

# Calcareous index nannofossils (coccoliths) of the lowermost Paleocene originated in the late Maastrichtian

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**ABSTRACT:** The calcareous nannofossil species *Neobiscutum romeinii*, *N. parvulum*, and *Cruciplacolithus primus*, are considered in modern zonation schemes as index species for the lowermost Paleocene. Our studies, however, reveal that they are consistently present in upper Maastrichtian calcareous nannofossil zone CC26. The two *Neobiscutum* species were found several meters below the Cretaceous-Paleogene (K-P) boundary in cores from Brazos River (Texas) and Antioch Church (Alabama), and in outcrops at Geulhemmerberg (the Netherlands), El Kef (Tunisia), and Jebel Qurtasiyyat (Jordan). Except for the Jordanian record, the same applies to the occurrence of *C. primus*. These coccoliths are extremely small, ranging from 0.8 to 2.5 µm for *Neobiscutum* and 1.5 to 3.5 µm for *C. primus*, and they constitute less than 1% of the calcareous nannofossil association. This may explain why they were not consistently detected below the K-P boundary in earlier investigations. Since these species are not exclusively Paleocene indicators only their prominent acmes or, alternatively, the index species *Biantholithus sparsus* should be used to unambiguously identify the lowermost Paleocene. The geographic coverage in our study indicates that the late Maastrichtian appearances of *N. romeinii*, *N. parvulum* and *C. primus* are typical for marginal seas of the Northern Hemisphere.

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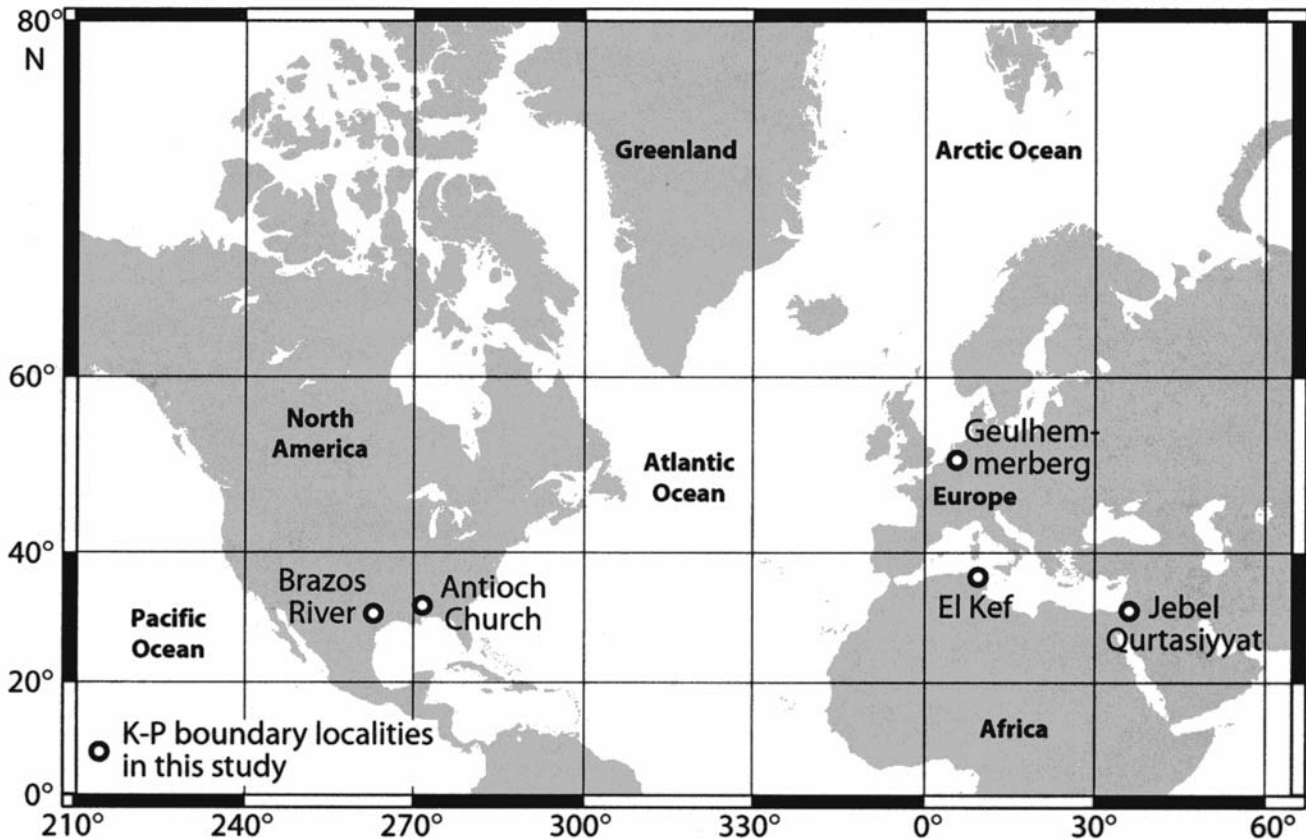
## INTRODUCTION

