Integrated biostratigraphy and palaeoenvironments of the Upper Cretaceous in the Petrich section (Central Srednogorie Zone, Bulgaria)

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ABSTRACT:


The Upper Cretaceous succession (Coniacian to lowermost Maastrichtian, with focus on the Campanian) at Petrich, Central Srednogorie Zone in Bulgaria, is described and calibrated stratigraphically based on nannofossils, dinoflagellate cysts and inoceramids. The following standard nannofossil zones and subzones are identified: UC10–UC11ab (middle to upper Coniacian), UC11c–UC12–UC13 (uppermost Coniacian to Santonian), UC14a (lowermost Campanian), UC14bTP–UC15cTP (lower Campanian to ‘middle’ Campanian), UC15dTP–UC15eTP (upper Campanian), UC16aTP (of Thibault et al. 2016; upper part of the upper Campanian), and UC16b (Campanian–Maastrichtian boundary). The base of the Campanian is defined by the FO of Broinsonia parca parca (Stradner) Bukry, 1969 and Calculites obscurus (Deflandre) Prins and Sissingh in Sissingh, 1977 (a morphotype with a wide central longitudinal suture). The Areoligera coronata dinoflagellate cyst Zone (upper lower Campanian to upper Campanian) is identified, corresponding to the UC14bTP–UC16aTP nannofossil subzones. The inoceramid assemblage indicates the ‘Inoceramus’ azerbaydjanensis–‘Inoceramus’ vorhelmensis Zone, correlated within the interval of nannofossil subzones UC15dTP–UC15eTP. The composition of the dinoflagellate cyst assemblages and palynofacies pattern suggest normal marine, oxic conditions and low nutrient availability within a distal shelf to open marine depositional environment during the Campanian.

Key words: Upper Cretaceous; Campanian; Calcareous nannofossils; Dinoflagellate cysts; Inoceramids; Biostratigraphy; Palaeoenvironments.

INTRODUCTION

The upper part of the Upper Cretaceous (the ‘Senonian’ in older terms; d’Orbigny 1842) comprises the Coniacian, Santonian, Campanian and Maastrichtian (89.39–66.04 Ma; Gale et al. 2020) and archives a major change in the Earth system and palaeoclimate, from the mid-Cretaceous hothouse to cooler greenhouse conditions (e.g., Hay and Floegel 2012). Especially the Campanian (83.65–72.17 Ma; Gale et al. 2020), the longest stage of the Upper Cretaceous, represents a major turning point in Earth history, considering palaeoclimate and palaeoceanography. The Campanian is characterized by a generally high sea level and decreasing global surface temperatures after the Cretaceous Thermal Maximum.
around the Cenomanian–Turonian (Haq et al. 1987; Jenkyns et al. 1994; Hardenbol et al. 1998; Clarke and Jenkyns 1999; Huber et al. 2002; Hay and Flögel 2012). Increasing marine seaways and oceanic turnover has led to a transition from typical Mesozoic to ‘modern’ oceanic circulation, including the final oceanic anoxic event OAE 3 in the Santonian (Premoli Silva and Sliter 1999; Wagreich 2012; Mansour and Wagreich 2022). The detailed understanding of such Late Cretaceous environmental changes requires a precise stratigraphical framework, including the characterization of important bloom groups such as inoceramids, calcareous nannofossils and dinoflagellate cysts (dinocysts).

The biostratigraphy of the ‘Senonian’, and especially of the Campanian, is already well-established, based on different important fossil groups, such as ammonites in US Western Interior Basin (see Cobban et al. 2006), inoceramids (Walaszczyk 1992, 1997, 2004; Walaszczyk et al. 2001, 2008), and calcareous nannofossils (e.g., UC zonation by Burnett 1998) (see the review in Gale et al. 2020). Their zones and ranges have provided a firm dataset for the subdivision of the Campanian and detailed correlation. Dinoflagellate cysts seem to be a group with a rising potential for the stratigraphic subdivision of the Late Cretaceous and especially the Campanian and its boundaries, supported by studies from both the Tethyan and Boreal realm (Kirsch 1991; Roncaglia and Corradini 1997; Antonescu et al. 2001; Schiøler and Wilson 2001; Roncaglia 2002; Skupien and Mohamed 2008; Radmacher et al. 2014; Slimani et al. 2021; Niechwedowicz and Walaszczyk 2022). These studies provide valuable information on dinoflagellate cyst ranges, as well as first and last occurrence events (FO and LO) for establishing a sound palynostratigraphic framework of the Campanian. Dinoflagellate cyst assemblages can also infer information to interpret the depositional environments in terms of water depth, depositional energy, temperature, nutrient availability and productivity by using the ratio of peridinioid to gonyaulacoid (P/G) dinocysts and palaeoenvironmental sensitive dinocyst groups (Brinkhuis 1994; Wilpshaar and Leereveld 1994; Zonneveld et al. 2013; Frieling and Sluijs 2018; Houben et al. 2019; Niechwedowicz et al. 2021).

The present paper reports first results of an integrated stratigraphic investigation of the Petrich section, Central Srednogorie Zone in Bulgaria, with special emphasis on the Campanian. Our study creates a comprehensive calibrated dataset for the Campanian, in which dinoflagellate cyst and nannofossil taxa ranges and inoceramid occurrences provide valuable markers for the age assessment and the stratigraphic subdivision of the Campanian. Palaeoenvironmental analysis in this study is mainly based on dinocyst assemblages and palynofacies data.

GEOLOGICAL SETTING

The Srednogorie Zone in Bulgaria represents a chain of strike-slip and pull-apart basins, which are a part of the peri-Tethyan arc/back-arc basin system (Ivanov 2017; Vangelov et al. 2019). The Upper Cretaceous volcano-sedimentary sequence in the western part of the Central Srednogorie tectonic subzone forms two strips called the Chelopech and Panagyurishte strips, spanning the Turonian–Maastrichtian and unconformably overlying different pre-Cretaceous rocks (Text-fig. 1). In the Srednogorie Zone, the Upper Cretaceous is represented by various rock successions, including siliciclastic sequences, volcanoclastic and epiclastic deposits, which are overlain by white, red and grey limestones, with a fast transition into sandy, low-density turbidites. The similarities between these strips (in lithological and chronostratigraphical terms) allow to assume the presence of either a single Cretaceous basin or a connected basin system, disrupted by Cenozoic tectonics.

According to Vangelov et al. (2019), the Upper Cretaceous volcano-sedimentary sequence in the entire Panagyurishte strip comprises a basal siliciclastic terrigenous unit (middle Turonian), a volcanoclastic unit (upper Turonian), an overlying lower epiclastic unit (Coniacian–lower Santonian), the pelagic Mirkovo Formation (Santonian–lower Campanian), an upper epiclastic unit (upper Campanian) and the Chugovitsa Formation (upper Campanian–Maastrichtian) (see Text-figs 1, 2).

