

# Calcareous nannofossils and sequence stratigraphy of the Cretaceous/Tertiary transition in Bulgaria

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**Abstract** Five Cretaceous/Tertiary transitional sections were examined for calcareous nannofossil content and analysed in terms of sequence stratigraphy. Sections for study were selected in order to represent a variety of depositional environments. Calcareous nannofossils were examined in order to provide a detailed biostratigraphy. This study is restricted to sediments from the Upper Maastrichtian (nannofossil biozones CC25-26) and the Lower Danian (biozones NP1-2). Three basic depositional environments were recognised: 1) a shallow-water environment, represented by carbonate-dominated sediments; 2) a hemipelagic environment represented by marly limestone sediments deposited on the shelf margin and the upper slope; and 3) a deep-water environment consisting of flysch-type turbidite sequences. Specific lithologies and calcareous nannofossil occurrences characterise each depositional setting. In terms of sequence stratigraphy, three third-order depositional sequences were identified, two in the Upper Maastrichtian (Ma3 and Ma4) and one in the Lower Danian (Da1). These are described herein and their boundaries are calibrated with the calcareous nannofossil biozonations.

**Keywords** Calcareous nannofossils, Cretaceous/Tertiary transition, biostratigraphy, sequence stratigraphy, Bulgaria

## 1. Introduction

The Cretaceous/Tertiary (K/T) boundary has been studied in marine sediments worldwide by numerous researchers over the past 20 years (*e.g.* Thierstein, 1981; Perch-Nielsen *et al.*, 1982; Pospichal & Wise, 1990, 1992; Pospichal, 1991; Pospichal & Bralower, 1992). Situated in south-eastern Europe, Bulgaria is currently the only country in the Balkans where complete K/T transitional sections have been documented (Stoykova & Ivanov, 1992; Preisinger *et al.*, 1993a, b; Ivanov & Stoykova, 1994; Stoykova *et al.*, 2000; Figure 1).

Since the discovery of the first continuous section across the K/T boundary near Byala (Stoykova & Ivanov, 1992), many authors have explored this locality. Subsequently, the sections on the Black Sea coast near Byala have attracted international interest due to the research of Preisinger *et al.* (1993a), Rögl *et al.* (1996) and Adatte *et al.* (2002) (Figures 1, 2). The palaeoecology and biostratigraphical events across the K/T boundary in these sections have been discussed by Ivanov & Stoykova (1994, 1995).

Additional K/T boundary sections have been reported from a turbidite succession near Emona (Sinnyovsky & Stoykova, 1995) and from the Mezdra region (NW Bulgaria), where Sinnyovsky (1999) reported an iridium anomaly at the K/T boundary in a clay bed, situated within shallow-water carbonate sediments. A summary of all data that has been obtained from a variety of studies

(stratigraphical, sedimentological, palaeontological, mineralogical and geochemical) has been presented by Stoykova *et al.* (2000).

In this paper, we present the results of a new study that incorporates calcareous nannofossil biostratigraphic analyses with sequence stratigraphic interpretations of five K/T boundary sections in northern Bulgaria (Figure 1). The sections are representative of differing depositional environments. This study focuses on Upper Maastrichtian (nannofossil biozones CC25-26) and Lower Danian (biozones NP1-2) sedimentary sequences. This sequence stratigraphic analysis is important because: 1) the boundaries of the sequence units represent important correlative (isochronous) surfaces; 2) the sequence stratigraphy gives essential new information about sea-level changes; and 3) together, the nannofossils and sequence stratigraphy provide a more integrated picture of events through this important interval across one basin.

## 2. Materials and methods

The studied sections are situated in the north-western, central and eastern parts of northern Bulgaria (Figure 1b). They display a sedimentary record across the K/T transition from a variety of basin environments (Figure 1c). The Moravitsa section is situated in NW Bulgaria (Mezdra area), about 1.5km south of the village of Moravitsa. The K/T transitional succession consists of packstones and wackestones, interbedded with chert nodules, lenses and

beds, of the Mezdra Formation. Sinnyovsky (1999) described the K/T boundary clay-layer as being situated between two limestone beds in the middle part of this section.

turbidite sediments of the Emine Formation. Sinnyovsky & Stoykova (1995) first described this turbidite locality in Bulgaria.

The Marash section is situated in the East Balkan, NE

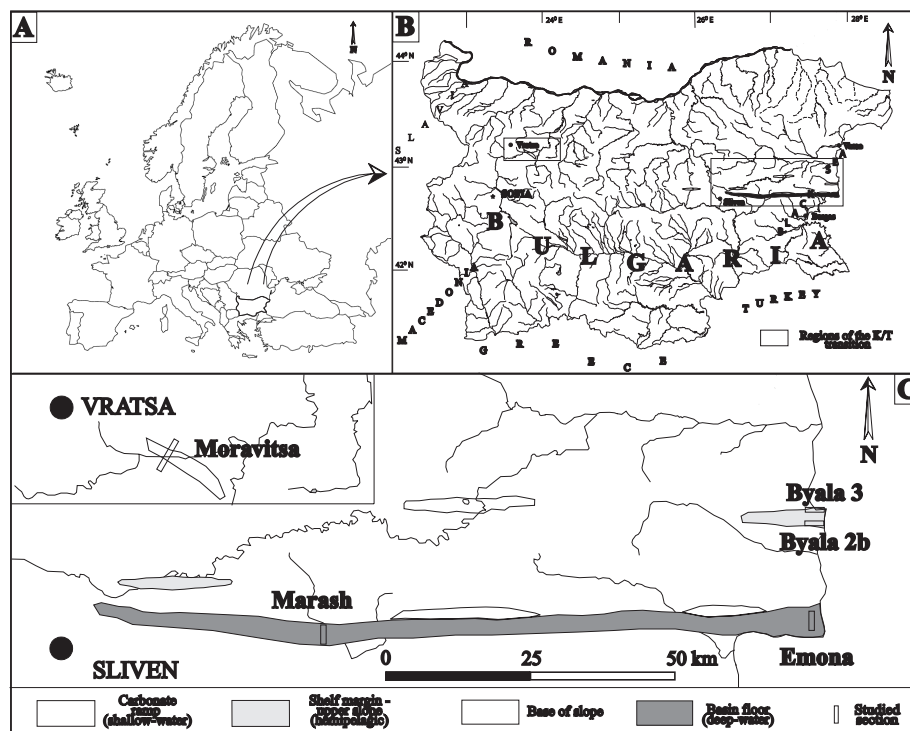
of the village of Gorno Alexandrovo and 1.5km north of the Petoluchkata crossroad. The Maastrichtian-Danian succession is exposed along the right bank of the Marash River and consists of typically rhythmic turbiditic sediments of the Emine Formation. The thickness of the K/T transition here is approximately 105m.

The sections were measured, and the lithology was examined and described with particular emphasis placed on recognising depositional trends, specific bed-surfaces, cross-stratification and bio-turbation.

Calcareous nannofossils were examined from 163 samples: Moravitsa – 21 samples, Byala 2b – 43 samples, Byala 3 – 26 samples,

Emona – 33 samples, Marash – 40 samples. In order to precisely document calcareous nannofossil first (FO) and last occurrences (LO), sample-spacing across the K/T boundary was at 5-15cm intervals, increasing to one sample per 1-5m away from the boundary. All samples were prepared by scraping dry sediment from a cleaned sample-surface onto a glass coverslip, then mixing it using a drop of distilled water until the sediment had completely broken down. The suspension was smeared across the coverslip to give the required density, and dried rapidly. The smear-slides were made using Canada Balsam as a fixative. Nannofossil slides were examined using a Jenapol polarising-light microscope at 1250x magnification. Each slide was observed under cross-polarised and normal light for an average of 40-60 minutes; critical samples were examined for several hours. Fully-authored, fully-referenced taxonomic listings appear in Perch-Nielsen (1985a, b).

