

Nannofossil stratigraphy and global events in the Paleocene and lower Eocene of northern Bulgaria

Kristalina Stoykova



Bulgarian Academy of Sciences
Geological Institute “Strashimir Dimitrov”

**Nannofossil stratigraphy and global events
in the Paleocene and lower Eocene
of northern Bulgaria**

Kristalina Stoykova

Sofia • 2022



Prof. Marin Drinov Publishing House of
Bulgarian Academy of Sciences

This work has been carried out in the framework of the National Science Program "Environmental Protection and Reduction of Risks of Adverse Events and Natural Disasters", approved by the Resolution of the Council of Ministers No. 577/17.08.2018 and supported by the Ministry of Education and Science (MES) of Bulgaria.

(Agreements No. D01-230/06.12.2018; No. D01-322/18.12.2019;
No. D01-363/17.12.2020; No. D01-279/03.12.2021)

Contents

1. Introduction	11
1.1. Background	11
1.2. Object of the study	13
1.3. Acknowledgements	13
2. Materials and methods	15
2.1. Materials	15
2.2. Methods	15
2.2.1. Sample processing methods for calcareous nannofossils	15
2.2.2. Paleontological-stratigraphic methods	17
2.2.3. Quantitative methods and their application	18
2.2.4. Paleomagnetic method	19
2.3. Computer Software used	22
3. Previous research	23
3.1. Progress on the knowledge of Paleocene and lower Eocene in northern Bulgaria	23
3.2. Biostratigraphic schemes based on different fossil groups, applied in Bulgaria	27
4. Lithostratigraphy of the Paleocene and lower Eocene sediments	31
Kladorub Formation	31
Limestone-marl formation	32
Mezdra Formation	32
Limestone formation	33
Sandstone formation	33
Komarevo Formation	34
Bozhuritsa Formation	35
Izochnik Formation	36
Pavolche Formation	36
Petrevene Formation	37
Lukovit Formation	37
Shemshevo Formation	39
Boynovtsi Formation	39
Staropatitsa Formation	40
Ugarchin Formation	42
Beloslav Formation	42
Krivnya Member	43
Variegated marl-clayey formation	44
Dikilitash Formation	44
Aladan Formation	45
Avren Formation	47
Limestone-marl formation	48
Tepe-Tarla Formation	49
Thick-bedded sandstone formation	50
Emine Formation	52
Byala Formation	54
Kozichino Formation	56
Dvoynitsa Group	57
Sveti Atanas Formation	57
Bardarevo Member	58
Gebesh Formation	60
Meshelika Member	61

5. Biostratigraphic subdivision and correlation of key sections	63
5.1. Kula Unit	63
Kladorub	63
Rakovitsa	69
5.2. West Fore-Balkan	69
Moravitsa	69
Mezdra	72
Lyuti dol	75
Rumyantsevo	77
Golyama Brestnitsa – Daben	78
5.3. Central parts of the Moesian Platform	80
Petarnitsa	82
Pleven – Kailaka	84
Yasen	86
Bivolare	87
Bozhuritsa	88
Riben	91
Komarevo	94
Kreta	96
Somovit	98
5.4. Central Fore-Balkan and Balkan	99
Veliko Tarnovo – Ledenik	99
R-1hg Gabrovo	101
Vrabtsite	103
Iztochnik	103
Zhaltesh – Yaseni	104
Belitsa	105
Mishemorkov han	106
Drenta	110
Tabelite	111
Kipilovo	111
Zheravna	112
Ichera – Gradets	113
Marash	115
Krastets railway station	117
Stanchov han	117
5.5. East Fore-Balkan and Balkan	120
Esen	120
Podvis	120
Prilep	124
Ruen – Snyagovo	124
Kamenyak	126
Chudnite skali	126
Bardarevo	131
Kozichino	135
Emona	139
Mona Petra	141
Obzor – Meshelika	144
Sveti Atanas	146
Byala 2b	148
Byala 4 (upper part)	154
Byala 3	157
Goritsa	157
C-30 Goritsa	160
5.6. Eastern parts of the Moesian Platform	164
Yankovo	164
Sindel	165

Trastikovo	167
Beloslav – South	169
Beloslav – North	172
5.7. Black Sea offshore area	173
Samotino-More	173
Galata-1	175
Galata-2	176
Varna-West	180
Yury Shimanov	181
6. Biostratigraphy	185
6.1. Introduction	185
6.2. Biostratigraphic zones	185
6.2.1. Upper Cretaceous – Maastrichtian Stage	187
Zone CC26 <i>Micula prinsii</i>	187
6.2.2. Paleocene Series – Danian Stage	187
Zone NP1 – <i>Biantholithus sparsus</i>	187
Zone NP2 – <i>Cruciplacolithus tenuis</i>	191
Zone NP3 – <i>Chiasmolithus danicus</i>	193
Zone NP4 – <i>Ellipsolithus macellus</i>	196
6.2.3. Paleocene Series – Selandian Stage	198
Zone NP5 – <i>Fasciculithus tympaniformis</i>	198
Zone NP6 – <i>Heliolithus kleinpellii</i>	200
6.2.4. Paleocene Series – Thanetian Stage	203
Zone NP7 – <i>Discoaster mohleri</i>	203
Zone NP8 – <i>Heliolithus riedelii</i>	203
Zone NP9 – <i>Discoaster multidariatus</i>	206
6.2.5. Lower Eocene Subseries – Ypresian Stage	209
Zone NP10 – <i>Rhomboaster bramlettei</i>	209
Zone NP11 – <i>Discoaster binodosus</i>	213
Zone NP12 – <i>Tribrachiatus orthostylus</i>	214
Zone NP13 – <i>Discoaster lodoensis</i>	221
Zone NP14 – <i>Discoaster sublodoensis</i>	221
Subzone NP14a	224
Subzone NP14b	228
7. Chronostratigraphy	229
7.1. Development of the concept concerning chronostratigraphic subdivision in the Paleocene and lower Eocene	229
7.1.1. Paleocene Series	229
7.1.2. Lower Eocene Subseries	231
7.2. Chronostratigraphic units	233
7.2.1. Adopted chronostratigraphic scheme	233
7.2.2. Paleocene Series	233
Danian Stage	233
Selandian Stage	236
Thanetian Stage	238
7.2.3. Lower Eocene Sunseries	240
Ypresian Stage	240
8. Global events and their impact on the nannofloras	243
8.1. Cretaceous/Tertiary boundary (K/T) event	243
8.1.1. Introduction	243
8.1.2. Global expression of the event	244
8.1.3. Documenting the event from Bulgarian localities	247
8.2. Middle Paleocene biotic event (MPBE)	254
8.2.1. Introduction	254

8.2.2. Globally identified trends in the manifestation of the event	254
8.2.3. Documenting the event from Bulgarian localities	256
8.3. Paleocene/Eocene boundary event – PETM	257
8.3.1. Introduction	257
8.3.2. Globally identified trends in the manifestation of the event	258
8.3.3. Documenting the event from Bulgarian localities	261
9. Main results and unresolved problems	273
9.1. Main results	273
9.2. Unresolved problems	274
10. Taxonomical index of calcareous nannofossil taxa	277
11. References	281

Chapter 1

Introduction

The end of the Cretaceous and the beginning of the Paleogene mark one of the most remarkable passages of time in the geological development of the Bulgarian lands, filled with many events. According to the latest data, this interval covers the time between 65.5 (± 0.3) and 48.6 (± 0.2) million years (Ma) (Luterbacher et al., 2004). It is highly dynamic period with regard to the evolution of our planet – a number of remarkable global events occur, the most striking of which was the mass extinction of organisms at the Cretaceous – Tertiary boundary, as well as the unusual warming of 4–8 °C at the boundary between the Paleocene and Eocene Epoch (the Paleocene-Eocene thermal maximum).

1.1. Background

This study is focused on the stratigraphy and global events in the Paleocene-early Eocene time in northern Bulgaria, based on the study of calcareous nannofossils. Research has been conducted by the author in the period 1986–2008 and for the first time in the Paleogene stratigraphy of Bulgaria, based on the group of calcareous nannofossils. Most of the calcareous nannofossils are remains from the calcite cell-wall covering of unicellular algae – the coccolithophores (phylum Haptophyta). Coccolithophores are one of the main components of phytoplankton in modern seas and oceans. The term “calcareous nannofossils” is used for all calcareous microfossils with dimensions smaller than 30 μm . Although they were discovered as early as the 19th century by the German naturalist Christian Ehrenberg, their crucial importance for biostratigraphy was realized in the 1950s with regard to oil and gas exploration and oceanic drilling. Their crucial biostratigraphic value was particularly verified during the global research programs – Deep Sea Drilling Project (DSDP, 1968–1983) and Ocean Drilling Project (ODP, 1985 – present day). In these programs, calcareous nannofossils are the first priority group (ortho-group) during the stratigraphic subdivision of the majority of the well sections. Typical for the nannofossils is their incredible abundance and the fact that they are commonly occurring in marine sediments deposited in the last 220 Ma of the geological history of our planet – from the late Triassic

to the present. Currently zonal schemes based on nannofossils represent one of the main standards in the Cenozoic with biostratigraphic resolution of between 1 million and 60 000 years.

I undertook the research of calcareous nannofossils in the Paleogene sediments, mainly under the influence and visionary advices of my teacher – late academician Todor Nikolov and also thanks to the suggestions of the late Prof. Vasil Vuchev. I am deeply obliged to both for their scientific intuition and the confidence that this is a new, promising research field, which is worth developing in Bulgaria.

Of course, the beginning was extremely difficult. After a long period (1986–1990) of collection of refer-



Fig. 1.1. Working onboard at the drilling Rig “Ocean Liberator” of Texaco, June 1993



Fig. 1.2. The “basket” – an exotic elevator for getting on and off the drilling Rig “Ocean Liberator”

ences and experimenting with different techniques for processing and preparing of nannofossil samples, I published my first article on the Paleogene in the Pleven area (Stoykova, 1990). A huge role in my professional career and my development as a nannofossil expert was played by my participation in the Austrian-Bulgarian project “Mesozoic boundaries in Bulgaria. Permian/Triassic and Cretaceous/Tertiary Boundary”. Within this project I had the opportunity to work 18 months during the period 1991-1993 in Vienna, under the guidance of Prof. A. Preisinger (TU Vienna) and under the direct supervision of Prof. Herbert Strander (Geologische Bundesanstalt – Vienna). It is through my work on the Cretaceous/Tertiary in the Austrian-Bulgarian project that I got the big chance in May 1993, to work on board of the exploration drilling rig “Ocean Liberator”, which did the first drilling for Texaco Exploration Offshore Ltd. on the Black Sea shelf – Galata-1 well (Figs. 1.1, 1.2). This well discovered the first commercial gas field in the shelf, in Upper Cretaceous-Paleocene sediments, which is developed now and provides about 16% of the needs of the country (Fig. 1.3, 1.4).

Then in 1993 on board of Texaco drilling rig, I had the unique opportunity to apply an on-site biostratigraphic analysis – through dating of sediments by nannofossils during the drilling (express well-site nannofossil dating, for the first time in Bulgaria). Later I realized that for the first time in the world, my colleague Mitch Covington applied on-site nannofossil dating on an oil rig of Exxon, in the Gulf of Mexico in 1989 – only 4 years earlier. I admit I am particularly satisfied when I see the application of my research in practice for the purposes of hydrocarbon exploration and oil geology. This gave me a special incentive and

motivation for my further work. Thus, after 1993 I had the opportunity to perform biostratigraphic subdivision and correlation based on calcareous nannofossils in all offshore drilling activities that followed, made by different oil and gas companies. I also had the opportunity to process a few previously drilled wells – Samotino-More, Samotino-Iztok, R-79 Shkorpilovtsi (Stoykova, 1994), Nanevo and Elizavetino (my unpublished data). Nannofossil stratigraphy is of crucial importance not only for the stratigraphic subdivision of sections, but also in regional-stratigraphic explorations and studies. Over the past 20 something years I have had the opportunity to work in cooperation with various colleagues – regional geologists, stratigraphers, tectonicists, hydrogeologists and engineering geologists, applying nannofossil dating of sediments in the Jurassic – Neogene interval.



Fig. 1.3. Testing of the gas pressure of the newly discovered gas field Galata-1, “Ocean Liberator”, August 1993

1.2. Object of the study

The main goal pursued by this research is to summarize the existing stratigraphic data on the Paleocene – lower Eocene interval and based on that, to detect and reveal the most important global events in the geological past of northern Bulgaria for this time period. This achievement is based mainly on my own research, however data from previous authors are also included, published in the explanatory notes to the 1:100 000 geological map sheets of Bulgaria. Most of the data by other authors are expressed through my reinterpretation, as a result of the implemented revision and resampling I did in all major regions of Paleocene and lower Eocene sediments in northern Bulgaria. Of crucial importance for me was also my involvement in the project “Geology of Bulgaria”, developed by the Geological Institute, particularly in the part “Paleogene geology of Bulgaria”. In course of this project, in the period 2000-2006, I was actively involved in field research and revisions of the Upper Cretaceous and Paleogene, which outcrops over large areas of the country – mainly in the Central Fore Balkan, East Balkan, Eastern Srednogie. This gave me the opportunity to have my own regional-stratigraphic field observations and to construct a modern biostratigraphic scheme for dating the Upper Cretaceous – Paleogene lithological units. I believe

that it is necessary to make a modern summary of the new data, accumulated in the past 50 years, since the last summary of work on the Paleogene is that of Belmustakov (1968) in Stratigraphy of Bulgaria, over 50 years ago.

1.3. Acknowledgements

I am indebted to the leadership of the Geological Institute “Strashimir Dimitrov” of BAS, for its full support – including financial support for field trips on the project “Geology of Bulgaria”, and their understanding during the completion phase of this book.

To Melrose Resources SARL, owners of the first gas production field in the Black Sea shelf “Galata-1”, thanks for the opportunity to use all their data from offshore areas and to publish some of them.

I am grateful to many of my colleagues who have, to varying degrees, contributed for the successful completion of this study. I owe a debt of gratitude primarily to my teacher, late academician Todor Nikolov, for the modern level of theoretical knowledge in biostratigraphy and paleontology, which he has been giving since my university years, and which I subsequently supplemented and broadened.



Fig. 1.4. Production Platform “Galata” of Melrose Resources SARL, Black sea, June 2004

The biggest impact on my shaping as a specialist has my colleague Marin Ivanov, with whom I share more than 40 years of fruitful professional partnership and complementarity. We have made together most of the field studies and research on various scientific topics. His rational criticism and appropriate suggestions have always been stimulating and virtually priceless for me.

A turning point in my career as a nannofossil worker was my three-year Post-doc training in Vienna, Austria, working on the joint Austrian-Bulgarian project on the Cretaceous/Tertiary boundary. The project was led by the late Prof. Anton Preisinger, to whom I am particularly indebted. He was a tireless opponent during stimulating discussions, and also provided the opportunity to specialize on nannofossil taxonomy with a world-recognized expert and the pioneer of nannofossil palaeontology and stratigraphy – Prof. Herbert Stradner from the Austrian Geological Survey.

My long-standing professional collaboration, discussion and exchange of data and literature with my colleague Prof. Dimitar Sinnyovsky has been invaluable. We both learned from each other and together explored nannofossil stratigraphy and taxonomy.

In recent years my collaboration with Dr. Jaime Dinarès-Turell from the Institute of Geophysics and Volcanology in Rome, Italy, has proven to be very fruitful. As a member of the Working Group of Paleocene stratigraphy to the International Commission of Stratigraphy, he provided me with the latest data on the stage stratotypes and the leading criteria for drawing their boundaries, as well as data for the orbital cyclicity in the classical Zumaia section, Basque Country, Spain.

Positive influence on my personal development has come from numerous informal discussions with colleagues from the Department of Palaeontology, Stratigraphy and Sedimentology: the late Platon Tchoumatchenco, Ivo Sapunov, Iskra Lakova, Elena Koleva-Rekalova, Daria Ivanova, Valeri Sachanski, Polina Andreeva, Georgi Granchovski.

Last but not least, I am grateful to my colleagues from other departments of the Institute and outside it, with whom I have worked together on various projects: the late Christo Dabovski, Ivan Zagorchev, Georgi Dimov, Sava Juranov, Ivan Boyanov, Alexander Goranov, Dimcho Evstatiev, Yordan Evlogiev, and Doncho Karastanev.

In the process of illustration of this book, I have been provided with significant technical assistance (drawing of graphics and processing of photographs) by Dr Vyara Idakieva, Mrs Theodora Sakaliyska and Mrs Magdalena Yurukova, to whom I am deeply indebted.

I thank my colleague Prof. Jozef Michalik, Earth Science Institute of Slovak Academy of Science, Bratislava, for generously supporting SEM access and photography of selected nannofossil samples.

Finally, I would like to warmly thank Prof. Michael Sandy (University of Dayton, Ohio, USA) for his invaluable linguistic suggestions and constructive comments that considerably helped me to improve the book. Without his elegant professional intervention this book would not be as it is.

Chapter 2

Materials and methods

2.1. Materials

The study area comprises the entire territory of northern Bulgaria – from the river Timok to the Black Sea, including the Bulgarian continental shelf. To the west, north and east it reaches the state border of Bulgaria. To the south its border runs roughly along the Balkan and Srednogorie tectonic zone – Fig. 2.1 (Dabovski et al., 2002).

The materials, which served as a basis of the work, are derived from surface outcrops and subsurface well sections, located throughout the entire region. The studied sections and outcrops are in the Kula zone, the Moesian Platform, West and Central Fore Balkan as well as in the Central and East Balkan. Fifty five different sections have been studied – main and additional (Fig. 2.2), as well as hundreds of single outcrops. Offshore sections (5 drilled wells – Galata-1, Galata-2, Samotino-More, Varna-West, Yuri Shimanov) are biostratigraphically subdivided and correlated by nannofossils. Apart from them, for the final interpre-

tations was used data from the wells Bogdanov-East, Epsilon, Galata-East, Samotino-1, Samotino-2, Elizavetino and Nanevo.

The location and age of the samples studied can be identified on 1:100 000 geological maps. These locations are shown on Fig. 2.2. It is difficult to calculate the exact number of analyzed samples. For example, solely in the sections around Byala, around 450 to 500 samples have been examined. The same number of samples was studied for the sections in Central northern Bulgaria (Pleven), and for the Kladorub section 226 samples were logged. In any case, the total number of samples analyzed is between 3800 and 4000.

2.2. Methods

2.2.1. Sample processing methods for calcareous nannofossils

Nannofossils represent a fossil group that is very

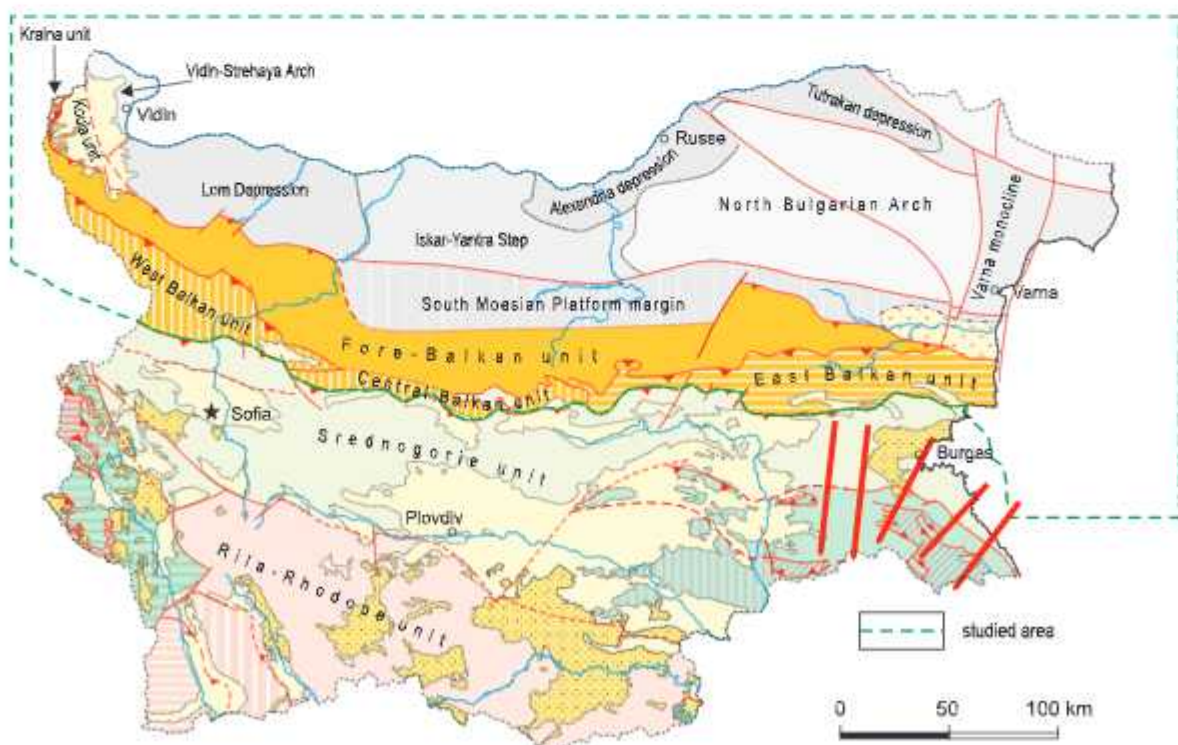


Fig. 2.1. Study area (entire territory of northern Bulgaria), indicated on the tectonic map of Dabovski et al. (2002)



Fig. 2.2. Location of the investigated sections and outcrops – a total of 55 land sections and offshore well sections, situated in the territory of northern Bulgaria

well suited for study, as they are found in almost all lithological types of sediments and the processing of samples is quick and easy. Their small size (2–30 μm) allows taking very small samples as an amount of sediment – usually a piece of rock as big as a grain of rice is enough for a sample. The size of the nanofossils is their greatest advantage, because even the smallest rock pieces (ditch-cuttings) obtained during drilling can be analyzed – without the need to drill a core. This advantage easily becomes a disadvantage, as they are very often reworked and can be contaminated when water flows into the cracks (from top to bottom in the outcrop) or even when you touch them with your fingertips. Thus, establishing whether there is reworking or contamination requires special attention, experience and expertise of the researcher.

Sampling

The sampling of sections (exposures and drillings) for nanofossil contents is done by selecting appropriate lithological types of sediments.

Usually soft rock types are preferred, such as marl and marly limestone, mudstone, calcareous clay. Sometimes well preserved, rich associations are also found in clayey sands, glauconitic sandstones, silts and siltstones. Moreover, other things being equal, lighter carbonate-rich sediments are the preferable choice. Pure limestone, conglomerate and firm sand-

stone are less favorable for extraction of nanofossils. Metamorphic processes have a negative effect on the nanofossil content of sediments. In metamorphosed sediments nanofossils are found only in those affected by low-grade metamorphism – such is the case with the nanofossils of Miers Bluff Formation, cropping out around the Bulgarian Antarctic Base on Livingston Island, Antarctica (Stoykova et al., 2002; Pimpirev et al., 2006).

The sampling interval depends on the study's objectives – at 20–50 m pilot sampling or at 1–5–10 cm in the case of detailed sampling in order to identify certain events. Usually a sampling interval of 1–5 m is sufficient to subdivide the section and determine the biostratigraphic zones. A fresh chip of rock measuring around 2–3 cm^3 is used. During the laboratory preparation of the sample, all outer surfaces of the specimen are trimmed, so there is no chance for surface contamination of the sample. Subsequently we can proceed with the appropriate treatment.

Standard methods of processing

Simple smear-slide preparation

A “simple” microscope slide preparation means making it directly from the rocks without any treatment, so as to preserve a maximum amount of the original nanofossil association contained in the sample. All outer

surfaces of the sample are trimmed, a small portion of sediment is scraped with a needle onto a glass smear slide. Then a drop of distilled water is placed on this and a needle is used to homogenize the suspension, as larger particles are pushed to the edge of the slide. The suspension is spread evenly, with an average density along the entire slide and is quickly dried on a warm table. The dried suspension is affixed with a glass coverslip and mounting medium (Canadian balsam), carefully, avoiding air bubbles inside the smear slide. Applying a very layer thin of the mounting medium is highly desirable. This is done so you can properly focus the nannofossils while examining them under the light microscope. The sample is labeled and left for about 30 minutes on a warm table to complete the solidification of the Canadian balsam. Some synthetic adhesives like Norland optical adhesive, etc., having a similar refraction index, can be used to replace the Canadian balsam successfully.

Recently, very interesting studies that show the rapid dissolution of the nannofossils after their removal from the drill core have been published (Self-Trail & Seefelt, 2005). The nannofossil content of a core sample strongly depends on the time when the processing has been performed. If it is done within the first week after the extraction from the core (1-6 days), the original nannofossil association is 100% preserved. After the 7th day, however, a process of dissolution begins and the number of species and specimens gradually decreases over time. The process continues until total dissolution is reached after around 7 months (Self-Trail & Seefelt, 2005). Therefore, in order to preserve as much as possible from the original nannofossil assemblage and to make reasonable interpretations, it is necessary that the samples are processed and affixed in permanent smear slides immediately after sampling.

Centrifuging

Using a centrifuge, the fraction between 2 and 30 μm (which is believed to contain the majority of nannofossils) is separated. The sample is crushed to powder, placed in a test tube and distilled water is added. Then it is centrifuged briefly (around 15 seconds) at 350 rpm. The suspension is decanted into another tube, the residue consisting of the largest particles is discarded. The suspension is centrifuged again for 30 seconds at 1000 rpm, and then the upper fluid containing the finest particles is decanted. Distilled water is added and the procedure is repeated several times up until the sample is clear. Finally, the resulting residue is prepared on a slide, affixed with Canadian balsam as described above.

Preparation of samples for SEM

When observing and photographing the nannofossils with a Scanning Electron Microscope (SEM) the samples have to be cleaned in advance using the centrifuge technique in order to concentrate the residue of nannofossils. Otherwise searching for the nannofossils amongst the other rock particles is a waste of valuable time.

1. The sample is centrifuged to form a suspension and is placed with a pipette on a thin glass coverslip.
2. The coverslip is dried and attached to a metal stub using colloidal silver.
3. The sample is coated with gold (500 Å) or even better with a double-layered coat – carbon and then gold.
4. Observations and capturing of the nannofossils are made with a magnification of 5 000 to 30 000, occasionally even up to 50 000 times.

Detailed paleontological research, especially description of new taxa, is impossible without SEM study.

Routine determinations for stratigraphic purposes are made with a light polarizing microscope. With the progress of digital photography in microscopic images, it is now possible to illustrate nannofossil species quickly and with a relatively good quality, as seen with an ordinary microscope.

2.2.2. Paleontological-stratigraphic methods

Paleontological-stratigraphic methods are fundamental methods for subdivision and correlation of sediments. They are based on the principle of irreversibility of the organism's evolution throughout geological time.

For biostratigraphic subdivision of the sections, characteristic bio-events such as first occurrence, last occurrence, co-occurrence, abundance (acme) of particular taxa are used for correlation. Depending on the criteria, different types of biostratigraphic units are defined (Salvador, 1994 – International Stratigraphic Guide).

I will not dwell on different types of biostratigraphic zones here. I will only highlight that calcareous nannofossils are one of the two basic groups (together with planktonic foraminifers) of marine plankton, with the highest evolutionary rates during the Cenozoic. Zonal schemes are based primarily on evolutionary events: the first and last occurrence of important nannofossil species, supplemented by some abundance-events. The most frequently used type of

biostratigraphic zones are *interval zones*, whose zonal boundaries (bio-horizons) are defined by bio-events. The first occurrence of a given planktonic taxon is usually considered as an almost synchronous event in spatial and temporal terms, since the time for its global proliferation in marine conditions is geologically virtually instantaneous.

The huge volume of data concerning the stratigraphic distribution of nannofossils in the Cenozoic is summarized in two fundamental zonal schemes – those of Martini (1971c) and Okada and Burky (1980), with additions of Perch-Nielsen (1985a). These schemes have proven their broad applicability and have been largely used as global zonal standards. Recently, Agnini et al. (2014) proposed a new low- to mid-latitude biozonation for the Paleogene. It is based on semi-quantitative counting of biostratigraphically useful nannofossil taxa from DSDP/ODP sites and on-land sections in the Atlantic, Pacific and Tethyan regions, however it is not yet commonly used.

Special emphasis should be put on the fact that nannofossil zonal schemes are matched and calibrated to the zonal divisions of other fossil groups: ammonites, belemnites, planktic foraminifers, spores and pollen, radiolarians, as well as to magnetostratigraphic units – magnetic polarity chrons.

2.2.3. Quantitative methods and their application

These methods were developed in the last three decades in respect to the rapid development of palaeoecology, sequence stratigraphy and seismostratigraphy, particularly when drilling for oil and gas. Numerous case studies, concentrated mainly in the Gulf of Mexico, have shown that the maximum (peak) in abundance of micro- and nannofossils in combination with lithologic data, can be used to identify the maximum flooding surfaces (mfs) within depositional sequences. Vice versa, the minimum in abundance and change in the nature of nannofossil associations is usually associated with sequence boundaries (Armentrout, 1996; Emery & Myers, 1996).

Special attention should be paid to the interpretation of abundance peaks – in particular determining whether they are connected to the maximum flooding or resulted from specific sedimentary processes such as gravitational flows, landslides, etc. The standard nannofossil zonation scheme of Martini (1971c) for the Paleogene and Neogene is correlated to the global scheme of Haq et al. (1988). Therefore, using quantitative methods of counting, along with precise biostratigraphic control, we can distinguish sequence stratigraphic units of third order in a sedimentary sequence (well-section or exposure).