One of the most representative and continuous sedimentary sequences in the Panagyurishte strip is exposed in the vicinity of Petrich village (Text-figs 2, 3). The herein newly studied Petrich section, with a total thickness of 596 m, is cropping out 1 km east of the village of Petrich and is here described in detail. In the Petrich section, the lithostratigraphical units mentioned above are with a confined chronostratigraphic range as follows: the base of the section is composed of limy, medium-bedded, mica-bearing volcanoclastic sandstones assigned to the so-called lower epiclastic unit (lower Coniacian), followed by thin- to medium-bedded grey, pink and red, sometimes mottled limestones of the Mirkovo Formation (Moev and Antonov 1978; CORB sensu Wang et al. 2011) (middle Coniacian–lower Campanian;
The middle and upper parts of the section consist of muddy turbidites of the Chugovitsa Formation (Campanian–Maastrichtian), composed of an alternation of thin to medium-bedded silty marlstones, marlstones and sandstones. The lower part of the Chugovitsa Formation, known as the Voden Member (Moev and Antonov 1978) is 83 m thick and comprises grey thin-bedded marlstones, intercalated with rare sandstone beds. The Voden Member of the Chugovitsa Formation yielded comparatively rich macro- and microfossil assemblages (Text-fig. 3). This complete and uninterrupted part of the Petrich section has been studied.

**MATERIAL AND METHODS**

The Petrich section was sampled for dinoflagellate cysts and calcareous nannofossils during two field campaigns in order to document its biostratigraphy. Thirty-five palyno- and nannofossil, cross-calibrated samples were collected during the first field campaign in 2020. Additional sampling took place in August 2021 in the framework of the joint Bulgarian-Austrian project (WTZ, KP-06-Austria/9) and a total of forty-five samples were investigated. Inoceramids were collected during both field campaigns, but found only in one level – in the upper part of bed 21 (Voden Member of the Chugovitsa Formation) (Text-fig. 3).

Palynological samples were processed at the Polish Academy of Sciences, Laboratory of the Geological Sciences Institute, Kraków (Poland). About 50 g of sediment was processed by HCl and HF treatment and heavy liquid separation. The residues were finally sieved through 10 µm nylon meshes. Strew mounts were made in glycerine jelly. From each sample, two palynological strew mounts were prepared and analyzed for their palynological content. The slides are stored in the collections of the Sofia University “St. Kliment Ohridski”, Bulgaria.
Text-fig. 2. Geological sketch map of the area of the Petrich village (after Vangelov et al. 2019). 1 – Quaternary (Q), 2 – Chugovitsa Formation (cuK2cp-mt), 3 – upper epiclastic unit (6K2cn), 4 – Mirkovo Formation (miK2st-cp), 5 – lower epiclastic unit (5K2cn-st), 6 – marl-limestone unit (4K2cn), 7 – volcanoclastic unit (3K2t), 8 – Vran Kamak magmatic centre (2K2t), 9 – basal terrigenous unit (1K2t), 10 – Moesian Terrigenous-Carbonate Group (T3), 11 – Iskar Carbonate Group (T1-3), 12 – Petrohan Terrigenous Group (T1), 13 – Palaeozoic high-grade metamorphites (Pz1), 14 – location of the section studied.

Text-fig. 3. Lithological column of the Petrich section (Bulgaria) with ranges of selected dinoflagellate cysts (black), calcareous nannofossils (red) and inoceramid taxa (blue). 1 – limy, medium-bedded volcanoclastic sandstones with muscovite, 2 – thin-bedded limy siltstones, 3 – grey, medium-bedded silty limestones, 4 – grey, medium-bedded limestones, 5 – grey, thin-bedded limestones, 6 – red to pink medium-bedded limestones, 7 – thin-bedded red to pink limestones, 8 – yellow to yellowish limestones, 9 – unclearly bedded limestones, 10 – not well exposed limestones, 11 – red marlstones, 12 – grey marlstones, 13 – thin- to medium-bedded sandstones, 14 – inoceramid bivalves, 15 – samples for dinoflagellate cysts, 16 – samples for calcareous nannofossils, 17 – ‘Inoceramus azerbaydjanensis – ‘Inoceramus vorhelmensis’ Zone.
The readers are referred to Fensome et al. (2019) for dinoflagellate cyst taxonomy.

Quantitative analysis of dinocyst associations were based on counts of 100 specimens, where possible, per slide. These are described in terms of rare (1–9 specimens), common (10–20 specimens) and abundant (more than 20 specimens). Palynofacies analysis involved counting the relative abundance of sedimentary organic constituents based on 400 particles per slide. Three main groups of kerogen constituents proposed by Tyson (1995), Radmacher et al. (2020) and Slimani et al. (2021) have been recognized in the slides, namely: 1) phytoclasts (opaque and translucent organic particles), 2) palynomorphs (dinoflagellate cysts, spores and pollen), and 3) amorphous organic matter (AOM). The data were plotted in the ternary AOM–Phytoclast–Palynomorph plot of Tyson (1993) and in the Microplankton–Spore–Pollen ternary plot (after Fedorova 1977; Duringer and Doubinger 1985). Palynofacies parameters, such as the ratio of continental to marine particles (C/M ratio), the ratio of opaque to translucent phytoclasts (OP/TR ratio) (Tyson 1993, 1995), as well as the ratio of peridininoid to gonyaulacoid (P/G) dinocysts (Brinkhuis 1994; Wilpshaar and Leereveld 1994; Harris and Tocher 1997; Schioler et al. 1997; Sluijs et al. 2005; Zonneveld et al. 2013; Frieling and Sluijs 2018; Houben et al. 2019; Niechwedowicz et al. 2021) were estimated to characterize the palaeoenvironmental settings.

Nannofossil samples from the studied section were taken at different sampling intervals according to outcrop conditions, vegetation and soil-covered intervals. All in all, forty-five suspension slides were prepared for calcareous nannofossil investigation using scratched sediment powder suspended with distilled water in a beaker (e.g., Wolfgring et al. 2018). After two hours, the supernatant was removed, and a new suspension was prepared from which droplets were put on a glass cover plate, air dried and then fixed with Canada Balsam© on a glass slide. The slides were examined qualitatively for nannofossil fixed with ammonium chloride and illustrated in natural size. The specimens used for this work are stored at the inoceramid collection of the Museum of Palaeontology and Historical Geology of the Sofia University “St. Kliment Ohridski”, Bulgaria.

CAMPANIAN AND MAASTRICHTIAN STAGE AND SUBSTAGE SUBDIVISION

The Petrich section includes biostratigraphic records of several inferred stage boundaries of the Upper Cretaceous, i.e., Santonian, Campanian and Maastrichtian. However, the presence of the Coniacian–Santonian boundary interval is only inferred from a somehow poorly preserved nannofossil record without correlation to other fossil groups, therefore, we restrain from discussing this boundary in more detail. The reader is referred to the GSSP data published by Lamolda et al. (2014), with the first occurrence (FO) of the inoceramid bivalve Platyceramus undulatoplicatus (Roemer, 1852) as the boundary marker.