The Cretaceous-Paleogene (K-P) boundary is marked by a mass extinction of calcareous nannofossils (e.g., Bramlette and Martini 1964; Perch-Nielsen et al. 1982; Gartner 1996; Pospichal 1996; Mai 1999). Some 90% of all Maastrichtian species are assumed to have become extinct immediately at the boundary and/or during the earliest Paleocene and there is consensus that there was no gradual turnover before the K-P boundary (MacLeod et al. 1997; Gartner 1996; Gardin 2002). The discussion on possible survivorship into the earliest Paleocene is, however, rather controversial. For instance, Perch-Nielsen et al. (1982) argued based on stable isotopic differences between Maastrichtian and earliest Paleocene bulk samples from various sections that many Cretaceous taxa must have survived into the Paleocene. This argument was refuted by Pospichal (1994), arguing that the proportion of Cretaceous taxa to the Paleocene bulk sediments was rather limited and concluded that most Cretaceous taxa are reworked into the Paleocene. If indeed most taxa became extinct at the boundary, it is an interesting issue, which ancestors actually survived to provide the stocks for new Paleocene lineages. The genera *Neobiscutum*, *Cruciplacolithus* and *Chiasmolithus* are generally thought to have originated in the earliest Paleocene. Recent investigations (e.g., Romein et al. 1996; Mai 1999; Gardin 2002), however, suggest that these genera might have originated in the Maastrichtian. Romein et al. (1996) reported on the presence of *Neobiscutum romeinii*, *N. parvulum* and *Cruciplacolithus primus* in upper Maastrichtian (CC26) deposits at Geulhemmerberg, in the Maastrichtian type area, the Netherlands. These observations were made with a scanning electron microscope (SEM) at high resolution, but since the authors did not obtain the same results with a light microscope, they were reluctant to consider the SEM observations for the biostratigraphic zonation. Subsequently, Mai (1999) re-investigated several K-P boundary sections of the Maastrichtian

type area and showed that all three coccolith taxa consistently occur in the upper Maastrichtian (CC26). In the Maastrichtian type locality of the ENCI quarry these taxa (including also entire coccospheres) are even found just above the Lichtenberg Horizon, situated about 40 m below the top of the uppermost Maastrichtian strata exposed. As outlined in Mai (1999), the question whether these autochthonous coccoliths indicate an early Paleocene age of the studied strata, or conversely if they evolved in the late Maastrichtian could not be answered. To resolve these ambiguities, sections with an unambiguous K-P boundary (through independent biostratigraphy and/or chemostratigraphy) should be investigated. In the present study, four additional sections were chosen to investigate Maastrichtian calcareous nannofossil assemblages (text-figs. 1, 2). Together with data from the Maastrichtian type region, they cover a variety of environmental settings and wide depth range of marginal seas of the Northern Hemisphere

