig. A1.17) occur at Anthering, the first section from the western Tethys in which this species was recorded (Heilmann-Clausen & Egger, 2000; Egger et al., 2000). In the North Sea Basin of the North Atlantic realm *Apectodinium augustum* has only been recorded with certainty within the CIE interval (Heilmann-Clausen, 1985; Steurbaut et al., 2003; Schmitz et al., 2004). At Anthering the range likewise is closely related to the CIE interval, although a questionable earlier record cannot be excluded (Fig. A1.16).

Comparison between hemipelagic and turbiditic samples

A comparison between hemipelagic and turbiditic samples revealed no significant difference in the composition of the *in situ* cyst assemblages. A higher amount of older reworked cysts occur - as expected - in the turbidites, but in most turbidites the main part of the cysts are apparently of nearly the same age as the turbidites themselves. This indicates that the turbidites consist mainly of newly deposited sediment, or, if the proportion of older sediment is more substantial, it must be a sediment type poor in dinoflagellate cysts, like chalk and calcareous mud (Egger et al., 2000). The semi-contemporaneity of the turbidite-assemblages can be demonstrated by the fact that percentages of *Apectodinium* in the turbidites in the CIE-interval are higher than in all samples from the underlying strata (Fig. A1.16). They cannot, therefore be reworked from older levels. The similarity of the assemblages in hemipelagic and turbiditic layers indicates that the surface waters were similar over the basin slope where the turbidites originated, and over the basin floor.

Biostratigraphic correlation of the interval with bentonites

The first occurrence of the genus *Wetzeliiella* in the upper part of the Anthering section (Fig. A1.16) provides a tool for correlation to sections in the North Sea Basin recording the main ash series related to the opening of the NE Atlantic (Egger et al., 2000; Heilmann-Clausen & Egger, 2000). In the most offshore settings of the North Sea Basin, e.g. in Denmark, the main ash phase is bracketed by a strong *Apectodinium* acme (coinciding with the CIE) below, and by the first occurrence of *Wetzeliiella* spp. above. The bentonites in the Anthering section occur in the same position relative to these bracketing events, indicating that the bentonites are of similar age as the North Sea main ash phase, and thus may represent distal parts of the same ash layers.

SILICEOUS PLANKTON

Throughout the Anthering section the fossil remains of siliceous plankton (radiolaria, diatoms as well as rare ebridians and silicoflagellates) have been replaced by pyrite. Silica dissolution prior to this replacement, and damage caused by the pressure of pyrite crystals growing inside the shells, can make identification difficult. In particular, radiolarians are very poorly preserved and are all taxonomically indeterminate spheroidal or lenticular spumellarians (Christopher Hollis, oral communication). If pyrite fillings only are preserved, the outline and shape of diatom frustules can be recognized, but a specific and often generic determination is impossible. However, in the more robust frustules, even relatively fine pores and cribra covering the areolae are preserved, and thus allow species determination.

Most samples have diatom floras dominated by the taxa *Paralia sulcata* var. *biseriata*, *Paralia sulcata* var. *crenulata*, *Coscinodiscus antiquus*, and by species of the genera *Auloplicata* and *Stephanopyxis*. The recent relatives of the latter two genera occur in coastal-neritic as well as in oceanic environments. This may also be the case for the less common species of the genera *Hemiaulus* (e.g. *H. peripterus*), *Actinoptychus* and *Sceptroneis*. Species of the genus *Trochosira*, which are also rather rare, are considered to have been fully planktonic, whereas specimens of *Craspedodiscus*, *Trinacria*, *Sheshukovia* and *Aulacodiscus* probably indicate a coastal-neritic environment. Other genera can be considered to

have been fully benthic, e.g. species of the genera *Auliscus* and *Arachnodiscus*. In neritic assemblages, resting spores should be abundant, but in the studied samples only single specimens of resting spores were found. These belong to the form groups *Xanthiopyxis*, *Pterotheca* and *Bicornis*. As resting spores are most resistant to dissolution, their scarcity indicates that the encountered diatoms represent an oceanic assemblage (Fenner, 1994). The minor admixture of coastal and neritic specimens may have been caused by storm events that whirled up freshly deposited sediment in shallow regions which thereafter settled out from suspension beyond the shelf edge.

The occurrence of *Craspedodiscus* spp. and *Trinacria* spp. in deep-water deposits at Anthering is highly remarkable as these genera are usually restricted to neritic environments. We can rule out redeposition of these specimens because in that case, resting spores and benthic species would have been redeposited in considerable amounts. This suggests that water-depth was not the limiting factor for the occurrence of *Craspedodiscus* spp. and *Trinacria* spp.. Probably, the preference of these genera for neritic settings was due to the higher level of dissolved nutrients in these areas.

AGGLUTINATING FORAMINIFERA

Individual samples contain up to 65 species and more than 700 specimens (Fig. A1.18) of agglutinated foraminifera. More than 90 species were identified and grouped into four morphogroup assemblages (tubular genera, infaunal passive deposit feeders, active deposit feeders, epifaunal active herbivores and omnivores). Distributional patterns of morphogroups of agglutinating foraminifera are related, more or less directly, to food supply and food utilisation processes (Jones and Charnock, 1985).