The Campanian Stage was introduced by Coquand (1857). In Europe, its base was originally defined with the lowermost occurrence of the ammonoid species Placenticeras bidorstaum (de Grossouvre, 1901) (e.g., Birkelund et al. 1984). The last occurrence of the stemless crinoid Marsupites testudinarius (Scholethoim, 1820) has been also proposed as a marker for this boundary (Gale et al. 1995; Hancock and Gale 1996). Due to the limited occurrence of Marsupites spp. in certain palaeoenvironments and palaeogeographic realms, discussion has started to define the base of the Campanian at the lower boundary of the reversed polarity chron C33r (Ogg and Hinove 2012; Wolfgring et al. 2018; Gale et al. 2021). In the North American Western Interior Basin, the base of the Campanian is correlated to the base of the Scaphites leei III ammoneite zone (Cobban et al. 2006).

In general, the Campanian stage is subdivided either into two substages, or into a lower, middle and upper substage – but no substage boundary markers or GSSP definitions have been yet proposed (Ogg and Hinove 2012; Gale et al. 2020). In the US Western Interior, the
three-partite subdivision of the Campanian is widely accepted (Cobban et al. 2006), whereas in Europe only the lower and upper Campanian are more commonly used, and provisionally referred to herein. The first occurrence of *Belemnitella mucronata* (Schlotheim, 1813) marked the lower/upper Campanian boundary in northwest Europe (Christensen 1999), which is slightly below the middle/upper Campanian boundary in the North American three-partite subdivision (Ogg and Hinov 2012). In the US Western Interior Basin, the lower/middle and middle/upper Campanian boundaries are marked by ammonites (Cobban et al. 2006). In Europe the base of the US middle Campanian substage is within the lower portion of the ‘*Inoceramus* azerbaydjanensis–*Inoceramus* vorhelmensis’ Zone, proposed for the lower part of the European upper Campanian (Walaszczyk 1997; Walaszczyk et al. 2008), whereas the US middle/upper Campanian boundary is placed in Europe at the base, or within the ‘*Inoceramus* tenuilineatus’ Zone (Walaszczyk 2004; Ogg and Hinov 2012). Using calcareous plankton biostratigraphy, the base of the upper Campanian may correspond to the base of nannofossil subzones UC15a, UC15b or UC15c (e.g., Burnett 1998) and to the base of the classical *Globotruncana ventricosa* planktonic foraminifera biozone, a concept that was strongly questioned by Petrizzo et al. (2011).

The Campanian/Maastrichtian boundary is defined by a ratified GSSP for the base of the Maastrichtian in a quarry at the vicinity of the village of Tercis, SW France, as the arithmetic mean of twelve bioevents including first and last occurrences of ammonites, inoceramid bivalves, planktonic and benthic foraminifera, dinoflagellate cysts and calcareous nannofossils.
(Odin and Lamaurelle 2001; Ogg and Hinnov 2012). The base of the Maastrichtian was correlated to the last appearance of the nanofossil Uniplanarius trifidus (Stradner in Stradner and Papp) Hattner and Wise in Wind and Wise, 1983 (formerly Quadrum trifidum of e.g., Perch-Nielsen 1979) at the GSSP section of Tercis (Odin and Lamaurelle 2001) and later on in Tethyan zonations (e.g., Thibault et al. 2016). The UC16b19 subzone, according to Thibault et al. (2016, p. 64), emends the UC16/UC17 zonation given by Burnett (1998) and redefines the (standard) nanofossil marker succession around the base of the Maastrichtian. However, at Tercis, the LO of Uniplanarius trifidus was not consistently reported by different nanofossil workers (Odin 2001), and positioned some 19 m below the Golden Spike point in Odin and Lamaurelle (2001), thus giving a higher range of uncertainty for correlation with the Maastrichtian GSSP.

RESULTS

Calcareous nanofossils

In general, the preservation of calcareous nanofossils is rather poor to very poor, with diagenetic overgrowth dominantly in the lower interval of the section, and additional dissolution and etching of nanofossils in the upper, siliciclastic, turbiditic part of the section (Text-fig. 4). The abundances of nanofossils are low to very low, from a maximum average of 8 specimens per field of view (FOV) to 1 specimen per 30 FOV; one sample was barren (Text-fig. 5). Low abundances and poor preservation are regarded responsible for the low diversity of these Upper Cretaceous assemblages, with a maximum of thirty-one taxa (see Appendix 1 for alphabetical list of calcareous nanofossil taxa from the Petrich section), as compared to reports of more than forty to fifty from other Santonian–Campanian assemblages (e.g., Püttmann and Mutterlose 2021).

Dinoflagellate cysts

Dinoflagellate cysts have a comprehensive record through the middle and upper part of the sampled interval in the Petrich section (from bed 12 upwards) with more than 50% palynologically positive samples. The dinocyst species diversity is moderate, with thirty documented species. Terrestrial palynomorphs are poorly represented with the occurrence of 1–2 taxa in productive samples from the upper part of the sampled interval.

Samples from P-6 to P-17, corresponding to the sampling interval beds 16–31 in the section yielded the most diverse and well preserved dinoflagellate cyst assemblages (see Appendix 2 for complete list of encountered dinoflagellate cyst taxa). Cannosphaeropsis utinensis, Palaeohystrichophora infusorioides and Odontochitina porifera occur already in sample P-6 and consistently range up to P-16 (Text-figs 3, 6). This dinocyst impoverished interval includes also the following species characteristic for the Campanian: Achomosphaera crassipellis, A. fenestra, A. ramulifera, A. regiensis, A. sagena, Areoligera coronata, Chatangiella ditissima, C. tripartita, Corradinosphaeridium horridum, Exochosphaeridium majus, Hystrichodinium pulchrum, Hystrichosphaeridium duplum, H. salpingophorum, H. tubiferum, Isabelidinium cooksoniae, Oligosphaeridium complex, O. pulcherrimum, Pervosphaeridium monasteriene, P. pseudhystrichodinium, Pterodinium cinulatum, Raetiaedinium truncigerum, Spiniferites ramosus, S. scabrosus, Surculosphaeridium longifurcatum and Tanyosphaeridium regulare (Text-figs 6–8). The most common dinocyst species within the assemblages are P. cinulatum, O. complex, S. ramosus, C. horridum and C. utinensis (Text-fig. 6). Areoligera coronata is represented by rare specimens and is documented in samples P-8 and P-9. Most Chatangiella spp. and Isabelidinium utinensis occur in the sample set P-9 to P-15 (Text-figs 3, 6).

Palynofacies data

Palynofacies data were considered from the Campanian interval in the section. The organic matter (OM) in the samples is represented by opaque and translucent phytoclasts and dinoflagellate cysts. In the lower and middle part of the section, corresponding to samples from P-5 to P-11 (bed 12 to bed 23), the opaque phytoclasts show a very high proportion together with abundant dinoflagellate cysts. Opaque phytoclasts are typically equidimensional, rarely lath and of medium size. The interval contains also rare translucent phytoclasts of small size and equidimensional shape.