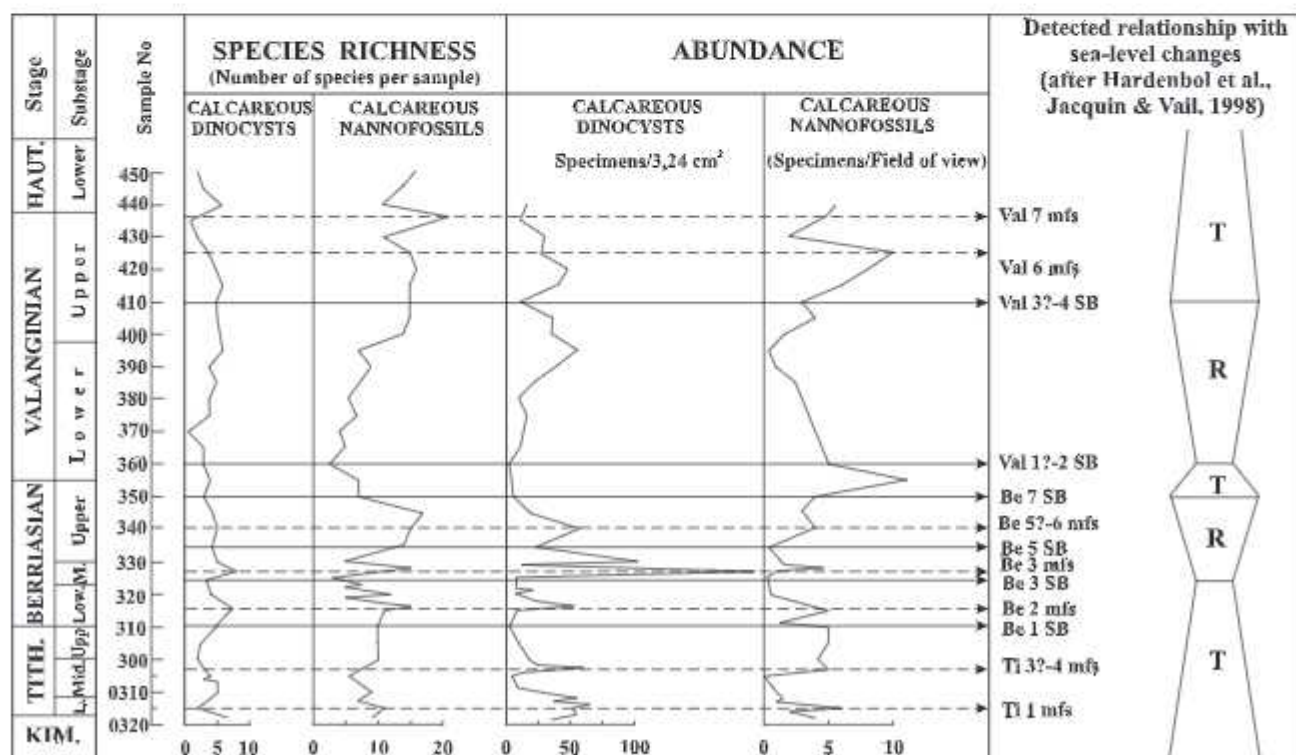


Fig. 2.3. Application of quantitative methods for sequence stratigraphic subdivision of the sections at Barlya and Gorno Belotintsi (after Stoykova & Ivanova, 2000, 2001)

In Bulgaria the first attempt to use quantitative analysis of marine microplankton (calcareous nannoplankton and calcareous dinocysts), in the interpretation and division of sequences from the second and third order, was made by Stoykova and Ivanova (2000, 2001). It was performed in the Upper Jurassic – Lower Cretaceous sequences and based on the assumption that the peaks in species diversity and quantitative abundance reflect peaks in sea level rise (mfs), while the minima correspond to the boundaries of the sequence units. Thus, with precise biostratigraphic control, in the Kimmeridgian – upper Valanginian interval, three second order sequence units and 10 third order sequences have been identified, and were compared with the global scheme of Hardenbol et al., 1998 (Fig. 2.3).

When applying quantitative analysis of nannofossil associations, the brief procedure is as follows:

1. A smear slide is prepared from raw sediment of each sample, following the standard preparation technique (Bown & Young, 1998).
2. Nannofossil abundance and species richness were determined by counting all specimens per 100 fields of view at the central traverse of a given smear slide. Additionally, a random traverse was applied to spot some rare species. Another widely used approach is to count all observed nannofossil specimens until reaching 300.

3. Resulting data for the number of species represented in the sample and number of specimens of each species are depicted in a graph and Excel-table.

Semi-quantitative analysis

This technique identifies and registers the approximate amount of each species in a sample. The number of specimens/field of view is recorded, resulting in the following categories: R – rare ($< 1/\text{FOV}$), F – frequent ($< 1/\text{FOV}$), C – common ($> 1/\text{FOV}$), A – abundant ($> 10/\text{FOV}$). Quantitative data on the abundance of a species could be used for biostratigraphic purposes: usually the acme of certain species is an event, used for regional correlation. The data is normally presented in tabular form.

2.2.4. Paleomagnetic method

This method examines the residual magnetization, which is overprinted in the rocks during their formation. Usage of paleomagnetic data for subdivision and correlation of sections was demonstrated for the first time by Hramov (1957). It is well known that over geological time changes in the magnetic poles of the Earth's magnetic field occur, alternating between periods of normal and reverse magnetic polarity. Changes in magnetic polarity are carried out over a very short

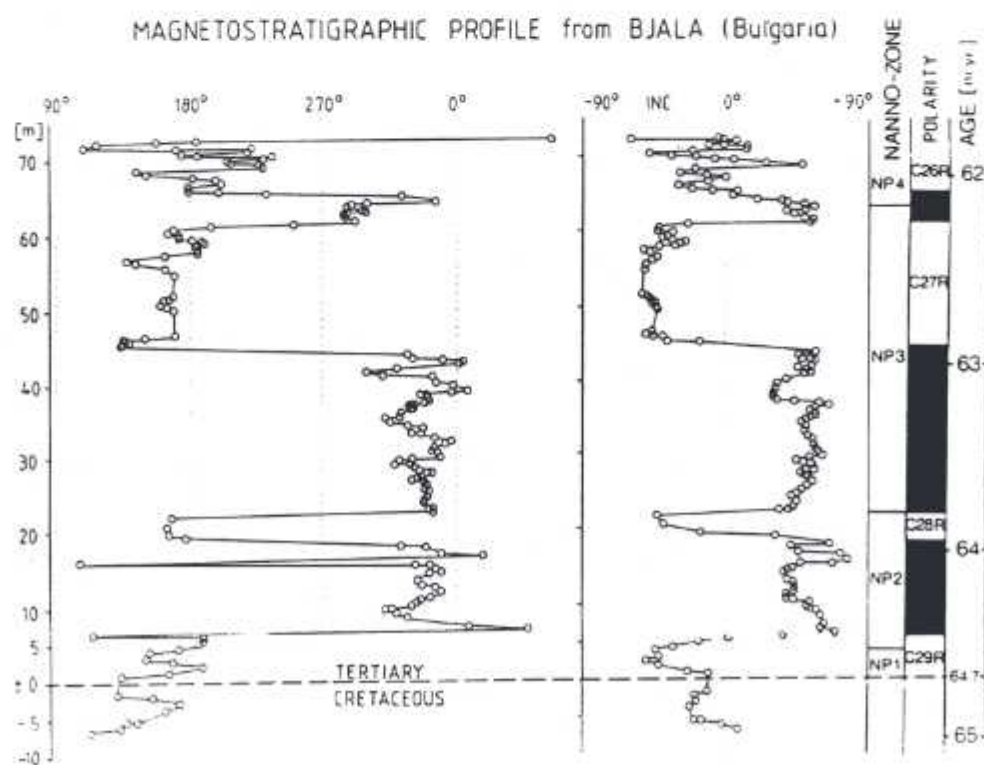


Fig. 2.4. Magnetostratigraphic subdivision of Byala 2b section across the Cretaceous-Paleogene boundary interval (according to Mauritsch & Scholger in Preisinger et al., 1993a)

time period, usually less than 5 000 years, but they are of differing length. The intervals of stable magnetic polarity vary from 30 ky to tens of millions of years. Since the change takes place in a geological sense instantaneously for the whole planet, the magnetostratigraphic units – magnetic chrons – have a global distribution and their boundaries are considered to be isochronous. Identifying them is only possible in parallel with implementation of the biostratigraphic method, otherwise only intervals of normal and reverse polarity can be determined by magnetostratigraphy. In combination with biostratigraphy, palaeomagnetism identifies a unique “bar code” for correlation of the

magnetic pole changes. In practice, palaeomagnetic correlation is the most accurate method for global correlation of all stratified rocks.

It has been accepted that chrons with normal polarity (matching the current position of the magnetic poles) be denoted by N (normal) and those with reversed polarity with R (reversal). A global magnetostratigraphic timescale has been created, by direct comparison and calibration of the palaeomagnetic data with detailed biostratigraphy in the same stratigraphic sequences (sections). Magnetic chrons of the Cenozoic and Late Cretaceous are numbered from 1 to 34 (from youngest

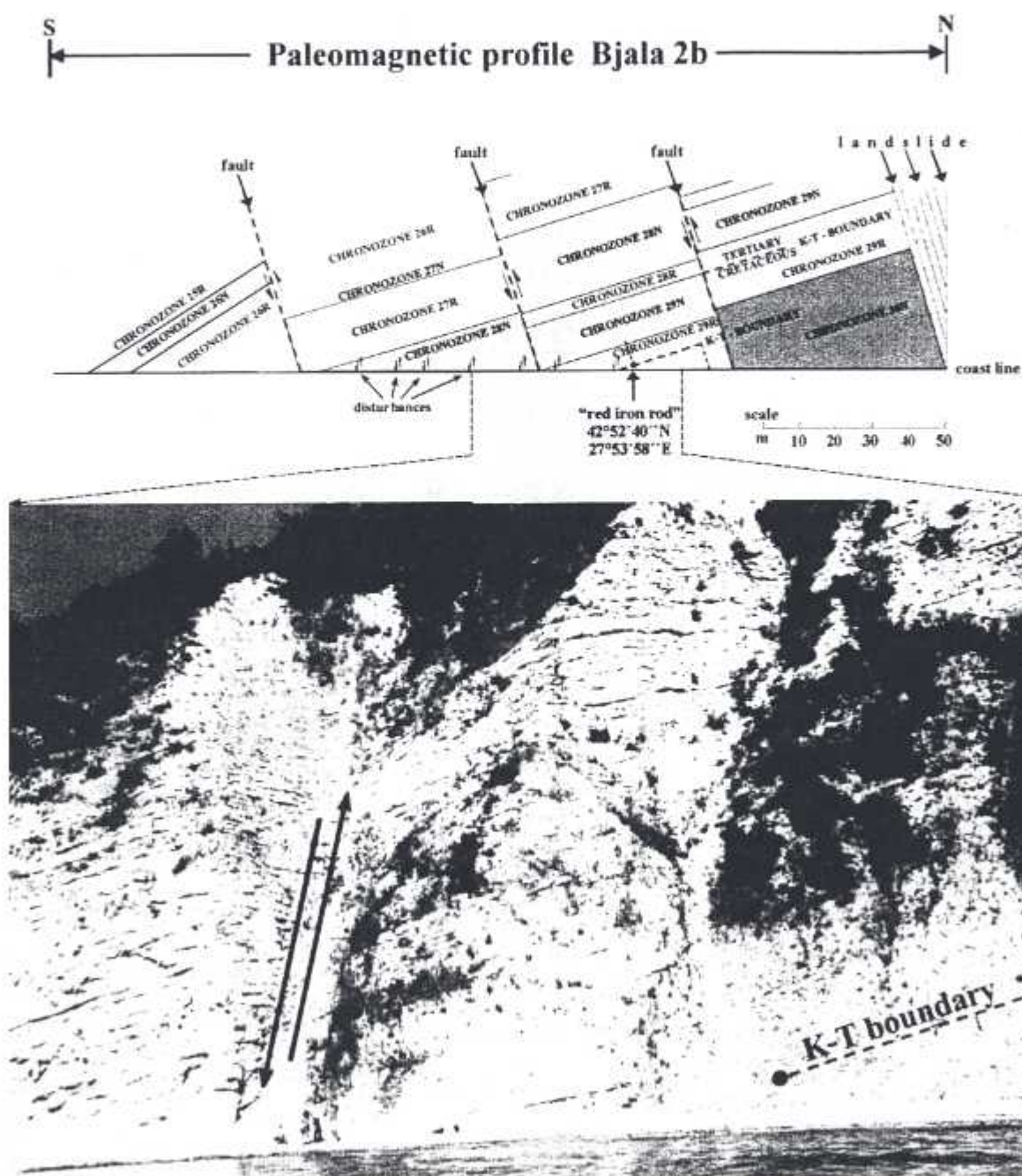


Fig. 2.5. Magnetostratigraphic subdivision of the Paleogene part of Byala 2b section (after Brandstätter in Preisinger et al., 2002)

to oldest) and bear index “C” (Cenozoic), while those from the Early Cretaceous to Late Jurassic, likewise, with numbers from 1 to 37 with index “M” (Mesozoic).

For the purposes of this study, detailed magnetostratigraphy combined with nannofossil biostratigraphy of the Byala section, was carried out at different times and by different groups of researchers. Fig. 2.4 and

Fig. 2.5 show the magnetostratigraphic subdivision of the section by Mauritsch & Scholger and Brandstätter (in Preisinger et al. 1993a, 2002).

Figure 2.6 illustrates the results of detailed magnetostratigraphy, biostratigraphy based on nannofossils and cyclostratigraphy for the same section, but by a different research group – Dinarès-Turell et al. (2006).

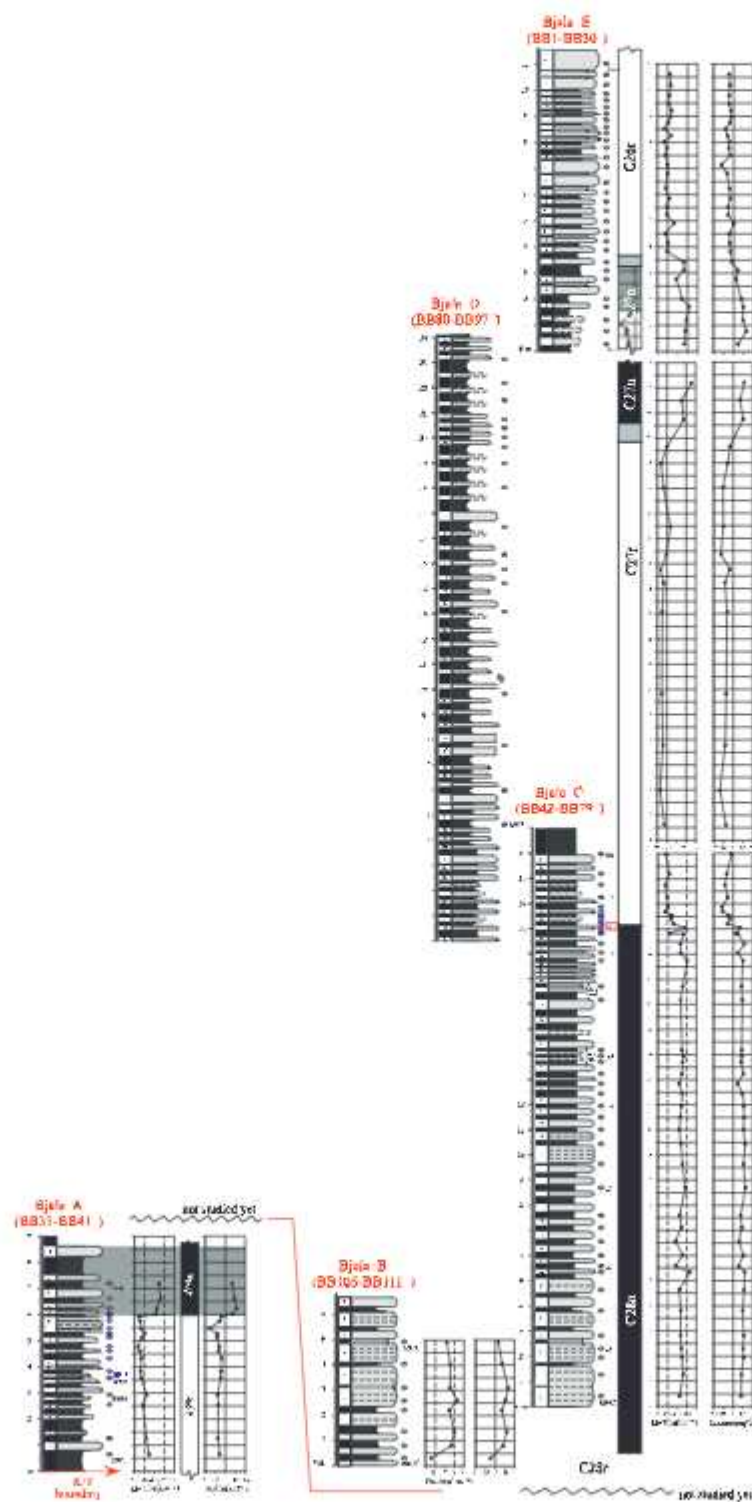
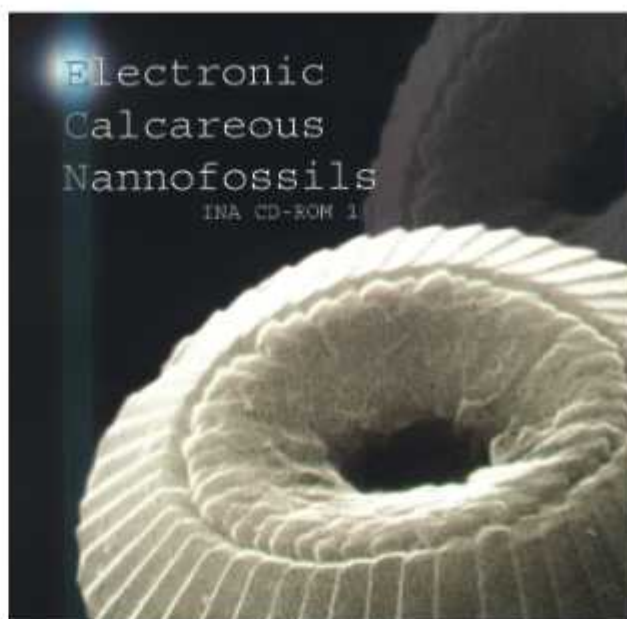


Fig. 2.6. Magnetostratigraphic subdivision of the Paleocene part of Byala locality, combined from the study of five separate segments (after Dinarès-Turell et al., 2006)

2.3. Computer Software used

In terms of taxonomic definitions and precise identification of the nannofossils, I have used BugWare package, version 2004.8.3 (before 2013). It was developed by a large team of specialists from the International Nannoplankton Association (Fig. 2.7). After 2013, I switched to the modern online catalog for calcareous nannofossils Nannotax3 (https://www.mikrotax.org/Nannotax3/index.php?dir=ntax_cenozoic), created by three colleagues: Dr. Jeremy Young, Prof. Paul Bown and Dr. Jackie Lees. It was launched at the International Nannoplankton Association conference in Washington DC, in September 2013 and has been continuously updated since then.



Nannotax 3 - Introduction



Objective: This site aims to provide an authoritative guide to the biodiversity and taxonomy of coccolithophores - a beautiful group of microscopic planktonic algae with an abundant fossil record and a key role in the global carbon cycle. It is both a working tool for specialists and an accessible reference source for anyone else looking for information on any coccolithophores.

What's on the site: The main sections of the site, as accessed from the menu bar, are:

- **About Nannotax:** a few pages describing the site, how to use it, how to cite it and our plans
- **Live & Cenozoic:** 1500 pages illustrated with 13,500 images describing the taxonomy of living coccolithophores and their Cenozoic ancestors. The pages also have occurrence frequency plots derived from the Neptune database.
- **Mesozoic:** a further 1300 pages and 9700 images describing Mesozoic coccolithophores.
- **Farnocot:** a catalog of original descriptions of 4300 species, cross-linked to the main taxon pages.
- **Non-cocco:** pages dealing with non-calcifying haptophytes, calcareous dinoflagellates, pinnules and other groups of interest to coccolithophore specialists (under development - 500 pages, 800 images).
- **Comments:** a forum for general comments on the site and a listing of all recent comments
- **Tools:** bibliography (ca 1800 entries), glossary, time-control (take a look), advanced search, zonation charts and a range-chart plotting tool.

Organisation: On higher taxon pages there is an automatically-generated table, this displays for each daughter taxon (a) representative images, (b) the diagnosis, and (c) a list of grand-daughter taxa. This is a novel approach to arranging taxonomic websites but we consider it preferable to any alternatives we have seen.

Geological search: A special feature of the site is that the taxa from a selected geological time period can be highlighted - via the *Time Control* page (Tools Menu). For example if the time period 10 to 20 million years ago is selected then taxa from this time period appear at the top of lists and are coloured blue while taxa outside this time period appear at the bottom of lists and are coloured olive green. The timescale underpinning the system is ETSD12, courtesy of Prof. James Ogg. All stratigraphic data on the site is stored in primary stratigraphic units (e.g. Albian, or Zone NN1.2) and so correlations to the timescale can be updated by changing a single lookup table.

monomorphic, all spine-bearing			
			
			
<i>Rhabdosphaera</i>			
Coccoliths without radial lath cycle: coccospheres			
			<i>R. chavira</i>
			<i>R. xiphiis</i>
			<i>R. sp.</i>
			<i>R. gracilentus</i>

Fig. 2.7. BugWare electronic catalog of Cenozoic nannofossil taxa (above) and Nannotax3 website (below) – the largest online database for taxonomic identification of nannofossils

Chapter 3

Previous research

Studies of the Paleogene System in Bulgaria first began with the geological excursions and writings of Ami Boué (1840) and Franz Toula (1892), as well as with the itineraries and descriptions of the first Bulgarian geologist Georgi Zlatarski (1884). The fundamental part of knowledge in this area, however, was accumulated between early 1930s until the end of the twentieth century, thanks to the many specialized studies of Bulgarian researchers. Among them can be distinguished the work of Gochev (1926, 1932, 1933, 1934, 1937), G. Bonchev (1926, 1927, 1929), Zhelev (1936, 1938), V. Tzankov (1936, 1943, 1946, 1951), Beregov (1946), Mandev (1955), Tzankov et al. (1961), Belmustakov (1956, 1958, 1960, 1961, 1963, 1968), Trifonova (1959, 1960), Atanasov (1961b), Aladjova-Hrischeva (1979, 1984a, 1990, 1991), Aladjova-Hrischeva et al. (1991), Juranov (1983, 1984, 1989), Juranov and Pimpirev (1989), Stoykova (1990), Stoykova and Ivanov (1992, 1994, 2004a, b; 2005, 2006a), Sinnyovsky (1993, 1999, 2003, 2004a, b; 2006), Dinarès-Turell et al. (2006, 2010, 2012, 2013a). It should be noted that the level of understanding of Paleogene geology varies widely between different parts of the country.

3.1. Progress on the knowledge of Paleocene and lower Eocene in northern Bulgaria

A few distinct stages can be identified regarding the study of the Paleocene and lower Eocene in northern Bulgaria: (i) 1840-1927; (ii) 1928-1946; (iii) 1947-1968; (iv) 1969-1991 and; (v) after 1992. The presence of the Paleocene series is recognized relatively late – as early as the third stage by Trifonova (1959), based on microfauna and Belmustakov (1960), based on macrofossils.

The first stage spans over a period from the mid 19th century until the 1930s (1840-1927). It is characterized by proving the presence of Paleogene sediments in Bulgaria and their initial description. Only the Eocene and Oligocene series were documented at this stage. The data obtained during this initial stage was summarized in the cornerstone work of Zlatarski (1927) – “Geology of Bulgaria”. In the Paleogene only the Eocene and Oligocene series were recognized. In the

so-called “middle Eocene”, the lithology of the sediments and their fossil content is characterized in detail for the following areas: around Veliko Tarnovo, to the west of Varna, in the area around Kamchia and south of the river, along the Black Sea coast, in the Eastern Rhodopes, Sakar Mountain and around Sliven. Faunal lists with typical nummulitids and mollusks were produced in this period.

The second stage covers the period from 1928 to 1946. It is characterized by the widening of regional research and a number of specialized studies, mostly on the paleontology-stratigraphy of Eocene sediments. At this stage, although completely based on intuition, the foundations of modern lithostratigraphy of the Paleogene are established by the works of Gochev (1929, 1932, 1933), G. Bonchev (1926, 1927, 1929) and Zhelev (1934, 1936).

The key contribution of Gochev's work dating from the 1930s, is the exact description of the Eocene sequences and their subdivision in to named “horizons” – the prototype of today's lithostratigraphic units – Formations. In his research at the Black Sea coast between the Kamchia River inlet and Cape Emine, Gochev (1932) determined an Eocene age for the sandstones and overlying flysch at Cape St. Atanas (previously considered by Zlatarski (1905) as Upper Cretaceous – Cenomanian and Campanian). He described in detail the Senonian in the Byala section and determined a Maastrichtian age for the grey marls, based on echinoid fossils. However, he mistakenly assigns the Emine flysch to the Eocene, based on their lithological similarities to the flysch exposed in the vicinity of Obzor. In his work on the Eocene in the Varna area, Gochev divides several “horizons”. He clearly states their definitive lithological characteristics, their vertical stratigraphic sequence and fossil content. Based on the abundant finds of nummulitids, mollusks and echinoids, he assigns them to the Lutetian Stage. Gochev (1935) made the first attempt to correlate and compare Paleogene sediments of the Balkan countries, based mostly on nummulitid finds. In his summary on the Eocene of NE Bulgaria, Gochev (1937) shows his remarkable geological intuition when dividing and describing 5 facies zones, parallel to the Balkan range: 1. zone of the thrust Balkan;

2. zone of the northern (autochthonous) Balkan; 3. Kamchia zone; 4. North Bulgarian zone; 5. Dobrudzha zone. Essentially these are structural-paleogeographic zones, which with some modifications, could be distinguished in modern research. In Gochev's works particularly impressive are his clear geological and lithofacial concepts, outgrowing his contemporaries and demonstrating modern lithostratigraphical thinking, as early as the 1930s. Particularly topical are the following basic principles: "We should not forget that the facies changes and rocks change their appearance in a horizontal direction... It is known that... Often sediments of the same age, but of different facies have less similarity to each other than those of different ages, but of the same facies. Disregarding these facts may lead to major misinterpretations..." (Gochev, 1937).

Zhelev (1936) first reported the presence of the Eocene in Central northern Bulgaria – Pleven area. He found nummulitids in the glauconite-sandy sediments, that crop out in the vicinity of the villages of Grivitsa, Varbitsa, Opanskoto Bardo and in the Kaylaka area. These nummulitids were taxonomically determined by Gochev and the sediments assigned to the Lutetian (based on analogy with the Beloslav – Gebedzhe section in the vicinity of Varna). It is worth noting that in this work Zhelev indicates for the first time the presence of an *Ostrea*-level in Central northern Bulgaria, section Kailaka.

Zhelev and Gochev (1938) studied the Eocene in the central parts of northern Bulgaria, between the rivers Iskar and Osam. In this pioneer regional study, they wonder where the boundary between the Cretaceous (proven Maastrichtian with *Hemipneustes striatoradiatus*) and Eocene (proven by the presence of specific nummulitid species) might be. The sediments that lay between the proven Upper Cretaceous and Eocene are called the "Pleven Stage". It is represented by limestones – slightly sandy to clayey, exposed in the valley of the River Vit. Later, researchers proved that the "Pleven Stage" of Zhelev and Gochev is actually Paleocene in age (Thanetian Stage) in Central northern Bulgaria (Belmustakov, 1960, 1963, 1968; Tzankov et al., 1961; Tsaneva, 1964; Dachev, 1967, 1975).

In the works of G. Bonchev (1926, 1927, 1929), regional geological descriptions are made and lithological data for the Paleogene sediments of different parts of NE Bulgaria are presented – the Balkan area, Provadia and Varna vicinities.

During this stage, research on the Eocene of NE Bulgaria was made by Gellert (1929). In his dissertation he carried out the first geological mapping of the Eocene in the vicinity of Varna, subdividing it into

several horizons, mainly based on lithological characteristics.

Pollak (1932, 1933) studied the flysch sediments in the eastern parts of the Balkan, subdividing them from bottom to top: basic conglomerate; lower flysch molasse; exotic conglomerate; and upper flysch molasse. He assigned the two lower complexes to the Lutetian and the upper two to the Auversian based on the presence of *Nummulites variolarius*.

In a series of works V. Tzankov (Tzankov, 1936, 1943; Tzankov, Beregov, 1940; Tzankov & Cohen, 1941) presented new data on the biostratigraphy, geological structure and development of the Eocene in the plateaus of NE Bulgaria.

The end of this stage of investigation is marked by the comprehensive monograph "Fundamentals of the geology of Bulgaria" which includes data on the Senonian and Danian by Cohen (1946), on the Eocene by Beregov (1946) and biostratigraphic information on the Danian and Tertiary by Tzankov (1946).

It can be concluded that during the second stage new regional geological knowledge and data is acquired, lithologic units – horizons are recognized and the macrofossil content of the Eocene sediments is explored, mainly in the NE and central parts of northern Bulgaria.

The third stage covers the period between 1947 and 1968. During this period regional geological studies blossomed, as a result of geological mapping at 1:25 000 and 1:100 000 scales, which started in the 1950s and 1960s. These studies, in turn, provided a vast amount of information for further development in the paleontological and biostratigraphical fields. In northern Bulgaria, intensive research for mineral resources began – oil, gas and coal – which inevitably raised the need for specialized micropaleontological studies.

The first micropaleontological results, based on foraminiferal data were published – Trifonova (1959, 1960), Tsaneva in Tzankov et al. (1961), Tsaneva and Vaptsarova (1961), Tsaneva (1963, 1964). Macropaleontological research made significant progress, which peaked with the release of three volumes from the series "Fossils of Bulgaria": Volume IV Paleogene, large foraminifera (Belmustakov, 1959); Volume IVa Paleogene, Molluscs (Karagyuleva, 1964); Volume IVb Paleogene, Echinoids (Sapundjieva, 1964).

During this stage, the presence of Paleocene and lower Eocene in Bulgaria was paleontologically proven. The new data was summarized in the second volume

of the "Geology of Bulgaria" by E. Bonchev (1960).

The occurrence of Paleocene sediments in Bulgaria was first proved by Trifonova (1959, 1960) in the vicinity of Byala, Varna region. Soon after they were also recorded in Momino Plateau (Belmustakov, 1960), Elena and Kotel (Karagyuleva, 1961). During the next few years followed the publication of a number of specialized works, dealing with the stratigraphy of the Paleocene: in the plateaus in NE Bulgaria (Belmustakov, 1962), in the River Vit Valley (Belmustakov, 1963; Dachev, 1967), in the Gabrovo Syncline (Belmustakov & Jolkichev, 1965), and in drilling sections of NW and Central northern Bulgaria (Tsaneva in Tzankov et al., 1961; Tsaneva & Vaptsarova, 1961; Tsaneva, 1963, 1964).

The presence of lower Eocene – Ypresian in Bulgaria was paleontologically established for the first time by the Romanian geologist Bombita (1957), who assigned an Ypresian age to a fossil association derived from the base of the Eocene succession in Varna. Later on, Belmustakov (1962) confirmed the presence of the Ypresian Stage in the Varna, Provadia, Momino and Shumen plateaus, dividing it into lower and upper parts.

Karagyuleva (1960) reported for the first time the occurrence of the Ypresian Stage in the Lukovit Syncline. In the flyschoid sediments cropping out around the villages of Rumiantsevo, Malka Bretsnitsa, Toros and Petrevene, a rich nummulitid association, typical for the upper parts of the Ypresian Stage was documented.

Tsaneva made a significant contribution to the research on the microfossil content – foraminifera of the Paleogene. She published foraminiferal data from the lower Eocene in Central northern Bulgaria (Pleven high) and NW Bulgaria (Lom Depression), mainly based on drilling data (Tsaneva in Tzankov et al., 1961; Tsaneva & Vaptsarova, 1961; Tsaneva, 1963, 1964). At the end of this extremely fruitful stage, knowledge of lithology and biostratigraphy of the Paleogene System was summarized in "Unified stratigraphic schemes" for the Paleogene in different parts of Bulgaria – NW, Central Northern and NE Bulgaria, including the Balkanides (Belmustakov & Tsaneva, 1965).

The most essential and fundamental synthesis on the Paleogene in Bulgaria so far, was made by Belmustakov (1968) in the monograph "Stratigraphy of Bulgaria". It is based on a vast amount of paleontological, biostratigraphic and lithological data on the Paleogene sediments, exposed throughout Bulgaria. Three series were recognized – the Paleocene, Eocene and Oligocene, but only some of the stages that

we have adopted today can be clearly distinguished – the Thanetian, Ypresian, Lutetian and Priabonian. This work, although published over 50 years ago, still serves as a starting point for any new study concerning the Paleogene in Bulgaria.