Biostratigraphic interpretations are based on the FOs or LOs of stratigraphically-important nannofossil taxa. Samples taken from across the K/T boundary transition, and near biozonal boundaries, were especially minutely examined. In order to achieve an accurate biostratigraphic correlation between the studied sections, the widely-used biozonation of Sissingh (1977), as modified by Perch-Nielsen (1985a), was employed for the Maastrichtian and that of Martini (1971) for the Danian (Figure 2). Calcareous nannofossil range-charts were pro-



**Figure 1:** A) Map showing the location of Bulgaria relative to SE Europe. B) Area of study and distribution of K/T transitional deposits. C) Depositional environments during the Late Maastrichtian and Early Danian

The Byala 2b section is located about 0.8km north of the central entrance to the beach of Byala. The K/T transitional sequence consists of alternating marl and marly limestones of the Byala Formation. The K/T boundary is marked by a 2-4cm-thick, dark grey to black clay-layer, containing an iridium anomaly of 6.1ppb (Preisinger *et al.*, 1993a). Exposures along the Black Sea coast near Byala were the first complete K/T boundary sections to be documented in Bulgaria (Stoykova & Ivanov, 1992). As a result, they have been the subject of a variety of different studies, including biostratigraphical, palaeontological, magnetostratigraphical, geochemical, mineralogical and cyclostratigraphical (Preisinger *et al.*, 1993a, b; Ivanov & Stoykova, 1994, 1995; Rögl *et al.*, 1996; Stoykova *et al.*, 2000; Sinnyovsky, 2001; Adatte *et al.*, 2002; Figure 2).

The Byala 3 section is located 2km north of Byala and 1.3km north of the Byala 2b section. At this locale, the sediments of the Byala Formation are dominated by marls and clays. The K/T boundary consists of a thicker (0.03-0.06m) clay-bed than previously described, in which Preisinger *et al.* (1993a, b) measured 7ppb iridium. The Maastrichtian to Danian succession crops out 1.5km north of the village of Emona, not far from the Black Sea shore, along the Irakli-Emona road. It consists of thinly-bedded

duced for each of the sections studied (Figures 3-7).

All rock samples and smear-slides are stored in the Geological Institute of the Bulgarian Academy of Sciences, collection of K. Stoykova. The negatives of the microphotographs of the figured calcareous nannofossils are kept in the Palaeontological Museum, Sofia University (Nos K<sub>2</sub> 205, K<sub>2</sub> 206, K<sub>2</sub> 207 and K<sub>2</sub> 208).

### 3. Results

In this study, we recognised three types of depositional environment, based on lithology, across the K/T transition in Bulgaria: shallow-water, hemipelagic and deep-water (Figure 1c). The continuity and completeness of each section strongly depends on its depositional environment (*i.e.* palaeolocation in the basin). In the shallow-water section, Moravitsa, deposited on the carbonate ramp, several unconformities and/or short-time hiatuses were detected, both lithologically and biostratigraphically (Figure 3). Our field observations and nannofossil data from the hemipelagic sections, Byala 2b and Byala 3, did not reveal any unconformities or wash-outs (Figures 4, 5). In the deep-water sections, Emona and Marash, the sedimentary record is continuous across the K/T boundary, evidenced by complete successions of the biostratigraphic zones and sequence stratigraphic units (Figures 6, 7).

Generally, the calcareous nannofossil assemblages were poorly- to moderately-preserved throughout the sections, and common in abundance in the sediments. Reworking is notably manifested in the turbidite sequences. Reworked or survivor Cretaceous nannofossil species were recorded from the basal Danian (biozones NP1 and lower NP2).

**Figure 2:** Correlation of different biostratigraphic schemes with magnetostratigraphy and sequence stratigraphy for the studied region

Age (Ma) Berggren et al., 1995	System Stage	Substage	Magnetostratigraphy Preisinger et al. (1993a)	Sequence stratigraphy this study	Biozonation				
					Calcareous nannofossils this study	Planktonic Foraminifera Rögl et al. (1996) Adatte et al. (2002) Peybernes et al. (2003)		Ammonites Ivanov & Stoykova (1994) Ivanov (1995)	Echinoids Ilieva (1998)
64	PALAEOGENE DANIAN	LOWER	C 28R	Da 2 TST	NP 3				
				SB Da1					
				HST	NP 2	P1b	P1b		<i>Cyclaster danicus</i>
				Da 1 nfs					
65	CRETACEOUS MAASTRICHTIAN	UPPER	C 29R	TST	NP 1	P1a	P1a		<i>Coraster vilanovae - Cyclaster danicus</i>
				SB Ma5					
				HST	CC 26	CF 1		<i>Anapachydiscus terminus</i>	
				Ma 4 nfs					
66				TST	CC 25 c	No data		<i>Pachydiscus gollevillensis gollevillensis</i>	<i>Hemiphaedusa striatiradiatus</i>
				SB Ma4					
				Ma 3 HST	CC 25 b			<i>Anapachydiscus freisvillensis</i>	
					CC 25 a				

### 3.1 Calcareous nannofossil biostratigraphy

#### 3.1.1 Moravitsa section (shallow-water environment)

Two samples are barren (Mo-14, Mo-15). Species richness is low to moderate compared to that of other hemipelagic environments; 47 species were identified. Preservation generally improves up-section, from poor in the lower, to moderate in the upper, part of the Mezdra Formation. Figure 3 shows the nannofossil biostratigraphy (CC24 to NP3). As stated above, several unconformities and/or short-time hiatuses were detected in Moravitsa: at the CC24/CC25a boundary, within CC25, and at the CC25c/CC26b boundary. These are interpreted as sequence boundaries (Figures 3, 8).

The Moravitsa section contains the best record of penultimate of all of the sections studied here: *Braarudosphaera* and *Micrantholithus* are considered to be indicators of shallow-water deposition, preferring a shelf or marginal slope environment (Perch-Nielsen, 1985a). *Braarudosphaera bigelowii*, *B. discula*, *B. turbinea* and *Micrantholithus* spp. frequently occur within the K/T transitional interval, from CC25 to NP3 (Figure 3).