Upwards, within samples P-12 to P-22, corresponding to the interval from bed 24 to bed 37, a slight change occurs in the palynofacies composition (Text-fig. 9). The proportion of opaque phytoclasts and dinocysts decreases slightly and large translucent structured phytoclasts, such as woody tissues and cuticles, appear in the palynofacies. The continental input increases upwards in this interval with structured translucent phytoclasts and spores. Samples P-14, P-21 and P-24 include moderate content of
Text-fig. 5. Range chart of nannofossil species and nannofossil zones of Burnett (1998) identified in the Petrich section, with lithostratigraphy and meter in section (see Text-fig. 3 for details); red limestone interval marked in red; turbidite-shale interval marked in dark grey. Inoceramid-bearing bed marked in light grey. Individual taxon abundance is classified as: C – common (more than 1 specimen per FOV), F – few (more than 1 specimen per 10 FOVs), R – rare (less than 1 specimen per 10 FOVs).
Text-fig. 6. Quantitative range chart of dinoflagellate cyst species from the Campanian interval in the Petrich section, Bulgaria. Abundance of species is classified as R – rare (1–9 specimens), C – common (10–20 specimens), A – abundant (more than 20 specimens).
Text-fig. 8. Microphotographs of characteristic dinoflagellate cyst species from the Petrich section, Bulgaria. 

A – Areoligera cf. coronata (Wetzel) Lejeune-Carpentier, 1938, sample P-8, bed 21. 
C – Pterodinium cingulatum (Wetzel) Below, 1981, sample P-14, bed 27. 
E – Spiniferites sp., sample P-7, bed 19. 
F – Odontochitina porifera Cookson, 1956, sample P-8, bed 21. 
G – Chatangiella ditissima (McIntyre) Lentin and Williams, 1976, sample P-10, bed 22. 
H, I – Chatangiella tripartita (Cookson and Eisenack) Lentin and Williams, 1976, sample P-10, bed 22; H – high focus, I – low focus. 
K, L – Palaeohystrichophora infusoriodes Deflandre, 1935, sample P-8, bed 21; K – high focus, L – low focus. 

All photomicrographs were taken using transmitted light microscopy. For position of samples in section see Text-fig. 3.
terrestrial palynomorphs and spores, belonging to *Verrucosisporites* spp. and *Cyathidites* spp.

**Inoceramid bivalves**

The described and herein illustrated inoceramid fauna is the first inoceramid record established from Campanian strata of the Panagyurishte strip. All specimens were obtained from a single level of light grey to grey marlstones, belonging to the upper part of bed 21 (Text-fig. 3), which is a part of the Voden Member of the Chugovitsa Formation.

The collected inoceramid assemblage is dominated by medium- to large-sized representatives of *Cataceramus* spp., *Cordiceramus* spp., *Sphaeroceramus* spp. and ‘*Inoceramus*’ spp. (Text-figs 10–17). The described and discussed taxa are as follows: *Cataceramus ellipticus* (Giers, 1964), *Cataceramus pteroides* (Giers, 1964), *Cataceramus ex gr. balticus* (Böhm, 1907), *Cataceramus sp. A, Cataceramus sp. C, Cordiceramus sp., ‘Inoceramus’ agdjakendsis Aliev, 1952 and *Sphaeroceramus sarumensis* (Woods, 1911).

**BIOSTRATIGRAPHY**

**Nannofossil zonation and age assessment**

(Text-fig. 5)

**Nannofossil zones UC10–UC11ab**

The two lowermost samples of the Petrich section (PE-1, PE-2) yielded only solution resistant nannofossils like *Watznaueria barnesae* (Black) Perch-
Nielsen, 1968, *Prediscosphaera cretacea* (Arkhangelsky) Gartner, 1968, and *Retecapsa crenulata* (Bramlette and Martini) Grün in Grün and Allemann, 1975, which have only poor biostratigraphic utility.

The first biostratigraphically interpretable sample (PN-1) from bed 3 included *Micula staurophora* (Gardet) Stradner, 1963, whose FO defines nannofossil zone UC10 and starts in the middle Coniacian (Burnett 1998). Due to the low abundance and the poor preservation, the absence of other, more delicate, dissolution prone and generally rare (subzonal) markers like *Lithastrinus grillii* Stradner, 1962, and *Quadrum gartneri* Prins and Sissingh in Sissingh, 1977, cannot be used for further biostratigraphic subdivision. Therefore, these zones define only a broad interval from the uppermost Coniacian to upper Santonian. In addition, *Marthasterites inconspicuus* Deflandre, 1959, is present within this interval.

**Nannofossil zone UC11c–UC13**

The next sample interval starts with bed 4 (sample PE-3) up to bed 10 (PE-9) and includes the lower to middle part of the red limestone interval (Mirkovo Fm.) in the Petrich section. This interval is characterized by the co-occurrence of *Micula staurophora* with *Lucianorhabdus cayeuxii* Deflandre, 1959 and *Calculites obscurus* (Deflandre) Prins and Sissingh in Sissingh, 1977. The FO of *L. cayeuxii* defines the base of UC11c. Together with the common occurrence of *C. obscurus* this suggests a late Coniacian age (Burnett 1998). However, the following zonal marker *Lithastrinus septenarius* Forchheimer, 1972 (whose LO defines the base of UC12) was not found, and the marker *Arkhangelskiella cymbiformis* Vekshina, 1959 (Text-fig. 4A; its FO defines the base of UC13) occurs only sporadically in higher samples of the Petrich section above UC14. Therefore, these zones define only a broad interval from the uppermost Coniacian to upper Santonian. In addition, *Marthasterites inconspicuus* Deflandre, 1959, is present within this interval.

**Nannofossil zone UC14a**

The FO of *Broinsonia parca parca* (=*Aspidolithus parcus parcus* of other authors, e.g., Miniati et al. 2020) in sample PN-6 defines the base of zone UC14 and the base of subzone UC14a (Burnett 1998). This bioevent is recorded in bed 11 (at c. 145 m) of the Petrich section, near the top of the red limestone interval. At the same level, the FO of *Calculites obscurus* with a wide central longitudinal suture is noted, which was reported by Wolfgring et al. (2018) as starting just below the FO of *B. parca parca*. Both bioevents bracket the base of the Campanian as defined by the base of Chron C33r (Wolfgring et al. 2018) with *B. parca parca* starting slightly above the Santonian/Campanian boundary.

**Nannofossil zone UC14bTP–UC15cTP**

The FO of *Broinsonia parca constricta* Hattner, Wind and Wise, 1980 in sample PE-13 (=*Aspidolithus parcus constrictus*; e.g., Miniati et al. 2020) defines the base of UC14b in the Tethyan–Intermediate province zonation of the lower Campanian (Burnett 1998). However, other following bioevents are missing in the Petrich section, e.g., the successive FOs of *Bukryaster hayi* (Bukry) Prins and Sissingh in Sissingh, 1977, *Ceratolithoides verbeeki* Perch-Nielsen, 1979, and *Monomarginatus pleniporus* Wind and Wise in Wise and Wind, 1977, or are higher up in the section and do not follow the defined stratigraphic succession as noted for *Ceratolithoides aculeus* (Stradner) Prins and Sissingh in Sissingh, 1977, and *Uniplanarius*
sissinghii (Perch-Nielsen) Farhan 1987. Therefore, this interval can only be very generally assigned to the interval of UC14bTP to UC15cTP, which spans the lower to upper Campanian boundary (Burnett 1998). Consequently, this interval ranges from the upper lower Campanian to the lower upper Campanian using a twofold subdivision of the Campanian.