## GEOLOGICAL SETTING AND STRATIGRAPHY OF STUDIED SECTIONS

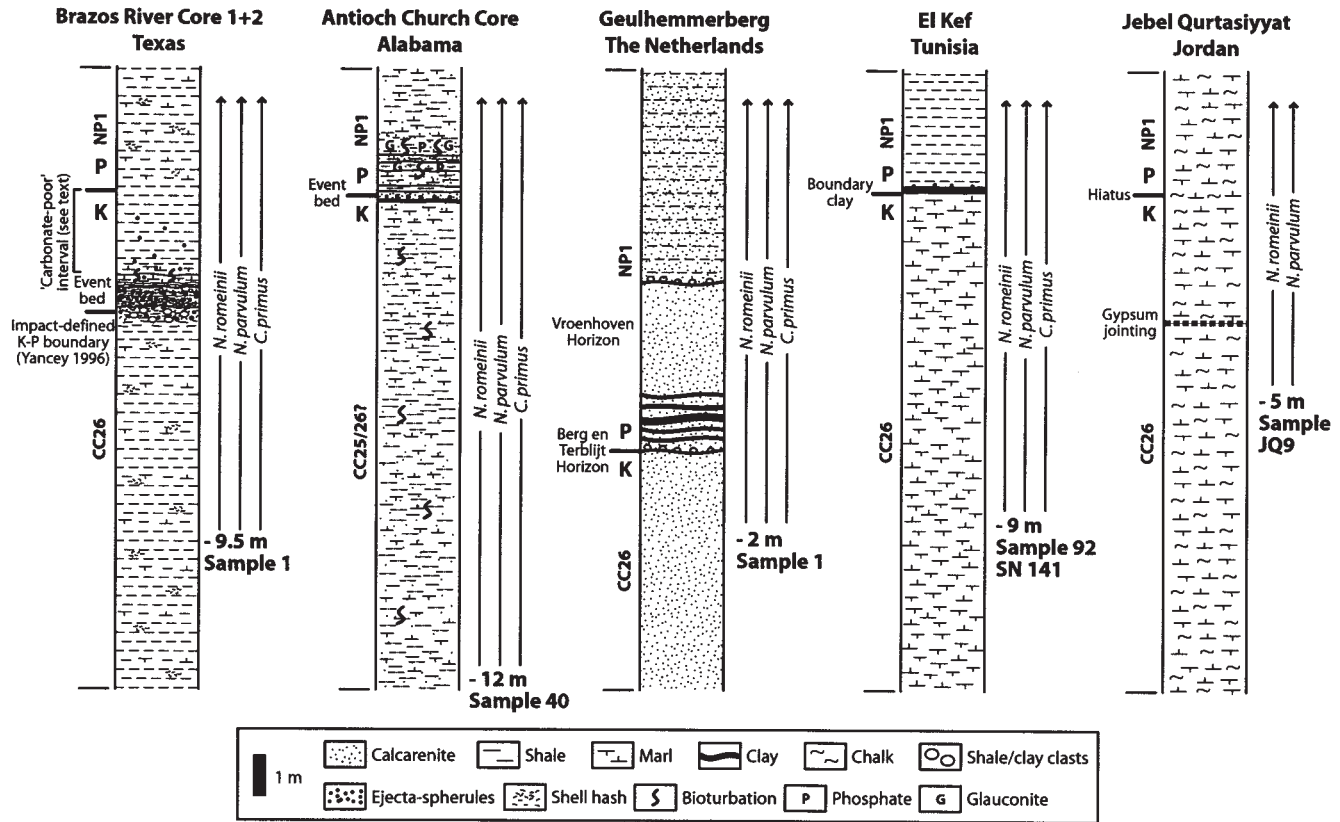
**Brazos river**, cores 1 and 2, Texas, USA: The two cores were drilled in close proximity near the Brazos River, about 100m to the northwest of the 'Brazos River sections' (see Hansen et al. 1993a, fig. 2). The two cores have a several meter overlap of the K-P boundary interval. The composite succession is made up of the upper Maastrichtian of core 2 and the lower Paleocene of core 1. The upper Maastrichtian shales of the Corsicana Formation are discordantly overlain by a normal graded 0.5m thick succession of shale clasts, sand, shell hash, and limestone, which is commonly referred to as "event bed." It includes impact ejecta (e.g., spherules, lapilli) at its base (Hansen et al. 1987, 1993a, b; Smit et al. 1996; Yancey 1996) and possibly originated as tsunamite-tempestite, genetically linked to the Chicxulub impact on the Yucatán peninsula (Smit et al. 1996;