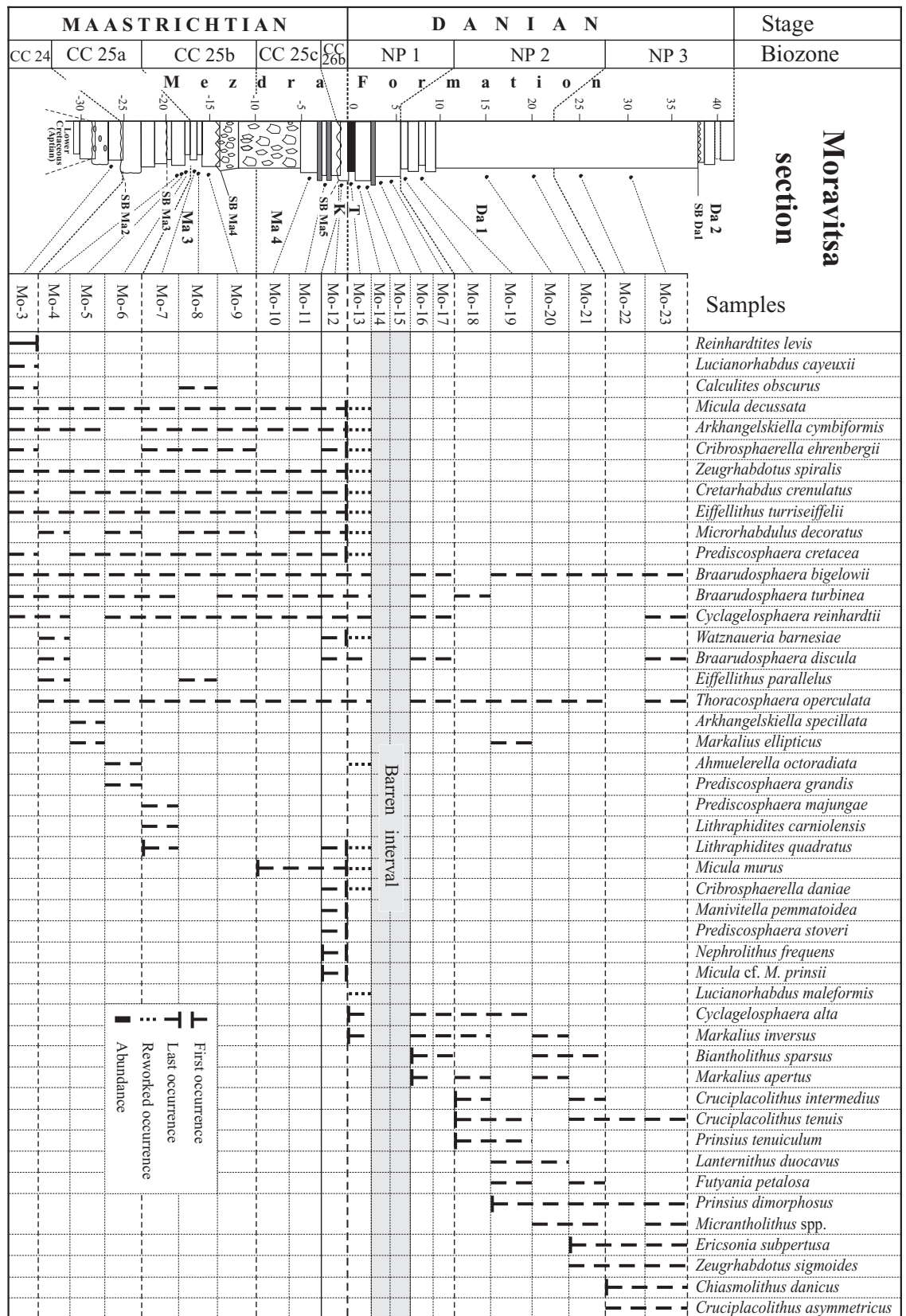
The K/T boundary is marked by a 2-3cm-thick, dark brown clay bed, in which Sinnyovsky (1999) reported an iridium enrichment of 7-11ppb. This bed (sample Mo-13) yielded mainly Cretaceous and so-called survivor species. However, the FO of *Cyclagelosphaera alta*, which was used by Varol (1989) in the North Sea to define the base of the Paleocene, was also recorded here. Samples from immediately above the K/T boundary clay (Mo-14, Mo-15) were barren of calcareous nannofossils due to the unfavourable grainstone lithology. *Biantholithus sparsus* and *Markalius apertus* have their FOs in the next marly sample (Mo-16), suggesting NP1.

The FO of *Cruciplacolithus tenuis* defines the base of NP2, and occurs in Mo-18. Within NP2, the successive FOs of *Prinsius dimorphosus* and *Ericsonia subpertusa* were recorded. Finally, the FO of *Chiasmolithus danicus*, in Mo-22, marks the base of NP3.

#### 3.1.2 Byala 2b section (hemipelagic environment)

The nannofossils of this section have previously been studied in detail by Stoykova (in Ivanov & Stoykova, 1994) and Perch-Nielsen (in Rögl et al., 1996). For the present study, we resampled some critical intervals both below and above the K/T boundary, in order to determine precisely the FOs and LOs of the strati-

Figure 3: Calcareous nanofossil distribution and lithology, Moravitsa. Height in metres. Nanofossil zones after Sissinigh (1977) and Martini (1971)



graphically-important nannofossil species. Our findings are consistent with those of the previous studies. The nannofloral assemblages are relatively high in species richness – 71 species were identified but are poorly preserved throughout the section.

In this outcrop, *Micula prinsii* occurs sporadically in the uppermost Maastrichtian. Its FO is in sample B2b-8 (17m below the K/T boundary). Reworking of specimens of *M. prinsii* into the overlying Danian sediments occurs as well. *Thoracosphaera operculata* and *Braarudosphaera bigelowii*, both considered to be survivor species (e.g. Thierstein, 1981; Perch-Nielsen, 1985b; Pospichal & Wise, 1992), are abundant and dominate the nannofloral assemblages in the K/T boundary clay and through NP1, as recorded by previous researchers (Preisinger *et al.*, 1993a, b; Ivanov & Stoykova, 1994; Rögl *et al.*, 1996). The FOs of *Cyclagelosphaera alta* and *Biantholithus sparsus* occur at +0.05m (sample B2bT-1), immediately above the K/T boundary clay. Figure 4 shows the biostratigraphy.

### 3.1.3 Byala 3 section (hemipelagic environment)

Ivanov & Stoykova (1994) placed sediments of this outcrop in CC25c-26 and NP1-2, based on calcareous nannofossils. Re-examination of the calcareous nannofossil biostratigraphy has resulted in some minor revisions, which are summarised below.

Nannofossil abundance is high, preservation is good, and 47 species were identified. The base of CC26 is placed at 7.5m below the top of the Maastrichtian, based on the FOs of *Micula prinsii* and *Nephrolithus frequens* (sample B3-61; Figure 5). At this outcrop, *M. prinsii* and *N. frequens* occur more consistently than in the Byala 2b section. Identification of the K/T boundary is based on the FOs of *Cyclagelosphaera alta* and *Biantholithus sparsus* immediately above the clay (sample B3T-1). The first consistent occurrence of the NP2 zonal marker, *Cruciplacolithus tenuis*, occurs at 5.20m above the K/T boundary (sample B3-7). Therefore, the thickness of NP1 is expanded from 3.5m in our previous study (Ivanov & Stoykova, 1994) to 5.2m here. The simultaneous FOs of *Chiasmolithus danicus*, *C. edwardsii* and *Prinsius martinii* at +25.0m (sample B3-11) mark the base of NP3. The co-occurrence of these taxa is due to the large sampling distance and is not considered to be indicative of an unconformity (Figure 5).

### 3.1.4 Emona section (deep-water environment)

The nannofloral assemblages of this locale display high abundance and relatively high species-richness. Fifty-nine species were identified, and CC25b-26 and NP1-3 were recognised. Preservation is good to very good throughout the section. A significant amount of reworked Cretaceous taxa were observed through NP1, gradually decreasing up-section (Figure 6).

*Micula prinsii*, *Ceratolithoides kamptneri* and *Nephrolithus frequens* first occur in sample E-6, 27m below the K/T boundary. The K/T boundary is placed at the base of a light greyish clay-bed, at sample E-12, based on the FOs of *Cyclagelosphaera alta* and *Biantholithus sparsus*. *Thoracosphaera operculata* dominates the nannofossil assemblages of NP1 and lower NP2 here. The successive FOs of *Neocrepidolithus dirimosus* (E-121, +0.6m), *Neobiscutum romeinii* (E-123, +4.0m), and *Cruciplacolithus primus* (E-125, +8.70m) suggest an earliest Danian age. *Cruciplacolithus intermedius* and *Prinsius dimorphosus* co-occur in sample E-126 (+10.0m) in upper NP1. The FO of *Cruciplacolithus tenuis* in E-13 (+13.20m), marks the base of NP2. Respectively, the FO of *Chiasmolithus danicus* (E-19, +38.0m) traces the base of NP3, followed by the FOs of *Prinsius martini* (E-20), *Prinsius bisulcus* and *Neochiastozygus modestus* (both in E-21). This section displays a continuous K/T transition in a deep-water environment, proved by the completeness of the nannofossil biostratigraphy. No iridium anomaly has been registered in this high-sedimentation-rate environment.