The fourth stage marks the beginning of elaboration of formal lithostratigraphy of the Paleogene sediments. Extensive paleontological and biostratigraphic research were implemented. Besides, in addition to the traditional groups – nummulitids and foraminifera, calcareous nannofossils were explored for the first time.

Tsaneva (1971a) summarizes foraminiferal data on stratigraphy of the Paleogene in NW and Central northern Bulgaria. In her work she does not define biostratigraphic zones, but clearly outlines foraminiferal associations in the Paleocene, and the lower and middle Eocene. Her pioneering research on the phylogeny of the genus *Globorotalia* enabled significant biostratigraphic and paleogeographic conclusions about the specifics of the marine basin (Tsaneva, 1971b).

Dachev (1967, 1975) contributes to the lithostratigraphy of the Paleocene series in the Pleven area. He distinguished originally two packets, later formalized as the Komarevo and Bozhuritsa Formations.

Aladjova-Hrischeva (1979) published a comprehensive study on the Paleogene stratigraphy of the Lukovit Syncline. She identified several lithological units – packets, tracking their spatial relationships and describing their nummulitid content. The nummulitid associations she found, confirmed the opinion of Karagyuleva (1960) regarding the presence of lower Eocene in the Lukovit Depression, contrary to views of Belmustakov (Belmustakov, 1969; 1980). In her doctoral thesis Aladjova-Hrischeva (1980) applied "Mediterranean" chronostratigraphic divisions, by introducing the Illeridian and Cuisian Stages in the lower Eocene (each divided into three substages). Biostratigraphic zones, based on nummulitids were also suggested.

Aladjova-Hrischeva et al. (1983) integrated biostratigraphic data on nummulitids, calcareous nannoplankton and planktic forams in the Paleocene-lower Eocene sections of NE Bulgaria. They documented paleontologically an early Eocene age for the Beloslav, Dikilitash, Aladan and the base of the Avren Formation in the classic section near Beloslav, Varna region. A year later, Aladjova-Hrischeva (1984a) proposed the Beloslav Formation, as well as formation rank for both the Dikilitash and Aladan Formations.

Juranov (1984) recognized three packets in the sedi-

mentary succession around Byala and Goritsa, Varna area. Later on, he formalized some of them as formations in co-authorship (Juranov & Pimpirev, 1989). At the same time, he published the first complete zonation based on planktic foraminifers for the Paleocene and lower Eocene (Juranov, 1983). Ten interval biozones, from *Subbotina pseudobulloides* in the lower Paleocene to *Acarinina pentacamerata* in the lower Eocene are identified and characterized in detail. Juranov and Darakchieva (1986) described typical lower and middle Eocene planktic foraminifers, originating from drilling sections in the Dobrudzha area.

During this stage, chronostratigraphy of the Paleocene, lower and middle Eocene is the subject of continuous discussions. Disputes revolve around the applicability of various bio- and chronostratigraphic schemes in Bulgaria, which have been used in Western Europe, Crimea and the Caucasus (Belmustakov, 1980, 1984; Aladjova-Hrischeva, 1984c).

Stoykova (1990) examined for the first time the nanofossil content of the Paleocene – Eocene successions of several sections along the River Vit Valley, Central northern Bulgaria. Based on the recorded nanofossil associations, she recognized two zones in the upper Paleocene (NP 6 and NP 7) and two zones at the base of the middle Eocene (NP 14b and NP 15).

At the end of this fruitful stage, Aladjova-Hrischeva published several articles, summarizing stratigraphy of the Paleogene in northern Bulgaria (Aladjova-Hrischeva, 1990, 1991). Thus, the formal lithostratigraphic subdivision of the Paleogene in NE Bulgaria is completed. The chronostratigraphic range of the lithological units is determined by nummulitid biostratigraphy.

Aladjova-Hrischeva et al. (1991) introduced six new formations and two new members, initiating a formal lithostratigraphic scheme in the West and Central Fore-Balkan and Balkan Mountains (from the Kula area westward to the Tryavna area to the east). Attempts were made at paleogeographical reconstruction of the basin development during Paleocene – early Eocene time.

The fourth stage can be described as a stage of construction and completion of the basic outlines of the lithostratigraphic scheme describing the Paleogene sediments in northern Bulgaria. During the same period expansion and intensification of biostratigraphic research based on different fossil groups and different zonal schemes blossomed.

The fifth stage began after 1992. Between 1992 and 1995, map sheets with explanatory notes to the

geological map of Bulgaria (1:100 000) were published. They summarized all existing data regarding the distribution, lithostratigraphy, fossil content and chronostratigraphic range of the Paleogene sediments (Kanchev, 1995a, b, c, d; Filipov & Cheshitev, 1995a, b; Tzankov, 1995a, b). The map users, however, faced considerable difficulties, when they tried to follow the same Paleogene units on two adjacent map sheets made by different research teams (e.g. map sheet Gabrovo – Tsankov, 1995a, and Tvarditsa – Kanchev & Nikolov, 1995).

The other summary of significant importance for the Paleogene lithostratigraphic units can be found in "Dictionary of the formal Bulgarian lithostratigraphic units (1882-1992)". It classified all lithostratigraphical terms and concepts used for Paleogene rocks in the country (Juranov, 1993; Ivanov, 1993a).

During this stage attention is drawn to some global geological events, affecting our planet – impact events, climatic changes, sea level changes. Thus, the research on their record in Bulgaria started by applying calcareous nanofossil biostratigraphy as a powerful tool. In this way, the continuous section across the Cretaceous/Tertiary boundary at Byala, Varna vicinity, was discovered (Stoykova & Ivanov, 1992). It contained a boundary clay bed with high iridium content, as a result of the impact event at this boundary (Preisinger et al., 1993a, b; Ivanov & Stoykova, 1994).

Scientific interest in the research of this important geological boundary followed, leading to the discovery of new sections in different depositional environments throughout northern Bulgaria (Sinnyovsky & Stoykova, 1995; Sinnyovsky, 1999; Sinnyovsky et al., 2002). The events around this boundary are studied in detail and in various aspects: biostratigraphic, mineralogical, geochemical, sedimentological, magnetostratigraphic (Rögl et al., 1996; Ivanov & Stoykova, 1994, 1995; Stoykova & Ivanov, 2002a, b, 2004a; Stoykova et al., 2000; Kostov & Tsankarska, 1997, 2000; Preisinger et al., 2002; Adatte et al., 2002; Peybernès et al., 2004; Dinarès-Turell et al., 2006).

Vangelov and Sinnyovsky (2000) published new data on the lithostratigraphic and paleogeographic development from the Late Cretaceous to the Eocene, obtained as a result of new mapping of the East Fore-Balkan (scale 1:25 000).

Vangelov and Sinnyovsky (2001) divide several types of depositional environments and facies in the East Balkan (Emine basin) and made interpretations for its geodynamic development during the Late Cretaceous to middle Eocene.

During this stage, the first attempts for sequence stratigraphic subdivision of the Paleocene – lower Eocene interval were published. Sinnyovsky (1999, 2004) suggested two third-order sequences in the Upper Cretaceous – lower Paleocene section along the valley of the River Kamenitsa, southwest of Mezdra (near the villages of Moravitsa and Chelopek). In his Ph.D. thesis Vangelov (2000) distinguished six sequences of third order in the Paleocene – middle Eocene interval of NE Bulgaria.

Stoykova and Ivanov (2002b, 2004a) identified and traced four sequence stratigraphic units in the Maastrichtian – Danian interval in northern Bulgaria.

For the first time cyclostratigraphic research was undertaken. The object of these studies was the recognition and analysis of orbitally forced cyclicity in the marl-limestone successions around the Cretaceous/Tertiary boundary in Mezdra and Byala, Varna area (Sinnyovsky, 1999, 2001a; Preisinger et al., 2002; Dinarès-Turell et al., 2006, 2010, 2012, 2013a).

During the fifth stage global paleoclimatic events and their impact on the sedimentary record were analyzed and addressed. This is the case with the Paleocene-Eocene thermal maximum evidenced in several Bulgarian sections (Stoykova & Ivanov, 2005; Stoykova et al., 2005b, 2006).

It can be concluded that during this last stage, huge amounts of new information and data on regional geology and stratigraphy of the Paleogene sedimentary sequences was accumulated. In addition, completely new approaches were applied – nannofossil biostratigraphy, sequence stratigraphy, basin analysis, magnetostratigraphy, cyclostratigraphy and event stratigraphy.

3.2. Biostratigraphic schemes based on different fossil groups, applied in Bulgaria

Even the first scientists exploring the Paleogene in Bulgaria had separated chronostratigraphic subdivisions such as Eocene, Oligocene and Paleocene, based on the fossil finds in the sediments, in short based on biostratigraphic criteria. Initially, in order to determine a particular series and prove its age, they used to quote the so-called “marker species”. Usually these are representatives of large foraminifers (nummulitids), mollusks (bivalves and gastropods) and echinoids. Characteristic fossil associations were identified, enabling correlation between different lithologies and regions. In this way, biostratigraphic zonation of the Paleogene began, i.e. creating zonal schemes based on different fossil groups.

One of the first biostratigraphic schemes for subdivision and correlation of the Paleogene in Bulgaria was created by Belmustakov and Tsaneva (1965) in “Unified and regional schemes on the stratigraphy of PR Bulgaria”. In this work, data concerning macrofauna, microfauna (small foraminifers) and lithological composition of the Paleogene sediments in different parts of the country were correlated. Primary fossil groups are nummulitids and mollusks. In the Paleocene series, only the Thanetian Stage is separated (upper Paleocene) and in the lower Eocene – the Ypresian Stage (Fig. 3.1).

Tsaneva (1971a) separates associations of planktic foraminifers in the Paleogene of northern Bulgaria, which can be considered as biostratigraphic zones (Fig. 3.1).

Zonation based on nummulitids was made for the first time by Aladjova-Hrischeva (1980) in her PhD thesis, as she adopted the Mediterranean chronostratigraphic subdivision and the biostratigraphic scheme of Schaub (1981) – Fig. 3.1. However, in her later works, Aladjova-Hrischeva replaced the term “zone” with “nummulitid complex” or “association” (Aladjova-Hrischeva et al., 1983; Aladjova-Hrischeva, 1984a, b).

The first zonation of the Paleocene – lower Eocene interval in the modern sense, was published by Juranov (1983). He examined the vertical range of the planktic foraminifers and defined ten interval biozones – Fig. 3.1. This division is a solid background for regional and global correlations, as it is based on a planktic microfossil group with fast rates of evolution and high stratigraphic value. In terms of chronostratigraphy, the author believes that the traditional stage concepts for the Paleocene and lower Eocene are compromised and should be replaced with Sub-series.

Stoykova (1990) documented the presence of two zones in the upper Paleocene – NP6 and NP7, clearly defining their boundaries and nannofossil associations, using the standard biozonation of Martini (1971c).

In a series of articles, dedicated to the detailed biostratigraphic subdivision of the interval around the Cretaceous/Tertiary (K/T) boundary, Stoykova (in Stoykova & Ivanov, 1992, 1994, 2002a, 2004a; in Preisinger et al., 1993a, b) distinguished and characterized the following nannofossil zones: *Micula murus* and *Micula prinsii* in the Upper Maastrichtian and zones NP1, NP2, NP3, NP4 and NP5 in the Danian and Selandian Stages (Fig. 3.1).

Sinnyovsky et al. (2002) proved for the first time a

	Belmoustakov, Tsaneva (1965)		Tsaneva (1971)		Aladjova-Hrischeva (1980)		Aladjova-Hrischeva et al. (1983)		
	Ypresian		Ypresian		Cuisian			<i>A. pentacamerata</i>	<i>D. subloboensis</i>
LOWER EOCENE		<i>Nummulites leopoldi</i>			Upper	<i>Nummulites maffredi</i>			
					Middle	<i>Nummulites praelevigatus</i>		<i>Nummulites distans</i>	<i>Discoaster lodoensis</i>
		<i>Nummulites planulatus</i>			Lower	<i>Nummulites planulatus</i>		<i>N. planulatus</i>	
	Thanetian	<i>Cyprina lumulata</i> , <i>Cucullaea crassatina</i> , <i>Ventricularia pectuncularis</i>			Upper	<i>Nummulites involutus</i>		<i>N. irregularis</i>	<i>Discoaster binodosus</i>
					Middle	<i>Nummulites exilis</i>		<i>N. crimensis</i>	
					Lower	no fauna			
								<i>Discoacyclina seunesi</i>	<i>Pl. pseudomenardi</i>
									<i>Discoaster gemmeus</i>
									<i>Heliolithus kleinpellii</i>
PALEOCENE	Thanetian								

	Juranov (1983)		Stoykova (1990)	Stoykova, Ivanov (1992, 1994, 2002, 2004a)	Stoykova, Vangelov (1997)	Sinuyovsky (2002, 2004a,b)	Stoykova, Ivanov (2004b, 2005, 2006)
	lower Eocene						
EOCENE		<i>A. pentacamerata</i>					NP14 <i>D. subloboensis</i>
							NP13 <i>D. lodoensis</i>
		<i>Morozovella aragonensis</i>			NP12 <i>T. orthostylus</i>		NP12 <i>T. orthostylus</i>
		<i>Morozovella formosa formosa</i>					NP11 <i>D. binodosus</i>
		<i>Morozovella subbotinae</i>			NP10 <i>R. bramlettei</i>		NP10 <i>R. bramlettei</i>
	upper	<i>Morozovella velascoensis</i>				NP9 <i>D. multiradiatus</i>	NP9 <i>D. multiradiatus</i>
		<i>Planorotalites pseudomenardi</i>			NP8 <i>Heliolithus riedeli</i>	NP8 <i>Heliolithus riedeli</i>	NP8 <i>Heliolithus riedeli</i>
			NP7 <i>D. mohleri</i>		NP7 <i>D. mohleri</i>	NP7 <i>Discoaster mohleri</i>	NP7 <i>Discoaster mohleri</i>
			NP6 <i>H. kleinpellii</i>			NP6 <i>H. kleinpellii</i>	NP6 <i>H. kleinpellii</i>
						NP5 <i>F. tympaniformis</i>	NP5 <i>F. tympaniformis</i>
PALEOCENE	middle	<i>Morozovella angulata</i>					
		<i>Morozovella tuncinata</i>					
	lower	<i>Subbotina trinidadensis</i>				NP4 <i>Ellipsolithus macellus</i>	NP4 <i>Ellipsolithus macellus</i>
		<i>Subbotina pseudobulloidensis</i>				NP3 <i>C. danicus</i>	NP3 <i>C. danicus</i>
						NP2 <i>C. tenuis</i>	NP2 <i>C. tenuis</i>
						NP1 <i>B. sparsus</i>	NP1 <i>B. sparsus</i>

Fig. 3.1. Biostratigraphic subdivision and zonation by various fossil groups (discussed in text) applied in Bulgaria

continuous succession across the K/T boundary in the Carpathian type Upper Cretaceous near Kladorub. They found rich nannofossil associations, typical for the zones *Micula prinsii* (uppermost Maastrichtian), NP1 *Biantholithus sparsus* and NP2 *Cruciplacolithus tenuis* (lowermost Paleocene).

Sinnyovsky (2004a, b) reviewed the nannofossil biostratigraphy of the Upper Cretaceous – Paleocene sediments in the Kladorub and Emine Formations. Detailed zonation of the Paleocene series is made, defining the boundaries, associations and distribution of the nannofossil zones from NP1 to NP 9. Unfortunately,

due to a technical error in the definition of zone NP9, both articles listed wrong criteria for zone NP8.

Stoykova and Ivanov (2004b, 2005, 2006a) prove the full range of nannofossil zones in the Paleocene – lower Eocene interval – from NP1 in the base of the Paleocene, to NP14a in the uppermost parts of the lower Eocene. They have been documented in a number of sections around Byala, Varna area, Mezdra area and in Central northern Bulgaria – Pleven area (Fig. 3.1). In the Paleocene Series the Danian, Selandian and Thanetian Stages are differentiated, and in the lower Eocene – the Ypresian Stage.

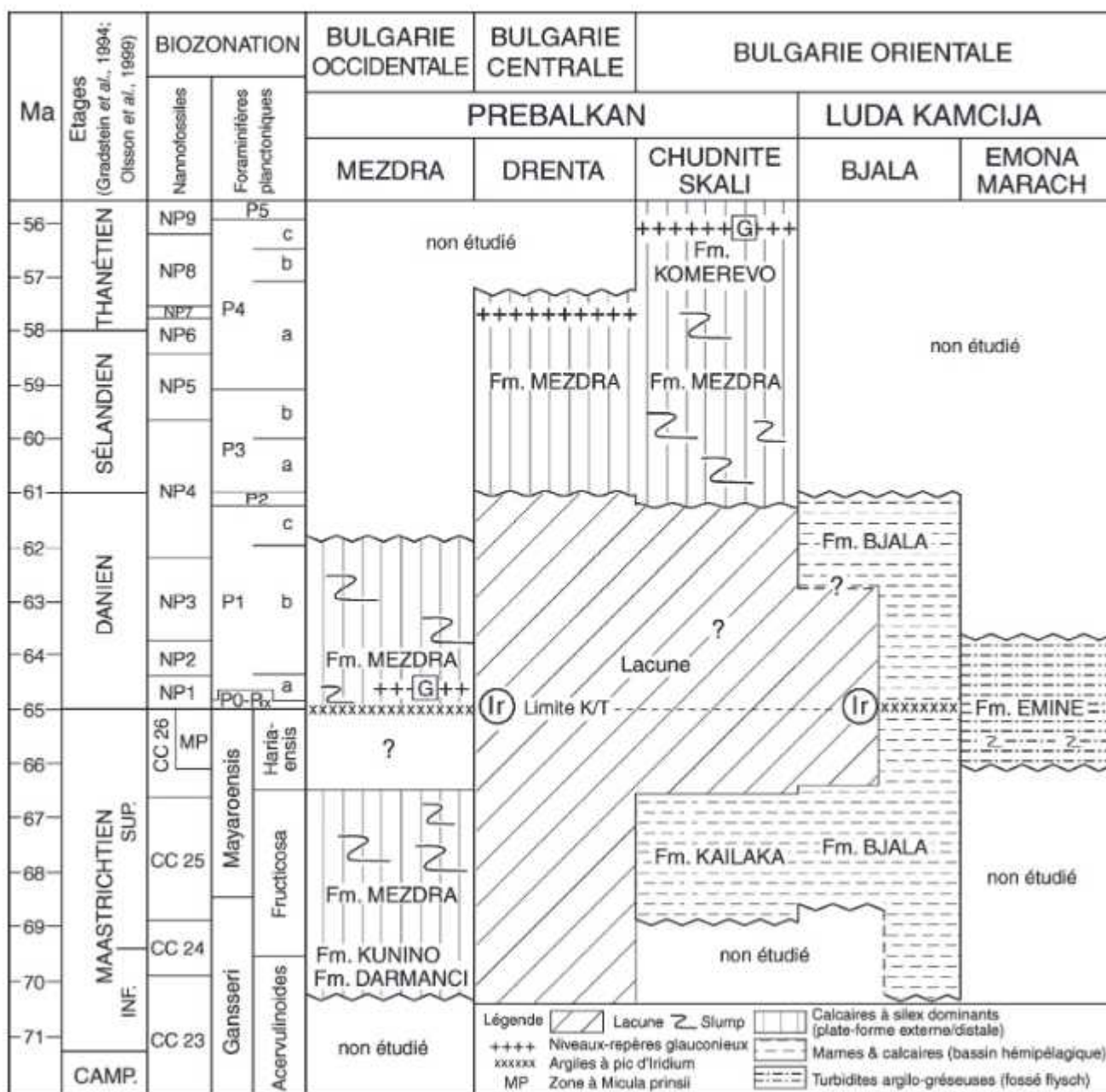


Fig. 3.2. Correlation of zonal schemes by planktonic foraminifera and calcareous nannofossils in the Maastrichtian – Paleocene interval (after Peybernès et al., 2004)

There have also been attempts to calibrate the nanofossil and planktic foraminifer biozonations. Peybernès et al. (2004) correlated the data of these two planktic groups, studying several key sections of the Paleocene in northern Bulgaria (Fig. 3.2). Stoykova et al. (2005a) directly tied bioevents and biozonations based on nannoplankton and planktic foraminifers in the Paleocene section of Goritsa, Varna District (Fig. 3.3).

At the end of this review, it can be concluded that various biozonations of macro- and microfossils (mollusks, nummulitids, planktic foraminifers and nannoplankton) have been applied for the subdivision and correlation of the Paleogene sediments in Bulgaria. During the last two decades of the 21st century, an approach based on planktic microfossil groups is more preferred, because of their high stratigraphic resolution and reliability for precise correlations on a regional and global level.

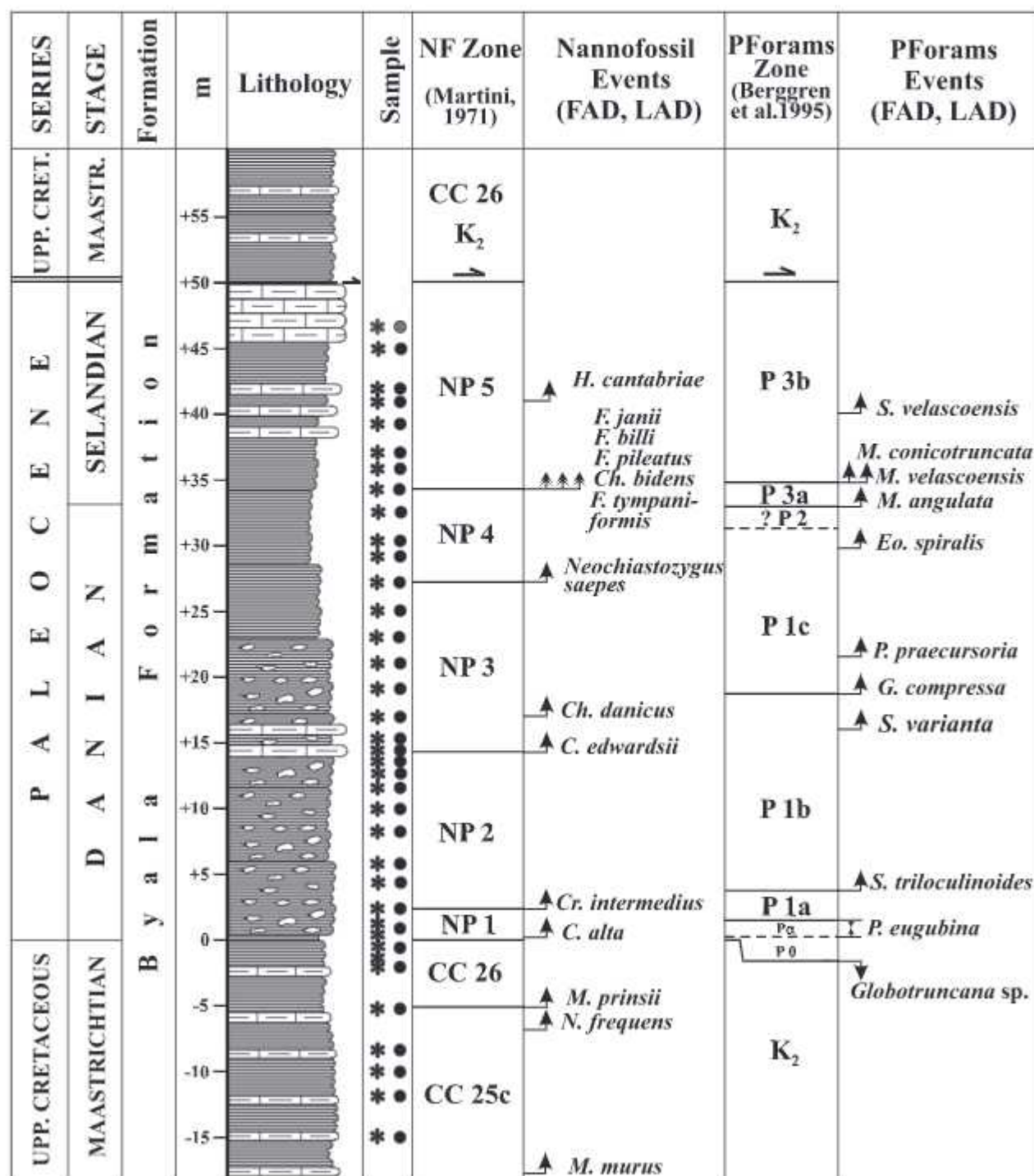


Fig. 3.3. Correlation of zonal schemes and bioevents by planktonic foraminifers and calcareous nannofossils in the Maastrichtian – Selandian interval in the section near Goritsa (after Stoykova et al., 2005a)

Chapter 4

Lithostratigraphy of the Paleocene and lower Eocene sediments

Twenty-four formal lithostratigraphic units (Formations) and six informal units (formations) have been introduced in the Paleocene – lower Eocene interval of northern Bulgaria. They are briefly reviewed and described in this chapter, presented from west to eastwards and from older to younger units. The aim of this chapter is to summarize and synthesize all available data on the lithostratigraphy of the studied interval in northern Bulgaria.

Kladorub Formation (Tzankov, 1972)

Nomenclature. The name of the Formation was introduced by Tzankov (1972) as “Kladorub Complex”. A type section, although not described, is indicated on the right bank of the Vrabska bara River, Kladorub village. An auxiliary section is traced along the Tsiganski dol valley, east of the village. The rank of the unit – Formation, is given by Filipov and Cheshitev (1995b).

Lithological characteristics. The Formation is built up by monotonous grey-greenish, indistinctly bedded sediments, dominated by clayey-calcareous siltstones and minor quantities of silty marls (Sinnyovsky et al., 2002, Fig. 4.1). Among them at different levels, rare layers of bioclastic, detrital and clayey limestones occurred.



Fig. 4.1. Clayey-carbonate siltstones and silty marls in the upper portion of the Kladorub Formation along Tsiganski dol, SE of Kladorub. Tape measure = 1m

Regional aspects. The surface exposures of the Formation are rather limited – they can be traced only around Kladorub and Rakovitsa villages, Vidin District (NW Bulgaria). It is quite probable, however, that it continues to the east and northeast in the Lom Depression. Rocks of the same lithology and similar age have been penetrated by numerous wells there. The reason for this suggestion being the description of the sediments penetrated by wells R-6 Dulgodeltsi (Tsaneva, Vaptsarova, 1961), R-4 and R-5 G. Gnojnitsa, R-2 Medkovets, C-1 Drenovets and C-7 Lom (Tsaneva, 1964, 1971a). Thicknesses there vary from 10-20 m to more than 100 m.

The lower boundary of the Kladorub Formation is not exposed. It is assumed that the Formation is underlain by and laterally passes to the Kula Fm (Tzankov, 1972). At the section along Tsiganski dol, southeast of Kladorub village, the contact is tectonic (along a fault) with granodiorites of the Belogradchik pluton.

The upper boundary of the Formation is erosional. It is unconformably covered by the Staropatitsa Fm sandstones and conglomerates (lower-middle Eocene?) or the Rakevo wedge of the Krivodol Fm (Neogene).

The thickness of the Formation in the best exposures along Tsiganski dol, southeast of Kladorub village, is around 210 m (Sinnyovsky, 2004b).

Spatial-temporal relationships of the Kladorub Formation with other lithobodies are shown on Fig. 4.2. To the east, near the Lom Depression, its lower parts possibly passed to the limestone-marl formation, separated by Filipov (1992). In this direction, presumably also expands its chronostratigraphic range. Reasons for such claims are found in the planktonic foraminifera biostratigraphic data in the Paleocene – Eocene section of the wells in the Lom Depression (Tsaneva, 1964).

Chronostratigraphic range. The age of the Kladorub Formation is constrained based on macro- and microfossils – ammonites, inoceramids, foraminifera and calcareous nannoplankton (Tzankov, 1964; Tsaneva, 1964; Sinnyovsky, 2004b; Stoykova & Ivanov, 2005). It comprises the interval from the Upper Campanian in

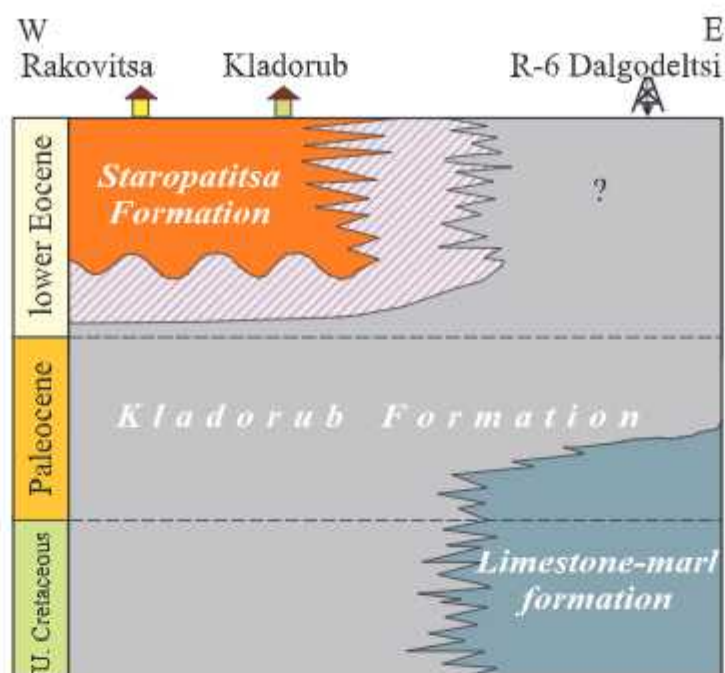


Fig. 4.2. Spatial-temporal relationships of the Kladorub Formation with other lithobodies

the Upper Cretaceous (Sinnyovsky, 2004b) to the lower parts of the Ypresian in the lower Eocene (Stoykova & Ivanov, 2005). Of a total thickness 210 m in the section at Tsiganski dol, 135 m are assigned to the Upper Cretaceous (Upper Campanian – Maastrichtian, Sinnyovsky, 2004b; Granchovski, 2019) and 75 m to the Paleocene and lower Eocene.

Limestone-marl formation (Filipov et al., 1992)

Nomenclature. The name was introduced as an informal unit in the Explanatory Note to the Geological map in scale 1: 100 000 by Filipov et al. (1992, 1995b). However, its sediments have been previously described in several articles on the stratigraphy of the Carpathian type Upper Cretaceous and Paleogene in the wells of NW Bulgaria – Vidin Uplift and Lom Depression (Tsaneva & Vaptsarova, 1961; Vaptsarova, 1963; Tsaneva, 1963, 1964).

Lithological characteristics. It consists of alternating grey clayey limestones and marl packets of variable thickness. Concentrations of glauconite and cherty concretions are occasionally observed at some levels (Vaptsarova, 1963).

Regional aspects. Up to the present date, no surface outcrops of this formation are known. It is distinguished based only on well data from NW Bulgaria (Moesian Platform, on the periphery of the Lom Depression and the Vidin Uplift). Its thickness reaches up to 650 m (Filipov et al., 1992, 1995b).

Its lower boundary is unconformable with Lower Cre-

taceous rocks (Slivnitsa and Simeonovo Formations), and its upper boundary is probably a gradual transition to the sediments of Kladorub Fm (Fig. 4.2).

Chronostratigraphic range. The complete stratigraphic range of the formation based on microfossil data (foraminifers) is Cenomanian – Danian (Vaptsarova, 1963).