Nannofossil zone UC15dTP–UC15eTP

The FO of Uniplanarius trifidus in sample PE-18a (bed 21, at 253 m; Text-fig. 4O) defines the base of UC15d of the Tethyan–Intermediate (TP) province zonation of Burnett (1998), and occurs in the inoceramid bed described below. This interval is assigned to the lower part of the upper Campanian according to Burnett (1998). Reinhardtites levis Prins and Sissingh in Sissingh, 1977, and Ceratolithoides aculeus have also their FOs within the same sample, which apparently is a sign of some preservational bias, as these marker species should have been present already below this interval (see Burnett 1998). Within the range of U. trifidus also rare specimens of Ceratolithoides kamptneri Bramlette and Martini, 1964, are found. The top of this interval is defined by the last regular occurrence of Eiffellithus eximius (Stover) Perch-Nielsen, 1968, the LO of which marks the base of UC16, whereas the Santonian–Campanian marker Reinhardtites anthophorus (Deflandre) Perch-Nielsen, 1968, is totally missing from the Petrich section.

Nannofossil subzone UC16aTP

Uniplanarius trifidus is extremely rare (only found in 2 samples), therefore we use the LO of Uniplanarius sissinghii in bed 37 in bed 37 (sample PN-18, 528 m) as an alternative marker for the top of subzone UC16aTP as emended by Thibault et al. (2016). This subzone marks the upper part of the upper Campanian according to Thibault et al. (2016).

Nannofossil subzone UC16bTP

The presence of Reinhardtites levis and Tranolithus orionatus (Reinhardt) Reinhardt, 1966, together with Broinsonia parca constricta, but without any Uniplanarius spp. in sample PN-20 indicates subzone UC16bTP of Thibault et al. (2016) and marks the base of the Maastrichtian in the interval between PN-18 (528 m) and the topmost sample PN-20 (bed 41 at 585 m). However, due to the poor preservation with some dissolution and etching in this turbiditic interval, the presence/absence data may show some bias, and further work is needed to assure the base of the Maastrichtian in the Petrich section.

Dinocyst biostratigraphy

The present study provides detailed and calibrated dinocyst data in the discussed stratigraphic interval. The outlined dinocyst succession is new and first reported from Bulgaria.
Biostratigraphic interpretations are based on comparisons with several previous dinocyst studies in Europe, namely in the Campanian historical stratotype section at Charente in France (Masure 1985), the Maastrichtian type area in Limburg (Robaszynski et al. 1985; Slimani 2001, 2011), the GSSP for the base of the Maastrichtian at Tercis les Bains in France (Antonescu et al. 2001; Schiøler and Wilson 2001), northern Spain (Radmacher et al. 2014), the Campanian in Bavaria (Kirsch 1991), Austria (Mohamed and Wagreich 2013), Czech Republic (Skupien and Mohamed 2008), south-eastern Poland (Niechwedowicz and Walaszczyk 2022; Slimani et al. 2021), as well as Italy (Corradini 1973; Roncaglia and Corradini 1997; Roncaglia 2002), and regions of the Northern Hemisphere (Stover et al. 1996; Williams et al. 2004).

Based on these correlations it can be concluded that some taxa, such as Achomosphaera fenestra, Areoligera coronata, Cannosphaeropsis utinensis, Chatangiella ditissima, Chatangiella tripartita, Corradinisphaeridium horridum, Hystrichodinium pulchrum, Odontochitina porifera, Palaeohystrichophora infusorioides, Pervosphaeridium pseudohystrichodinum and Raetiaedinium truncigerum appear to have a similar distribution pattern and thus may prove important interregional marker species. These taxa and their concurrent range have been estimated as key markers for the Campanian on a wide geographic scale.

The entire dinocyst assemblage from the Petrich section points to the Campanian. Cannosphaeropsis utinensis appears in the latest Santonian (Williams et al. 2004), and Achomosphaera fenestra, A. regiensis and Areoligera coronata in the earliest Campanian (Kirsch 1991). According to Kirsch (1991), the FO of Corradinisphaeridium horridum is a good proxy for the middle Campanian. The species has its LO roughly at the Campanian–Maastrichtian boundary (Antonescu et al. 2001; Schiøler and Wilson 2001; Mohamed and Wagreich 2013; Radmacher et al. 2014), similarly as Raetiaedinium truncigerum (Antonescu et al. 2001; Slimani 2001). A good proxy for the upper part of the upper Campanian is the LO of Odontochitina porifera (Niechwedowicz and Walaszczyk 2022), also considered to represent a potential marker for the Campanian–Maastrichtian boundary (CMB) in the type boundary section at Tercis, southwest France (Schiøler and Wilson 2001), as well as in Zumaia, northern Spain (Radmacher et al. 2014). In the Petrich assemblages, important Campanian markers are also Chatangiella ditissima and C. tripartita. Most species of the genus Chatangiella Vozzhennikova, 1967 disappear during the late Campanian in the Northern Hemisphere, according to Vozzhennikova (1967) and Slimani (2021).

The encountered dinocyst association indicates the Areoligera coronata Zone sensu Kirsch (1991) in the Petrich section with a stratigraphical range from the upper part of the lower Campanian to the upper Campanian and direct calibration to the nannofossil subzones UC14b1P–UC16a1P. The zone is indicated both, by the presence of the index species, but also by the characteristic zonal association and concurrent range of Achromosphaera fenestra, Areoligera coronata, Cannosphaeropsis utinensis, Chatangiella ditissima, C. tripartita, Corradinisphaeridium horridum, Hystrichodinium pulchrum, Odontochitina porifera, Palaeohystrichophora infusorioides, Pervo-
**Inoceramid biostratigraphy**

During the Late Cretaceous, inoceramid bivalves were distributed worldwide and had a rapid rate of evolution, therefore inoceramid assemblages provide a powerful tool for a refined biostratigraphy in the Cenomanian through to middle Maastrichtian strata. In the last two decades, the knowledge about the taxonomy, biozoning and high correlation potential of Campanian and Campanian–Maastrichtian inoceramid records has been greatly enriched (Walaszczyk 1997, 2004; Walaszczyk et al. 2001, 2002a, b, 2008, 2014; Jagt et al. 2004; Walaszczyk and Dhondt 2005; Kennedy et al. 2007; Jurkowska 2016). Moreover, a detailed inoceramid stratigraphy and biozonation was proposed and widely accepted for the Campanian stage (Walaszczyk 1992, 1997, 2004; Walaszczyk et al. 2008).

In Bulgaria, the Campanian inoceramid record is relatively poorly known, excluding uppermost Campanian inoceramid faunas recorded mainly from the Western Fore-Balkan Mountains (northwestern Bulgaria) (Jolkićev 1962; Tsankov 1981; Dochev et al. 2018; Pavlishina et al. 2020). It should be noted that inoceramids collected from the Eastern Fore-Balkan Mountains, previously recorded by Jolkićev (1962), and referred to as Maastrichtian in age, were revised and recognized as late Campanian (see Walaszczyk 1997 and Walaszczyk et al. 2002).