### 3.1.5 Marash section (deep-water environment)

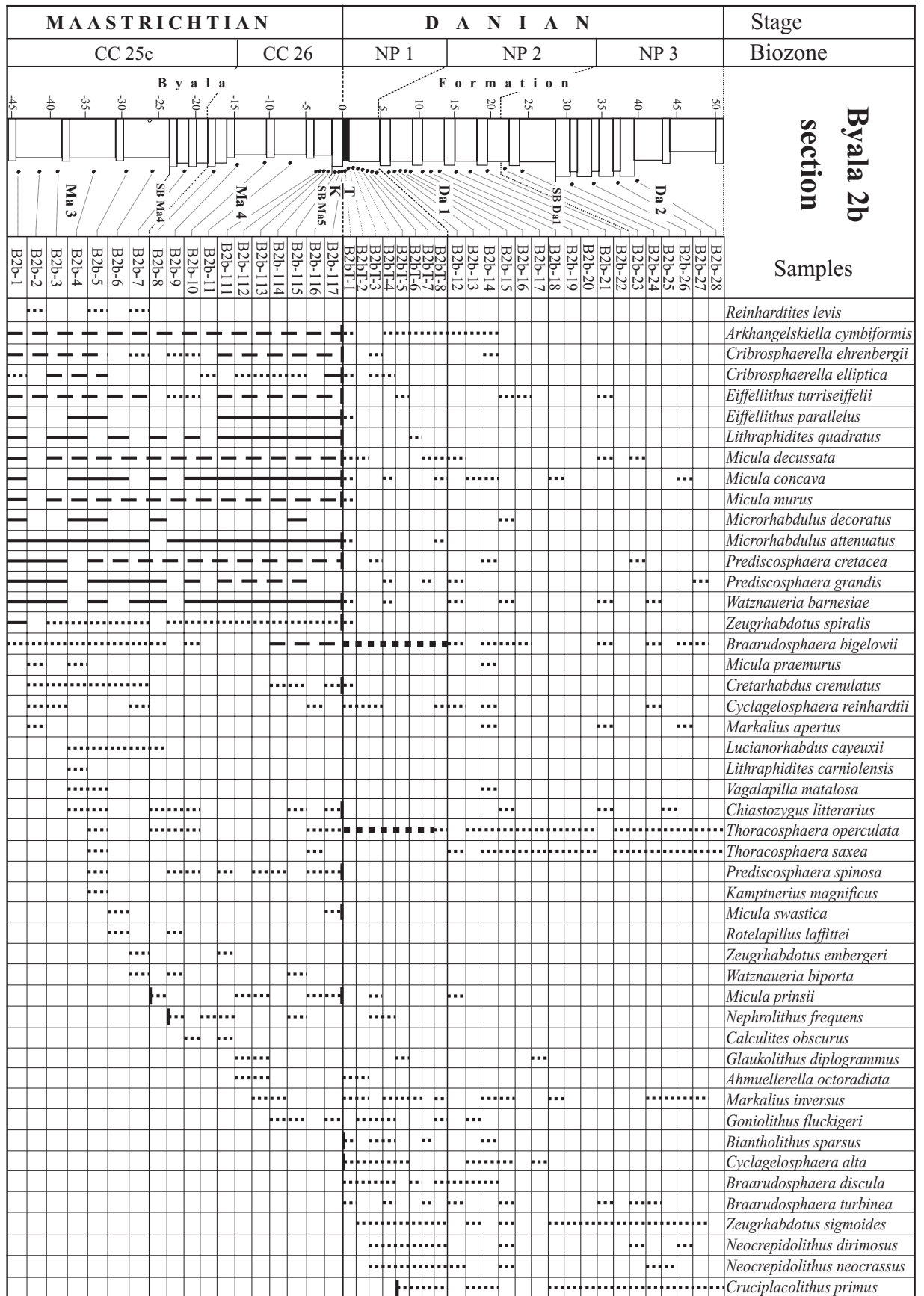
Species richness is relatively moderate (47 species identified) and the outcrop can be subdivided into CC25b-26, and NP1-3. Figure 7 shows the nannofossil biostratigraphy. It is worth mentioning that the FO of *Micula prinsii* (sample Ms-12) precedes the FOs of *Ceratolithoides kamptneri* and *Nephrolithus frequens* (Ms-13). The K/T boundary is placed between samples Ms-135 and Ms-134, based on the FO of *Cyclagelosphaera alta* at Ms-135 and the LOs of *Nephrolithus frequens*, *Micula prinsii* and most of the Maastrichtian taxa at Ms-134. The preservation of the specimens is good throughout the Upper Maastrichtian, however, a significant impoverishment of the nannofloral assemblage is recorded above the K/T boundary. Rare, broken and overgrown specimens dominate in the basal 3m of the Lower Danian. Reworking of Cretaceous taxa occurs mainly through NP1, but persists into NP2 and NP3. Calcareous nannofossil species-richness and abundance gradually increases throughout NP1 and lower NP2. The base of NP3 is drawn at the FO of *Chiasmolithus danicus* (Ms-21). Representatives of the genus *Braarudosphaera* are absent from this locality.

## 3.2 Sequence stratigraphy

The sequence stratigraphic approach has only recently been applied to the K/T transitional sequence in Bulgaria (Sinnyovsky, 1999). A complete sequence stratigraphic scheme for the Maastrichtian-Danian interval has recently been proposed (Stoykova & Ivanov, 2002). They suggested four depositional sequences (DS) in the Maastrichtian and three in the Danian. The sequence units are third-order cycles, which by definition are bounded by unconformities or their conformable continuations (Haq



Figure 4: Calcareous nanofossil distribution and lithology, Byala 2b Section. Height in metres. Nanofossil zones after Sissingh (1977) and Martini (1971)