Mezdra Formation (Jolkichev, 1986)

Nomenclature. The Formation was introduced by Jolkichev (1986), formalizing the previously divided cherty-carbonate formation (Jolkichev, 1982). Later on, the same author (Jolkichev, 1993) classify the name “Mezdra cherty-carbonate Formation” as usable, but invalid, due to homonymy with the “Mezdra sandstones” of Bonchev and Kamenov (1934). However, geological practice in Bulgaria over the last 25 years, endorsed the use of the Mezdra Formation of Jolkichev (1986). The type section of the Formation is located between the village of Darmantsi and Mezdra town.

Lithological characteristics. The Formation is built up of thin to medium-bedded micritic limestone (in the Fore-Balkan) and chalky limestones (in the Moesian Platform), enriched with cherty nodules. The presence of cherty nodules and layers is a fundamental, definitive feature of the Formation.

Regional aspects. The Formation is widespread over the entire area of northern Bulgaria – in the Moesian Platform, Fore-Balkan and Central Balkan. Most of



Fig. 4.3. Exposures of the Mezdra Formation in its type area near the town of Mezdra

the Formation belongs to the Upper Cretaceous Series (Upper Campanian – Maastrichtian), but its upper parts in the Mezdra region are proven to be Paleocene (Sinnyovsky, 1993a, 1999; Stoykova et al., 2000; Sinnyovsky et al., 2004).

In the type area in the region of Mezdra town and south of it (Fig. 4.3), the lower boundary of the Formation is a gradual transition from the sediments of the Kunino Formation or it unconformably lies on Lower Cretaceous rocks (Roman Formation). The presence of macro and microfossils – ammonites, bivalves, echinoids, foraminifers, and calcareous nannoplankton have been recorded in the Formation.

The spatial and temporal relationships of the Mezdra Formation with the other Upper Cretaceous units over different parts of the Moesian Platform, the Fore-Balkan and the Central Balkan were regionally traced and documented by Jolkichev (1989) and will not be listed here because of their lack of direct relevance to this work.

The upper boundary of the unit appears to be sharp with the Kailaka and Dobrina Formations (Jolkichev, 1989). Within the West Fore-Balkan (near Lyuti dol village) it is traced as a gradual transition to the limestone formation or is unconformably overlain by the sandstone formation (Fig. 4.4, Sinnyovsky & Sinnyovska, 1993).

The thickness of the Formation varies widely from several meters up to 90 m.

Chronostratigraphic range. The total stratigraphic range of the Mezdra Formation proved by nannofossils is Upper Campanian – Danian (Sinnyovsky, 1993a).

Limestone formation (Sinnyovsky & Sinnyovska, 1993)

The unit is introduced by Sinnyovsky and Sinnyovska (1993) to designate grey thin-layered clayey-sandy limestones in alternation with chalky limestones without cherty nodules. Also present are mixed terrigenous-carbonate varieties.

The formation is found in the vicinity of Lyuti dol, Tipchenitsa and Perchovtsi villages in the West Fore-Balkan.

Its lower boundary represents a gradual transition from the Mezdra Fm limestones, the upper boundary being erosional with the sediments of the sandstone formation overlying, outcropping near Brusnika hamlet, west of Lyuti dol village. The relationships between the formation and neighboring lithobodies are shown on Fig. 4.4.

Chronostratigraphic range. The Formation is uppermost Maastrichtian (zone CC25 *M. murus*) – lower Danian (NP2 *Cruciplacolithus tenuis*) according to Sinnyovsky and Sinnyovska (1993).

Sandstone formation (Sinnyovsky & Sinnyovska, 1993)

The unit was proposed by Sinnyovsky and Sinnyovska (1993) to typify sandstones and siltstones, well cemented at the base and loosely cemented in their upper parts, with parallel and cross bedding. The formation is detected only in the core of the Lyuti dol Syncline, West Fore-Balkan (west of Tishovska hamlet, Lyuti dol village).

The lower boundary of the formation is sharp. It lies unconformably over the limestone formation at Brus-

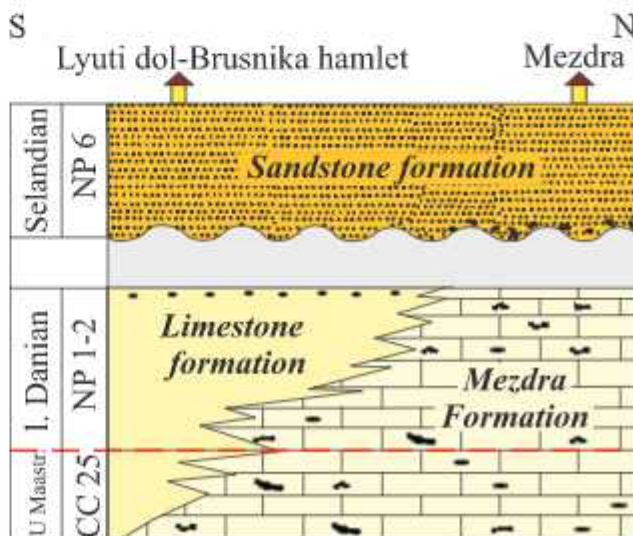


Fig. 4.4. Spatial-temporal relationships of the Mezdra Fm, limestone and sandstone formations south of Mezdra town (after Sinnyovsky & Sinnyovska, 1993 with refinements)



Fig. 4.5. Exposures of the Komarevo Fm in the gully between the villages of Kreta and Komarevo, Pleven District

nika hamlet and the Mezdra Formation elsewhere (with a basal conglomerate with clasts of limestones, phosphorite nodules, etc. – Fig. 4.4). The upper boundary is a present-day erosional surface.

The thickness does not exceed 10 m. Before 1993, the rocks of this formation had been referred to the Eocene by analogy with the other clastic sediments cropping out in the syncline core.

Sinnyovsky and Sinnyovska (1993) determined the chronostratigraphic range of the formation within the middle Paleocene, NP6 *Heliolothus kleipelli* zone, based on identified characteristic nannoflora.

Komarevo Formation (Dachev, 1975)

Nomenclature. The name “Komarevo Formation” was introduced by Dachev (1975) for sediments, previously described by the same author as „Kailaka formation“ (Dachev, 1967). Although not legitimate and against the rules of the National Stratigraphic Code (the name has been qualified as *invalid* by the Glossary of Bulgarian lithostratigraphic units), the geological practice in the last 25 years has recognised the use of Komarevo Formation in the sense of Dachev (1975). The type section is situated near Komarevo village, Pleven District, on the right bank of Vit River.

Lithological characteristics. The Formation is composed of white and creamy clayey and clayey-sandy limestones. At different levels, usually in the lower parts, the sediments are enriched in cherty nodules.

The rocks are represented by transitions between various types of mixed terrigenous-carbonate (hypo-) rocks: from skeletal packstones-wackestones with abundant red algae skeletons and large benthic foraminifera, to mixed calcarenites and sandstones.



Fig. 4.6. Sharp lower boundary of the Komarevo Fm (Thanetian) in the quarry at Chudnite skali, marking the stratigraphic unconformity with underlying Selandian sediments

Glauconite is often detected, particularly in the lower parts. Phosphorite concretions (nodules) are observed locally in some places at the base of the Formation.

Regional aspects. The Formation is widespread across Central northern and NE Bulgaria – in the Moesian Platform and the Fore-Balkan. Kanchev (1995a, b) has not adopted the idea of expanding distribution of the Formation from the Moesian Platform into the Fore-Balkan. The name he used for the rocks with similar lithology and age in Central and East Fore-Balkan is “limestone formation”.

The lower boundary of the Komarevo Fm is everywhere sharp and erosional with the underlying organogenic limestones of Kailaka Fm (Moesian Platform, Central northern Bulgaria), with the sandstones of the Iztochnik Fm (Central Fore-Balkan and Balkan) or overlying directly the Mezdra Fm (Moesian Platform, NE Bulgaria).

The upper boundary of the Komarevo Fm in Central northern Bulgaria to the north of Pleven is sharp with the marls of the overlying Bozhuritsa Fm, thus probably reflecting a short-term gap in sedimentation (Fig. 4.14). To the south of Pleven, where the Bozhuritsa Fm is not present, the upper boundary of the Komarevo Fm is erosional and it is unconformably overlain by glauconitic marls or glauconitic-sandy sediments. The latter are conditionally assigned to the Beloslav Fm or to the grey clayey marls of the Avren Fm (Filipov et al., 1995c; Stoykova & Ivanov, 2004b).

In NE Bulgaria, the Komarevo Fm is cropping out both in the Moesian Platform and in the Kamchia Zone. The unit is penetrated by the wells in the Black Sea offshore. Its lower boundary is traced as a strati-



Fig. 4.7. Exposures of the Bozhuritsa Fm – marls with cherty nodules in its type section near the village of Bozhuritsa, Pleven District, at the right bank of the Vit River

graphic unconformity marking an interruption in sedimentation – with Upper Cretaceous or older Paleocene rocks below (Fig. 4.6). Its upper boundary is also unconformable with the Beloslav Fm, while only in the Kamchia Zone, in the section along the Razkrachenitsa River, it is followed as a gradual transition to the sandstones and sands of the Beloslav Fm (Vangelov & Sinnyovsky, 2000).

The thickness of the unit varies between 4 and 30 m. In central northern Bulgaria it is around 25–30 m, in the platform part of NE Bulgaria about 4–5 m, whereas to the south, in the Kamchia Zone, it reaches up to 30 m.

Chronostratigraphic range. The total stratigraphic range of the Komarevo Formation is Thanetian – NP6 (uppermost parts), NP7 and NP8 nannofossil zones (Fig. 4.14). It is supported by abundant macrofossil data (bivalves, gastropods, shark teeth – Belmustakov, 1963; Dachev, 1975) as well as by microfossils – calcareous nannoplankton (Stoykova, 1990; Sinnyovsky, 1992; Stoykova & Ivanov, 2004b), and large foraminifers (Aladjova-Hrischeva, 1980).

Bozhuritsa Formation (Dachev, 1967)

Nomenclature. This unit was introduced by Dachev (1967) as the “Bozhuritsa formation” and the formal “Formation” rank appears in a later publication (Dachev, 1975). The type section is located in the SW end of Bozhuritsa village, Pleven District, in the vast quarry on the right bank of the Vit River (Fig. 4.7).

Lithological characteristics. The Formation is based on the predominance of marls enriched in cherty concretions. In the upper parts of the unit the number of these concretions decreases, while the clastic compo-



Fig. 4.8. Exposure of the uppermost parts of the Bozhuritsa Fm in its type section near Bozhuritsa, Pleven District – it is overlain by a parallel unconformity at the base of the “Beloslav” Fm (marked with red line)

nent increases and mixed hypo-rocks occur – sandstones, siltstones, silty and clayey marls. At some levels these are enriched with glauconite and ferruginous hydroxides.

Regional aspects. The Formation is largely distributed throughout Central northern Bulgaria, along the right bank of the Vit River in the vicinity of Bivolare, Bozhuritsa, Riben and Komarevo villages. It is also traced in the offshore Black Sea, where it is penetrated by Varna-West and Yuri Shimanov wells (drilled in 2004).

Its lower boundary with the Komarevo Fm is sharp, possibly referring to a short-term hiatus in sedimentation which cannot be detected by biostratigraphic methods (within the accuracy of the method).

The upper boundary near Riben village is represented by rapid transition to glauconitic sandstones and loosely cemented sands of the “Beloslav” Fm. In the rest of the sections – near Bozhuritsa and Komarevo villages, it is sharp erosional boundary. At these locations the Formation is overlain by the “Beloslav” Fm glauconitic sandstones. A marker horizon, rich in *Ostrea* shells, phosphorite concretions, glauconite and clasts of magmatic rocks is seen at the base (Fig. 4.8).

The presence of the unit in the Gabrovo District (around Tranito village and between Bozhentsi and the town of Tryavna) is still not convincingly proved.

The thickness of the Formation in Central northern Bulgaria ranges between 20 and 25 m. The rocks are rich in fossils – shark teeth (Dachev, 1967; 1975), bivalves, gastropods (Belmustakov, 1963; 1968) and microfossils – calcareous nannoplankton (Stoykova & Ivanov, 2004b) and planktic foraminifera.

Chronostratigraphic range. The total stratigraphic range of the Bozhuritsa Formation is Thanetian Stage, NP8 and NP9 nannofossil zones (Fig. 4.14).

Iztochnik Formation (Aladjova-Hrischeva et al., 1991)

Nomenclature. The Formation was introduced by Aladjova-Hrischeva et al. (1991). It is named after Iztochnik village, Gabrovo District, in the northern part of which is located the type section. The unit corresponds to the „main – sandy horizon of the Thanetian“ (Belmustakov & Jolkichev, 1965).

Lithological characteristics. The Formation consists of various coarse to medium-grained quartz sandstones. Limestones and siltstones, also characteristic, appear in the type section along with the sandstones. Locally, the latter pass into siltstones or gravels. The well-rounded to semi-rounded quartz grains are the main clastic component. The cement is fine-sandy-calcareous. Poorly preserved relics or whole shells of mollusks (mainly mussels) and single corals are also noted. At different levels, mainly in the lower and upper part of the Formation, the calcareous content increases and limestones, sandy limestones and calcareous sandstones appear to be present, too.

Regional aspects. The number of outcrops of this Formation is limited. It occurs as a continuous strip between the towns of Gabrovo and Tryavna and isolated outcrops on the northern ends of the Paleogene outcrops in Gabrovo District (NE of Tranito, Mogilata villages and near Petkova niva). Recently, the unit has also been recognised in the Paleocene section near Drenta village, Elena region (Stoykova, unpublished data; Nikolov et al., 1998).

The lower boundary is sharp and transgressive over the Upper Cretaceous Kailaka Fm limestones (in the Gabrovo region) or directly overlying the Lower Cretaceous Kostel Fm marls (near Drenta village, Elena region).

The upper boundary appears unclear in the holostratotype section. Aladjova-Hrischeva et al. (1991) supposed that it has a gradual transition into the Komarevo Fm. This assumption has been refuted by the subsequent studies of the unit. Our observations of the section near Drenta village, Elena region, indicated that the upper boundary of the Iztochnik Fm is sharp and erosional with the overlying Komarevo Fm (Nikolov et al., 1998). Similar results have been obtained in the course of the biostratigraphic study of the core from a hydrogeological well near the town of Gabrovo (R-Ihg Gabrovo, unpublished data of K. Stoykova). North of the type area, the Formation pinches out. To the south it probably passes lateral-

ly into the calcareous-marly formation (Kanchev & Nikolov, 1995), developed in the Central Balkan – Elena-Tvarditsa Stara Planina area.

The thickness of the Formation varies between 20 m to 80 m.

Chronostratigraphic range. It is only recently that precise biostratigraphic data on the age of the Iztochnik Formation have been acquired. These prove its range to fall within the Selandian stage, NP4 and NP5 nannofossil zones and P3a planktic foraminifera zone (Stoykova, unpublished data; Fondacave-Wallez and Stoykova in Nikolov et al., 1998; Peybernès et al., 2004). Belmustakov and Jolkichev (1965) and Belmustakov (1968) reported a rich mollusk association they consider to be of Thanetian age. However, more recent understanding indicates that the mollusks cannot be relied upon for definite conclusions on the age of the Paleocene sediments.

Pavolche Formation (Aladjova-Hrischeva et al., 1991)

Nomenclature. The Formation was introduced by Aladjova-Hrischeva et al. (1991). Named after the village of Pavolche, Vratsa District, the type section is located in the southern end of the settlement. The unit corresponds to the lowermost part of the presumably middle Eocene „sandy horizon“ in the region of Mezdra (Bonchev & Kamenov, 1934).

Lithological characteristics. The Formation is built up of various quartz or polymictic sandstones. These often appear to be loosely cemented, with grains of various size, thick-bedded to massive. Tightly cemented beds and lenses of typically spheroidal weathering are rarely observed. The color of the sandstones on the weathered surface varies from light-grey, yellowish to whitish. Locally, the sandstones pass into siltstones, gravels or clayey sandstones.

A peculiar feature is the total lack of any sorting of the clastic component composed of quartz grains and muscovite. The cement is sandy or clayey-sandy.

Regional aspects. The Formation is traced only in the region of Mezdra, where it outcrops as a continuous strip in the vicinity of Pavolche, Moravitsa, Ruska Byala, Mezdra and Brusen and SW of Varbeshnitsa.

Its lower boundary is transgressive – occurring unconformably over Upper Cretaceous (Mezdra Fm) or Paleocene (limestone formation) rocks.

The upper boundary is a gradual transition to the overlying Ugarchin Fm.

Due to the limited distribution of the unit (only in the region of Mezdra), no lateral relationships with other Paleogene lithobodies have been identified. Its temporal analogues in the Lukovit region are the Petrevene and Lukovit Fms, and in Gabrovo region – the Boynovtsi and Lukovit Fms.

The thickness of the Formation reaches up to 60-70 m.

Chronostratigraphic range. The nummulitids, detected in the sediments of the Formation near Ruska Byala village, Mezdra region, indicate an age within the early Eocene – Ypresian Stage (the nummulitid association has been re-interpreted by Aladjova-Hrischeva et al., 1991).

Petrevene Formation (Aladjova-Hrischeva et al., 1991)

Nomenclature. The Formation was proposed by Aladjova-Hrischeva et al. (1991). Named after the village of Petrevene, Lukovit region, it corresponds to „the polymictic sandstone formation“ of Aladjova-Hrischeva (1979). The type section is situated some 250 m NE of Golyama Brestnitsa village, in the large gully along the road to Daben village.

Lithological characteristics. It is composed of grey-greenish and yellowish medium-grained, medium-bedded polymictic sandstones. These show massive, occasionally stratified structure. Thin interbeds of silty marls are also traced. The base of the Formation consists of monotonous grey clayey marls, separated as the Belyanska Member (Aladjova-Hrischeva et al., 1991).

Regional aspects. The Formation is locally distributed along the southern periphery of the Paleogene outcrops in the Lukovit area – in the region of Petrevene, Rumyantsevo, Golyama Brestnitsa and Peshterna villages. The best sandstone exposures are seen north of Rumyantsevo village, along the road to Petrevene and in the large gully NE of Golyama Brestnitsa. In the latter locality the clayey marls of the Belyanska Member are rather poorly exposed. They are traced only as single outcrops in the gully.

The lateral relationships of the Formation are unclear. Presumably, it passes to and is covered by the Lukovit Fm in a NE direction.

The lower boundary of the Formation is transgressive – the clayey marls of the Belyanska Member lay unconformably over the Kailaka Fm.

The upper boundary is a gradual transition to the Lukovit Fm siliciclastic sediments. It is overlain by

clayey marls of the Aglen Member, at the base of the Lukovit Fm. The thickness of the Petrevene Formation varies from 100 to 250 m.

A rich nummulitid fauna, typical for the upper parts of the lower Eocene, has been identified in the Petrevene Fm sandstones (Aladjova-Hrischeva, 1979). The Belyanska Member clayey marls contain plankton foraminifers and calcareous nannoplankton.

Chronostratigraphic range. The revisions of the Paleogene in the Lukovit District I have undertaken, resulted in a more precise assessment of the chronostratigraphic range of the Formation. Rich nannofossil associations assigned to NP12 nannofossil zone have been recorded in the Belyanska Member and in the Petrevene Fm sandstones near Rumyantsevo and Golyama Brestnitsa villages. Therefore, the revised chronostratigraphic range of the Formation is middle parts of the Ypresian (lower Eocene).

Lukovit Formation (Aladjova-Hrischeva et al., 1991)

Nomenclature. The Formation has been introduced by Aladjova-Hrischeva et al. (1991). Named after the town of Lukovit, it corresponds to the flysch-like sediments of „the formation of alternating marls and thin-layered sandstones“ (Belmustakov, 1963) and to „the flysch-like formation“ of Aladjova-Hrischeva (1979). The type section is located 250 m NE of Golyama Brestnitsa village, in the large gully along the road to Daben village.

Lithological characteristics. The Formation consists of irregular alternations of sandstones, siltstones and clayey marls of flysch-like nature (Fig. 4.9). Its Aglen Member, composed of homogenous clayey marlstones to calcareous clays is distinguished only occasionally at the base of the Formation (Fig. 4.13). Upwards, within the alternating intervals, interbeds of gravels and fine-grained conglomerates occur.

The sandstones are fine- to medium-grained, with cross and convolute bedding (Fig. 4.10), with numerous ripple-marks and flute casts on the lower bed surfaces (Fig. 4.11). Thick sandstone layers of typical spheroidal weathering appear in the middle parts (Fig. 4.12).

Regional aspects. According to Aladjova-Hrischeva et al. (1991), the Formation is basically distributed in two regions – Lukovit and Gabrovo. In the vicinity of Rumyantsevo, Petrevene and Lukovit, the Aglen Member – clayey marls to calcareous clays (Fig. 4.13) is clearly outlined. The Formation is primarily developed in the Gabrovo region, where it can be traced along the northern periphery of the Gabrovo Syncline.



Fig. 4.9. Exposures of the Lukovit Fm in its type area – in the railway cutting between Rumyantsevo and Todorichene villages, Lukovit area

Recent field studies revealed rather substantial resemblances between of the lower Eocene lithological sequences in the Mezdra, Lukovit and Gabrovo region and the ones occurring in the East Balkan and the East Fore-Balkan. In the East Balkan, within the same stratigraphic interval, the Dvoynitsa Fm (Juranov & Pimpirev, 1989) is used (here erected to Group rank). This Formation shows similar stratigraphic position



Fig. 4.11. Flow casts on the lower bed surface of the turbidite layer in the Lukovit Fm



Fig. 4.12. Thick-bedded sandstones with spheroidal weathering in the middle part of the Lukovit Fm



Fig. 4.10. Convolutions in the turbidite layer of the Lukovit Fm – in the railway cutting between Rumyantsevo and Todorichene villages, Lukovit area



Fig. 4.13. Claystones of the Aglen Member of the Lukovit Fm, exposed in the quarry near Lukovit town

and displays the same sequence of lithological varieties (lower rank lithobodies). It is quite possible that the units (Formations and Members) as introduced by Aladjova-Hrischeva et al. (1991) including the Lukovit Fm, may appear to be invalid – subjective synonyms of different Formations within the Dvoynitsa Group, the latter having priority due to their earlier date of publication.

The lower boundary is an unconformity with the Kailaka Fm or represents a gradual lithological transition from the Petrevene Fm. In the Gabrovo region it is transgressive over Upper Cretaceous or Paleocene rocks (Iztochnik and Komarevo Fms) or a gradual transition from the Boynovtsi Fm.

The upper boundary in the Lukovit region is manifested as a gradual transition to the Ugarchin Fm and in the Gabrovo region – as a rapid transition and lateral passing southwards to the Staropatitsa Fm (Aladjova-Hrischeva et al., 1991).

The thickness of the Formation reaches up to 130 m.

Chronostratigraphic range. When introducing the unit, Aladjova-Hrischeva et al. (1991) defined its range as the upper part of the lower Eocene to the base of the middle Eocene based on nummulitid finds within the stratotype section – the gully north of Golyama Brestnitsa village.

The revision studies and biostratigraphic analysis using calcareous nannoplankton of the same section rectified these data – the range of the Formation includes only the upper parts of the Ypresian. In this section, NP12, NP13 and the lowermost parts of NP14a zones are proved by abundant nannofossil associations. The same revised chronostratigraphic range applies to the Formation in the Gabrovo region – the sections near Belitsa, Zhaltesh, Vrabtsite, Gabrovo (Fig. 5.57, 5.59, 5.60).

Shemshevo Formation (Aladjova-Hrischeva, 1988)

Nomenclature. The unit was introduced by Aladjova-Hrischeva (1988a) and named after the village of Shemshevo, where the type section is described, 1 km east of the village, along the left bank of Yantra River.

Lithological characteristics. The Formation is built up of fine-grained sandstones to calcareous siltstones and silty clayey limestones. They are greenish-grey, clearly stratified. More rarely present are beds of clayey siltstones, clays, detrital sandstones and limestones. Glauconitic fine- to medium-grained sandstones and yellowish loose sands are noted at the base of the Formation, while the upper parts contain nodular silty-clayey limestones.

Regional aspects. The Formation's occurrence is limited to the Balvan Syncline only (Veliko Tarnovo District) – from Balvan to Sheremetiya villages. It crops out as patchy strips in the vicinity of Pushevo, Momin Sbor, Ledenik, Shemshevo, Malak Chiflik, Sheremetiya villages and the town of Veliko Tarnovo. In the easternmost parts of the area, near Sheremetiya, Konstantinova (1958) noted the presence of conglomerates as well. The uppermost levels of the Formation are represented by nodular silty-clayey limestones, which are exposed only around Ledenik and Shemshevo villages. The Stokish Member (Bonchev, 1960, the rank established by Aladjova-Hrischeva, 1988a) consists of organogenic biotrital calcareous sandstones to sandy limestones. It is traced only in the northern limb of the Balvan Syncline, east of Balvan village.

Lateral transitions with other lithobodies are not directly observed. Westwards, in the Pleven region, the sandy-glaucconitic marls and glauconitic sandstones of the so called "Beloslav Formation" (Filipov et al., 1995c; Stoykova & Ivanov, 2004b) are considered a temporal analogue of the Shemshevo Fm. While to the east, in the Varna region, the Beloslav Fm is its spatial analogue (Fig. 4.14).

The lower boundary of the Formation is everywhere unconformable. It lays transgressively over Lower Cretaceous formations: the Lovech Urganian Group, and to the east near Malak Chiflik village, the Gorna Oryahovitsa Fm.

The unit has a sharp upper boundary that is overlain by Avren Fm marls. The maximum thickness of the Formation is around 45 m.

The Shemshevo Formation contains abundant nummulitids, *Discocyclina* and mollusks. Calcareous nannofossils are also recorded, represented by poorly preserved, but characteristic associations.

Chronostratigraphic range. Aladjova-Hrischeva (1988) assigns its range to the Ilerdian and basal Cuisian. This range has been confirmed by the present nannofossil study in the sections near Ledenik and Veliko Tarnovo, as well as in single samples taken from the vicinity of Shemshevo village. The chronostratigraphic range is lower Eocene – lower parts of the Ypresian, NP10 and NP11 nannofossil zones.

Boynovtsi Formation (Aladjova-Hrischeva et al., 1991)

Nomenclature. The Formation is introduced by Aladjova-Hrischeva et al. (1991). It is named after the village of Boynovtsi, Gabrovo District, where the type section is located on the road near the former forestry

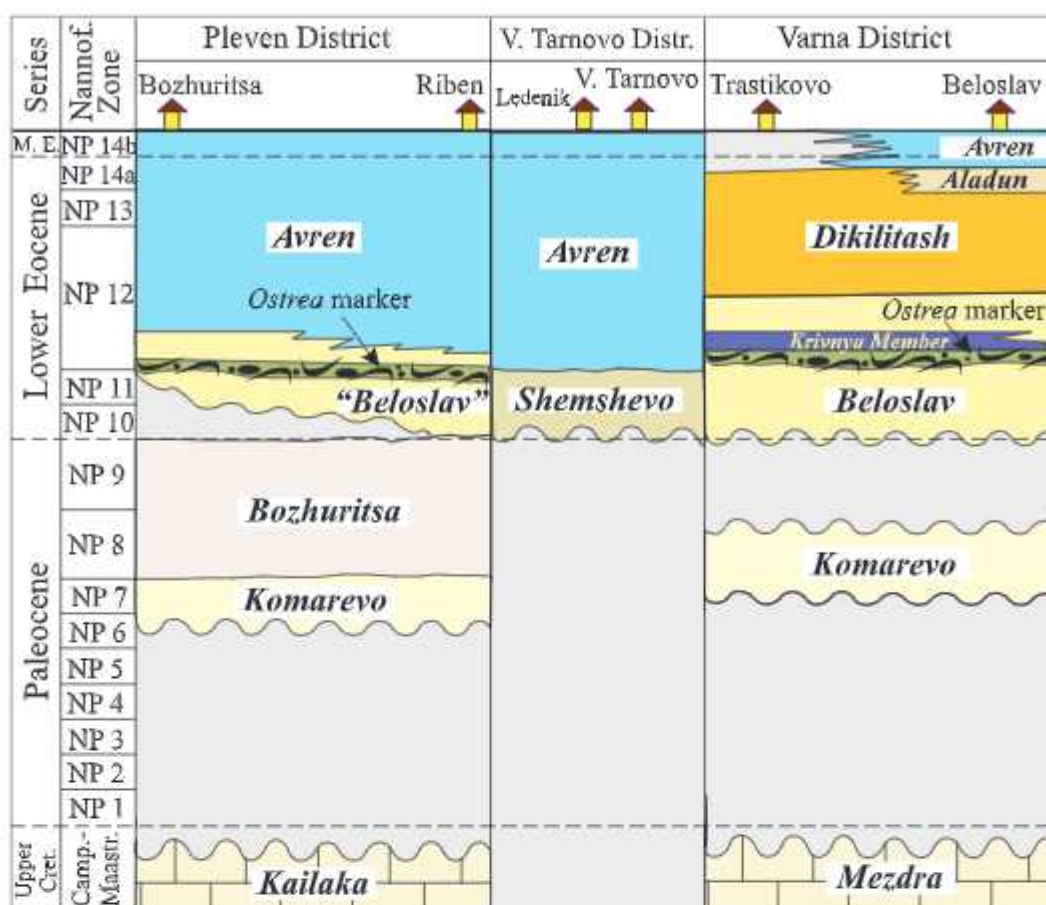


Fig. 4.14. Spatial-temporal relationships of the lithostratigraphic units, outcropping in the Moesian Platform in Pleven, Veliko Tarnovo and Varna area

farm, some 500 m NW of the center of Boynovtsi village, near the point where Trepetlik gorge flows into the Sinkevitsa River (Aladjova-Hrischeva et al., 1991).

Lithological characteristics. The Formation is predominant clayey to clayey-sandy marls that contain differing quantities of psephitic-sized clasts of mainly carbonate rocks. The sandy and silty components are irregularly distributed in the rock. The clasts are well-rounded, occurring as single pieces or concentrated in interbeds and lenses. They are built up primarily of sandy and organogenic, recrystallized limestones and shell detritus, no sorting was observed.

Regional aspects. The Formation is of limited distribution as a narrow strip between Boynovtsi and Genovtsi villages, SW of Gabrovo town. Beyond the type area, the Formation rapidly pinches out in all directions (Aladjova-Hrischeva et al., 1991). The Formation does not exceed 12 m in thickness.

The lower boundary is an angular unconformity over limestones of the Kailaka Fm or Komarevo Fm and the upper boundary is a rapid lithological transition to rhythmic flysch-like sediments of the Lukovit Fm.

Chronostratigraphic range. Typical foraminiferal associations have been recovered from the sediments of the Formation, thus fixing the range as lower Eocene, Ypresian (Aladjova-Hrischeva et al., 1991; Tzankov et al., 1995a).

Staropatitsa Formation (Aladjova-Hrischeva et al., 1991)

Nomenclature. The Formation is identified by Aladjova-Hrischeva et al. (1991). It is named after Staropatitsa village, Kula region, however, the type section is located along Tsiganski dol gully, SE of Kaldorub village, Vidin District.

Lithological characteristics. The Formation consists of irregular macro-rhythmic alternations of poorly sorted polygenetic sandstones, gravels and conglomerates, interbedded with siltstones, marls and clays.

Regional aspects. This unit integrates various clastic rocks, typical of a relatively shallow, coarse-terrigenous facies. Irregular alternation of thick packets of conglomerates, gravels, sandstones and sands (several tens of meters) and up to 30 m thick marl packets or packets of thin rhythmic alternations of sandstones, siltstones,

silty and clayey marls is observed (Figs. 4.15-4.18). Different sized olistoliths (occasionally of up to ten meters in diameter) are seen in the lower parts of the Formation. Well rounded clasts are typical (Fig. 4.15).