*sphaeridium monasteriense, P. pseudhystrichodium* and *Raetiaedinium truncigerum* (see Text-fig. 3).

The collected inoceramid assemblage from the Petrich section contains strongly oblique specimen of ‘Inoceramus’ agdjakendsis (Text-figs 10, 11), Cataceramus ellipticus (Text-fig. 12A), and Cataceramus pteroides (Text-figs 13B and 14C), all characteristic for the ‘Inoceramus’ azerbaydjanensis – ‘Inoceramus’ vorhelmensis Zone, recognized in the lower Upper Campanian (according to the European stage subdivision) as proposed by Walaszczyk (1997). The other taxa present Cordiceramus sp. (Text-figs 13A and 15A), Sphaeroceramus sarumensis (Text-fig. 16E), Cataceramus ex gr. balticus (Text-figs 12B, 17), Cataceramus sp. A (Text-fig. 15D, F), Cataceramus sp. (Text-figs 14A, B, 15B, C, E, 16A, B, D) and ‘Inoceramus’ sp. (Text-fig. 16C, F) are not stratigraphically diagnostic, although S. sarumensis seems not to range higher. The zone was also recorded in a coeval interval of the US Western Interior (lower Middle Campanian according to the three-fold North American subdivision) (Walaszczyk et al. 2001). The high correlation potential of the zone (and of its inoceramid association) for the European Campanian and its trans-Atlantic correlation was later confirmed by Jagt et al. (2004) and Walaszczyk et al. (2008).

As stated above, the described ‘Inoceramus’ agdjakendsis, Cataceramus ellipticus and Cataceramus pteroides are part of the inoceramid association characteristic for the ‘Inoceramus’ azerbaydjanensis – ‘Inoceramus’ vorhelmensis Zone, although the zonal taxa are missing.

CHRONOSTRATIGRAPHY

The nannofossil data from the Petrich section, although potentially biased due to the low nannofossil abundances and poor preservation, give evidence of a continuous succession of epiclastic, pelagic to turbiditic deposits from the middle/upper Coniacian (UC10, FO of Micula staurophora) to the Campanian–Maastrichtian boundary interval (UC16b17, above the LO of Uniplanarius spp.). The epiclastic base of the section, below UC10, may thus be assigned to the lower Coniacian or older. The base of the Santonian is not well defined, although two markers (Lucianorhabdus cayeuxii and Calculites obscurus) for the upper to uppermost Coniacian have a well-defined FO at bed 4 (c. 50 m) and thus define the start of the Coniacian–Santonian boundary interval. However, no other marker higher up in the section is available for further constraining the Coniacian–Santonian boundary within this not further subdivided interval of UC11c–UC13.

The base of the Campanian is well defined in the Petrich section by the first occurrence of Broinsonia parca parca in bed 11 (c. 145 m). Although very rare (only 2 specimens found in 500 FOV), these first specimen attributed to B. parca parca have a length above 9 µm, and a b/a ratio (see Gardin et al. 2001; Wolfgring et al. 2018; Miniati et al. 2020) of 1.3 to 1.1. A further subdivision of the Campanian into lower/middle/upper Campanian is not well defined by nannofossils within the Petrich section because of
poor preservation within the mostly reddish pelagic limestones, thus several zones or subzones have to be combined into one zone.

The base of the Maastrichtian is provisionally defined between the uppermost samples of the section (PN-18 and PN-20), between bed 37 and bed 41 (528 to 585 m). The last occurrence of *Uniplanarius* spp. and the continuous occurrence of *Brainsonia parca constricta* gives evidence for nannofossil subzone UC16bTP (Thibault et al. 2016) and thus indicates the provisional base of the Maastrichtian in this topmost part of the Petrich section.

The dinocyst record of the Petrich section is assessed by direct calibration to the outlined nannofossil zonation. The stratigraphical range of the recognized *Areoligera coronata* dinocyst Zone is within the interval of nannofossil subzones UC14bTP–UC16aTP and has a stratigraphical range from the upper parts of the lower Campanian to the upper Campanian in the section.

Based on the nannofossil bioevents and zonation, the inoceramid level (bed 21, assigned to the lower part of the upper Campanian, based on inoceramid zonal correlation), is placed within the interval of nannofossil subzones UC14bTP–UC16aTP and has a stratigraphical range from the upper parts of the lower Campanian to the upper Campanian in the section.

The frequent occurrence of *Spiniferites* spp., *Pterodinium* spp., *Achomosphaera* spp. and *Cannosphaeropsis* spp., and to a lesser extent, by *Palaehystrichophora* *infusorioides* spp. (Text-fig. 6). The species diversity is moderate, with 30 documented dinocyst species.

Marshall and Batten (1988) were among the first to notice that the dinocyst association can be directly related to the litho- and palynofacies. They recognized that the *Spiniferites*-dominated association, which generally occurs in chalks and marlstones that accumulated in an open marine environment, suggests the presence of well-oxygenated conditions in a stratified water column.

The frequent occurrence of *Spiniferites* spp., *Pterodinium* spp. and *P. infusorioides* in the European Upper Cretaceous successions allowed Pearce et al. (2003, 2009) and Prince et al. (2008) to identify two distinct types of assemblages based on diversity and assemblage composition. The first one was termed the ‘Spiniferites–*Palaehystrichophora* (S-P) Assemblage’ characterized by high diversities and abundances of gonyaulacid (*Spiniferites, Achomosphaera, Pterodinium*) and peridinioid (especially *P. infusorioides*) cysts in the Cenomanian/Turonian boundary interval in the Anglo-Paris Basin, plus *Chatangiella, Isabelidinium, Trithyrodinium* in the North Sea. This assemblage contrasts to the low diversity ‘*Circulodinium–Heterosphaeridium* (C-H) Assemblages’ that are typically dominated by gonyaulacid cysts (*Circulodinium, Heterosphaeridium*).

The authors analyzed these different types of dinocyst assemblages from all productive samples in the Petrich section are dominated by representatives of the genera *Pterodinium* spp., *Spiniferites* spp., *Achomosphaera* spp. and *Cannosphaeropsis* spp., and to a lesser extent, by *Palaehystrichophora* *infusorioides* spp. (Text-fig. 6). The species diversity is moderate, with 30 documented dinocyst species.

**Dinocyst palaeoenvironmental proxies**

Dinocyst assemblages from all productive samples in the Petrich section are dominated by representatives of the genera *Pterodinium* spp., *Spiniferites* spp., *Achomosphaera* spp. and *Cannosphaeropsis* spp., and to a lesser extent, by *Palaehystrichophora* *infusorioides* spp. (Text-fig. 6). The species diversity is moderate, with 30 documented dinocyst species.