TEXT-FIGURE 1  
Distribution of the selected sections

Yancey 1996; Heymann et al. 1998). According to these authors, the base of the “event bed” marks the impact-defined K-P boundary. The calcareous top of the “event bed” grades into macrofossil-free and carbonate-poor shale of the Kincaid Formation (basal Paleocene) that gradually becomes more fossiliferous and calcareous to the top of the core. The entire succession represents a middle to outer shelf facies with water depths between 70-200 m (Keller 1989a,b; Hansen et al. 1993a, b). Planktic foraminifera are excellently preserved and the absence of *Gansserina gansseri* (LAD at the top of biozone CF3; Li and Keller, 1998) in combination with the presence of *Plummerita hantkeninoides* and FAD at the base of biozone CF1 about 0.5m below the event bed, the entire sequence below the event bed is assigned to the upper Maastrichtian biozones CF1-2. Twenty samples were analyzed for nannofossils. The nannofossil results are in line with the planktic foraminiferal record, revealing a late Maastrichtian age (CC26, *Nephrolithus frequens* Zone with *Micula prinsii* as the youngest marker) for this interval. Above the event bed, a ‘carbonate-poor’ interval reveals a turnover in benthic foraminifera fauna, a significant drop in nannofossil and foraminifera abundance with the absence of planktic foraminifera index taxa (see also Keller 1989a,b), though the upper Maastrichtian CC26 nannofossil fauna is still present. The first unambiguously Paleocene sediments are found ~1.6 m above the event bed, as indicated by successive blooms of *Operculodinella operculata* (calcareous dinocyst) and *Braarudosphaera bigelowii* and *Neobiscutum romeinii*, and by the first Paleocene planktic foraminifera (*Parvularugoglobigerina extensa*).

**Antioch Church** core, Alabama, USA: The Antioch Church core site is located approximately 6 km southeast of the well-known Brags K-P locality (see Baum and Vail 1988; Donovan et al. 1988). The Antioch Church core comprises the shales and marls of the upper Maastrichtian Prairie Bluff, which is discordantly overlain by sands and limestones of the lower Danian Pine Barren (Clayton) Formation. The basal sandstone bed of the Clayton Formation contains rare spherules and limestone fragments, and is commonly interpreted as either lowstand deposit (Baum and Vail 1988; Donovan et al. 1988) or “event bed” associated with the Chicxulub impact (e.g., Olsson and Liu 1993; Olsson et al. 1996; Smit et al. 1996). The shallow water setting (between 30-100m) and the rareness of planktic foraminifera prevents a precise biostratigraphy based on foraminifera, though because of the absence of *G. gansseri* and the presence of several typical faunal elements of the biozones CF1-2, (Keller, written comm. 2001) estimates a CF1-2 age for the Prairie Bluff Formation. The first Paleocene foraminifera including *P. eugubina* (biozone P1a, lowermost Danian) are reported from a sample directly above the basal Clayton sands. Thirty samples from Antioch Church were analyzed for their nannofossil content. The succession of calcareous nannofossils does not allow a detailed biostratigraphy for the Prairie Bluff Formation. The youngest marker is *Lithraphridites quadratus*, common from the base to the top, indicating the upper Maastrichtian *L. quadratus* Zone, CC 25. The lowermost Danian Zone NP1, as indicated by a bloom of *N. romeinii* is observed directly above the basal Clayton sands.