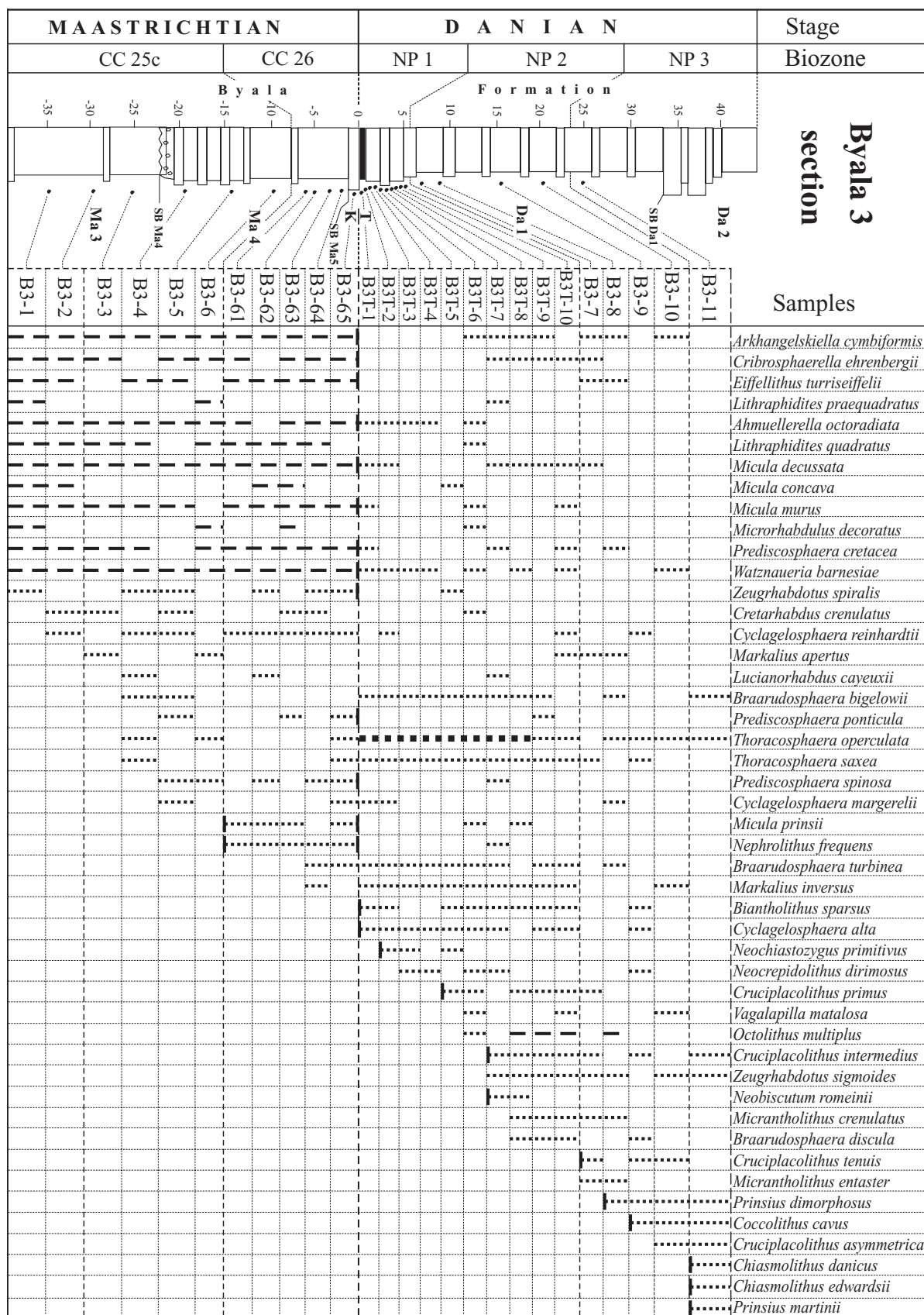


Figure 6. Calcareous nanofossil distribution and lithology, Emona. Height in metres. Nanofossil zones after Sissingh (1977) and Martini (1971)

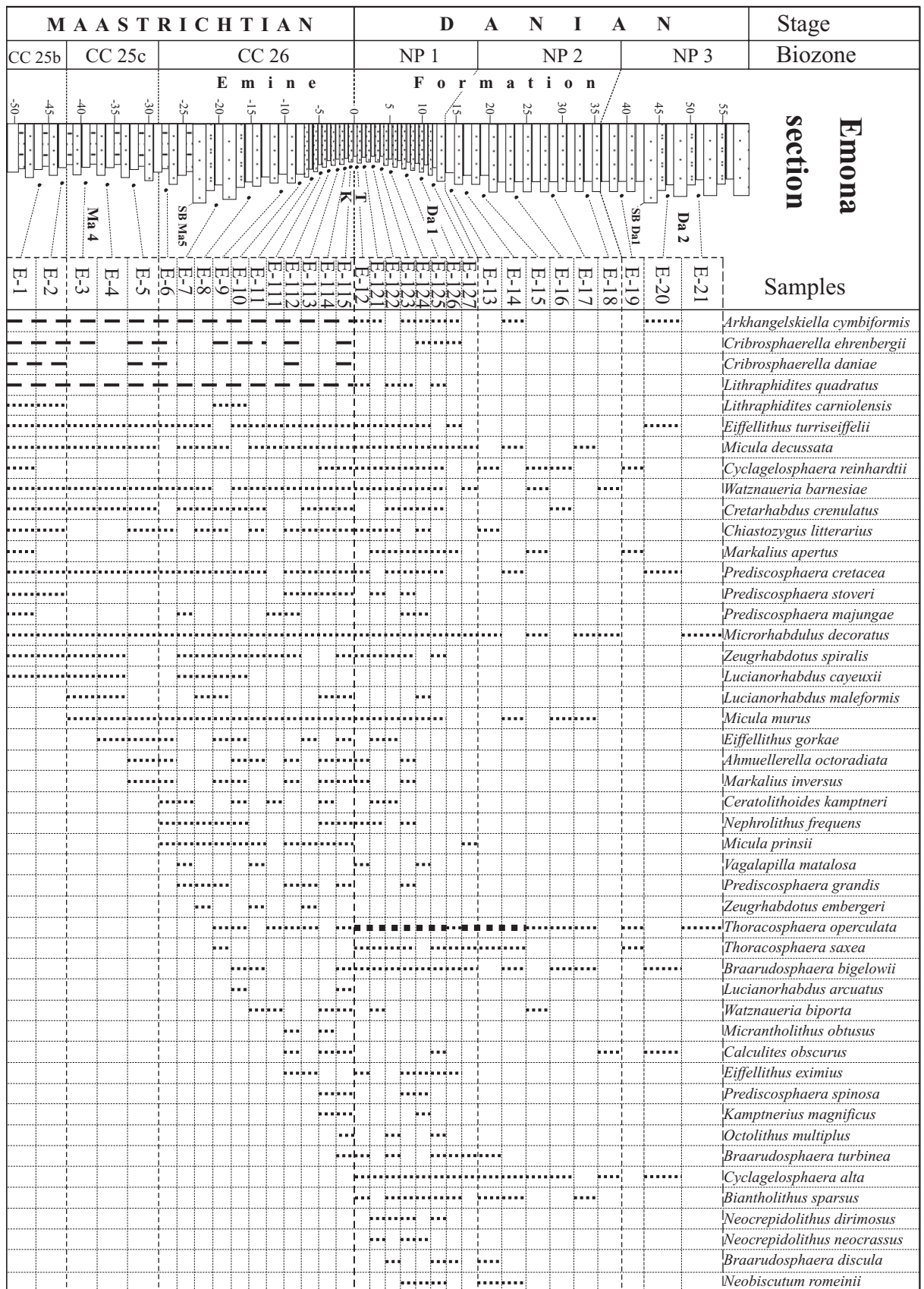
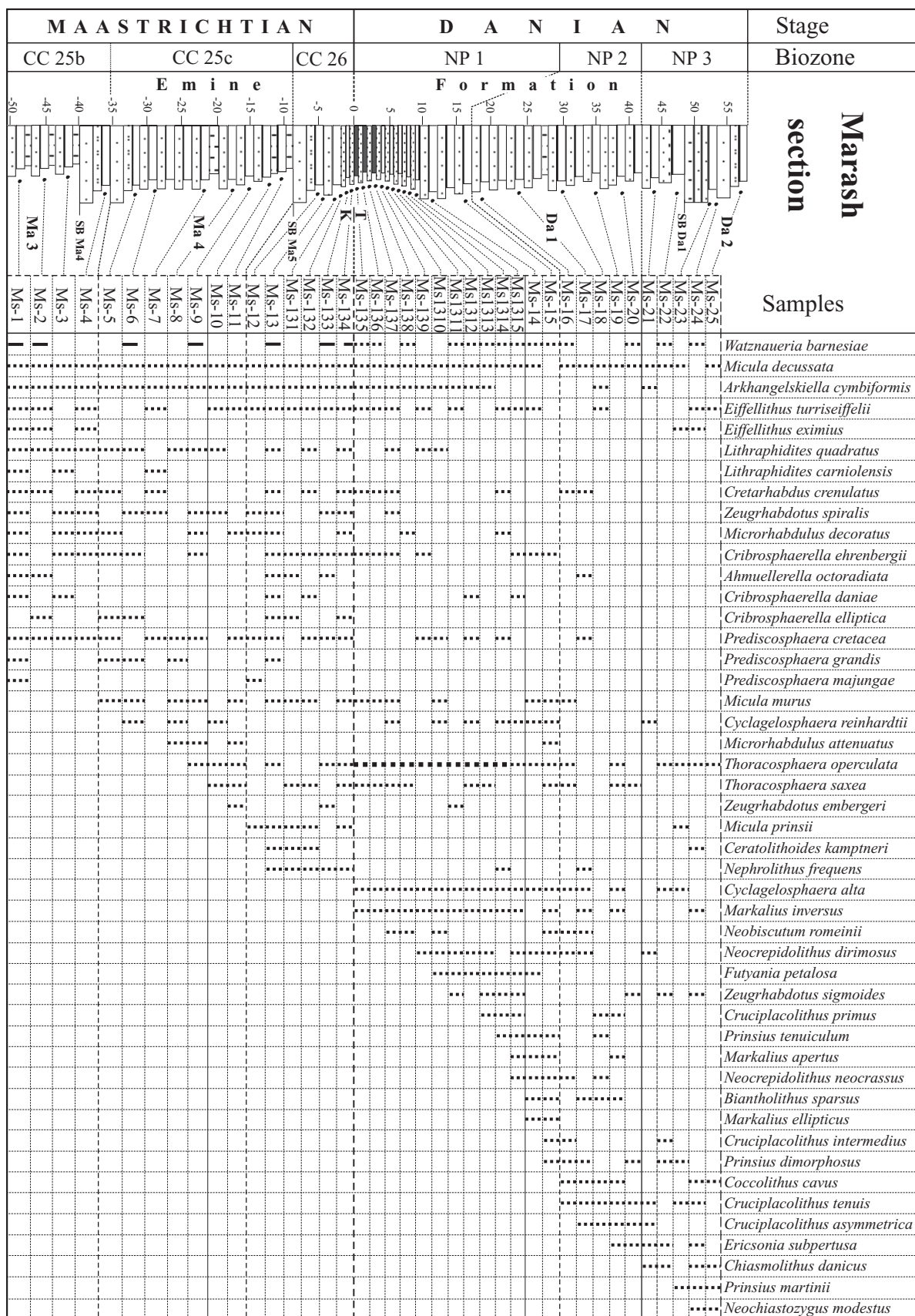