In the region of Gabrovo – Tryavna, predominantly conglomerates, gravels and sandstones (in the section around Belitsa village, for example) are developed. In this area the Staropatitsa Formation represents the highest levels of the lower Eocene section.

According to Aladjova-Hrischeva et al. (1991), the Staropatitsa Fm has the broadest distribution of all of the Paleogene lithobodies. Isolated and different sized outcrops of the Formation are detected in the regions of Kula, Belogradchik, Lukovit, Central Stara Planina Mt., Tryavna and Gabrovo. Field revisions in some of these areas, however, show that the coarse-terrigenous sediments (conglomerates) that occupy differ-

ent stratigraphic positions are incorrectly associated with the Staropatitsa Fm. In the East Balkan and Fore-Balkan such coarse-terrigenous sediments are known as exotic conglomerates, Obzor Fm, Dvoynitsa Fm, etc. It would be necessary to perform new studies in order to specify the distribution of the Formation and its relationships with the other conglomerate units in the East Fore-Balkan and Balkan.

In the south-easternmost part of the Paleogene outcrops near Lukovit, the Staropatitsa Fm passes northwards to the lower levels of the Lukovit Fm referred to the lower Eocene (Aladjova-Hrischeva et al., 1991). Similar relationships are also observed in the Gabrovo region – to the north, the Formation passes laterally to different levels of the Lukovit Fm.

The lower boundary of the Staropatitsa Fm is unconformable, over various older rocks. Within the type



Fig. 4.15. Conglomerates in the base of the Staropatitsa Fm in its type section – along Tsiganski dol SW of Kladorub, Vidin District



Fig. 4.17. Thin-rhythmic alternation of unconsolidated sandstones, siltstones, silty and clayey marlstones in the clastic packet of the Staropatitsa Fm



Fig. 4.16. Macro-rhythmic alternation of thick sandstone and marlstone packets in the type section of the Staropatitsa Fm



Fig. 4.18. Alternation of sandstones, gravels and conglomerates in the clastic packet of the Staropatitsa Fm



Fig. 4.19. Lower boundary (red line) of the Staropatitsa Fm in the type section – transgressive over the sediments of the Kladorub Fm

section and area (Kula region) it lays transgressively over the lower Eocene sediments of the Kladorub Fm (Stoykova & Ivanov, 2005).

The upper boundary is erosional and sections in the Formation show variably preserved sedimentary thicknesses.

The thickness of the Formation varies from several tens of meters to around 250-300 m within the type section.

In the more clayey levels of the type section, rich and diverse nummulitid associations (Aladjova-Hrischeva, 1973; Aladjova-Hrischeva & Hrishev, 1976) and calcareous nannoplankton (Stoykova & Ivanov, 2005) have been documented.

Chronostratigraphic range. The new biostratigraphic data for the type section based on calcareous nannofossils, determine its range as lower Eocene – upper parts of Ypresian, NP12-14 nannofossil zones. Aladjova-Hrischeva et al. (1991) assign a middle Eocene (Lutetian) age to this section based on a single nummulitid specimen, found among a “rich lower Eocene allochthonous pseudo-association”. The data from the calcareous nannoplankton from several levels of the Formation within the type area and in the Gabrovo region, definitely reject the middle Eocene age and justify an early Eocene age for the Staropatitsa Formation.

Ugarchin Formation (Aladjova-Hrischeva et al., 1991)

Nomenclature. The Formation was divided by Aladjova-Hrischeva et al. (1991). It is named after Ugarchin

town, Lovech District, and corresponds to the “micaceous sandstone formation” of Aladjova-Hrischeva (1979). The type section is located in the large gully in the vicinity of Daben village. The section near Ugarchin, along the path to the touristic base, is designated as an auxiliary section for the upper part of the Formation.

Lithological characteristics. The Formation is composed of poorly cemented, yellowish, highly micaceous (muscovite predominantly) sandstones. In the lower parts of the unit these are mainly fine-grained, with interbeds of clayey siltstones and silty-sandy clays. In the upper parts the sandstones become coarse-grained and thick-bedded.

Regional aspects. The Formation is widespread in the Mezdra and Lukovit areas. To the north, it pinches out and to the south its lowermost parts pass laterally to the Staropatitsa Fm.

The lower boundary is expressed as a gradual lithological transition from the Lukovit Fm (Lukovit region) or Pavolche Fm (Mezdra region). The boundary is set where the thick-bedded micaceous sandstones are seen to predominate. Locally it occurs directly over the Kailaka Fm limestones.

The thickness of the unit exceeds 150 m.

The clayey interbeds in the lower parts of the stratotype section reveal a rich nannofossil association, proving the uppermost part of lower Eocene (Stoykova, unpublished data).

Chronostratigraphic range. Since no fossil finds have been documented from the sediments of the Formation, the suggestion of about middle Eocene (Lutetian) age is based on its stratigraphic position in the succession (Aladjova-Hrischeva, 1979; Aladjova-Hrischeva et al., 1991). However, my revised studies clearly show that the lower parts of the Formation are of early Eocene age – uppermost part of Ypresian, NP14a nannofossil zone. Therefore, the corrected stratigraphic range is uppermost parts of the lower Eocene – middle Eocene.

Beloslav Formation (Aladjova-Hrischeva, 1984)

Nomenclature. The Formation is introduced by Aladjova-Hrischeva (1984). It includes “Ia – yellow beds horizon” outlined by Gochev (1933) but not geographically named. The type section is located in the SW end of Beloslav village, Varna District. It corresponds to the “main – clayey-sandy horizon” (Tzankov, 1936; Mandev, 1955) and to the “lower – marly-sandy horizon” (Bonchev, 1960).



Fig. 4.20. Yellowish clayey sands and sandstones in the lower parts of the Beloslav Fm in its type section near Beloslav, Varna District



Fig. 4.21. Grey-bluish claystones and marls, representing the Krivnya Member of the Beloslav Fm in the ravine near Krivnya village, Varna District

Lithological characteristics. The Formation consists of yellowish clayey sands, indistinctly bedded, with interbeds of calcareous sandstones and sandy marls. The sandstones are weakly cemented, well sorted, fine- to very fine-grained (Fig. 4.20). A few packets of white medium-grained quartz sands also occur. Levels rich in glauconite are usually identified at the base of the Formation. A specific marker horizon within the Formation is a bed, enriched with *Ostrea* shells, smaller bivalves, gastropods, echinoids and nummulitids.

The Krivnya Member, composed of grey-bluish marls and clays is separated within the Formation (Aladjova-Hrischeva, 1990).

Regional aspects. The Formation is widespread across the plateaus in NE Bulgaria. Its presence was also detected in the Kamchia Zone (Aladjova-Hrischeva, 1991) and it was penetrated by some wells in the Black Sea Shelf north of Varna (Yuri Shimanov).

In Central northern Bulgaria the unit is cropping out in sections along the Vit River, north of Pleven. The characteristic marker bed known as the “shelly bed” or “*Ostrea* level”, “shelly marker bed” (Belmustakov, 1962, 1968; Aladjova-Hrischeva, 1984a, 1991; Milanova & Cheshitev, 1992; Cheshitev, 1994; Stoykova & Ivanov, 2004b) is represented in the sections in both NE and Central northern Bulgaria (Fig. 4.14).

The *Krivnya Member* (Aladjova-Hrischeva, 1990) is divided as a body of homogenous lithology (marls and clays) within the middle parts of the Formation. Its thickness varies from 2 m to 30 m. (Fig. 4.21).

The spatial relationships of the Beloslav Fm and the other lithobodies are shown on Fig. 4.14 and Fig. 4.25. Its analogue to the west, in the Veliko Tarnovo region, is the Shemshevo Fm. South of Chudnite skali, in the Kamchia area, the Formation most probably passes to the variegated marl-clayey formation.

The lower boundary of the Beloslav Fm is typically marked by a stratigraphic unconformity – and overlies transgressively Upper Cretaceous rocks or the Paleocene Komarevo Fm (Aladjova-Hrischeva, 1984a, 1991; Stoykova & Vangelov, 1997).

In some of the sections in the Pleven region (the section near Riben village) it overlies the Bozhuritsa Fm with rapid lithological transition, but in others – near Bozhuritsa and Grivitsa villages and near Kailaka – it overlies transgressively (Stoykova & Ivanov, 2004b).

The upper boundary represents a gradual transition to the sediments of the Dikilitash Fm (NE Bulgaria) or Avren Fm (Central northern Bulgaria).

Abundant macro- and microfossils have been identified in the sediments of the Formation – bivalves, gastropods, nummulitids and calcareous nannoplankton.

Chronostratigraphic range. Lower parts of Ypresian, NP10 and NP11 nannofossil zones and the base of NP12 zone.

The range is proved by rich nummulitid associations (Aladjova-Hrischeva, 1990) and calcareous nannofossils (Stoykova & Vangelov, 1997).

Variegated marl-clayey formation (Juranov, 1983; Juranov, 1989 = "Goritsa" Formation)

Nomenclature. The name, "variegated marl-clayey formation", was used as an informal unit by Juranov (1983, 1989). The name denotes reddish and green clays, penetrated by some of the wells in the Byala area, East Stara Planina Mountain.

Lithological characteristics. The formation is represented by multicolored – pink, reddish, grey, greenish to whitish clayey marls to clays. They are indistinctly bedded of massive structure, greasy to the touch.

Regional aspects. The distribution of the formation is limited to the Kamchia area, in the vicinity of Goritsa and Byala, Varna District. The surface outcrops are rather limited due to the specific lithology – marls and clays that quickly weather into soil. Single outcrops are seen in the gullies north of Byala and Dolap Dere, SE of Goritsa village.

The most complete section of the formation has been penetrated by C-30 Goritsa well, located around 1 km north of the village. The section has also been studied stratigraphically by means of planktic foraminifera by Juranov (1989) and later – by calcareous nannofossils (Stoykova, unpublished data – Fig. 5.137).

The lateral relationships of the unit with other lithobodies have not been directly observed. Judging by its stratigraphic position, northwards, within the Moesian Platform, it correlates laterally with the Beloslav Fm, while southwards and westwards – with the thick-bedded sandstone formation.

The lower boundary of the formation is traced everywhere as a gradual lithological transition from the sediments of the underlying Byala Fm.

The upper boundary probably represents a rapid lithological transition to the sandstones of the Sveti Atanas Fm. Although not completely exposed, the boundary is seen in the southern end of the beach near Byala (Shelborun), where the marls turn into siltstones and sandstones with thin interbeds of sands and detrital sandstones enriched with ferruginous hydroxides (Fig. 4.22).

The thickness of the unit is difficult to estimate due to tectonic complications in the region of Byala and Goritsa (numerous faulted and thrust blocks). It is estimated to be 20-60 m thick.

The calcareous-clayey sediments of the formation are exceptionally rich in microfauna (small foraminifers) and nannoflora (calcareous nannofossils) which sup-

ported its chronostratigraphic range.

Chronostratigraphic range. Lower Eocene, lower parts of Ypresian, NP10 – NP12 nannofossil zones, P5–P6 plankton foraminifera zones. The age is justified by rich microfossil associations (Juranov, 1983; 1989; Stoykova, unpublished data).

Dikilitash Formation (Gochev, 1933)

Nomenclature. The Formation was identified by Gochev (1933) as "Ib – Dikilitash horizon". The rank of the unit was established by Aladjova-Hrischeva (1984a). The name comes from the type area, Dikilitash locality, Varna District. The lectotype section is exposed in the gully at the south-western end of Beloslav village, Varna District.

Lithological characteristics. The Formation is composed of white to light-grey sandstones and sands, very well sorted, loosely cemented. These are rather rich in fossil remains of large benthic foraminifera (nummulitids) and gastropods, found within vertical pillars and columns, known as "Pobitite kamani". Quite a number of hypotheses have been formulated on their origin (Gellert, 1929; Bonchev, 1934; Davitashvili & Zaharieva-Kovacheva, 1975; Mandev, 1970; Nachev & Nachev, 2001; De Boever et al., 2009, etc.). The sandstones and sands alternate with loosely cemented sandstones, calcareous sandstones and thin limestone layers and lenses.

Regional aspects. The distribution of the Formation is restricted within the plateaus of NE Bulgaria with the maximum thickness seen in the Franga plateau near Beloslav, Strashimirovo, Banovo and Slanchevo villages and along the northern edge of the Momino plateau. The best outcrops are located in a large quarry NW of Beloslav. There the pillars are developed in four levels separated by horizontal limestone layers (Fig. 4.23). The unit is also seen in the old quarry north of Dabravino village (Fig. 4.24).

The section on the Provaida plateau displays only the upper part of the Formation. Its distribution to the south is traced down to the Kamchia area (the section at Chudnite Skali).

The lower boundary of the Formation everywhere is manifested as a gradual lithological transition from the underlying sediments of the Beloslav Fm. The upper boundary is usually an erosional surface. In certain locations where overlain by sediments, it represents a rapid lithological transition to the limestones of the Aladan Fm. To the south, within the Kamchia area, it probably passes (partly) to and is covered by the Avren Fm (section Chudnite Skali) (Fig. 4.25).



Fig. 4.22. Gradual lithological transition between the variegated clayey-marl formation and the overlying sandstones of the Sveti Atanas Fm



Fig. 4.23. Dikilitash Formation, magnificently exposed in the large sandstone quarry NW of Beloslav



Fig. 4.24. Gradual lithological transition between the Beloslav and Dikilitash Formations in the quarry to the north of Dabravino, Varna area

The thickness of the Formation reaches up to 60 m.

The sediments of the Formation comprise abundant fossils of nummulitids, *Discocyclina*, mollusks, echinoids, corals, etc. (Fig. 4.26). The huge quantity of shallow-water fauna implies that the sediments have been deposited in the shallow shelf zone, above wave base.

Chronostratigraphic range. Middle parts of Ypresian, corresponding to NP12-13 nannofossil zones. The age has been proved by means of rich nummulitid associations (Aladjova-Hrischeva, 1990) and calcareous nannofossils (Stoykova, unpublished data).

Aladan Formation (Gochev, 1933)

Nomenclature. The Formation was distinguished by Gochev (1933) under the name "Aladan limestone" and the formal stratigraphic rank assigned by Aladjova-Hrischeva (1984a). The name is after Aladan village, nowadays known as Strashimirovo, where the type section is located. The unit corresponds to "Aladan limestone – Ic_2 " as described by Gochev (1933) and the "nummulite horizon" outlined by Mandev (1955) and to "Strashimirovo horizon" by Bonchev (1960).

Lithological characteristics. The Formation is represented by hardly cemented fossiliferous limestones (nummulitid predominantly, however remains of bryozoans and brachiopods are also seen, Fig. 4.27). At the base of the Formation, the limestones are slightly sandy and in the upper parts – slightly clayey. From the lithological point of view these are packstones and wackestones.

Regional aspects. The Formation is exposed in the Franga plateau and the northern part of the Momino plateau. Occasional outcrops are spotted in Provadia plateau, around Krivnya, Nenovo and Markovo villages. The unit is also detected in the wells, drilled on the Avren plateau (Cheshitev, 1994).

The lateral relationships with the other lithobodies are not directly observed. To the south it eventually is covered by the Avren Fm.

The lower boundary is manifested as a rapid lithological transition from the sandstones of the Dikilitash Fm.

The upper boundary is marked by a sharp change in lithology – it is overlain by grey-bluish marls of the Avren Fm (Fig. 4.28).

The sediments of the unit contain abundant fossil remains: large and coarse-ornamented shells of *Nummulites*, *Assilina*, *Operculina*, *Discocyclina*, mollusks

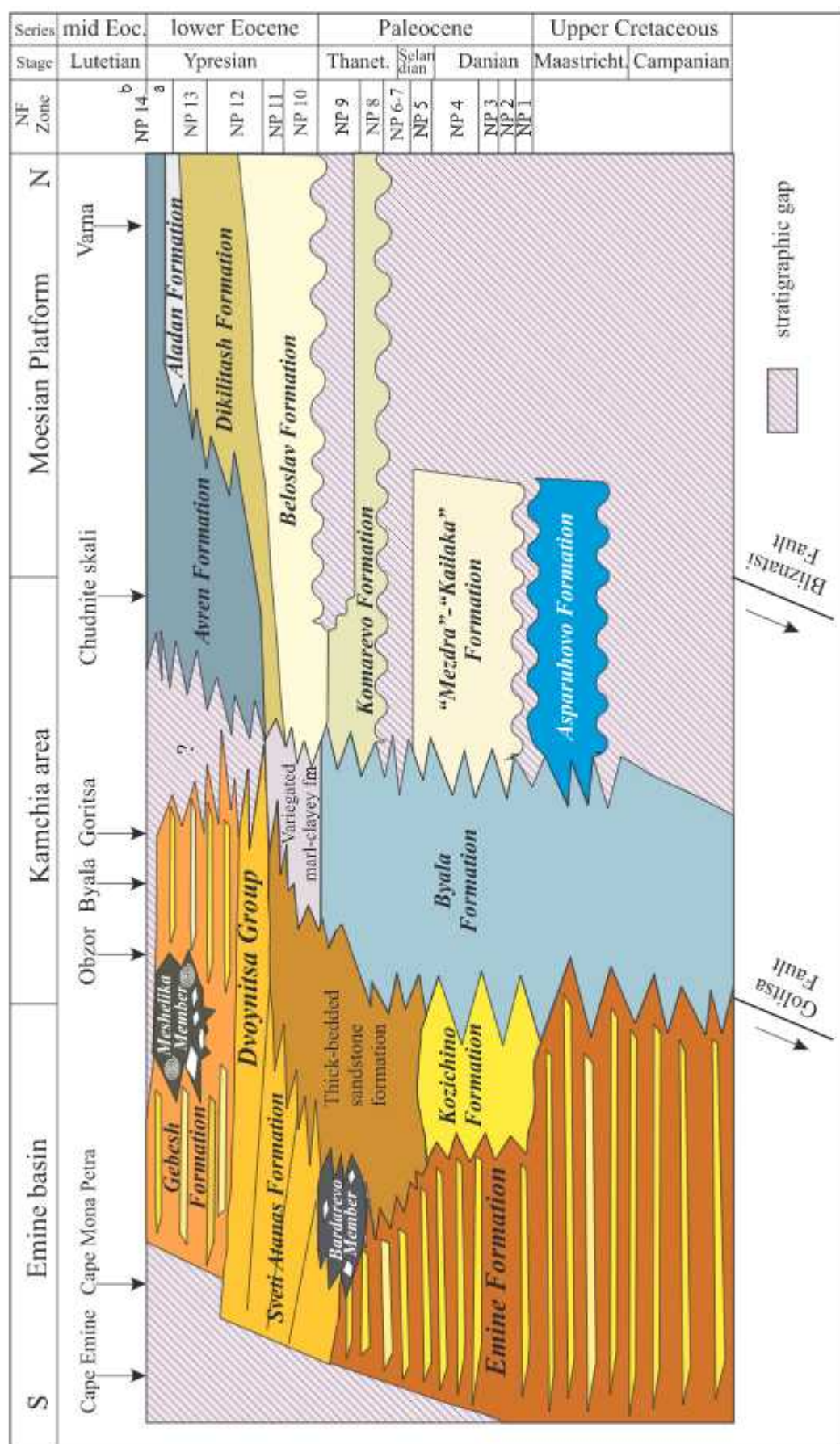


Fig. 4.25. Spatial-temporal relationships of the lithostratigraphic units in NE Bulgaria in a North-South transect, deposited in the Moesian Platform, Kamchia area and Emine basin



Fig. 4.26. Exposure of the Dikilitash Fm near Strashimirovo, Varna District

and echinoids (Aladjova-Hrischeva, 1990). Their composition and preservation suggest that the formation has been deposited in the inner part of the carbonate ramp-platform, rich in nummulitids.

The thickness of the Formation varies from 2 to 10 m and its thickness in wells reaches 40 m.

Chronostratigraphic range. Upper parts of Ypresian, evidenced by abundant nummulitid associations (Aladjova-Hrischeva, 1984b).

Avren Formation (Gochev, 1933)

Nomenclature. The unit was introduced by Gochev (1933) as “Avren marls” and Formation rank indicated by Juranov and Darakchieva (1986). It is named after Avren village, Varna District. The lectostratotype section, designated by Aladjova-Hrischeva (1991), is the one sketched by Gochev (1933) – along the valley between Sindel and Avren villages. Nowadays the section is almost entirely covered by vegetation.

Lithological characteristics. The Formation is built up of creamy, light-grey to grey-bluish marls alternating with thin interbeds of sandstones and siltstones. The marls vary from clayey, silty to sandy, indistinctly bedded.

Two members are distinguished within the upper part of the Formation – *Dolen Chiflik* and *Slaveykovo* Members. The Dolen Chiflik Member (Pollak, 1933) represents an alternation of clayey sandstones, siltstones and sandy marls. Its rank has been designated by Juranov (1993). The Slaveykovo Member (Aladjova-Hrischeva, 1991) consists of thick-bedded calcareous sandstones, alternating with thin interbeds of marls and detrital limestones.

Regional aspects. The Formation is broadly distributed in northern Bulgaria, outcropping in the plateaus



Fig. 4.27. Exposure of the Aladan Fm near Strashimirovo, Varna District



Fig. 4.28. Upper boundary of the Aladan Fm near Strashimirovo, Varna District. It is overlain (possibly with short period of wash-out) by the clayey marls of the Avren Fm

in NE Bulgaria and in the Kamchia area, as well as in Central northern Bulgaria. No surface outcrops have been identified in NW Bulgaria due to denudation, but most probably its sediments have been penetrated by many wells in the Lom Depression and Vidin Uplift (Tsaneva & Vaptsarova, 1961; Tsaneva, 1964, 1971a).



Fig. 4.29. Sharp upper boundary of the Avren Fm at Chudnite skali section – overlain by an angular unconformity at the base of the Obzor Fm (so-called “exotic conglomerate”)

In NE Bulgaria, the Formation is clearly divided into two parts: a lower one, with prevailing marls, and an upper one, dominated by sandy limestones, sandstones and siltstones (Dolen Chiflik and Slaveykov Members – middle and upper Eocene). Within the Moesian Platform, the Avren Fm covers only the uppermost parts of the lower Eocene section (plus the entire middle and upper Eocene). However, to the south, in the Kamchia area, it occurs at a significantly lower stratigraphic level – the upper half of the Ypresian (Fig. 4.25).

In Central northern Bulgaria the Formation is represented by thick marly packets (up to several tens of meters thick), with rare and thin beds of sandstones and siltstones (Veliko Tarnovo and Pleven regions).

In NW Bulgaria the wells drilled in the Lom Depression revealed predominantly marls, while the sandy and silty marls prevail in the Vidin Uplift (Tsaneva, 1964, 1971a).

The lower boundary of the Avren Fm shows different characteristics in the different regions – a conformable gradual transition or an unconformity (erosional contact on older rocks). In Central northern Bulgaria it is traced as a rapid lithological transition over the Beloslav Fm sediments (sections near Riben, Bozhuritsa, Kailaka, Grivitsa). In the Veliko Tarnovo region it overlies with a sharp lithological boundary the sediments of the Shemshevo Fm. In NE Bulgaria two types of contact are identified – an unconformity over Upper Cretaceous rocks (Royak plateau), more often traced as a rapid lithological transition over the Aladan Fm limestones (Strashimirovo, Beloslav – Fig. 4.28), or as a gradual transition over the Krivnya Member of the Beloslav Fm (north of Yankovo village). In the Kamchia area the lower boundary is a gradual transition from the underlying Dikilitash Fm.

The upper boundary of the Avren Fm in Central northern Bulgaria is either erosional or is covered by Quaternary sediments – loess (the sections near Riben, Bozhuritsa, Varbitsa, Pleven region). In NE Bulgaria it is either a sharp upper contact, with detrital sandstones and limestones of the overlying Arnautlar Fm (sections Avren, Dolen Chiflik, Rudnik), or a gradual transition to the overlying Ruslar Fm (Pripek). In the Kamchia area (south of Chudnite skali), the top surface of the Avren Fm is cut by an angular unconformity at the base of the Obzor Fm (thick-bedded unsorted conglomerates and sandstones, Fig. 4.29) marking the Illyrian tectonic phase.

Judging by the nature of the Avren Fm sediments, it is supposed that these have been deposited within the outer shelf and upper part of the basin slope.

The thickness of the Avren Fm varies from 100 m to 300-400 m.

As a general rule, the sediments are rich in microfossils – small foraminifera, calcareous nannofossils, which allows precise dating.

Chronostratigraphic range. The complete stratigraphic range of the Formation is lower Eocene (upper parts of Ypresian, NP12 nannofossil zone) – upper Eocene (Priabonian, NP19-20 nannofossil zones) determined based on abundant microfossil data (planktonic foraminifera and nannofossils).

Limestone-marl formation

Nomenclature. Kanchev (1995a, b, c, d; Kanchev & Nikolov, 1995) used the name „Byala limestones-marl formation“ to mark the carbonate sediments of the uppermost parts of the Upper Cretaceous section and the base of the Paleocene in Central and East Bal-

kan. Since these sediments appear to be quite different from the original definition of the Byala Fm, here we will consider these as a separate informal unit – limestone-marl formation. The lower part of the formation has also been named „Vetrila type of Senonian“ or „Vetrila marls“ (Paskalev, 1983).

Lithological characteristics. The formation is built up of light- to medium grey or grey-greenish micritic limestones and calcareous marls. They have undergone strong tectonic pressure, and very well developed cleavage is visible, which in most cases has entirely overprinted and eradicated the original bedding. Up section, an alternation of thin-bedded light-beige to whitish calcareous marls and light-grey clayey limestones gradually prevail.

Regional aspects. The formation is largely spread in the Central and East Balkan and particularly in Tryavna, Elena-Tvarditsa, Kotel and Kamchia parts of Stara Planina Mountain. The best outcrops are located across the passes of the Stara Planina Mountain – the Republika Pass (near Mishemorkov han village), Varbitsa Pass, Rish Pass, south of Plachkovtsi in the region near Krastets railway station.

The lateral relationships of the formation with other lithobodies are not clear and directly traceable. To the east, its temporal analogue is the Tepe-Tarla Fm and to the south the Emine Fm.

The lower boundary is a gradual transition from the limestone formation (Vetrila Fm?) and is drawn at the disappearance of the flint in the limestones. The upper boundary is marked by either a stratigraphic unconformity or a tectonic (faulted) contact with the thick-bedded sandstone formation, or the flyschoid sediments of the Lukovit/Gebesh Fm (in Republika Pass, at Mishemorkov han).

The thickness of the formation varies from 30 to 150 m in the Tryavna and Elena-Tvarditsa areas, from 150 to 300 m in the vicinity of Kotel, and from 20 to 100 m to the east in the Varbitsa and Kamchia parts of Stara Planina Mountain (Kanchev in Kanchev & Nikolov, 1995).

Abundant and diverse macro- and microfossils have been detected in the sediments – inoceramids, echinoids, ammonites and rarely belemnites in the Maastichtian portion and foraminifers and calcareous nannoplankton at different levels throughout the entire formation.

Chronostratigraphic range. The total stratigraphic range of the formation is Maastichtian (CC24 – CC26 nannofossil zones) – Danian (NP1–NP4 nannofos-

sil zones) determined based on abundant microfossil data (planktonic foraminifera and nannofossils).

Tepe-Tarla Formation (Kockel, 1927)

Nomenclature. This unit was introduced by Kockel (1927) who used the name “Tepe-Tarla kalk” to denote a limestone body, developed around Tepe-Tarla Peak and along the ridge of Aytos Mountain in the East Balkan.

The name “Tepe-Tarla Formation” was published by Kanchev (1995c) as a *nomen nudum* in the Explanatory Notes to the Geological map of Bulgaria 1:100 000 scale, Aytos map sheet. It is not valid since the requirements of Art. 57, paragraph 3 of the Stratigraphic Code of Bulgaria have not been complied with – no type section having been identified and described. Additionally, it was used in a sense that did not correspond to the original definition and thickness range as given by Kockel (1927). Vangelov and Sinnyovsky (2006b) designated the lectotype section near Tepe-Tarla Peak, north of Kamenyak village and described the unit in detail within the type area.

Lithological characteristics. The Formation is built of thick-bedded and massive limestones. These are light-grey, solid, compact, with single cherty concretions and nodules. Their structure is medium- to fine-grained, bioclastic to detrital in places. The terrigenous components are represented mainly by quartz grains and do not exceed 10% (Vangelov & Sinnyovsky, 2006b).

Regional aspects. Kockel (1927) gave the following description of the geological body he had identified: “Over the upper stages of Hornstein-Plattenkalke (through transgression conglomerates), a coarse-grained limestone lies – very characteristic, the beds being regular and of decimetres in thickness, without marls, pink to grey-pink in color, slightly sandy. Its thickness reaches only 20 to 50 m. Quite often it stands sharply as constructing the peaks – the ridge of Aytos Mountain and Tepe-Tarla Peak and to the east of Dasktona. Its microfauna is represented by thick-shell foraminifera, but macroscopically it cannot be confused. The irregularly dispersed plant remains and small pieces of shales and limestones indicates that it refers to a shallow-marine sediment”.

The distribution of the Formation is restricted to Aytos Mountain, between the villages of Daskotna and Kozichino.

The lower boundary represents a rapid lithological transition from the turbidites of the Emine Fm. The upper boundary is represented as a sharp lithological

contact with the thick-bedded sandstones formation (Fig. 4.30).

Its thickness reaches up to 120 m.

Chronostratigraphic range. The full stratigraphic range of the Formation is Upper Maastrichtian (CC25 and CC26 nannofossil zones) – Danian (NP1 to NP4 nannofossil zones) based on abundant nannofossil data (Sinnyovsky & Vangelov, 1997; Stoykova, unpublished data).

Thick-bedded sandstones formation (Kanchev, 1995)

Nomenclature. The name has been introduced as an informal unit, titled “thick-bedded flysch formation” on all map sheets for the East Balkan in the Explanatory Notes to the Geological Map 1:100 000 scale (Kanchev, 1995a, b, c, d; Kanchev & Nikolov, 1995). The name refers to a distinct lithological body, represented by rhythmic alternation of thick-bedded sandstones with thin interbeds of siltstones and clays.

Lithological characteristics. The main rocks are thick-bedded sandstones in rhythmic alternation with siltstones and clays. Minor presence of single beds of conglomerates and olistostrome packets.

Regional aspects. The formation is followed over a vast territory of the East Balkan Zone, from Tvarditsa almost to the Black Sea. Locally at the base of the section, a thick (up to 30–40 m) breccia-conglomerate occurs, composed of various-sized clasts of sedimentary rocks (limestones, sandstones, claystone, etc.) and small amounts of volcanic rocks – Kamenyak, Snyagovo (Fig. 4.30). The lower parts of the formation in many places (Kozichino, Kamenyak, Snyagovo, Podvis) is represented by thin rhythmic turbidite alternation of argillites and thin-bedded sandstones. Gradually upwards in the section, thick-bedded sandstones dominate, alternating with siltstones and clays.