TEXT-FIGURE 2  
Studied sections

**Geulhemmerberg** cave section, the Netherlands: The Geulhemmerberg cave section is located a few km west of Valkenburg in South Limburg, the Netherlands. The section comprises a complex of four sedimentary units (Roep and Smit 1996). The first 2 m consist of a homogeneously sorted and lithified fine to medium-grained calcarenite with many burrows in the upper part. The top is eroded and undulated, marking the Berg and Terblijt Horizon. This horizon is overlain by 75 cm of poorly sorted coarse-grained calcarenites with thinning-up and fining-up sequences, several clay intercalations, and a 10-15 cm thick clay layer at the top. In an airshaft near the main site, a unit with fine-grained yellow and white calcarenites that extend up to the Vroenhoven Horizon overlies the clay-bearing unit. The Geulhemmerberg succession probably represents a marginal marine inner neritic (20-40 m water depth) depositional setting close to a landmass with episodic storm wave activity (Smit and Brinkhuis 1996). The clay layers thought to comprise the K-P boundary contain only Cretaceous planktic foraminiferal survivor species, such as *Guembelitra cretacea* and *Hedbergella monmouthensis*, and no Paleocene taxa, suggesting an earliest Paleocene age (Biozone P0) for these layers (Smit and Zachariasse 1996). In terms of calcareous nannoplankton, the deposits below the Berg and Terblijt Horizon can tentatively be assigned to the late Maastrichtian *N. frequens* Zone, CC26. The unit above this horizon contains numerous *Markalius inversus*, *N. romeinii*, *N. parvulum*, *C. primus*, and *B. sparsus*, and therefore belongs to the early Danian NP 1 Zone. A more detailed subzonation cannot be obtained, as the cited coccolith species, in contrast to the opinion

of Romein et al. (1996), do not show differentiated acmes. For further information concerning the ENCI and Curfs quarries (Maastrichtian type locality and Maastrichtian type area, respectively), refer to Mai (1999).

**El Kef**, Tunisia: The Kef section is located five kilometers southwest of El Kef in northwestern Tunisia (see map in Smit et al. 1997). During the late Maastrichtian, this locality was situated in an upper bathyal setting, at about 300-500 m depth (Speijer and van der Zwaan 1996). The Kef section comprises the Global Stratotype Section and Point (GSSP) for the Cretaceous-Paleogene boundary and plays a key role in stratigraphic correlation worldwide (Cowie et al. 1989). The K-P boundary is situated in the middle part of a hemipelagic marl succession of El Haria Formation and is defined by a 2 mm thick reddish ferruginous layer containing, among others, the well-known iridium anomaly (e.g. Rocchia and Robin 1998). Biostratigraphically, the boundary is marked by the extinction of numerous planktic and benthic foraminiferal species (e.g. Brinkhuis and Zachariasse 1988; Speijer and van der Zwaan 1996). Two samples were available for study, at 9 and 5 m below the K-P boundary, respectively. These samples contain rich pelagic microfossil and nannofossil assemblages, including the planktic foraminifera *P. hantkeninoides* (CF1) and the calcareous nannofossil *M. prinsii* (CC26) both indicative of the uppermost Maastrichtian.

**Jebel Qurtasiyyat**, Jordan: The K-P boundary in Jordan is relatively unexplored. The Jebel Qurtasiyyat section is located 12

km southeast of Jurf ad Darawish and the Desert Highway (Moumani 1997). During the late Maastrichtian, this locality was situated in an outer neritic environment (~100-200m paleodepth) as indicated by the benthic foraminiferal assemblage. The K-P boundary is found in the upper part of the Muwaqqar Formation, consisting of hemipelagic marls and chalks. The lowermost Paleocene planktic foraminiferal zones P0 to P1a appear to be missing (pers. commun. with E. Guasti, 2002). The uppermost Maastrichtian, nevertheless, appears to be biostratigraphically complete as indicated by the presence of the uppermost Maastrichtian planktic foraminiferal marker species *P. hantkeninoides* in a 6.5m thick interval, marking Zone CF1. One sample, situated about 5 m below the K-P boundary, was investigated for calcareous nannofossils, and contained the uppermost Maastrichtian marker *M. prinsii* (CC 26).