Figure 7. Calcareous nannofossil distribution and lithology, Marash. Height in metres. Nannofossil zones after Sissingh (1977) and Martini (1971)



*et al.*, 1987; van Wagoner *et al.*, 1988; Vail & Audemard, 1991). In this study, we focus only on the DSs in the targeted K/T transition: Ma3 and Ma4 (Maastrichtian) and Da1 (Danian).

### 3.2.1 Maastrichtian

DS Ma3 ranges within the Upper Maastrichtian. Its lower and upper boundaries lie within CC25b and CC25c, respectively. DS Ma4 extends to the top of the Maastrichtian. Its upper boundary falls within CC26.

In the ramp and slope sections (Moravitsa, Byala 2b, Byala 3), Ma3 and Ma4 represent transgressive system tract (TST) and highstand system tract (HST) sediment deposition (Figure 8). Only in the shallow-water section, Moravitsa, are their boundaries marked by short hiatuses and/or wash-outs. The TST consists of intraclastic sediments (Moravitsa) and of marly limestones (Byala 2b, Byala 3). Gravity-flows and slumps are commonly observed at the base of these sequences (Moravitsa, Byala 3; Figure 8). The HST in Moravitsa is dominated by micritic and clayey limestones with cherty nodules and beds. In the outer shelf and slope sections (Byala 2b, Byala 3), the HST consists of marls, and in basin-floor sections (Emona, Marash), sediments consist of fine-grained distal turbidites.

The basin-floor sequences are dominated by turbiditic sediments. The DSs are constructed of lowstand system tract (LST) and HST sediments. Their boundaries are conformable, and the sections are continuous (Figure 8). The LST is represented by proximal turbidites which have measurable rhythmicity (0.3–0.5m).

### 3.2.2 Danian

The Danian DS, Da1, spans the uppermost Maastrichtian to the Lower Danian. Its upper boundary lies within NP3. Da1 displays specific development in the ramp (Moravitsa) and slope (Byala 2b, Byala 3) sections. In Moravitsa, its basal and upper boundaries are marked by a hardground, suggesting a hiatus in sediment deposition (Figure 3). The TST sediments consist of alternating bioclastic or clayey limestones with marls. The base of this system tract is dominated by limestones that usually form thick, prominent bioclastic beds. The HST here is composed of nodular limestones. In the slope sections (Byala 2b, Byala 3), the HST is represented by marls. In the basin-floor sections (Emona, Marash), Da1 is sedimentologically similar to the Maastrichtian Ma3 and Ma4 sequences. The basal sequence consists of coarsely-bedded, rhythmic (0.3–0.4 to 1–1.2m) proximal turbidites that form the LST. The HST is dominated by thinly- to medium-bedded, rhythmic distal turbidites. The maximum flooding surface (mfs) falls within the thinly-bedded rhythmic turbidites. The position of the K/T boundary in the deep-water sections is very close to the mfs (Figure 8).

## 4. Discussion and conclusions

### 4.1 Depositional environments

In this study, we have recognised three main types of depositional environment from the K/T transition in Bulgaria: 1) a shallow-water environment, represented by carbonate-dominated sediments; 2) a hemipelagic environment, represented by marly limestone sediments deposited on the shelf margin and the upper slope; and 3) a deep-water environment, represented by turbidite sequences of flysh type (Figures 1, 8). Specific lithologies and calcareous nannofossil occurrences characterise each depositional setting.

The section at Moravitsa in NW Bulgaria is herein inferred to be a shallow-water environment. The sediments consist of packstones and wackestones that were deposited on a carbonate ramp. Calcareous nannofossil species-richness across the K/T transition is relatively low here (47 species), compared to the hemipelagic and deep-water sections (over 70 species). The preservation of the nannofossils is poor to moderate, which probably has affected the species-richness. A hemipelagic environment of deposition is inferred for the sections around Byala. Nannofossil assemblages across the K/T boundary are relatively rich, comprising more than 80 species. Preservation varies from poor (Byala 2b) to moderate (Byala 3). A deep-water setting is inferred for the turbiditic sections at Emona and Marash. *Ceratolithoides kamptneri*, considered to be a useful biostratigraphical datum in the Upper Maastrichtian (Self-Trail, 2001, 2002) is found only in these sections. Its FO is at the base of CC26 together with the FO of *Micula prinsii* (Emona), or a little above (Marash). The sediments represent proximal and distal turbidites, deposited on the basin floor by turbidite-flows. Nannofossil biozones attain a much greater thickness in these deep-water sections than elsewhere in the study area (Figure 8). The turbiditic sections yielded abundant and diverse nannofloras (>60 species identified). However, reworking is apparent in these sediments, as evidenced both in the Emona and Marash sections (Figures 6, 7, respectively). Reworking of Cretaceous taxa in the Danian extends into NP3.