The sandstone beds are usually from 1 to 5 m thick. In composition these are polymictic, fine- to coarse-grained, passing into gravels in places. They are composed of quartz, feldspar, mica, rock clasts and the cement is clayey-calcareous. On a wet surface they are grey in color, while when slightly weathered, they acquire a typical grey-yellowish to rusty brown color. Spheroidal weathering similar to that observed in the sandstone packets of the Sveti Atanas and Lukovit Fms is rather typical. The sandstones and siltstones show typical flyschoid structures – gradational bedding, lamination, convolution, cross bedding. Biogenic and mechanical sole markings are detected on the lower bed surfaces. The fine portion of the turbidites is represented by calcareous clays to clayey marls.

The lateral relations of the thick-bedded sandstones formation are shown on Fig. 4.25. To the north, in the Kamchia Zone, its stratigraphic analogue appears to be the upper parts of the Byala Fm and the overlying variegated marl-clayey formation. To the south, it probably equates laterally with the Emine Fm.

The lower boundary of the formation is usually sharp, marked by an unconformity. It lays with a sharp contact over the Emine Fm in the section along the Marsh River (north of Petolachkata road junction, Sliven region), near Zheravna, Esen, Podvis and in the Aytos



Fig. 4.30. Three views of the Tepe-Tarla Fm in its type area (in the road cutting between Kamenyak and Snezha, Aytos area). The sharp upper boundary with the thick-bedded sandstone formation is seen in the lower picture



Fig. 4.31. Gradual transition between the Kozichino Fm and thick-bedded sandstone formation NW of Kozichino village

Pass – Trite Chuchura. A similar relationship appears to be in the section around Tepe-Tarla Peak, where it overlies transgressively (in places with basal conglomerate) the Tepe-Tarla Fm (Kamenyak, Snyagovo – Fig. 4.30). A gradual transition is exposed in the sections near Kozichino (Fig. 4.31) where it passes from the Kozichino Fm, and in the Ichera-Gradets section from the Emine Fm (Fig. 4.32).



Fig. 4.32. Exposures of the thick-bedded sandstone formation in the Ichera – Gradets section

The upper boundary is a gradual transition to the Dvoynitsa Group (Sveti Atanas Fm or Gebesh Fm). Practically, it is difficult to distinguish the thick-bedded sandstones from the sandstones of the Sveti Atanas Fm.

The thickness of the formation is quite significant, but due to the folding of the sediments it is impossible to



Fig. 4.33. Exposures of the Emine Fm at Cape Emine, Black Sea coast (Campanian part of the section)



Fig. 4.34. Bioturbation with ichnofossils on lower bed surface of a turbidite layer in the Emine Fm at Cape Emine



Fig. 4.35. Slumping and soft-sediment deformation in turbidite sediments of the Emine Fm at Cape Emine

directly measure it. Most authors estimate that the formation is 2000 – 3000 m thick (Kanchev, 1995b, c).

The sediments of the formation are generally poor in fossil remains – both macrofossils and microfossils. In a number of sections, however, calcareous nannoplankton have been detected thus allowing precise dating (Stoykova, unpublished data).

Chronostratigraphic range. Kanchev (1995a, b, c, d) suggests a Paleocene – middle Eocene age for the unit, based on micropaleontological data from foraminifera. The revision studies performed in many of the East Balkan sections in the recent years recorded the presence of rich calcareous nannoplankton associations in the thick-bedded sandstone formation. The actual data and their interpretation are shown in Chapter 5, devoted to the geological sections. Based on these, the full stratigraphic range of the formation is middle Paleocene (Selandian, NP5 zone) – lower parts of the lower Eocene (Ypresian, NP11-12 zones).



Fig. 4.36. Exposures of the Paleocene part of the Emine Fm (Danian Stage, NP2) in the Marash River valley, to the north of Petolachkata



Fig. 4.37. Exposures of the Emine Fm around the Cretaceous/Tertiary boundary, Aytos Pass

Emine Formation (Gochev, 1932)

Nomenclature. The unit is introduced by Gochev (1932) as „Emine layers“ and the rank of Formation applied by Bonchev et al. (1975). It is named after Cape Emine where the best outcrops are located (Fig. 4.33).

Juranov and Pimpirev (1989) designated the lectrostratotype section, situated along the Black Sea coast from the Vaya River inlet to 300 m north of Cape Kochan. They also describe an auxiliary section for the lower levels of the Formation, starting from Cape Emine and traceable up to 1.5 km northwards.

Sinnyovsky (in Dabovski et al., 2009) reviewed in details the historical background on the evolution of the studies and ideas on the age and the subdivision of formations within the unit.

Lithological characteristics. The Formation is represented by rhythmic alternating sandstones, siltstones, marls, clayey limestones and clays. These form com-



Fig. 4.38. Olistostrome packet in Emine Fm at 1.2 km N-NE of Daulite, Sliven Balkan

plete or cut (type Tb-Td) Bouma sequences. The sequences reveal all specific turbidite features: sharp lower surface, gradational, convolute and cross bedding, parallel lamination, subsea slumps, sole mark indicating paleotransport direction (E-SE), bioturbation (with ichnofossils *Rhizocorallium*, *Zoophycos*, *Cruziana*, *Palaeodictyon*, etc. – Figs. 4.34–4.35). The turbidite portion of the sequences is made up of calcareous clasts with admixtures of quartz, orthoclase, acid plagioclase (albite), muscovite and chlorite. Volcanoclastics are observed at single levels – andesite lithoclasts and crystalloclasts of acid plagioclases, pseudo-hexagonal biotite, and psilomelane.

Regional characteristic. The unit is broadly distributed throughout the entire East Balkan Zone and crops out from Emine Cape, Black Sea to the west of the town of Sliven. The lower part of the Formation has higher carbonate content and thicker rhythms, while the upper part appears to consist of thin rhythms and lower carbonate content.

Different levels of the section in the westernmost outcrops of the unit in the Sliven part of Stara Planina (the Upper Cretaceous part mainly) contain abundant olistostromes (Fig. 4.38). Continuous outcrops are traced along Sliven – Ichera road, along the Marash River valley, at the road from Petolachkata road junction to Kotel (Fig. 4.36), along the Kamchia River valley near the villages of Esen, Podvis, and Prilep, in the Aytos (Fig. 4.37), Dyulino and Obzor Passes.

In one of the best outcrops of the Formation, between Emine Cape and Kochan Cape along the coast, Sinnyovsky (2004a) distinguished 15 nannofossil zones covering the Upper Campanian – Upper Paleocene stratigraphic interval. He measured for the first time the total thickness of the unit, 1 670 m. The lowermost 820 m he referred to the Upper Cretaceous and the remaining 850 m to the Paleocene. The Cretaceous-



Fig. 4.39. Exposure at Mona Petra Cape of the boundary between the Emine and Sveti Atanas Fms: a – Mona Petra dislocation; b – overturned south limb of the Obzor Syncline, built by sandstones of the Sveti Atanas Fm

Paleogene boundary is fixed in three locations: at 2 km north of Emona village (Sinnyovsky & Stoykova, 1995), near Kozichino village (Sinnyovsky, 2003) and north of Kochan Cape (Sinnyovsky, 2004a), based on calcareous nannofossil studies.

The lower boundary of the Formation is a gradual transition from the volcanogenic sedimentary rocks of Draganovo Fm (Burgas region). It is best exposed NW of Tankovo village, in the cutting of the road to Burgas (Sinnyovsky & Sinnyovska, 1988; Sinnyovsky & Sultanov, 1994) where it is within the Upper Campanian.

The upper boundary in the easternmost outcrops near the shore represents a gradual transition to the Sveti Atanas Fm sediments (Dvoynitsa Group). It is best observed in the section near Mona Petra Cape, Black Sea coast, where the transition between both units is seen within the uppermost Paleocene NP9 nannofossil zone (Fig. 4.39). Gradual transition between the Emine Fm and the thick-bedded sandstone formation is also traced along the road between Ichera and Gradets villages (Fig. 4.32). More often, however, the upper boundary appears as a sharp surface, unconformably overlain by the thick-bedded sandstone formation.



Fig. 4.40. Exposures of the Byala Formation at the northern end of the beach of Byala town

The rhythmic turbidites of the Formation testify that deposition took place in the deepest, axial part of the marine basin with an E-SE paleotransport direction.

The maximum thickness 1 670 m, was measured by Sinnyovsky (2004a).

Mostly microfossils have been documented in the Emine Fm sediments: foraminifers (Juranov, 1994; Dimitrova, 1994a, b), calcareous nannofossils (Sinnyovsky & Sultanov, 1994; Sinnyovsky & Stoykova, 1995; Stoykova et al., 2000; Sinnyovsky, 2004a; Stoykova & Ivanov, 2004a; 2021).

Chronostratigraphic range. The complete stratigraphic range of the Formation is Upper Campanian (Uniplanarius gothicus zone) – lower Ypresian (NP10 zone), proved by microfossils – foraminifera and calcareous nannoplankton (Sinnyovsky, 2004a; Stoykova & Ivanov, 2021).

Byala Formation (Bonchev, 1926)

Nomenclature. The unit was introduced under the name “Byala clayey marls” by G. Bonchev (1926) and Formation rank was assigned by Juranov (1991).

The first description of these rocks came from Zlatarski (1907). Bonchev (1926) used the geographic toponym „Byala” to name the „Senonian clayey marls” he had described in the region of Byala and thus introduced the unit in the Bulgarian lithostratigraphic nomenclature. The marls near Byala were also mentioned in the works of Gochev (1932), Cohen (1938) and Botev (1953) who all referred these to as North European Upper Cretaceous. Trifonova (1960) de-

scribed the rocks as Southern type Senonian with foraminifera and proved the occurrence of Paleocene in them (Trifonova, 1959). Juranov (1984, 1989) named the unit as “limestone-marl formation” and later he used the name “Byala Formation” (Juranov, 1991). Kanchev (1995a) reduced the thickness of the Formation, leaving only the limestones exposed in the northern end of the beach near Byala and erroneously considers these to be Maastrichtian. He separated the marl outcrops in the southern end near Byala as an independent “marl formation”. Actually, these are the upper levels (Danian and Selandian) of the Byala Fm.

No type section is indicated. The most complete section from a stratigraphical point of view, although strongly tectonized, is at the northern end of the beach at Byala, near Beliya nos and Byala reka (Stoykova & Ivanov, 2004a, 2006a, b; Sinnyovsky, 2006b; Dinarès-Turell et al., 2006, 2010, 2012, 2013a, b; 2014 – Fig. 4.40).

Lithological characteristics. The Formation consists of rhythmic alternation of limestones and marls (thickness of the beds varying from 0.1 to 0.5 m) which alternate with thicker (up to several tens of meters) marl packets. Fresh surfaces show the rocks as grey to light-grey in color, and nearly white where weathered. The marls are whitish, indistinctly bedded, massive and thin-bedded. The limestones are white to light-grey, solid, thin- to medium-bedded. The limestone/marl ratio varies within the different stratigraphic levels.

Regional aspects. The Formation is of rather limited distribution – only in the coastal part of the East Balkan, in the vicinity of Byala town and Gortisa village, Varna region. Single outcrops have been detected west of Bardarevo village.



Fig. 4.41. The lowest parts of the Byala Fm (Campanian, right of photo), exposed at Belia Nos

Lateral transitions of the Byala Formation are not exposed at the surface due to its limited distribution. These are, however, identified through detailed biostratigraphic correlation and comparison with lithobodies from surrounding areas within the same time interval and some of them are illustrated in Fig. 4.25. Lateral analogues of lower parts of the Byala Fm to the north in the Kamchia area appear to be the Mezdra and Asparuhovo Fms, of the middle parts – the Mezdra and Kailaka Fms, and of the upper parts – the Komarevo Fm. Going further northwards, the stratigraphic hiatus between the Upper Cretaceous and the upper Paleocene is supposed to correspond to the unit.

To the west, it probably passes into the Kozichino Fm, the limestone-marls formation, Vetrila Fm and the thick-bedded sandstone formation. Southwards, to the Emine basin it is totally replaced by the Emine Fm turbidite sediments.

The lower boundary of the Formation in the region of Byala and Goritsa is a tectonic one (Fig. 4.41 – normal fault at Beliya nos) and a normal stratigraphic succession is not identified.

The upper boundary in the type area (Byala and Goritsa) appears as a gradual lithological transition to the variegated marl-clayey formation (= “Goritsa marls”). It can be seen in the outcrops located in the gullies north of Byala and in Dolap dere, SE of Goritsa village, as well as in the well sections around Goritsa village.

However, uninterrupted successions are exposed in the Byala Fm rocks in particular places along the Black Sea coast and it is in these rocks that the Cre-

taceous/Paleogene boundary was discovered for the first time in Bulgaria (Stoykova & Ivanov, 1992; Preisinger et al., 1993 a, b; Ivanov & Stoykova, 1994, 1995; Stoykova et al., 2000; Stoykova & Ivanov, 2004a).

Due to intensive tectonics manifested in the sediments of the Formation, its thickness may not be precisely measured. It is estimated to be around 150 m thick. Detailed biostratigraphic, magnetostratigraphic and cyclostratigraphic studies of the section near Byala carried out recently by a Bulgarian-Spanish team (Dinarès-Turell et al., 2006; Dinarès-Turell et al., 2010, 2012, 2013a, b; 2014) proved 77 m of Paleocene strata within the Byala Fm.

The sediments of the Formation were most probably deposited in the outer part of the shelf – around the shelf margin and the upper parts of the slope, evidenced by the lithology as well as by the rich fossil presence of planktonic and nektonic organisms.

Abundant and various remains of macro- and microfossils have been documented in the rocks of the Formation, including ammonites, belemnites and inoceramids (Ivanov, 1993b; Ivanov & Stoykova, 1994), echinoids (Ilieva, 2000), foraminifera (Juranov, 1983, 1984, 1989; Valchev, 2006), calcareous nannofossils (Sinnyovsky, 1990; Stoykova & Ivanov, 1992; 2004a; Preisinger et al., 1993a, b; Ivanov & Stoykova, 1994, 1995; Dinarès-Turell et al., 2006; Sinnyovsky, 2006b; Dinarès-Turell et al., 2010, 2012, 2013a).

Chronostratigraphic range. The complete stratigraphic range of the Formation is Lower Campanian (zone *Broinsonia parca*, Sinnyovsky, 2006b) – uppermost

Paleocene – Thanetian (NP9 zone – Stoykova & Ivanov, 2006 a, b). The age is supported by microfossils – foraminifera and calcareous nannoplankton.

Kozichino Formation (Bonchev, 1960)

Nomenclature. The “Kozichino Formation” name was published for the first time by Bonchev (1960, p. 10). Stancheva (1961) described foraminifera from the unit, assigning a Paleocene age. Further publications assign its sediments to the so-called “terrigenous formation” (Karagyuleva & Kostadinov, 1977).

In nominating the Dvoynitsa Fm, Juranov and Pimpirev (1989) suggest that the rocks in the region of Kozichino village may belong to the lower levels of the Dvoynitsa terrigenous Fm. Juranov (1993) qualifies the name as unusable. In describing the geology of the Dolen Chiflik 1:100 000 geological map Kanchev (1995a) assigns the lithostratigraphic rank for the Kozichino Formation, defines its type area, and describes the type section of the Formation in the gorge south of Kozichino village and along the gully in the vicinity of the village. Moreover, he describes the Formation with its boundaries, relationships, and thickness and provides data on its age.

The revising studies performed under the Geology of Bulgaria project, confirmed a distinct, separate lithological body developed in the region of Kozichino village, that has no matching unit within the whole East Balkan.

Lithological characteristics. The key defining feature of this unit is the thick-bedded fine- to coarse-grained sandstones, passing into gravels in places (Fig. 4.42). These are rusty-brownish to yellowish in color. The development of rare beds and packets of grey micritic

limestones with chert concretions among coarse-terrigenous sediments is a particular feature of the unit. Also present are local beds and lenses of breccia-conglomerates. Parallel and cross-bedding with lateral variations and truncation of the underlying beds are observed, too. The clastic component in the uppermost levels becomes significantly finer-grained, with development of thin-bedded rhythmic clayey-sandy turbidites (Fig. 4.43).

Regional aspects. The unit is distributed only in the vicinity of Kozichino village, East Balkan. The presumed lateral relationships of the Kozichino Fm with other lithobodies are shown in Fig. 4.25. To the south and west, the unit rapidly pinches out, passing to the Emine Fm turbidites. The temporal analogue of the Formation to the north, in the Kamchia area, is the middle part of the Byala Fm.

The lower boundary of the unit is sharp, probably related to a short break of sedimentation or submarine scouring/wash-out. It is reliably traced in the gully, located south and south-east of Kozichino village (Fig. 4.44) as well as on the road cut exposure at the entry point to the village. Continuity of the sequence across the Cretaceous/Tertiary boundary is evidenced south of the village. The K/T boundary itself is biostratigraphically documented by nannofossil finds in the uppermost parts of the Emine Fm (Vangelov & Sinnyovsky, 2001; Sinnyovsky, 2003). Very good outcrops of the unit are observed in the gully within the village.

The main portion of the Formation is built up of alternating thick-bedded sandstones of variable grain-size passing to gravels and fine-grained conglomerate-breccia. Their lower surface is uneven, with flow marks. At several levels, beds of light-beige and grey



Fig. 4.42. Exposure of sandstones and gravels with limestone intercalations in the Kozichino Fm in the gully by the village



Fig. 4.43. Thin-bedded rhythmic clayey-sandy turbidites, developed in the topmost part of the Kozichino Fm



Fig. 4.44. Sharp contact at the base of the Kozichino Fm with underlying turbidites of the Emine Fm

colored micritic limestones with or without cherts occur. The assumption is that the sediments of the unit have been deposited in the middle part of a submarine fan, but these could also be interpreted as channel deposits, filling a submarine canyon.

The upper boundary is a gradual lithological transition, well exposed in the gully north-west of the village, where a packet of thin-bedded sandy-clayey turbidites are taken to mark the transition to the thick-bedded sandstone formation both vertically and laterally to the north (Fig. 4.43, Fig. 4.25).

The thickness of the unit is estimated at 200-300 m.

The fossiliferous intervals are concentrated within the fine-grained and calcareous interbeds among the coarse clastic sediments. Foraminifera (Stancheva, 1961) and calcareous nannoplankton (Stoykova, unpublished data) have been recorded.

Chronostratigraphic range. The complete stratigraphic range of the unit is determined based on finds of calcareous nannofossils in particular stratigraphic levels. It is specified as lower Paleocene – Danian Stage to the base of the Selandian, NP1 to NP5 nannofossil zones (Stoykova, unpublished data).

Dvoynitsa Group (Juranov & Pimpirev, 1989)

The unit is introduced as the Dvoynitsa Formation by Juranov and Pimpirev (1989). The type section is designated along the Black Sea coast, from Sveti Atanas Cape to Luna camping site (the mouth of Perperi Dere gully, now – Sol Luna Bay touristic complex).

The Dvoynitsa Fm combines a variety of lithologies – thick-bedded sandstones, alternations of clayey limestones and marls, conglomerate packets, gravels and siltstones, as well as typical thin-bedded rhythmic turbidites. All these are quite different in com-



Fig. 4.45. Type section of the Sveti Atanas Fm – Cape Sveti Atanas, Black Sea coast

position and may not be mechanically referred to as one unit. The main lithological types are three: thick-bedded sandstones; thin-rhythmic turbidites; and clast-supported and matrix-supported conglomerates. The most practical approach from a lithostratigraphical viewpoint would be to separate the three clearly distinguished and laterally traceable lithobodies as independent units whereby changing the rank of the Dvoynitsa Fm into a Group. This is done for the first time in this work.

Composition. The Dvoynitsa Group comprises two Formations: the Sveti Atanas Fm (thick-bedded sandstones) and the Gebesh Fm (thin-rhythmic clayey-sandy turbidites). Locally developed conglomeratic bodies with olistostromes, ranked as members near Bardarevo and Solnik villages and in Meshelika locality south of Obzor – the Bardarevo Member and the Meshelika Member – could be part of the Sveti Atanas Fm.

Sveti Atanas Formation (new Formation)

Nomenclature. Nominated for the first time in this work, it corresponds to the lower part of the “Dvoynitsa Fm” (sensu Juranov & Pimpirev, 1989), “Erkech sandstones” (Bonchev, 1926), and to a part of the terrigenous formation (Karagyuleva & Kostadinov, 1977). The section starts at the southern end of Byala beach (Shelborun locality) and ends at Obzor Bay after Sveti Atanas Cape, is designated here as type section. It is named after Sveti Atanas Cape on the Black Sea coast, which is entirely built up by the sandstones of the Formation (Fig. 4.45).

Lithological characteristics. The key definitive feature of the Formation appears to be the thick-bedded coarse- to medium-grained amalgamated massive sandstones. These are poorly sorted, with quartz grains prevailing, and with a clayey matrix. Limited amounts of lithoclasts and feldspar are seen. The



Fig. 4.46. Spheroidal weathering in thick-bedded massive sandstones of the Sveti Atanas Fm – Cape Sveti Atanas

grains are angular, the pores being filled with clayey minerals. Spheroidal (ball-shaped) weathering forms are common on the face of the outcrop (Fig. 4.46).

Thin interbeds of gravels and breccia are usually observed at the base of the lower erosional bed surface. These include numerous clasts and angular pieces of the Byala Fm (Fig. 4.47).

Beds of siltstones up to several centimeters thick are detected among the thick-bedded sandstone layers and packets.

Regional aspects. The unit is traced only in the easternmost parts of the East Balkan. Along the coast it crops out in the northern and southern limb of the Obzor Syncline – south of Byala to Sveti Atanas Cape and south of Obzor near Mona Petra Cape. Onshore, like the Byala Fm, it is traced only to the region of Bardarevo and Solnik villages.

Bardarevo Member. A body of boulder conglomerates (1 to 3 m in size) and conglomerate-breccia is locally developed at the base of the Formation in the region of Bardarevo and Solnik villages. These are matrix-supported, floating in clayey or silty matrix. No distinct



Fig. 4.47. Rounded clasts of volcanic rocks and angular clasts of marly limestones of the Byala Fm in the base of thick sandstone bed of the Sveti Atanas Fm – Cape Sveti Atanas



Fig. 4.48. Exposures of conglomerates and breccia-conglomerates of the Bardarevo Member of the Sveti Atanas Fm – in the valley to the west of Bardarevo

bedding is seen and the clasts are chaotically distributed (Fig. 4.48). The clasts display various lithologies, including grey micritic limestones, red dolomites (Triassic?), grey clayey limestones (Byala Fm?), sandstones (Kozichino Fm?), quartzites (Jurassic – Sinivir Fm?), volcanic rocks (Upper Cretaceous of the Srednogo-rie?), and reefal limestones. The body composed of conglomerate clasts has a transgressive lower boundary – unconformably overlying grey limestones (Upper Cretaceous). The upper boundary is a rapid transition to the Sveti Atanas Fm sandstones (Fig. 4.49).

Its thickness is around 150 m. Here this body is distinguished under the name *Bardarevo Member* of the Sveti Atanas Fm. The type section is designated as the one exposed in the gully, located west of Bardarevo village and north of Bardarevo – Golitsa road. The calcareous nannofossils, recovered from different levels of the matrix suggest its chronostratigraphic range is uppermost Paleocene (Thanetian, NP9) to lowermost Eocene (Ypresian, NP10).

The observed and assumed spatial and temporal relations of the Sveti Atanas Fm are shown in Fig. 4.25. Westwards, it probably passes to the thick-bedded sandstone formation. To the north, within the Moesian Platform, its temporal stratigraphic equivalents are the Komarevo Fm and the Beloslav Fm (Fig. 4.25).

The lower boundary of the Formation is seen as a rapid lithological transition from the variegated marly-clayey formation (south of Byala) or from the Emine Fm (near Mona Petra Cape).

The upper boundary is a rapid lithological transition to the thin-bedded rhythmic turbidites of the Gebesh Fm and is observed in the exposures between Sveti Atanas Cape and Luna camping site. It follows the disappearance of the thick sandstone beds and their replacement by thin-rhythmic alternations of siltstone and clayey marls.



Fig. 4.49. Conformable contact of the sandstones of the Sveti Atanas Fm overlying the conglomerates of the Bardarevo Member

The thickness of the Formation varies between 100 and 300 m, being greater in the southern limb of the Obzor Syncline. Stratigraphically important calcareous nannofossil species have been identified in the sandstones, as well as in the silty and clayey interbeds.

Chronostratigraphic range. The complete stratigraphic range of the Formation is upper Paleocene (Thanetian, NP8-9 nannofossil zones) – lower parts of the lower Eocene (Ypresian, NP12 nannofossil zone), based on the recovered nannoflora (Stoykova, unpublished data).

Gebesh Formation (Pollak, 1933)

Nomenclature. The Formation is introduced as “Gebesfazies” and “sudliche (Chifte-Dere) Fazies” by Pollak (1933). His work makes it perfectly clear that he separates the thin-bedded, marl-dominated flysch in the easternmost parts of Stara Planina Mountain as a body of specific lithology under the name “upper molasse flysch”. In the valley of the Dvoynitsa River (Chifte Dere) he names this feature “Chifte-Dere Fazies” and in the outcrops located more northwards, in the region of Krivini (Gebesh) village, he refers to it under the name “Gebesfazies”.

Juranov and Pimpirev (1989) have unjustifiably rejected as unusable the names for this unit given by

Pollak (1933) by including its sediments in the Dvoynitsa Fm that they themselves had separated. Kanchev (1995a) reinstates the name Gebesh Formation in the Bulgarian lithostratigraphic nomenclature, without specifying a type section. He had however, erroneously assigned an “upper Eocene age” to this unit.

The section traced along the sea coast south of Sveti Atanas Cape to the Luna camping site should be considered as lectotype section of the Formation.

Lithological characteristics. The Formation is composed of thin- to medium-bedded (10-40 cm) rhythmic alternation of sandstones, siltstones, marls and clays (Figs. 4.50; 4.51). The lower bed surfaces of the sandstones reveal well expressed sole marks (paleo-transport direction to south-east), bioturbation, ichnofossils, etc., typical for the turbidites. Cross and graded bedding, fining upwards, lamination and convolution are all observed in the sandstones. The rocks look grey-bluish in color on fresh wet surfaces and yellowish to beige on weathered ones.

Regional aspects. The distribution of the unit is followed only in the eastern portions of Stara Planina Mountain. It is seen in the coastal area between Byala and Obzor (Fig. 4.51) and in the vicinity of Krivini village with the westernmost outcrops being observed



Fig. 4.50. Tectonized thin-rhythmic turbidites of the Gebesh Fm in its lectotype section south of Cape Sveti Atanas



Fig. 4.51. Thin-rhythmic turbidites of the Gebesh Fm in its lectotype section north of Luna camping site (Sol Luna Bay)



Fig. 4.52. Exposure of thin-rhythmic turbidites of the Gebesh Fm near the village of Kipilovo

in the region of Kipilovo village (Fig. 4.52).

The lower boundary represents a gradual lithological transition from the underlying Sveti Atanas Fm sediments and is marked by the disappearance of the last bank of massive sandstones.

The upper boundary in the valley of the Dvoynitsa River (Obzor area) is hidden by river alluvium. It is probably overlain by a stratigraphic unconformity (that marks the Illirian tectonic phase) by the Obzor Fm conglomerates (middle? upper? Eocene).

It is assumed that the sediments have been deposited in the basin plain by low-density turbidite flows.

The thickness of the Formation reaches up to 300 m.

Microfossils – foraminifera and nannoplankton are detected in the finer portion of the rhythms allowing determination the age of the Formation.

Meshelika Member. A body of specific lithology, distinguished in the upper parts of the Formation south of Obzor, Meshelika locality. The type section crops out along the sea coast south of the main, central beach of Obzor, in Meshelika locality.

Thick (up to 300 m) indistinctly bedded siltstones and large marly blocks (up to 2-3 m) and clasts of thin-bedded rhythmic turbidites (Gebesh Fm – Fig. 4.53), limestones with nummulitids (Dikilitash? Aladan? Fms – Fig. 4.54), clayey limestones and marls (Byala Fm – Fig. 4.55) are present. Smaller sized clasts of rounded sandstone pieces (to several centimeters), quartz gravel and volcanic rocks (Upper Cretaceous from the Srednogie Zone) are also noted. The conglomerate blocks and lenses and beds are developed at several levels in the sequence. The limestones and coarse-grained sandstone layers contain abundant shallow-water fossil fauna: nummulitids, gastropods, corals, echinoids and bivalves (Fig. 4.54).



Fig. 4.53. Boulder-sized blocks of Gebesh Fm, floating in siltstone matrix south of Obzor – Meshelika Member of the Gebesh Fm.



Fig. 4.54. Limestone blocks with abundant nummulitids (Dikilitash? or Aladan? Fms) in siltstone matrix south of Obzor – Meshelika Member of the Gebesh Fm

It is suggested that the deposition of these sediments has taken place in the deep (axial) part of the basin as a result of a series of high-density debris flows and slumps. The chaotically deposited shallow water sediments are transported by a debris flow as a result of destruction (destabilization, possibly earthquake generated) of the already consolidated sediments from the edge of the carbonate platform to the north. A smaller volume of the material has been transported from the south, as a consequence of weathering, erosion and transport of Srednogorie volcanic rocks.

The stratigraphic range of the Meshelika Member based on abundant calcareous nannofossil finds is the upper part of the lower Eocene (Ypresian, NP13-14a nannofossil zone).

Chronostratigraphic range. The complete stratigraphic range of the Gebesh Fm is within the upper parts of the lower Eocene, Ypresian Stage, NP12-14a nannofossil zones.



Fig. 4.55. Clasts of Byala Fm and volcanic inclusions in limestones with nummulitids south of Obzor – Meshelika Member of the Gebesh Fm

Chapter 5

Biostratigraphic subdivision and correlation of key sections

This chapter presents the results of the biostratigraphic study of fifty-five key sections from both onshore and offshore northern Bulgaria, based on calcareous nannofossils. These sections exhibit various stratigraphic levels of the Paleocene-lower Eocene interval, which are complete to varying degrees. Their subdivision and correlation has been accomplished through precise tracing of the vertical distribution of stratigraphically significant nannofossil species. This chapter presents the sections arranged from west to east and from south to north, following the geological structural zones.

5.1. Kula Unit

Two sections have been studied within the Kula Zone – near Kladorub and Rakovitsa villages, Vidin District, where the Kladorub and Staropatitsa Fms are exposed.

Kladorub

The section is located some 1.3 km SE of Kladorub village, Vidin District, and is followed along the Tsiganski dol valley. It is one of the most thoroughly studied sections in all of northern Bulgaria, with a series of bioevents identified and traced by calcareous nannofossils. It is thus considered to be the reference, key section in interpreting the stratigraphy and the main events in the studied interval.

The section near Kladorub village has been studied by a number of geologists – Beregov (1937), V. Tzankov et al. (1960), Tz. Tzankov (1964, 1972), Aladjova-Hrischeva et al. (1991). Recently, the Kladorub Fm has attracted intensive attention and study after some global events have been identified in the succession – the Cretaceous/Tertiary boundary impact event and the Paleocene/Eocene Thermal Maximum event (Sinnyovsky & Petrov, 2000; Sinnyovsky et al., 2002; Sinnyovsky, 2004b; Stoykova et al., 2005b; Stoykova & Ivanov, 2005; Stoykova et al., 2006).

In the course of this study the section cropping out along the Tsiganski dol, has been sampled with a vertical resolution of 2 m intervals (Fig. 5.1). In some

intervals with pronounced events, the sampling was more intense, being 0.2 – 0.1 m, or even 0.05 m.