## METHODS

A small amount of sample material from core and outcrop samples was ultrasonically treated in a weak ammonium solution for about 3 minutes. The resulting suspension was allowed to settle for 3 minutes and the obtained water column carefully decanted. The deposit was then again brought into suspension, and a few drops were spread over a graphitic SEM stub. After drying and coating with gold the stub was observed in a SEM at 2500x magnification. This magnification allows the detection of even the smallest coccolith specimen (0.8 to 1.5µm). This form of preparation and analysis of the samples was carried out three times for each sample to avoid erroneous results because of possible contamination. The biozonation with calcareous nannoplankton is based on the cosmopolitan zonal scheme of Perch-Nielsen (1985a, b).

## RESULTS

The **Brazos River** core furnishes *N. romeinii*, *N. parvulum*, and *C. primus* already in the lowermost sample available, 9.5 m below the K-P boundary within Zone CC26. Here the *Neobiscutum* species are ranging from 2.0 to 2.8µm in size and

*C. primus* yields diameters from 2.5 to 3.5µm. Their number is extremely low, well below 1% of the entire coccolith assemblage.

The **Antioch Church** core contains specimens of *N. romeinii*, *N. parvulum*, and *C. primus* as far as 12 m below the K-P boundary in the unit assigned to Zone CC 25. Sizes and frequencies are comparable to the Brazos River core.

In the **Geulhemmerberg cave** section, *N. romeinii*, *N. parvulum* and *C. primus* appear 2 m below the Berg and Terblijt Horizon in the unit comprising the calcarenites and belonging to Zone CC26. The specimens are very well preserved, and even entire coccospheres of the three mentioned species were observed. The sizes of *N. romeinii* and *N. parvulum* vary between 0.8 to 1.5µm, whereas *C. primus* ranges from 1.5 to 2.5µm. All are very rare, representing less than 1% of the whole nannofossil assemblage.

In the **El Kef** section, the three coccoliths occur in very low numbers 9 m below the K-P boundary in the unit representing Zone CC 26. Here *N. romeinii* and *N. parvulum* measure about 2µm, and *C. primus* around 3µm.

The sample 5m below the K-P boundary section at **Jebel Qurtasiyyat** reveals specimens of both *Neobiscutum* species with sizes from 2 to 2.5µm in very low numbers accompanied by a CC 26 nannofossil assemblage. *Cruciplacolithus primus* was not observed in this sample.

## DISCUSSION AND CONCLUSIONS

### Contamination or bioturbation?

Our data provide a consistent pattern of first appearances of *N. romeinii*, *N. parvulum* and *C. primus* in the upper Maastrichtian. The exact position of these first appearances in the standard biozonation is possibly within Zone CC25 (Antioch Church), but certainly within Zone CC26 (Brazos, Geulhemmerberg, El Kef, Jebel Qurtasiyyat). The very early appearances at Antioch

## PLATE 1

### **Brazos River**, Texas, USA, Core 2, sample 1

- 1 *Neobiscutum romeinii*, proximal 2.5µm
- 2 *Neobiscutum parvulum*, distal 2.3µm
- 3 *Cruciplacolithus primus*, proximal 3.3µm

### **Antioch Church**, Alabama, USA, Core, sample 40

- 4 *Neobiscutum romeinii*, proximal 2.4µm
- 5 *Neobiscutum parvulum*, distal 2.5µm
- 6 *Cruciplacolithus primus*, proximal 3.5µm