The overall composition of nannofossil and dinocyst assemblages, as well as palynofacies data are combined for palaeoenvironmental interpretations and settings (Tyson 1993, 1995). Numerous studies performed on Cretaceous dinoflagellate cyst assemblages have illustrated their utility to interpret the depositional environments in terms of water depth, depositional energy, sea surface temperature trend and productivity, by using the P/G ratio and the presence of environmentally sensitive dinocyst groups (e.g., Bujak 1984; Marshall and Batten 1988; Leereveld 1995; Pearce et al. 2003, 2009; Niechwedowicz et al. 2021).

**Nannofossil palaeoenvironmental indicators**

Nannofossil assemblages are dominated by *Watznaueria* spp. (1–3 specimens per FOV in better preserved samples) and more common *Calculites* spp., *Cribrophaerella* spp., *Lucianorhabdus* spp., *Micula* spp., *Prediscosphaera* spp., *Retecapsa crenulata* and *Zeugrhabdotes* spp. The predominance of *Watznaueria barnesae* (a warm-water species) and the rarity of typical low-latitude nannofossils such as *Uniplanarius* spp., *Ceratolithoides* spp., *Marthasterites* spp., and the occasional presence of cooler-water taxa like *Kampninerus* spp. indicates a peri-Tethyan influence (Burnett 1998; Thibault et al. 2016; Švábenická et al. 2022). The stable presence of preferably shallow-marine holococcoliths such as *Lucianorhabdus* spp. and *Calculites* spp. attests the link to more shallow, neritic shelf areas, although reworking and basin-ward transport into a more pelagic realm by turbidites may also be considered.

**PALAEOENVIRONMENTAL ANALYSIS**

The overall composition of nannofossil and dinocyst assemblages, as well as palynofacies data are combined for palaeoenvironmental interpretations and settings (Tyson 1993, 1995). Numerous studies performed on Cretaceous dinoflagellate cyst assemblages have illustrated their utility to interpret the depositional environments in terms of water depth, depositional energy, sea surface temperature trend and productivity, by using the P/G ratio and the presence of environmentally sensitive dinocyst groups (e.g., Bujak 1984; Marshall and Batten 1988; Leereveld 1995; Pearce et al. 2003, 2009; Niechwedowicz et al. 2021).
cyst assemblages and estimated them as a marker of water depth, surface water nutrient levels and temperature trend. The S-P Assemblage was considered to be indicative for more basinal areas with unstable hydrodynamic conditions and higher, but variable, nutrient levels.

Following these studies, the encountered Petrich dinocyst association could be attributed in general to the S-P assemblages. It is characterized by high diversity and abundance of gonyaulacoid (*Pterodinium*, *Spiniferites*, *Achomosphaera*, *Cannopsphaeropsis*) cysts (Text-fig. 6). The encountered low P/G ratio values in all samples, together with the presence, although subordinate, of high-productivity indicators like *P. infusorioides* indicates low nutrient levels and the development of a comparatively oligotrophic water mass within a distal neritic to open marine depositional environment. The occurrence of typical open oceanic dinocysts like *Pterodinium* confirms such conclusions (Harland 1983; Leereveld 1995; Niechwedowicz et al. 2021).

**Palynofacies analysis**

Palynofacies data corroborate well to the palaeoenvironmental interpretation. All samples from the Chugovitsa Formation and its Voden Member appeared to be rich in organic matter (OM). The organic matter is represented mainly by opaque phytoclasts and abundant dinoflagellate cysts with subordinate translucent phytoclasts, spores and woody tissues in the upper part of the succession. The opaque to translucent OP/TR ratio is high in all samples and especially in the sampling interval from bed 19 to bed 23 (samples P-7 to P-11; Text-fig. 3), where the highest amount of opaque phytoclasts and marine plankton is recognized, probably indicating a transgressive phase within this stratigraphical interval. Generally, the OP/TR ratio increases basin-wards due to fractionation processes and the higher preservation potential of opaque particles (Tyson 1993). Such a ratio is characteristic for distal shelf to open marine deposits. Opaque phytoclasts are typically equidimensional, rarely lath and of medium size. According to Tyson (1995) and Radmacher et al. (2020), a large proportion of equidimensional, small and rounded opaque phytoclasts points to the presence of a distal depositional environment that is located farther away from the continental source area. In the upper Campanian, corresponding to the interval from bed 25 to bed 37, a slight change occurs in the palynofacies composition (Text-fig. 9). The OP/TR ratio shows still high values, but opaque phytoclasts and dinocysts decrease slightly and large translucent structured phytoclasts as woody tissues and cuticles appear in the palynofacies. The continental input (influxes of structured translucent phytoclasts and spores) increases upwards in this interval, most probably indicating an increase in terrigenous influences during the late Campanian.

The distribution of palynofacies components is illustrated in the ternary AOM–Phytoclast–Palynomorph plot of Tyson (1993) and in the Microplankton–Spore–Pollen ternary plot (after Fedorova 1977; Duringer and Doubinger 1985; Text-fig. 9). Based on the phytoclast, palynomorph and AOM percentages, the samples plot mainly into field V reflecting the distal oxic shelf. Palaeoenvironmental interpretations are further analyzed by plotting on the Microplankton–Spore–Pollen diagram of Fedorova (1977) and Duringer and Doubinger (1985). The apparent predominance of the Microplankton group, mainly represented by dinoflagellate cysts, shows that all samples point to the offshore field. According to these data we can conclude that the inferred depositional environments in these plots suggest deposition within an oxic distal shelf to open marine low-energy environment. These data are in accordance to the palaeoenvironmental interpretations based on the dinocyst assemblages.

**CONCLUSIONS**

The Petrich section of the Central Srednogorie Zone (Bulgaria) records a continuous epiclastic, pelagic and turbiditic Upper Cretaceous sedimentation, spanning the middle Coniacian to the Campanian–Maastrichtian boundary. The section yielded high-resolution multistratigraphic data obtained from calcareous nannofossils, dinocysts and inoceramids, particularly in the Campanian. Nannofossils allowed to recognize the following standard nannofossil zones/subzones (zonation of Burnett 1998, with emendments by Thibault et al. 2016): 1) UC10–UC11ab (middle to upper Coniacian); 2) UC11c–UC12–UC13 (uppermost Coniacian to Santonian); 3) UC14a (lowermost Campanian), 4) UC14bTP–UC15cTP (lower Campanian to lower upper Campanian); 5) UC15dTP–UC15eTP (upper Campanian); 6) UC16aTP of Thibault et al. (2016) (upper upper Campanian); and 7) UC16bTP (lowermost Maastrichtian according to the emended zonation of Thibault et al. 2016).

The base of the Campanian is defined by the FO of *Broinsonia parca parca* (*Aspidolithus parcus par-
The dinocyst record of the Petrich section indicates the *Areoligera coronata* Zone with a stratigraphical range from the upper part of the lower Campanian to the upper Campanian and thus, a direct calibration to the UC14bTP–UC16aTP nannofossil subzones. The zone is indicated by the presence of the index species and ranges of other taxa, such as *Cannosphaeropsis utinensis*, *Palaeohystrichophora infusorioideae*, *Odontochitina porifera*, *Corradiansphaeraidum horridum*, *Hystrichodinium pulchrum*, *Achomosphaera fenestra*, *Raetiaedinium trincigerum*, *Pervosphaeridium pseudhystrichodinium*, *Chatangiella ditissima* and *Chatangiella tripartita*.