### 4.2 Calcareous nannofossil correlation

Based on the nannofossil biostratigraphy, a complete sedimentary sequence is present in all sections studied, except for Moravitsa. Good biostratigraphic control allows for precise correlation between sections in the Upper Maastrichtian–Lower Danian interval (Figure 8). CC25c is well developed in the deep-water and hemipelagic sections, attaining thicknesses of 20 to 40m. It is documented in the shallow-water section Moravitsa as well, but is thinner there (Figures 3, 8). CC26 is present in all deep-water and hemipelagic sections, with varying thicknesses (8–25m). In the ramp section, Moravitsa, its thickness is extremely reduced due to the wash-out and missing sediments, interpreted at its lower boundary (Figures 3, 8). NP1 is present in all of the studied sections. It has similar thicknesses in the shallow-water and hemipelagic sections (4–5m), but in the deep-water sec-

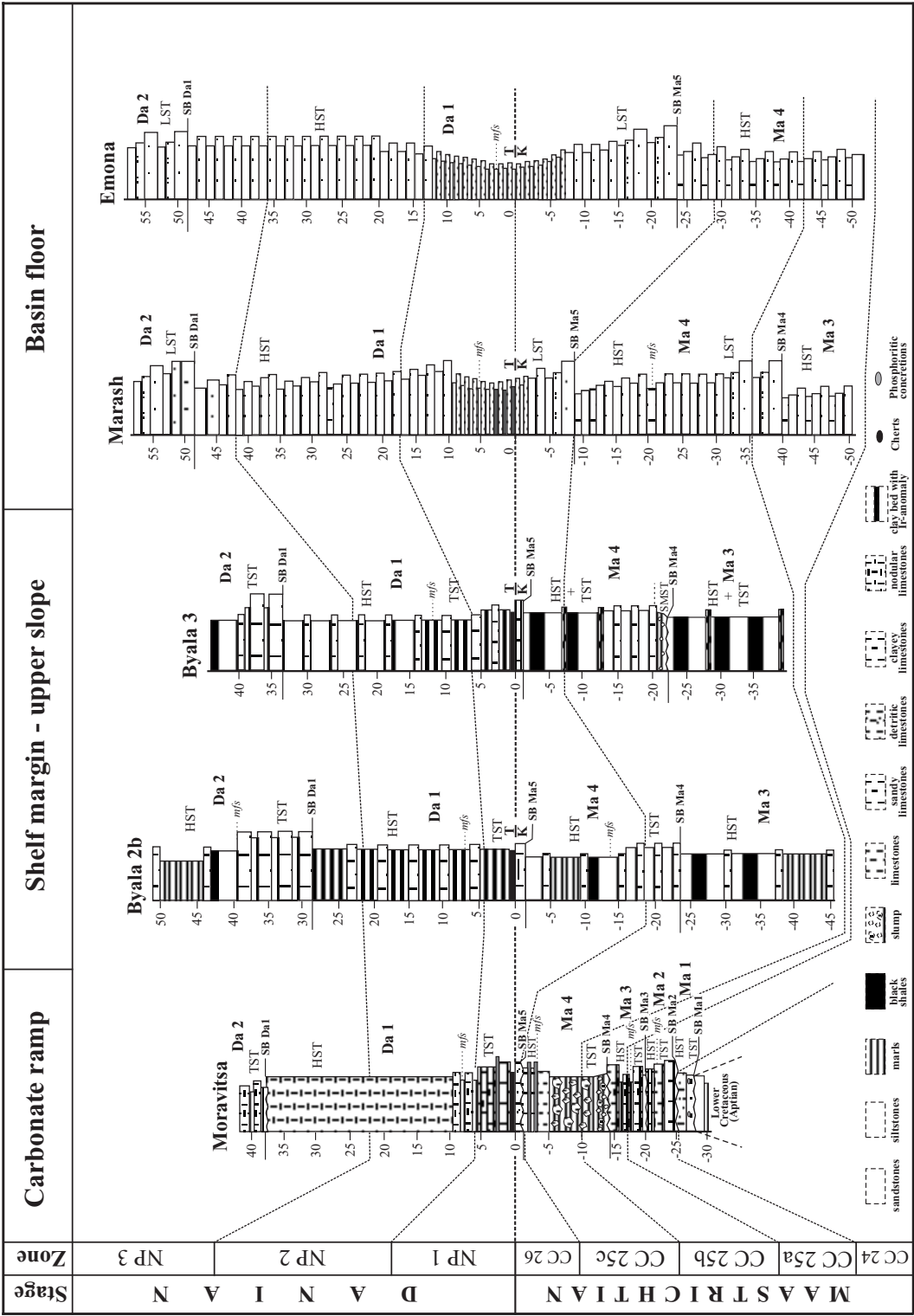


Figure 8: Nannofossil biostratigraphical and sequence stratigraphical correlation of the studied sections

tions, its thickness is much greater (13-15m) (Figure 8). NP2 is present in all sections, varying in thickness between 17 and 30m. Its distribution across the study area is similar to that of NP1 (Figure 8).

4.3 Biostratigraphic calibration of depositional sequences

The exact position of the sequence boundaries is directly

calibrated to the nannofossil zones. The lower boundary of Ma3 falls within CC25a, whereas its upper boundary lies within CC25b. Ma3 falls entirely within the Upper Maastrichtian. The upper boundary of Ma4 is also in the uppermost Maastrichtian (CC26). The lower sequence boundary of Da1, designated as SB Ma5 (Figure 8), is positioned at the top of CC26, the upper sequence boundary lying in NP3. The range of Da1 is thus uppermost

Maastrichtian to Lower Danian.

The divided sequence units show a good correlation across the different sections. There is a good agreement of our sequence subdivision with the interregional scheme of the European basins (Hardenbol *et al.*, 1998), as well as with some regional schemes (Pujalte *et al.*, 1995).

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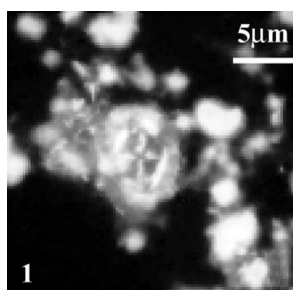
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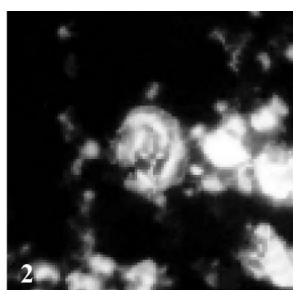
## Plate 1

Nannofossils from the K/T transition in the hemipelagic environment around Byala (Byala 2b, 3)

Heights in section given in metres above/below the boundary



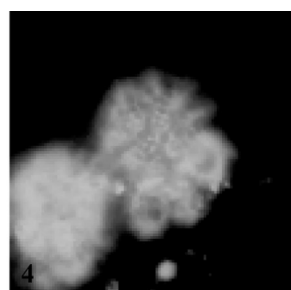
*Cruciplacolithus tenuis*  
Sample B2b-25, +30.6m



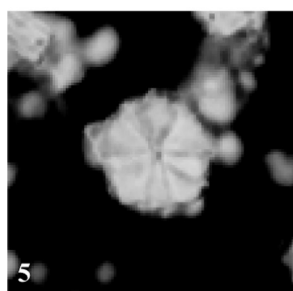
*Cruciplacolithus tenuis*  
Sample B2b-12, +5.5m



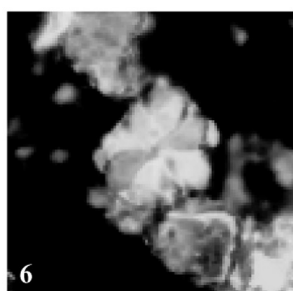
*Cruciplacolithus intermedius*  
Sample B2bT-7, +3.6m



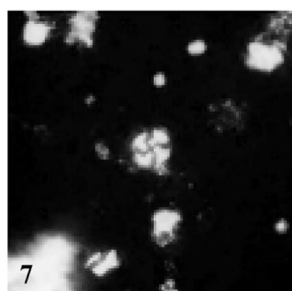
*Prinsius dimorphosus*  
coccosphere  
Sample B2b-14, +6.8m



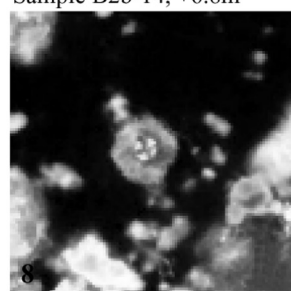
*Biantholithus sparsus*  
Sample B2bT-1, +0.03m