### **Geulhemmerberg cave**, the Netherlands, sample 1

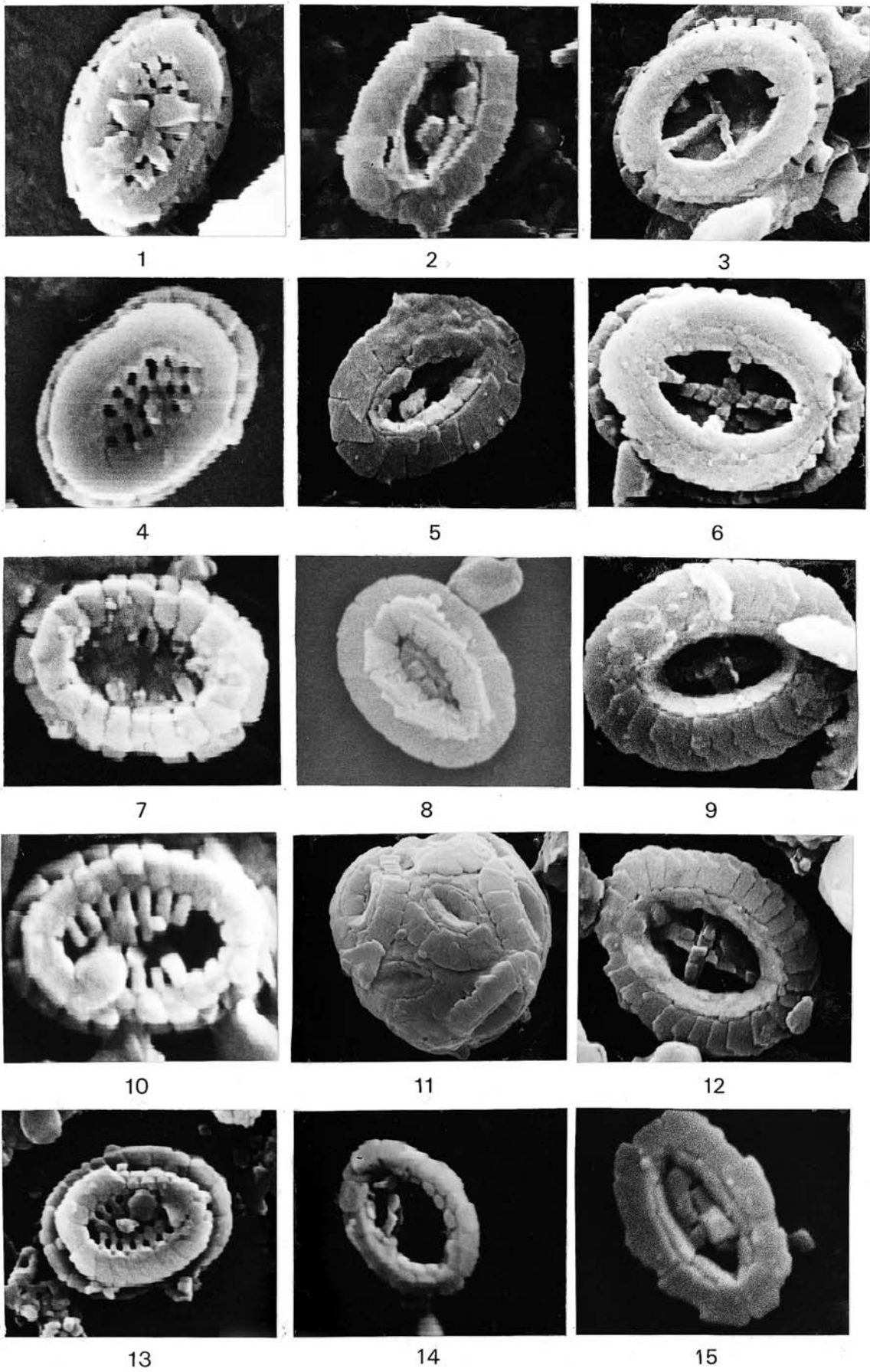
- 7 *Neobiscutum romeinii*, proximal 1.5µm
- 8 *Neobiscutum parvulum*, distal 1.5µm
- 9 *Cruciplacolithus primus*, distal 2.5µm