Grey-greenish to dark grey clayey-carbonate siltstones and silty marls (Sinnyovsky et al., 2002) with rare thin interbeds of limestones assigned to the Kladorub Fm are exposed. The beds are vertical and are poorly bedded (Fig. 5.1). The total thickness of this Formation is 205 m, 135 m of which are referred to the Upper Cretaceous (Upper Campanian and Maastrichtian) and the remaining 70 m to the Paleocene and lower Eocene (Danian, Selandian, Thanetian and the base of the Ypresian – Fig. 5.2). As a rule, the Kladorub Fm rocks contain abundant and diverse, perfectly preserved calcareous nannofossil associations. The Kladorub Fm is transgressively and unconformably overlain by the Staropatitsa Fm which consists of coarse-clastic sediments – sandstones, gravels and conglomerates, over 250 m thick (Fig. 5.4). Single horizons reveal also packs of finer-grained sediments – silty and clayey marls with specific nanoflora documented (Fig. 5.5).

Biostratigraphy. Sinnyovsky et al. (2002) proved biostratigraphically the presence of the Cretaceous/Tertiary (K/T) boundary, precisely fixing the position of the boundary clay bed within the continuous sedimentary succession of the Kladorub Fm. Sinnyovsky (2004b) divided the section into 14 nannofossil zones, five of them in the Upper Cretaceous and nine in the Paleocene (NP1 to NP9).



Fig. 5.1. Section along Tsiganski dol SE of Kladorub – upper parts of the Kladorub Fm (Thanetian, NP 8)

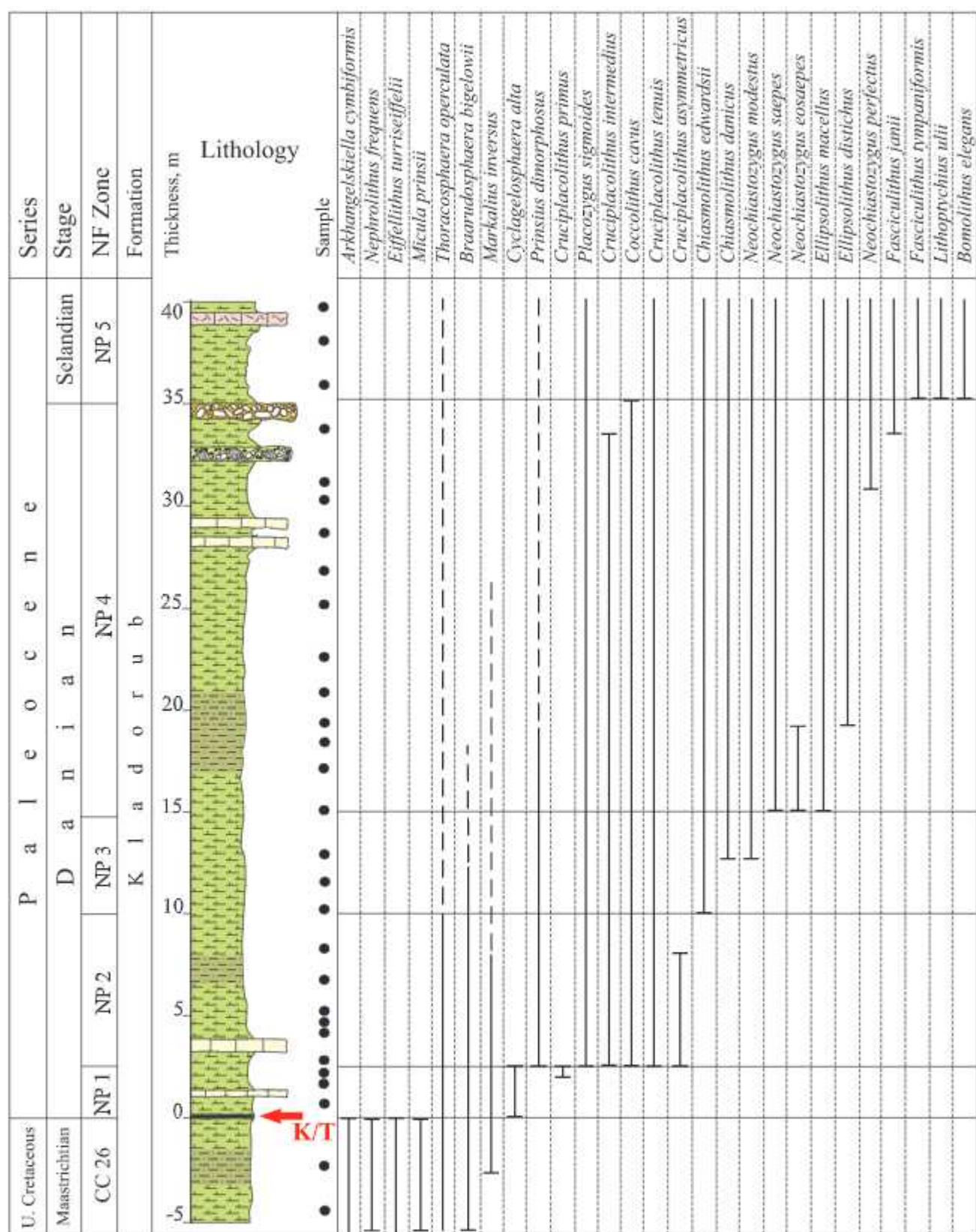


Fig. 5.2.1. Biostratigraphic subdivision of the Kladorub section by nanofossils – lower portion

The current study on the nanofossils in the Paleocene portion of the section generally confirms the zonation published by Sinnyovsky (2004b). The upper part of the Kladorub Fm, however, is proved to

be of early Eocene age by the presence of the Ypresian NP10 nanofossil zone (Stoykova & Ivanov, 2005). Moreover, the separation of Danian, Selandian and Thanetian Stages within the Paleocene series is

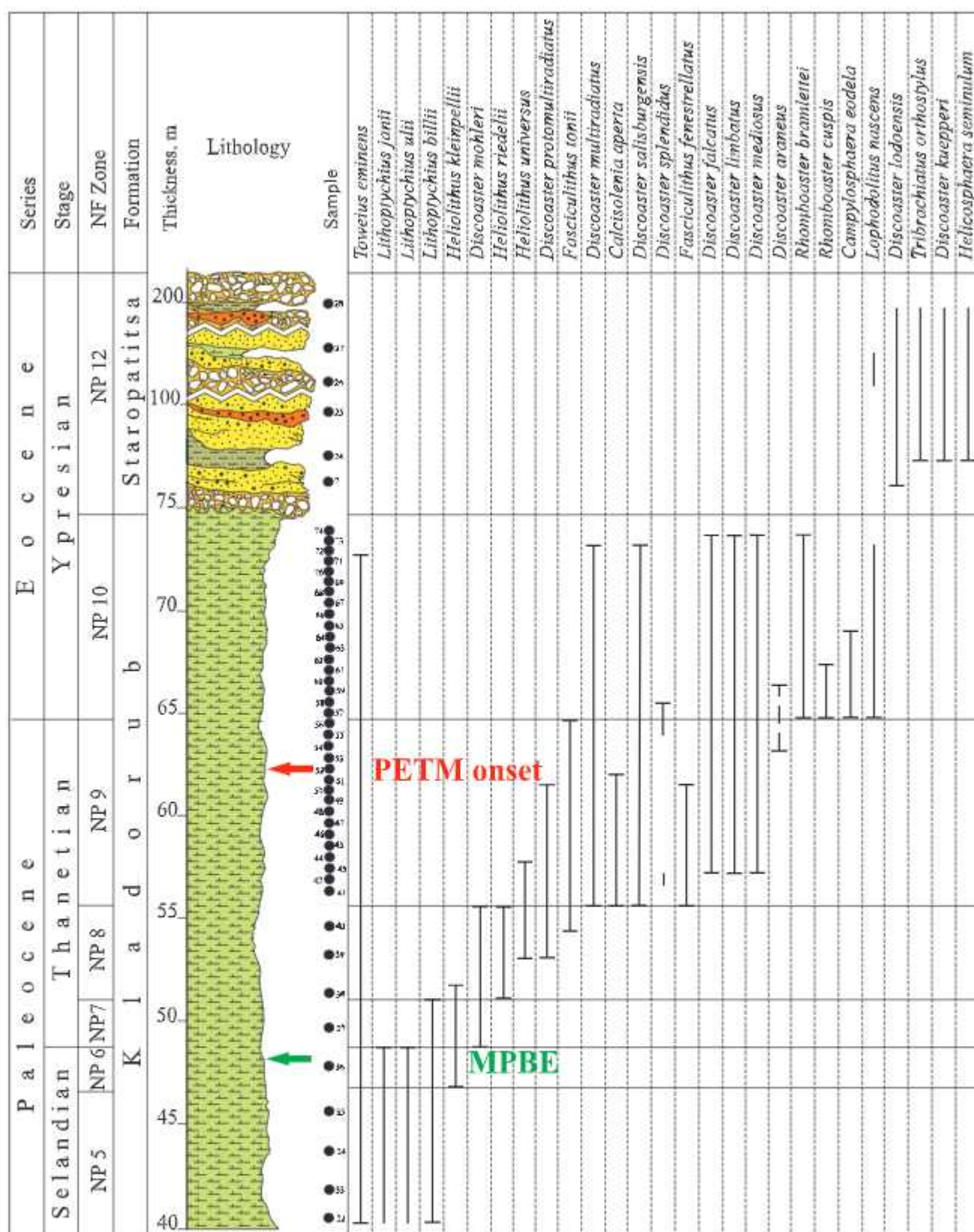


Fig. 5.2.2. Biostratigraphic subdivision of the Kladorub section by nannofossils – upper portion

based on characteristic zonal associations, while Sinnyovskiy (2004b) recognized lower, middle and upper sub-series of the Paleocene only.

The section near Kladorub encompasses one of the richest, most abundant and diversified, and very well preserved nannofossil associations in northern Bulgaria – over 100 different species of calcareous nan-

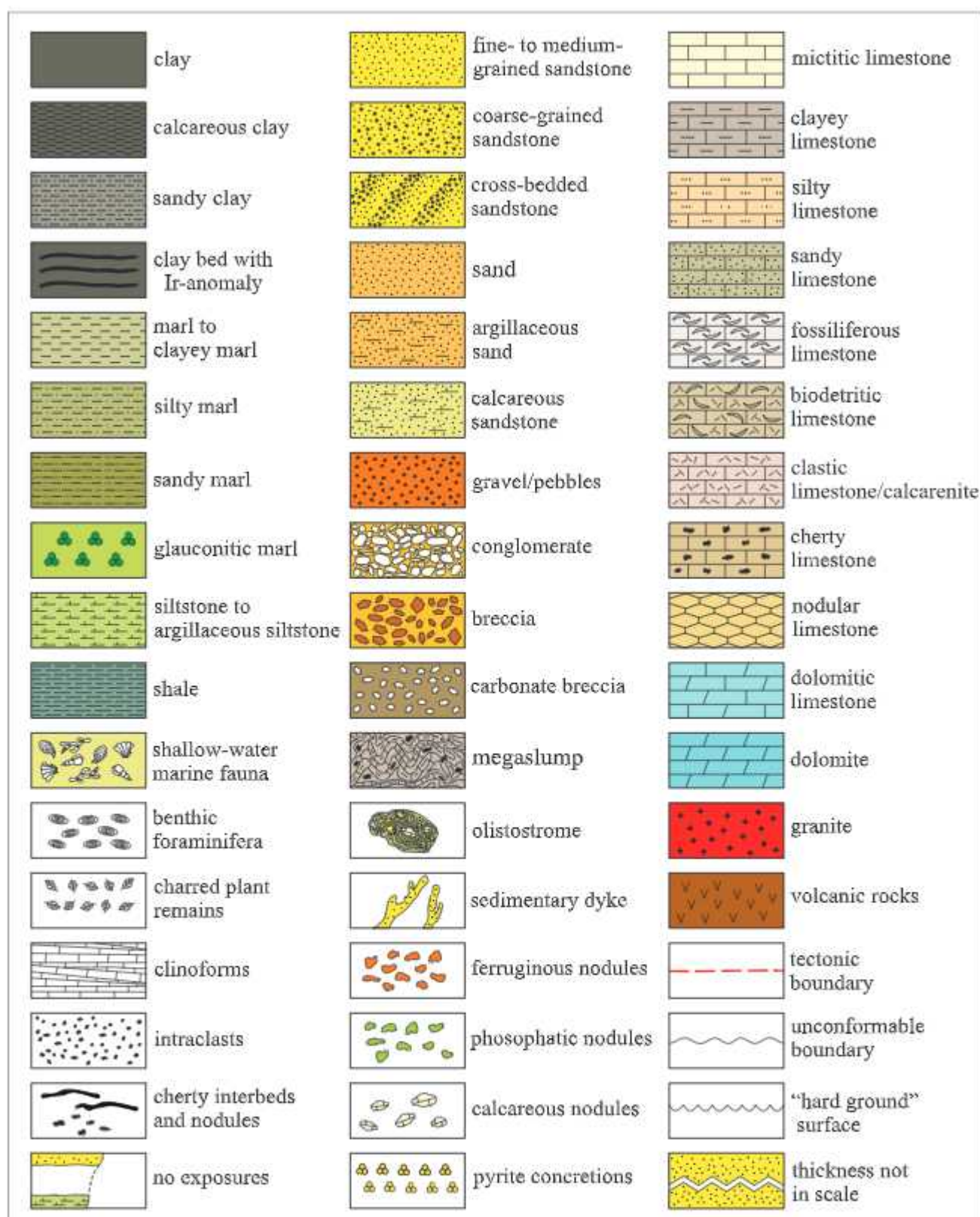


Fig. 5.3. Legend referring to all sections in chapter 5

nofossils have been recorded so far. The vertical distribution (range-chart) of the stratigraphically significant species, as well as the biostratigraphic subdivision of the section is shown in two successive figures (Fig. 5.2.1 and 5.2.2).

The K/T boundary in this section has been pinpointed by Sinnyovsky et al. (2002), located some 50 m north of the drainage. It is drawn at the boundary between *Micula prinsii* (uppermost Maastrichtian) and NP1 (lowermost Danian) zones and marked by a 2 cm



Fig. 5.4. Conglomerates and sandstones of the Staropatitsa Fm (Ypresian, NP12 zone) cropping out in Tsiganski dol

thick dark-coloured layer (Fig. 5.6). The boundary is noted as zero level (0 m) in the studied section.

The biostratigraphic zones are distinguished on particular bioevents: first occurrence (FO) or extinction (last occurrence, LO) of important stratigraphic taxa and represent interval zones. The lower boundary of NP1 zone is marked by a remarkable global event (K/T boundary meteorite impact) and will be discussed in a separate chapter. Biostratigraphically it marks the extinction of the vast majority of Cretaceous species, the explosive occurrence of the “survivor” species *Thoracosphaera operculata* and *Braarudosphaera bigelowii* and the FO of new Paleocene species such as *Cyclagelosphaera alta*, the first Prinsiacea and *Cruciplacolithus primus*.

The boundary between NP1 and NP2 zones is traced by the FO of *Cruciplacolithus intermedius* as well as of *C. tenuis*, *C. asymmetricus* and *Coccolithus cavus* (Fig. 5.2.1).

The boundary between NP2 and NP3 zones is marked by the FO of *Chiasmolithus edwardsii*, followed by *Chiasmolithus danicus* and *Neochiastozygus modestus*.

The co-occurrence of *Ellipsolithus macellus*, *Neochiastozygus eosaepes* and *Neochiastozygus saepes* at +15.00 m is used for setting the boundary between NP3 and NP4 zones. The thickness of NP4 zone is about 20 m, but one should consider the fact that it appears to be zone with the longest temporal range in the Paleocene (around 2.5 Ma – Dinarès-Turell et al., 2003; 2006).

The NP4 – NP5 boundary is traced by the FO of *Fas-*

ciculithus tympaniformis – a bioevent preceded by the first and second radiation of representatives of the genus *Fasciculithus*.

Heliolithus kleinpellii, *Discoaster mohleri* and *Heliolithus riedelii* mark the lower boundary of NP6, NP7 and NP8 zones, respectively. These first occur in a 5-6 m interval between +46.00 and +51.00 m, proving the relatively small thicknesses of these zones (Fig. 5.2.2).

Considerably greater thicknesses of about 10.00 m each have been established for NP9 and NP10 zones. The lower boundary of NP9 zone is traced by the FO of *Discoaster multiradiatus* and the base of NP10 zone by the FO of *Rhomboaster bramlettei*. The latter coincides also with the Paleocene/Eocene chronostratigraphic boundary, that has been recently



Fig. 5.5. Silty and clayey marlstone packet in Staropatitsa Fm with documented calcareous nannofossils (Ypresian, NP12 zone)



Fig. 5.6. The dark grey clay bed (red line), marking the K/T boundary in the Kladorub section, discovered by Sinnyovsky et al. (2002). Ruler = 30 cm

related to a prominent global climatic event – the Paleocene-Eocene Thermal Maximum (PETM). The Kladorub section, with its continuous sedimentation in the boundary interval has stored the best geological record of this event in Bulgaria (Stoykova & Ivanov, 2005).

The Paleocene portion of the Kladorub Fm is represented by a monotonous alternation of dark-grey clayey-calcareous siltstones and silty marls, occasionally interrupted at some levels by limy and sandy beds. Within the lowest Paleocene zone NP1, at some +1.3 m above the K/T boundary, a 12 cm thick limestone bed is documented. The next thicker (0.5 m) limestone bed occurs at +3.5 m to +4.0 m, in the NP2 zone. Several limestones and detritic beds have been observed in the upper part of NP4 nannofossil

zone. Two limestones beds, approximately 0.25 m thick, occur 1.10 m apart at +28.5 m (Fig. 5.7), and at +32.60 m, the latter a detritic bed composed of shallow marine fossil shells and clasts of sandstones, siltstones and limestones. Up section, at +34.69 m, the marlstones contain rounded gravel and conglomerate clasts, 5 to 10 cm in size (Fig. 5.8). The last calcareous bed is identified at +39.60 m, in the lower part of NP5 zone. It is 0.1 m thick, a whitish to white sandy limestone that passes upwards into calcarenite. All these beds are event markers, and are formed in the deeper parts of the basin as a result of various depositional events.

The upper parts of the Tsiganski dol section are represented by coarse-siliciclastic sediments – sandstones, gravels and conglomerates alternating with finer



Fig. 5.7. A couplet of two limestone beds, located at +28.5 m in an otherwise monotonous succession of the Kladorub Fm (upper part of Danian, NP4 zone). Limestone beds approximately 25 cm thick



Fig. 5.8. Well-rounded conglomerates and clasts, located at +34.69 m in the marlstones of the Kladorub Fm (Danian/Selandian boundary, NP4/NP5 zonal boundary). Coin is 2.5 cm in diameter

marlstone-clayey packets. These are over 250 m thick in total and represent the Staropatitsa Fm (Aladjova-Hrischeva et al., 1991) unconformably covered the Kladorub Fm (Fig. 5.9).

Relatively diverse and abundant nannofossil associations have been documented at several levels (in 6 out of a total of 27 samples) within the finer marlstone-clayey packs, intercalated with conglomerates and sandstones (Stoykova & Ivanov, 2005). These associations contain a number of distinctive species such as *Discoaster lodoensis*, *D. kuepperi*, *Tribrachiatus orthostylus*, *Helicosphaera seminulum* and *Chiasmolithus grandis*. These prove the presence of the lower Eocene NP12 zone and corroborate an early Eocene – Ypresian age for the Staropatitsa Fm in its type section (Stoykova & Ivanov, 2005).

Stratigraphic range. The complete stratigraphic range of the succession outcropping near Kladorub is Upper Campanian – lower Eocene (Ypresian, NP12).

Rakovitsa

The section is traced along the gully at the southern entrance of the village (crossing the road to Podgore village). In the course of this study, the presence of Paleocene sediments in this location (within the Kladorub Fm) is demonstrated by nannofossil finds. Its boundary is traced along a fault in the Belogradchik pluton.

Here the siltstones and clayey-silty sediments of the Kladorub Fm appear to be more compacted and more highly cleaved compared to those exposed at Tsigan-si dol near Kladorub. The beds are vertical and the best outcrops are observed on the river banks. An unconformity between the sediments of the Kladorub and Staropatitsa Fms is observed just across the river bridge.

Biostratigraphy. The nannofossil content of the sediments indicates the occurrence of thin, poorly preserved associations, which corresponds to the significantly higher degree of tectonic processing of the sediments (compaction, cleavage) at this locality. Nevertheless, the succession has been divided into Upper Cretaceous and Paleocene with the position of the Cretaceous/Paleogene boundary located, and the lowest two Paleocene zones – NP1 and NP2 are indicated by characteristic species (Fig. 5.10).

Although poorly preserved, the species *Neochiastozygus junctus* and *Discoaster lodoensis* are identified in the coarse-grained siliciclastic sediments of the Staropatitsa Fm, which implies lower Eocene, NP12-14a zone.

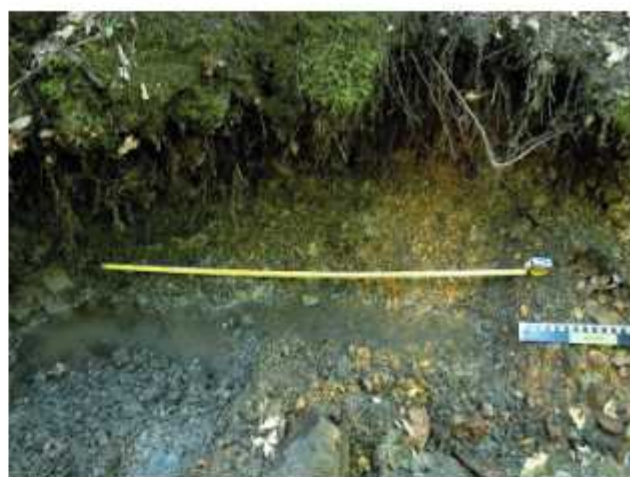


Fig. 5.9. Parallel stratigraphic unconformity between the Kladorub and Staropatitsa Fms. Ruler = 1 m

Stratigraphic range. The stratigraphic range of the succession, exposed in the section at Rakovitsa, is Upper Cretaceous (Campanian-Maastrichtian) – lower Eocene (Ypresian).

5.2. West Fore-Balkan

The sections studied in the West Fore-Balkan are grouped in two areas – Mezdra and Lukovit. Only three of the sections located in the Mezdra region are presented here – south of Moravitsa village, south of Mezdra town (near the swimming pool) and at Lyuti dol village, but analyses have been carried out at a far greater number of localities: near Perchovtsi, Chelopek, Darmantsi, Lipnitsa, Dilkovtsi villages and others.

Moravitsa

The section is located at 1.5 km south of the village, in the canyon of Kamenitsa River and is traced along the northern slope of the gully (Fig. 5.11). It is one of the most complete and representative Upper Cretaceous and Paleocene sections in the Mezdra region. The section was described as a succession of parallel outcrops between Moravitsa village and Mezdra town along the Kamenitsa River by Sinnyovsky (1999), who identified the Cretaceous/Tertiary boundary and a boundary layer of 7 to 11 ppb of iridium. The same author differentiated cycles of Milankovitch and two third-order sequences in the section (Sinnyovsky, 1999). The valley of the Kamenitsa River is included as a protected site in the Register of Geological Phenomena in Bulgaria.

Subsequently, Stoykova et al. (2000) analysed the section from the mineralogical-geochemical, sedimentological and event stratigraphy point of view, as

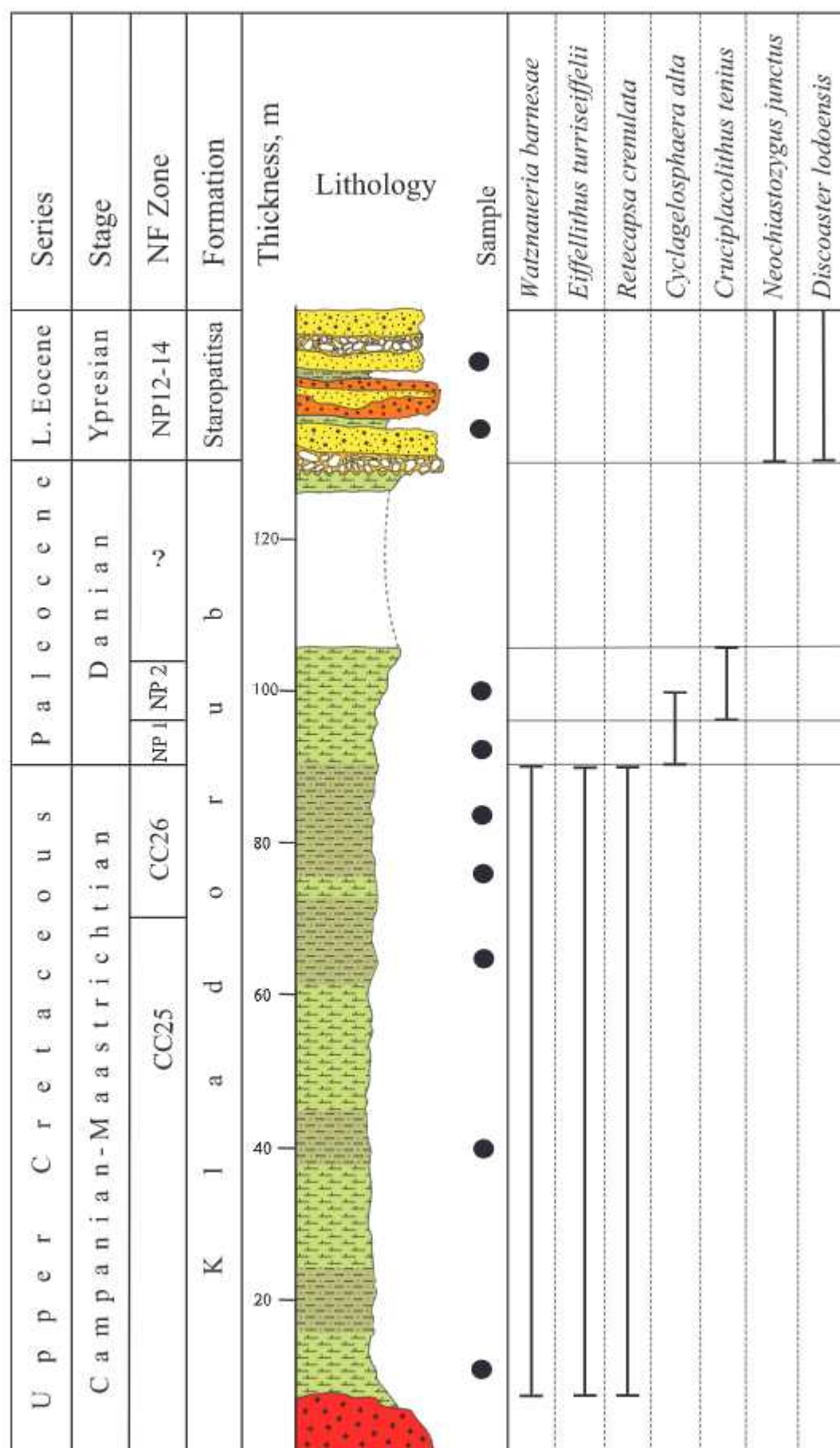


Fig. 5.10. Biostratigraphic subdivision of the Rakovitsa section by calcareous nannofossils



Fig. 5.11. Exposures of the Upper Cretaceous and Paleocene Series south of Moravitsa village, Mezdra area

well as for macrofossils – ammonites, inoceramids and echinoids. A detailed biostratigraphic subdivision by calcareous nannoplankton and the recognition of sequence stratigraphic units within the Maastrichtian and Danian was carried out by Stoykova and Ivanov (2002b, 2004a).

The sediments of the Darmantsi Fm (glauconitic sandstones), the Kunino Fm (limestones packed with *Inoceramus* shells) and the Mezdra Fm (limestones with chert nodules and whole beds of chert) are cropping from the bottom to the top. The total thickness is around 70 m, 30 m of which fall within the Upper Cretaceous and 40 m – in the Paleocene (Danian Stage, Fig. 5.11).

The lower portions of the Mezdra Fm are represented by micritic limestones with chert nodules and three thin ash layers (Fig. 5.12). Above these, with a sharp and uneven boundary, a packet of sediment occurs, formed during an underwater slump (5-6 m thick). This slumped interval is traced and identified in the Upper Maastrichtian part of all of the sections studied in the Mezdra region and acts as a marker, noting a regional event (Fig. 5.13). Its upper boundary is flat and covered by a packet of thin-bedded fine-grained limestones, interbedded with chert layers. The uppermost parts of the Maastrichtian are represented by a relatively thick bed (0.5-0.8 m) of massive bioclastic limestone that contains intraclasts of micritic limestone. The upper bed surface shows signs of scouring/wash-out.

The interval around the K/T boundary is composed of clayey limestones and grey silty marls with 2 cm dark-grey clayey layer included (Fig. 5.14). Sinnyovsky (1999) reported that increased iridium content is detected in this layer. Above follows a massive 1 m bed of solid micritic limestone with numerous



Fig. 5.12. Lower part of the Mezdra Fm in the section south of Moravitsa village, Mezdra area

chert nodules where no nannofossils were detected.

The upper parts of the Mezdra Fm are built of grey clayey limestones, rhythmically alternating with nodular micritic limestones and thin interbeds of silty marls. A well preserved nannoflora and remains of echinoids were found (Stoykova et al., 2000).

The section at Moravitsa has been interpreted as a relatively shallow-water one, deposited in the shelf environment over the carbonate ramp (Stoykova & Ivanov, 2004a).

Biostratigraphy. The results from the detailed biostratigraphic analyses of nannofossils and the subdivision of the section are shown in Fig. 5.15. Species diversity is relatively poor and preservation varies from poor to medium, improving in the Paleocene portion of the Mezdra Fm. A total of 47 species have been identified and 2 of the samples immediately above the K/T boundary are barren (Mo-14 and Mo-15).



Fig. 5.13. Slump interval in the upper parts of the Maastrichtian in the section south of Moravitsa village, marking a regional tectonic event



Fig. 5.14. The K/T boundary in the Moravitsa section, marked by dark grey clayey bed; Mezdra Formation

Representatives of the pentalites – *Braarudosphaera* and *Micrantholithus* that are assumed to indicate shallow-water environments (shelf zone or edge of the slope; Perch-Nielsen, 1985a) are the most abundant and diverse in the Moravitsa section. The species *Micrantholithus* spp., *Braarudosphaera bigelowii*, *B. turbinea*, *B. discula* are commonly observed in the boundary interval and in the Paleocene portion of the section.

Several breaks of sedimentation have been detected

at the boundaries of CC24/CC25a, within CC25 and CC25c/CC26b nanofossil zones. These have been interpreted as boundaries of third-order sequences (Stoykova & Ivanov, 2004a).

The K/T boundary clay layer contains predominantly Cretaceous nanofossil species, as well as some representatives of so called “survivor” species. However, the species *Cyclagelosphaera alta*, considered to be one of the first newly evolving species at the very beginning of the Paleocene, is also detected in the boundary clay layer.

The nanofossil association of the first Danian zone NP1 is exceptionally poorly represented by rare (reworked?) Cretaceous species and *Biantholithus sparsus* as well as sporadic *Markalius inversus* and *M. apertus*. The FOs of *Crucioplacolithus intermedius* and *C. tenuis* at around +6.00 m defines the lower boundary of NP2 zone. *Prinsius dimorphosus*, *Prinsius tenuiculum* and *Ericsonia subpertusa* appear within that zone. The FOs of *Crucioplacolithus asymmetricus* and *Chiasmolithus danicus* at around +25.00 above the K/T boundary proves the presence of NP3 zone in the uppermost portions of the exposed sequence.