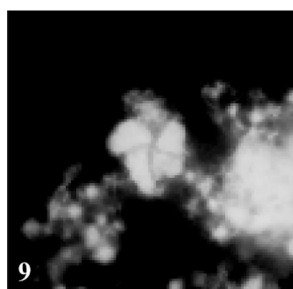
*Biantholithus sparsus*  
Sample B3T-2, +0.5m



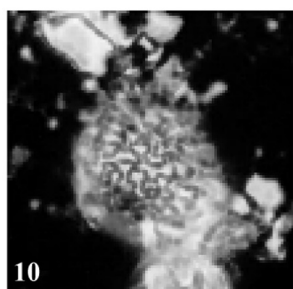
*Cyclagelosphaera alta*  
Sample B2bT-3, +0.97m



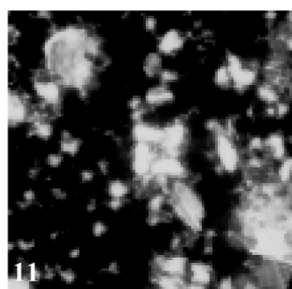
*Markalius inversus*  
Sample B3T-2, +0.5m



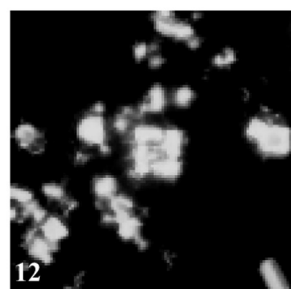
*Braarudosphaera turbinea*  
Sample B2b-24, +25m



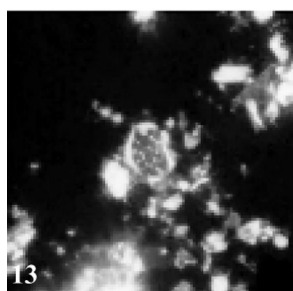
*Thoracosphaera operculata*  
Sample B2bT-1, +0.01m



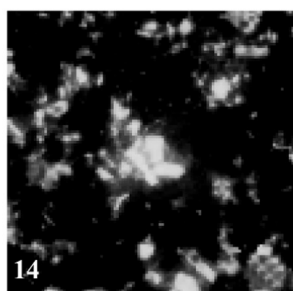
*Micula murus*  
Sample B2bT-1, +0.01m



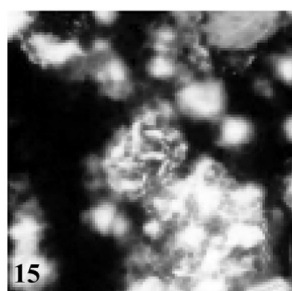
*Micula swastica*  
Sample B2b-117, -0.02m



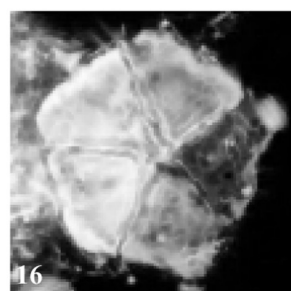
*Nephrolithus frequens*  
Sample B2b-115, -0.9m



*Micula prinsii*  
Sample B2b-117, -0.04m



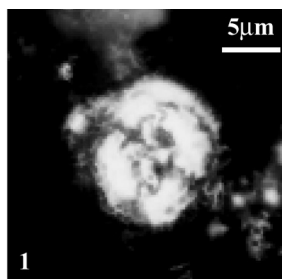
*Prediscosphaera ponticula*  
Sample B3-65, -0.02m



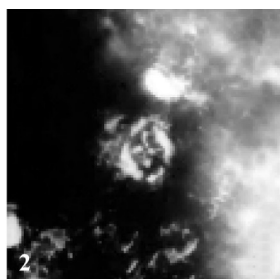
*Braarudosphaera bigelowii*  
Sample B3T-1, +0.05m

## Plate 2

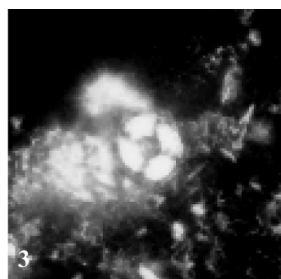
Nannofossils from the K/T transition in deep-water (Marash, Emona) and shallow-water (Moravitsa) environments  
Heights in section given in metres above/below the boundary



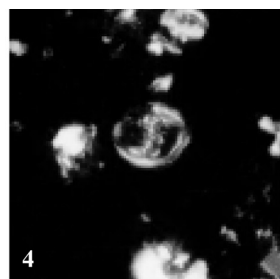
1  
*Crucioplacolithus tenuis*  
Sample E-13, +14.5m



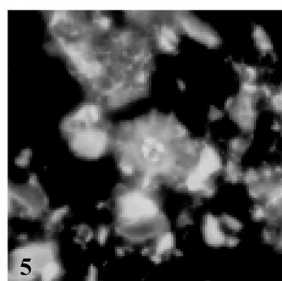
2  
*Crucioplacolithus intermedius*  
Sample Ms-15, +15.1m



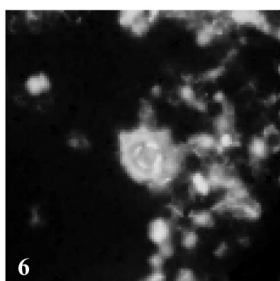
3  
*Ericsonia subperta*  
Sample Mo-21, +20m



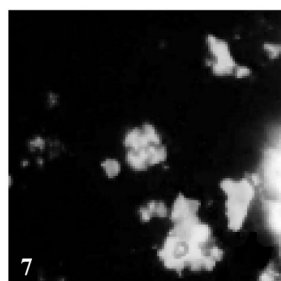
4  
*Zeugrhabdotus sigmoides*  
Sample Ms-13, +6m



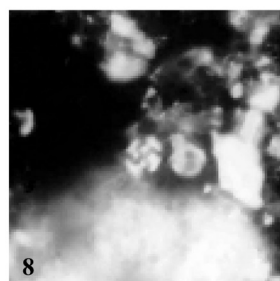
5  
*Markalius inversus*  
Sample Ms-137, +1.03m



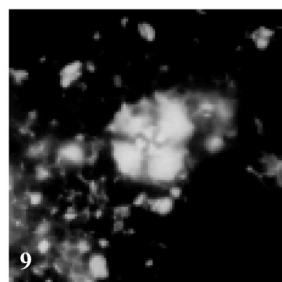
6  
*Markalius apertus*  
Sample Ms-137, +1.03m



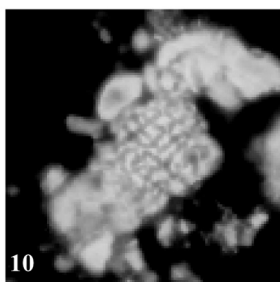
7  
*Cyclagelosphaera alta*  
Sample Mo-13, +0.05m



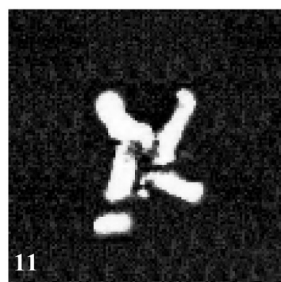
8  
*Cyclagelosphaera alta*  
Sample Ms-137, +1m



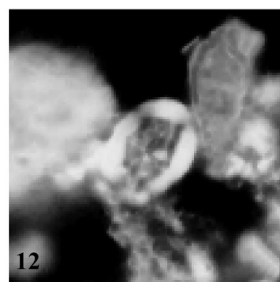
9  
*Cyclagelosphaera reinhardtii*  
Sample Mo-17, +4.55m



10  
*Thoracosphaera operculata*  
K/T boundary clay bed  
Sample Mo-13, +0.01m



11  
*Micula prinsii*  
Sample E-114, -2m



12  
*Arkhangelskiella cymbiformis*  
Sample E-11, -7m