### **El Kef**, Tunisia, sample 92 Sn 141

- 10 *Neobiscutum romeinii*, proximal 2.0µm
- 11 *Neobiscutum parvulum*, coccosphere 4.0µm
- 12 *Cruciplacolithus primus*, distal 3.2µm

### **Jebel Qurtasiyyat**, Jordan, sample JQ 9

- 13 *Neobiscutum romeinii*, proximal 2.0µm
- 14 *Neobiscutum romeinii*, distal 2.0µm



Church in Zone CC 25 might, however, only be apparent, being caused by a local absence of the marker species of CC 26 Zone. In the type locality in the ENCI quarry, the lower part of CC26 (Gulpen Formation) below the Lichtenberg Horizon, does not contain any of the here discussed species (Mai 1999). In previous works, it has been discussed whether early appearances as documented here, particularly that of *N. romeinii*, might be an artifact of contamination or might have resulted from bioturbation (e.g. Pospichal et al. 1990; Romein et al. 1996; Mai et al. 1997; Gardin 2002). As indicated above, careful laboratory procedures seem to exclude the role of contamination to have caused this pattern. The consistent distribution pattern of all three species and only these three species is in agreement with this. In some sections and ODP cores, bioturbation caused downward transport of lower Paleocene sediments into the Maastrichtian succession. For instance, Pospichal et al. (1990) documented such displacement up to 1.3 m within pelagic deep-sea sediments of Maud Rise, ODP Hole 690C. Similarly, Romein et al. (1996) suggested the anomalous presence of *N. romeinii* at 40 cm below the K-P boundary at Geulhemmerberg to have resulted from bioturbation. However, such a mechanism cannot account for our results because the specimens have been observed too far (up to twelve meters) below the K-P boundary. This indicates that *N. romeinii*, *N. parvulum*, and *C. primus* evolved already during the late Maastrichtian and not in the aftermath of the K-P boundary.

#### Consequences for proposed subzonation of the basal Paleocene

This conclusion bears consequences with respect to proposed subzonations of the lower Paleocene and rate of adaptive radiation after the K-P boundary. Various authors (e.g. Romein 1979; Perch-Nielsen 1981) previously recognized a sequence of first appearances of amongst others *N. romeinii*, *N. parvulum*, and *C. primus*, resulting in a subzonation of the basal Paleocene into five subzones (Perch-Nielsen 1981). Our data unequivocally demonstrate that a subdivision of the lower Paleocene based on these purported first appearances is not warranted. To unambiguously identify the basal Paleocene, the index species *Biantholithus sparsus* should be used. On the other hand, the successive blooms of the taxa discussed here are recognized in numerous localities all over the world and thus seem to provide a good indication of the relative position within the basal Paleocene. These blooms are an exclusively ecologic response to changing environments of the earliest Paleocene and thus do not provide any information of adaptive radiation after the K-P boundary event. Finally, our results underline the view of Gartner (1996) that electron microscopy is indispensable for correctly identifying the smallest coccoliths. As shown by Mai (2000), the images obtained by light microscope of different *Neobiscutum* species are very similar, and even the smallest *C. primus* cannot easily be identified without electron microscopy.

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#### APPENDIX 1

List of cited coccolithophorid taxa

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- Biantholithus sparsus* Bramlette and Martini 1964  
*Braudosphaera bigelowii* (Gran and Braarud) Deflandre 1947  
*Chiasmolithus* (Hay, Mohler and Wade) Varol 1992  
*Cruciplacolithus primus* Perch-Nielsen (1977)  
*Lithraphridites quadratus* Bramlette and Martini 1964  
*Micula prinsii* Perch-Nielsen 1979  
*Neobiscutum parvulum* (Romein 1979) Varol 1989  
*Neobiscutum romeinii* Perch-Nielsen 1981  
*Nephrolithus frequens* Gorka 1957