At Anthering, tubular forms comprise the genera *Nothia*, *Rhabdammina*, *Rhizammina*, *Psammosiphonella* and *Bathysiphon*. These typical „fysch-type“ elements have been interpreted as sessile suspension feeders (morphogroup A of Jones and Charnock). However, the ecological interpretation of some of these deep-sea genera is still under discussion (Gooday et al. 1997), e.g. the life habitat of *Nothia* has been re-interpreted as epibenthic detritivore (Geroch and Kaminski, 1992). Epi- and infaunal passive deposit feeders (morphogroup B1) comprise *Saccamina*, *Psammosphaera*, *Hormosina*, *Hormosinella*, *Trochamminoides*, *Paratrochamminoides*, *Lituotuba*, *Hyperammina* and *Kalamopsis*. Another epifaunal and shallow infaunal group of active deposit feeders (morphogroup B2) corresponds to the *Ammodiscus* - *Glomospira* assemblage of „Biofacies B“ (Kuhnt et al., 1989). It consists of the genera *Ammodiscus*, *Glomospira* and *Rzehakina*. The B3 assemblage of epifaunal active herbivores and omnivores (*Haplophragmoides*, *Trochammina* s.l.) may be restricted to omnivores in this deep-sea environment. The C-morphogroup of infaunal forms (*Gerochammina*, *Karrerulina*, *Reophax*, *Subreophax*, *Spiroplectammina*) are negligible in the abyssal setting of the Anthering section. The genera *Recurvoides* and *Thalmannammina* were summarized as *Recurvoides*-assemblage. The microhabitat preferences of this assemblage are questionable. In the Cretaceous „Hatteras Fauna“ of the Fardes Formation in southern Spain it co-occurs with *Glomospira* and *Ammodiscus*, and might, therefore, be indicative of oxygen deficient conditions (Kaminski et al., 1999). In our samples we did not find this correlation because the highest percentages of the *Recurvoides*-assemblage occur in high diversity faunas without any indication of oxygen depletion. It is noteworthy, that the *Recurvoides*-assemblage usually forms more than 10% of the agglutinated faunas within nannoplankton zone NP9 whereas in zone NP10 this percentage is much lower.

The highest diversity and the highest abundance of agglutinated specimens occur in the lower part of the section (samples NF2 to LF1). These assemblages display balanced proportions of infaunal, epifaunal and suspension feeding species. The high diversity of these agglutinated faunas is seen as typical for oligotrophic, food-limited environments where the various microhabitats are fully occupied. Several taxa have their last occurrences in this part of the section: *Ammodiscus cretaceus*, *Aschemocella* cf. *carpathica*, *A. grandis*, *Haplophragmoides horridus*, *H. suborbicularis*, *Hormosina trinitatis*, *Karrerulina* cf. *coniformis*, *Paratrochamminoides heteromorphus*, *P. multilobus*, *Recurvoides walteri*, *Remesella varians*, *Rzehakina complanata*, *R. epigona*, *R. fissistomata*, *Spiroplectammina* cf. *dentata*, *Spiroplectammina spectabilis*, *Thalmannammina* n. sp., *Thurammina papillata*.

Further up-section (samples J85 to JaF1) impoverished faunas with a predominance of the genus *Glomospira* appear. This „*Glomospira* event“ has been observed at numerous localities in the Tethys and northern North Atlantic (see Kaminski et al., 1996 for a review). Kaminski et al. (1989) speculated that the predominance of *Glomospira* indicates areas of high surface productivity that caused low-oxygen

levels at the sea-floor. However, this assemblage occurs also in well oxidized sediments and, therefore, it may be opportunistic rather than a reliable indicator for high productivity (Galeotti et al., 2000; Kaminski et al., 1996). With the onset of the CIE, even this opportunistic assemblage disappeared and over a period of at least 180 000 years the benthic communities suffered severely from unfavorable habitat conditions.

Between samples HF2 to EF1 the majority of the hemipelagic layers have an organic carbon content between 0.14% and 0.17% (0.15% on average), but several black shale layers (up to 1.22% TOC) occur. This suggests periodic eutrophication of the sea water probably by volcanic ashfall as closely spaced bentonites were found in that part of the section (Egger et al., 2000a). The black shales are usually devoid of benthic foraminifera and contain common framboidal pyrite indicating anoxic conditions (Egger et al., 1997). The agglutinating faunas of these layers are not as rich and diverse as those from further down the section. *Glomospira glomerata* has its first appearance in this part of the section. The faunal assemblage changed to a predominance of passive deposit feeders (B1-assemblage) and tubular genera (A-assemblage). These assemblages are dominant along the continental rises where bottom currents or distal turbidity currents occur (Kaminski et al., 1996).

In the uppermost part of the Anthering section (samples DA64a to BF1) a strong increase in the number of species and specimens of the DWAF, with relatively balanced assemblages, occurs indicating the return of ecological conditions similar as those at the base of the section.