The collected inoceramids from the lower part of the Chugovitsa Formation are correlated to the interval of nannofossil subzones UC15dTP and UC15eTP of the lower upper Campanian, corresponding to a middle Campanian in the North American three-fold subdivision. The inoceramid assemblage dates the middle Campanian in the North American time-scale.

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Appendix 1

List of calcareous nanofossil taxa encountered in the Petrich section, Bulgaria (according to Nannotax3: https://www.mikrotax.org/Nannotax3/)

- Ahmuellerella octoradiata (Górmka) Reinhardt, 1966
- Arkhangelskiella cymhiformis Vekshina, 1959
- Biscutum constans (Górmka) Black in Black and Barnes, 1959
- Biscutum cf. melaniae (Górmka) Reinhardt, 1969
- Braarudosphaera bigelowii (Gran and Braarud) Deflandre, 1947
- Broinsonia enormis (Shumenko) Manivit, 1971
- Broinsonia parca constricta Hattner, Wind and Wise, 1980
- Broinsonia parca parca (Stradner) Bukry, 1969
- Calculites obscurus (Deflandre) Prins and Sissingh in Sissingh, 1977
- Calculites obscurus (Deflandre) Prins and Sissingh in Sissingh, 1977 – wide morphotype
- Calculites ovalis (Stradner) Prins and Sissingh in Sissingh, 1977
- Ceratolithoides aculeus (Stradner) Prins and Sissingh in Sissingh, 1977
- Ceratolithoides kamptneri Bramlette and Martini, 1964
- Chiazozygus litterarius (Górmka) Manivit, 1971
- Corollithion cf. signum Stradner, 1963
- Cribrosphaerella circula (Risatti) Lees, 2007
- Cribrosphaerella ehrenbergii (Arkhangelsky) Deflandre in Piveteau, 1952
- Cylindricalithus sp.
- Eiffellithus eximius (Stover) Perch-Nielsen, 1968
- Eiffellithus gorkae Reinhardt, 1965
- Eiffellithus turriseifeli (Deflandre in Deflandre and Fert) Reinhardt, 1965
- Eproliithus floralis (Stradner) Stover, 1966
- Gartnerago sp.
- Helicolithus cf. trabeculatus (Górmka) Verbeek, 1977
- Kampnerago sp.
- Lithastrinus grillii Stradner, 1962
- Lithrhapidites carniolensis Deflandre, 1963
- Lithrhapidites praequadratus Roth, 1978
- Lucianorhabdus cayeuxii Deflandre, 1959
- Lucianorhabdus cayeuxii Deflandre, 1959 – curved morphotype
- Lucianorhabdus maleformis Reinhardt, 1966
- Manivitella penmatoidea (Deflandre in Manivit) Thierstein, 1971
- Marshateristes inconspicuus Deflandre, 1959
- Microrhabdulus decoratus Deflandre, 1959
- Micula cf. adumbrata Burnett, 1997
- Micula cubiformis Forchheimer, 1972
- Micula staurophora (Gardet) Stradner, 1963
- Micula cf. swastica Stradner and Steinmetz, 1984
- Operculodinella sp.
- Placozus spiralis (Bramlette and Martini) Hoffmann, 1970
- Prediscosphaera cretacea (Arkhangelsky) Gartner, 1968
- Prediscosphaera grandis Perch-Nielsen, 1979
- Quadrum cf. gartneri Prins and Perch-Nielsen in Manivit et al., 1977
- Reinhardtites levis Prins and Sissingh in Sissingh, 1977
- Retecapsa crenulata (Bramlette and Martini) Grün in Grün and Allemann, 1975
- Rhagodiscus angustus (Stradner) Reinhardt, 1971
- Rhagodiscus sp.
- Rucinolithus sp.
Staurolithites sp.
Tranolithus minimus (Bukry) Perch-Nielsen, 1984
Tranolithus orionatus (Reinhardt) Reinhardt, 1966
Uniplanarius gothicus (Deflandre) Hattner and Wise in Wind and Wise, 1983
Uniplanarius sissinghii (Perch-Nielsen) Farhan, 1987
Uniplanarius trifidus (Stradner in Stradner and Papp) Hattner and Wise in Wind and Wise, 1983
Watznaueria barnesae (Black in Black and Barnes) Perch-Nielsen, 1968
Zeugrhabdotus diplogrammus (Deflandre in Deflandre and Fert) Burnett in Gale et al., 1996
Zeugrhabdotus embergeri (Noël) Perch-Nielsen, 1984
Zeugrhabdotus erectus (Deflandre in Deflandre and Fert) Reinhardt, 1965

Appendix 2

List of dinoflagellate cyst taxa encountered in the Petrich section, Bulgaria

Achomosphaera crassipellis (Deflandre and Cookson) Stover and Evitt, 1978
Achomosphaera fenestra Kirsch, 1991
Achomosphaera sagena Davey and Williams, 1966
Achomosphaera ramulifera (Deflandre) Evitt, 1963
Achomosphaera regiensis Corradini, 1973
Areoligera coronata (Wetzel) Lejeune-Carpentier, 1938
Cannosphaeropsis utinensis Wetzel, 1933
Chatangiella ditissima (McIntyre) Lentin and Williams, 1976
Chatangiella tripartita (Cookson and Eisenack) Lentin and Williams, 1976
Corradinisphaeridium horridum (Deflandre) Masure, 1986
Exochosphaeridium majus (Lejeune-Carpentier) Peyrot, 2011
Hystrichodinium pulchrum Deflandre, 1935
Hystrichosphaeridium duplum Lentin and Williams, 1989
Hystrichosphaeridium salpingophorum (Deflandre) Deflandre, 1937 emend. Davey and Williams, 1966
Hystrichosphaeridium tubiferum (Ehrenberg) Deflandre, 1937
Isabelidinium cooksoniae (Alberti) Lentin and Williams, 1977
Odontochitina porifera Cookson, 1956
Oligosphaeridium complex (White) Davey and Williams, 1966
Oligosphaeridium pulcherrimum (Deflandre and Cookson) Davey and Williams, 1966
Palaeohystrichophora infusorioides Deflandre, 1935
Pervosphaeridium monasteriensse Yun, 1981
Pervosphaeridium pseudohystrichodinium (Deflandre) Yun, 1981
Pterodinium cingulatum (Wetzel) Below, 1981
Raetiaedinium truncigerum (Deflandre) Kirsch, 1991
Spiniferites membranaceus (Rossignol) Sarjeant, 1970
Spiniferites ramosus (Ehrenberg) Mantell, 1854
Spiniferites scabrosus (Clarke and Verdier) Lentin and Williams, 1975
Surculosphaeridium longifurcatum (Firtion) Davey, Downie, Sarjeant and Williams, 1966
Tanyosphaeridium regulare Davey and Williams, 1966