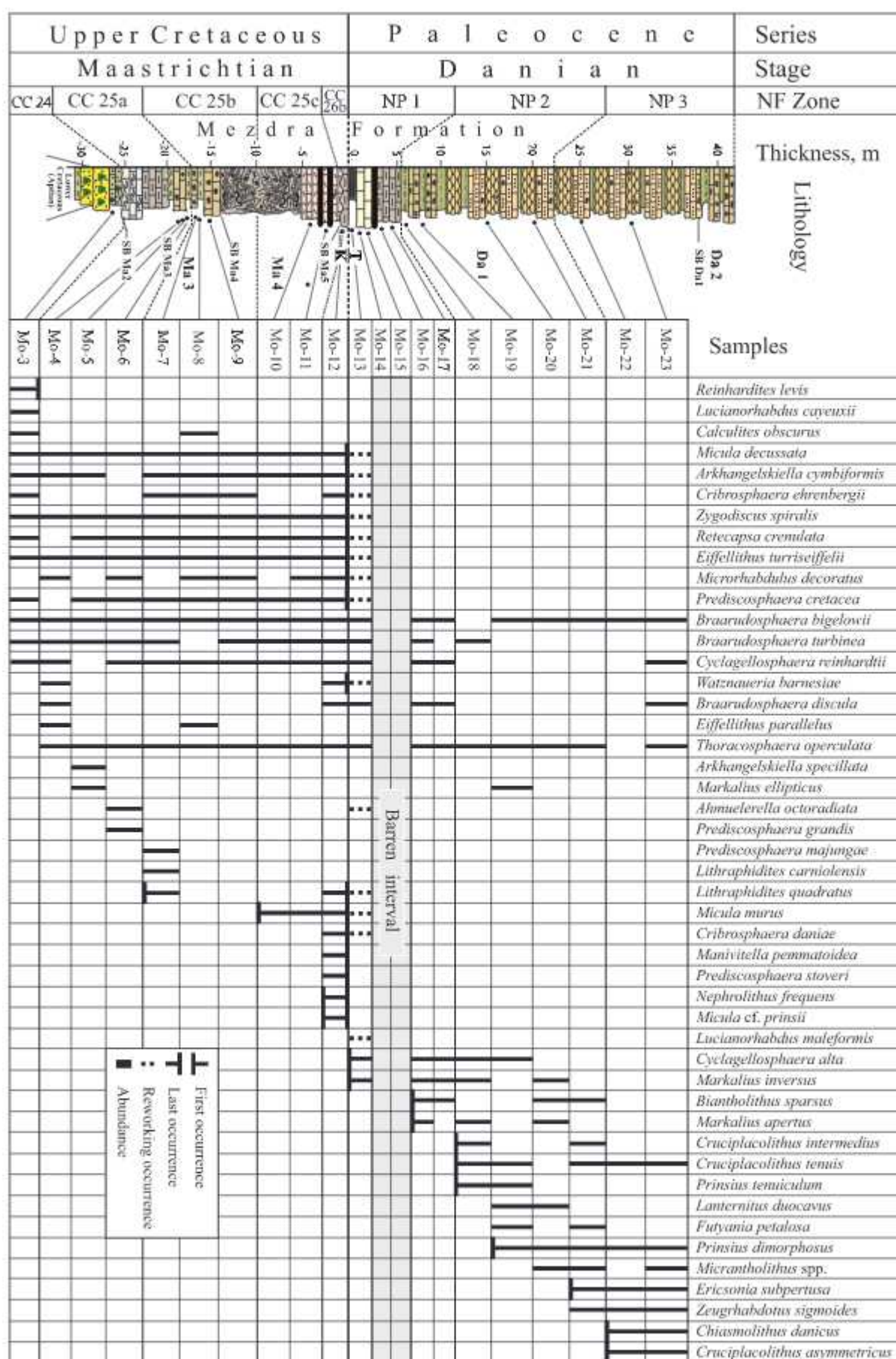
Stratigraphic range. The range of the section at Moravitsa village is Upper Cretaceous (Maastrichtian) – lower Paleocene (Danian, zone NP3).

Mezdra

The studied section is located immediately south of Mezdra town and is followed along the cutting on the Sofia-Mezdra highway (opposite the swimming pool – Fig. 5.16). The section has been analysed by Stoykova et al. (2000) with respect to tracing the K/T boundary, but due to the poor exposures of certain intervals, the location of the boundary is not precisely fixed.



Fig. 5.16. Exposures of the Upper Cretaceous and Paleocene Series south of Mezdra (at the swimming pool); Mezdra Formation



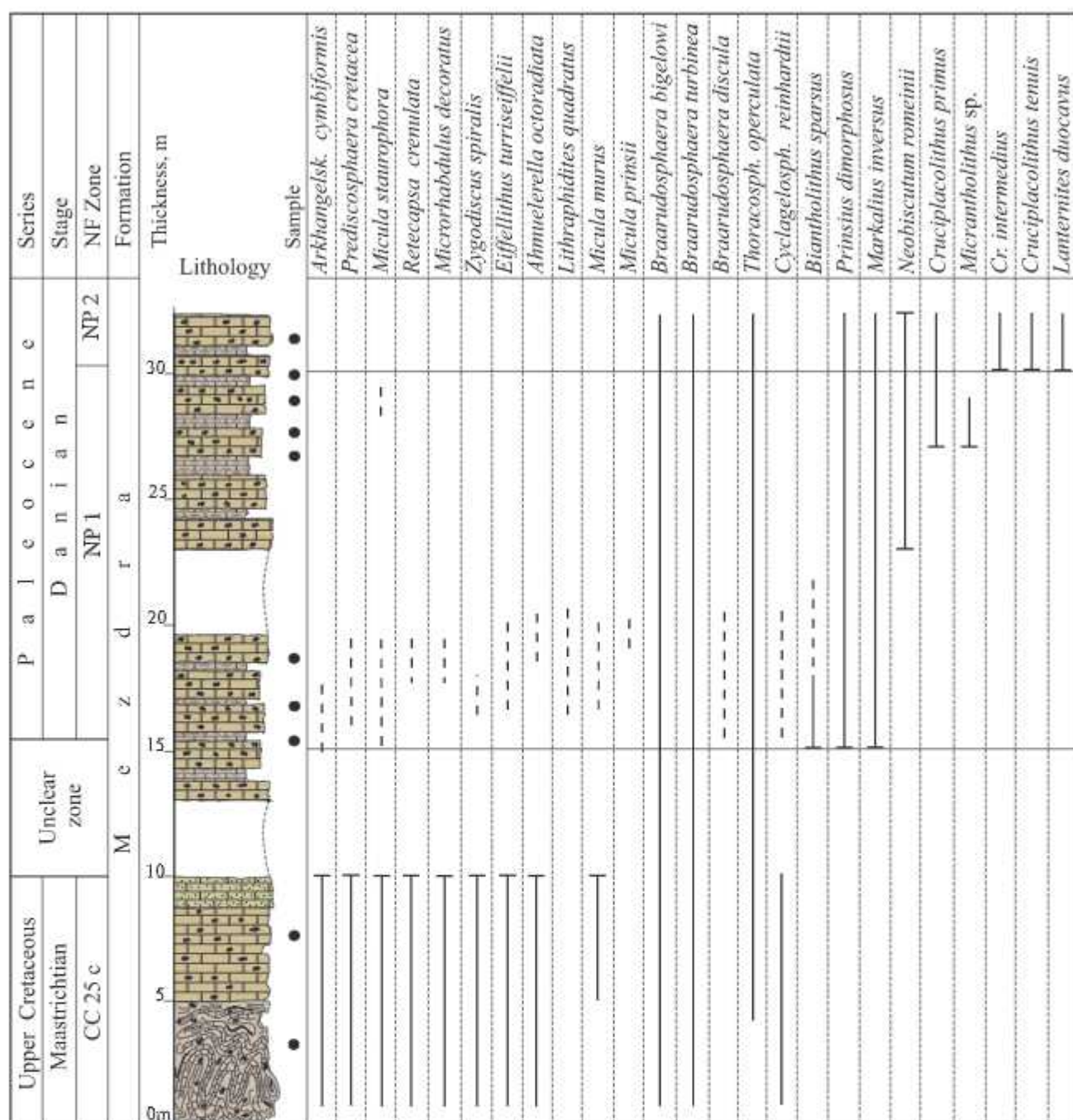


Fig. 5.17. Biostratigraphic subdivision of the section south of Mezdra (at the swimming pool) by calcareous nannofossils

The succession is around 50 m thick, comprising the sediments of the Mezdra Formation – uppermost parts of the Maastrichtian and base of the Danian. These are built of light-beige to whitish clayey limestones, alternating with marlstone packets. Clearly expressed in both this section and the other Mezdra sections is the sedimentological event marker – the slumped interval in the uppermost part of the Maastrichtian (in zone M. murus, Fig. 5.18).

Biostratigraphy. The biostratigraphic study of the nannofossils resulted in reliable identification of the zones CC25c *Micula murus* in the Maastrichtian and

NP1 and NP2 in the Danian stage. The difficult accessibility and poor exposure hampered the precise tracing of the zonal boundaries. The subdivision of the section is shown in Fig. 5.17.

Over 30 species have been identified and the pentalites are commonly observed here, too. The Upper Cretaceous part of the section contains *Lithraphidites quadratus* and *Micula murus*, whereas the index species for the last zone of the Upper Maastrichtian – *Micula prinsii* is found reworked in the Paleocene sediments of NP1 zone.



Fig. 5.18. The slumped interval in the upper part of the Maastrichtian in the section south of Mezdra (at the swimming pool); Mezdra Formation

The lowermost parts of the Paleocene is proved by the relatively diverse and abundant nannofossil association of NP1 zone, that comprises *Biantholithus sparsus*, *Prinsius dimorphosus*, *Cruciplacolithus primus* and *Neobiscutum romeinii* (along with re-worked Cretaceous taxa).

The NP1/NP2 boundary is traced by the FO of *Cruciplacolithus intermedius* and *C. tenuis* in the uppermost portions of the studied section.

Lyuti dol

Situated at the southern end of Lyuti dol village, in the road cut of the Sofia-Mezdra highway, this section has been investigated by Stoykova et al. (2000) to identify the K/T boundary and in trying to subdivide third-order sequence stratigraphic units.

The section at the northern end of the village, along the right bank of the Klisurska River, was described by Sinnyovsky and Christova-Sinnyovska (1993) who introduced the Lyuti dol Fm and also by Sinnyovsky (2001b). The Paleocene sediments of the autochthonous part under the Lyuti dol thrust were assigned to the Limestone formation (Sinnyovsky, 2001b)

Overall, the thickness of the studied succession is around 30 m. The Mezdra Fm here is represented by grey, thin-bedded clayey limestones with cherts, alternating with thin marlstone intercalations (Fig. 5.21). The slumped interval – the event marker in the uppermost portion of the Maastrichtian, is observed here as well (Fig. 5.22). The uppermost parts consist of thick-bedded, coarse-grained organogenic limestones referred to the Limestone formation. Carbonate breccias of the Lyuti dol Fm are thrust over the Limestone



Fig. 5.19. Section of the Upper Cretaceous and Paleocene Series south of Lyuti dol village, Mezdra area; Mezdra Formation



Fig. 5.21. Thin-bedded limestones of the Mezdra Fm south of Lyuti dol village, Mezdra area; Mezdra Formation

rence of the species *Biantholithus sparsus*, *Prinsius dimorphosus* and *Cruciplacolithus primus*, support the age assessment to the lowermost Paleocene NP1 zone. The zone NP2, proved by the identification of *Cruciplacolithus intermedius*, *C. tenuis*, *Futyania petalosa* and *Ericsonia subpertusa*, occurs above the NP1 zone, probably again after a short break (a wash-out) (Fig. 5.20). No nannofossils have been found in the Limestone formation samples.

Stratigraphic range. The range of the section south of Lyuti dol is Upper Maastrichtian – Lower Danian, CC25? – NP2 zones.

Several sections in the Lukovit area have been studied at the villages of Rumyantsevo, Petrevene, Todorichene, Dermantsi, Aglen, Golyama Brestnita – Daben and in the vicinity of Lukovit and Ugarchin towns. However, only two of them are presented here – near Rumyantsevo village and in the gully between Golyama Brestnitsa and Daben villages. Three Formations were introduced in the siliciclastic succession of the Paleogene in the Lukovit Depression: Petrevene, Lukovit and Ugarchin Fms (Aladjova-Hrischeva et al., 1991).

Rumyantsevo

The section is located at the south-western end of Rumyantsevo village, outside of the main road to Lukovit. The outcrops are exposed along the gullies that transect the hill north-west of the village. Its upper parts are well exposed in a cross-section along the Rumyantsevo-Lukovit railway line, at Todorichene railway station.

The section was studied by Aladjova-Hrischeva (1979)

and Aladjova-Hrischeva et al. (1991).

The lower parts of the section are built of grey-colored to greenish siltstones, sandy and clayey marlstones (Belyanska Member of the Petrevene Fm) that lie unconformably over Upper Cretaceous limestones. Above these follow coarse-clastic sediments – medium-grained polymictic sandstones of the Petrevene Fm. They are medium-bedded, greenish-brown to grey, with lens-like interbeds of coarse-grained sandstones and gravels and are interbedded with thin layers of clayey siltstones, marlstones and clayey sands. The nannofossil samples have been taken from the softer clayey interbeds.

The middle and upper parts are represented by a marlstone packet (Aglen Member) and a rhythmic alternation of thin-bedded sandstones, siltstones and clayey



Fig. 5.22. The slumped interval in the upper part of the Maastrichtian in the section south of Lyuti dol village, Mezdra area; Mezdra Formation

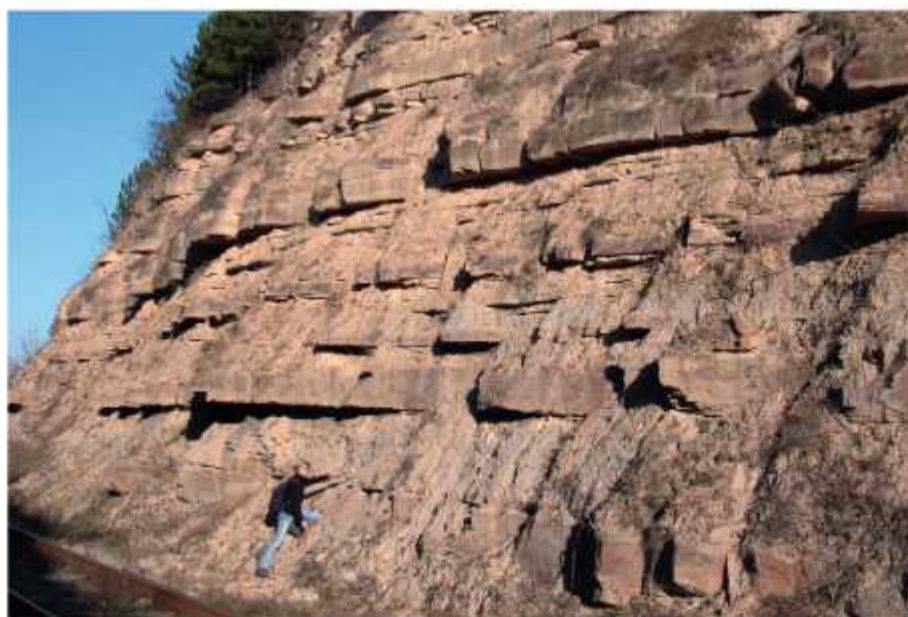


Fig. 5.23. Rhythmic alternation of thin and medium-bedded turbidites in the Lukovit Fm

marls, interpreted as turbidites and referred to the Lukovit Fm (Fig. 5.23). Thicker sandstone beds are observed as well, mainly in the middle parts of the turbiditic cyclicity.

Biostratigraphy. The analysis of the nannofossil associations recovered from almost all lithologies allowed subdivision of three zones – NP12, NP13 and NP14a (the middle and upper parts of the lower Eocene – Ypresian Stage). The abundance and preservation of the nannoflora varies from rare and poorly preserved in the coarse-grained sediments (siltstones) to rich and very well preserved in the clayey-marly sediments. Over 60 species of calcareous nannofossils have been identified, but Fig. 5.24 shows only those of crucial importance for tracing the biostratigraphic boundaries of the zones.

The lower parts of the section refer to the nannofossil zone NP12. The zone is proved by the co-occurrence of *Tribrachiatus orthostylus* and *Discoaster lodoensis* – the former making its last occurrence (LO) and the latter appearing (FO) in this zone. The lower boundary of NP13 zone is traced by the extinction of *Tribrachiatus orthostylus* and *Sphenolithus conspicuus*. The nannofossil associations of this zone indicate extensive reworking of Lower Cretaceous and Upper Cretaceous species (g. *Nannoconus*, *Zeugrhabdotus*, *Retecapsa*, *Comusphaera*), probably resulting from the coarse-grained siliciclastic composition of the sediments.

The uppermost parts of the section, pertaining to the Lukovit Fm, are assigned to the last early Eocene zone NP14a. Its lower boundary is clearly traced by the FO of the index species *Discoaster sublodoensis*. I have not detected any middle Eocene nannofossils in

the uppermost parts of the section and, therefore, the statement made by Aladjova-Hrischeva (1979) about the middle Eocene age of the Lukovit Fm is not supported by nannofossil data in this section.

Stratigraphic range. The range of the section, evidenced by nannoflora, is lower Eocene – middle and upper parts of the Ypresian Stage, zones NP12 – NP14a.

Golyama Brestnitsa-Daben

The section starts some 300 m north-east of Golyama Brestnitsa village, Lovech District, and is traced, with some gaps, along the road and in the gully between Golyama Brestnitsa and Daben. The end of the section is within Daben village, after the river bridge, in the rock cut along the road. It has been investigated by Aladjova-Hrischeva (1979) and Aladjova-Hrischeva et al. (1991). The holostratotype sections of the Petrevne, Lukovit and Ugarchin Fms were originally designated in this section (Aladjova-Hrischeva et al., 1991).

The base of the section is composed of bluish-grey, indistinctly bedded clayey marlstones. Their immediate contact with Upper Cretaceous limestones is not well exposed. The marlstones are rather irregularly exposed – mainly in the steep slopes of the gullies (due to the fact that they are quickly covered by soil). Up section, with fast lithological transition, these are followed by fine- to medium-grained sandstones with thin interbeds of siltstones and marls of the Petrevne Fm. Upwards the sandstones become massive, coarse-grained, with a lower Eocene nummulitic fauna detected in single lenses (Aladjova-Hrischeva et al., 1991).



Fig. 5.25. Thick-bedded sandstones with spheroidal weathering and conglomeratic lenses in the section between the villages of Golyama Brestnitsa and Daben, Lukovit area; Lukovit Formation

The middle and upper parts of the section are represented by irregularly alternating thin beds of sandstones, siltstones and marls. Individual horizons reveal matrix-supported conglomerates with unsorted clasts, and others of packs of thick-bedded sandstones with spheroidal weathering (Fig. 5.25) very similar to those of the Sveti Atanas Fm in the East Balkan.

The uppermost portions of the section gradually become predominantly thick-bedded micaceous sandstones with rare interbeds of calcareous clays best displayed within Daben village.

Biostratigraphy. Abundant nannofossil associations recovered from the clays and marls of this section, support its subdivision into four nannofossil zones – NP12, NP13, NP14a and NP14b (Fig. 5.26).

The nannofossil association of NP12 zone is rich and diverse – abundant *Discoaster lodoensis* and *Tribrachiatus orthostylus*, as well as *Discoaster septemradiatus*, *Chiasmolithus eograndis*, *Helicosphaera lophota* and *Ericsonia formosa* are recorded. The last occurrence (LO) of *Tribrachiatus orthostylus* along with the first occurrence of *Discoaster broennimanni*, have been used as bio-events for drawing the boundary between the zones NP12 and NP13 in this section.

Very abundant and diverse nannofossil associations are identified in the uppermost parts of the Lukovit Fm and in the basal portions of the Ugarchin Fm as well – just at the entry to Daben village. The concomitant occurrence of *Discoaster lodoensis*, *D. sublodoensis*, *D. kuepperi*, *D. binodosus*, *D. turkyensis* is noted there. Therefore, the sediments are assigned to the uppermost parts of lower Eocene – Ypresian

Stage, NP14a zone.

Discoaster saipanensis was recovered from the highest sample in calcareous claystone, in-between the thick-bedded sandstones from the upper level of the Ugarchin Fm. It indicates the presence of NP14b zone, and, the lowermost part of the middle Eocene (Lutetian Stage).

Stratigraphic range. The section covers the entire lower Eocene, developed in the Lukovit region – middle and upper parts of Ypresian, zones NP12-NP14a and base of middle Eocene (Lutetian), NP14b zone.

5.3. Central parts of the Moesian Platform

The outcrops of Paleogene sediments in the central parts of the Moesian Platform are located along the Vit River with the largest outcrops observed in the vicinity of Pleven town. Single spots are noted in the valley of the Osam River, too, as well as along the Danube River bank at Somovit village (Fig. 5.27).

Numerous sections have been studied in the region of Pleven: at the villages of Sadovets, Krushovitsa, Pertanitsa and Gradina, Kartozhabene, Tarnene, Grivitsa, Yasen, Varbitsa, Opanets, Bivolare, Bozhuritsa, Riben, Komarevo, Kreta, Somovit, Muselievo and Zhernov. Also, samples have been taken from several sections south of Pleven – in Kailaka Park, along the track to the tourist centre, in the large limestone quarry (Kachitsa Mine). All the acquired data has been used in regional stratigraphic interpretations and paleogeographic reconstructions of the geological evolution of the area.

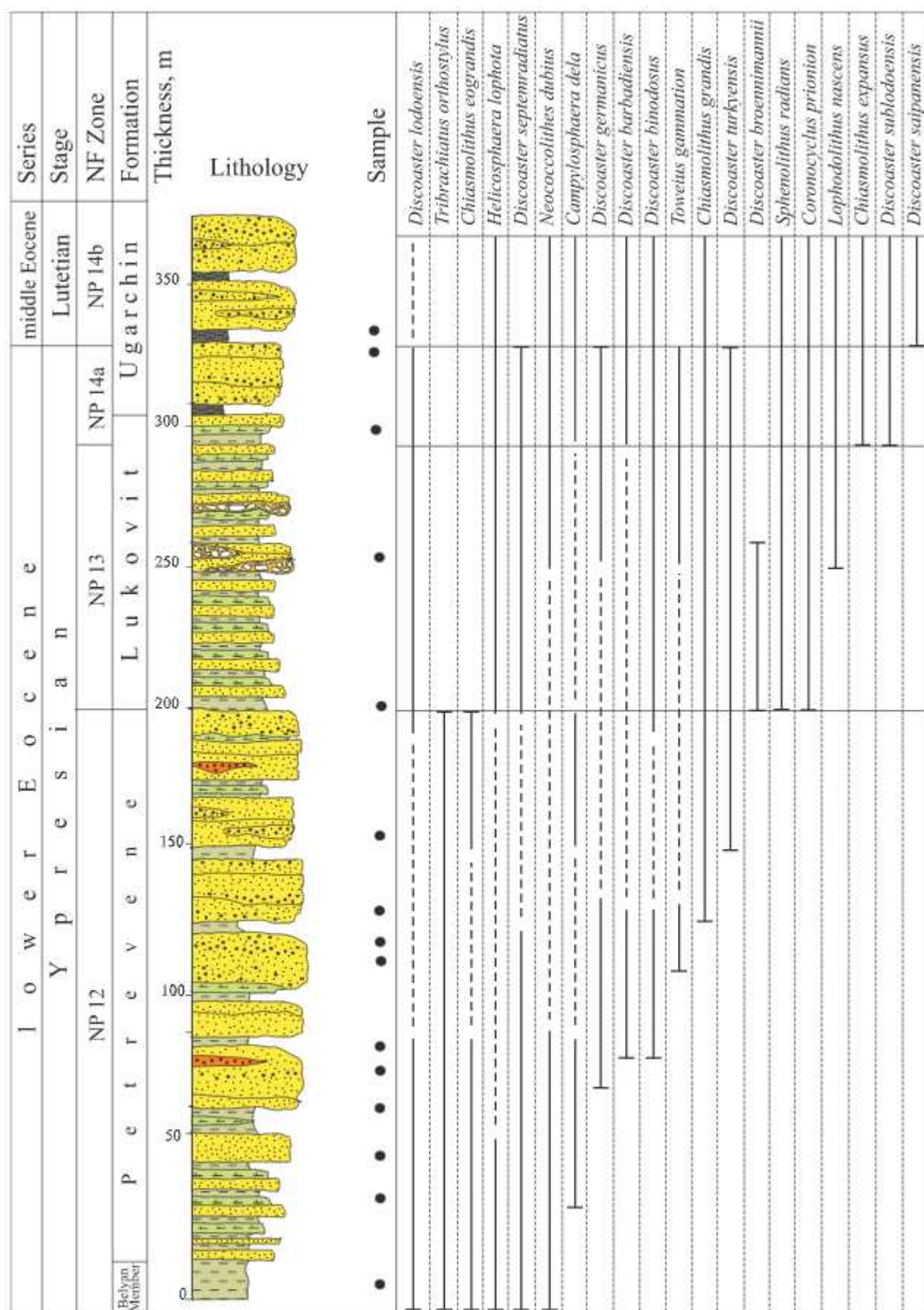


Fig. 5.26. Biostratigraphic subdivision of the section between the villages of Golyama Brestnitsa and Daben, Lukovit area, by calcareous nannofossils



Fig. 5.27. Exposures of the Paleogene sediments in the central parts of the Moesian Platform: 1 – exposures; 2 – locations of studied sections (after Stoykova & Ivanov, 2004b)

Petarnitsa

The section is traced at around 200 m south of the village, along the dirt road, in the small old abandoned limestone quarries (Fig. 5.28).

The outcropping sequence is about 20 m thick, 8 m of which comprises Paleogene rocks and the remaining 12 m represents Upper Cretaceous organogenic limestones of the Kailaka Fm.

The Kailaka Fm is represented by white to creamy, massive thick-bedded organogenic limestones. The upper boundary of the unit exhibits the features of a “hard ground”. The nature of the overlying sediments and their basal contact is unclear due to a lack of suitable outcrops (the first 0.5 m of the Paleogene section).

Upwards, a bank of medium-bedded sandy-silty limestones around 3.5 m thick is developed. Its upper sur-



Fig. 5.28. Section of the Upper Cretaceous and Paleocene Series (Selandian and Thanetian) south of Petarnitsa village, Plevna District, in the old quarries; Kailaka – Komarevo Formations



Fig. 5.29. Two limestone banks with thin marlstone layer in between, marking the MPBE in the old quarries south of Petarnitsa, Plevan District; Komarevo Formation

face is sharp – possibly marking a short-term break in sedimentation. Above the first limestone bank occurs a thin marlstone layer (10-15 cm thick), overlain by a second limestone bank (0.8 m). The section ends with a marlstone packet (over 5.0 m thick) – silty marls with calcareous nodules to siltstones (Fig. 5.29).

Biostratigraphy. The section has been sampled during several field campaigns to achieve 10 cm sampling resolution in order to pinpoint precisely the ages of the sediments. The results of the analysis and range-chart of the identified nannofossil species are shown in Fig. 5.30.

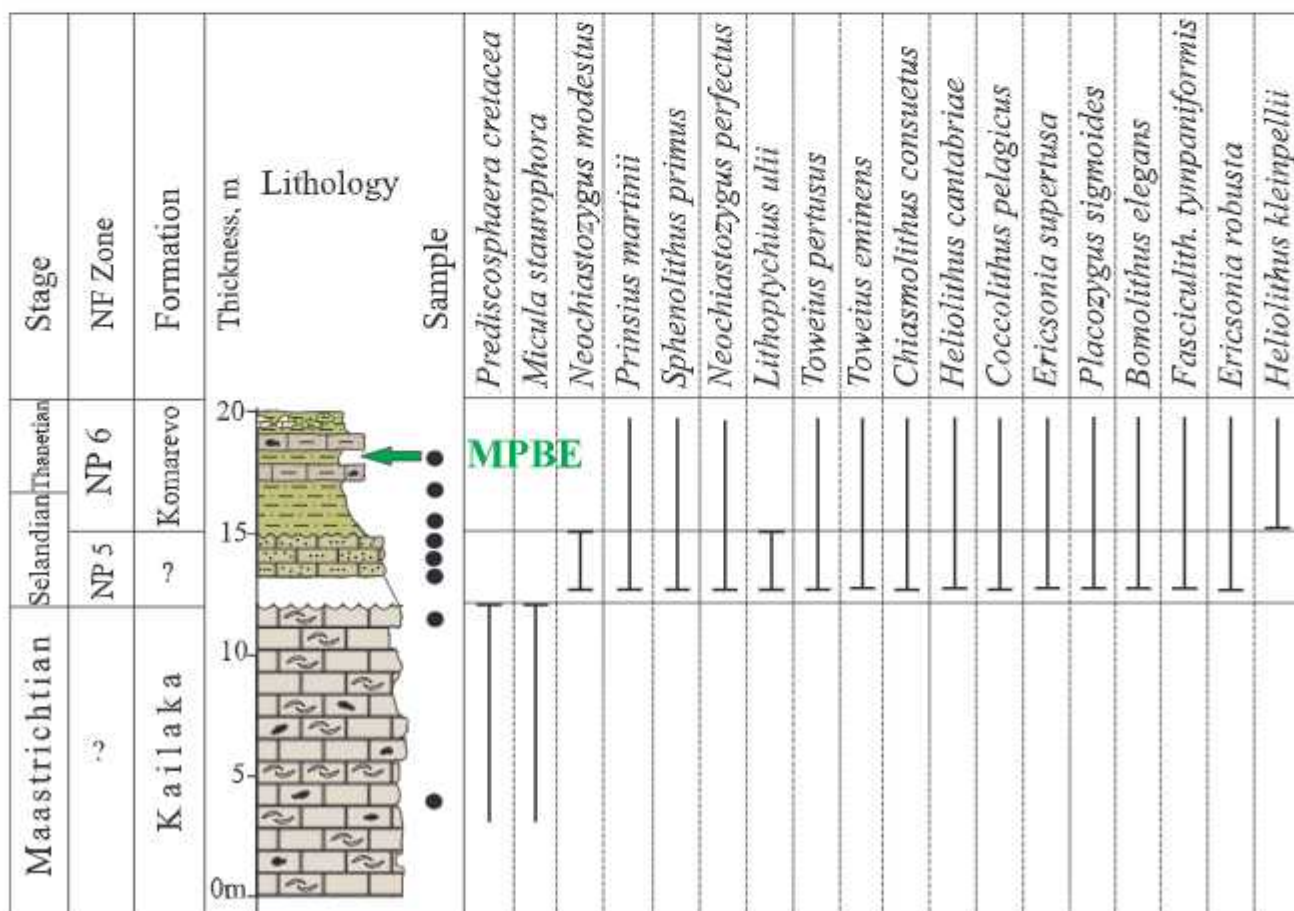


Fig. 5.30. Biostratigraphic subdivision of the section south of Petarnitsa village, Plevan District, by calcareous nannofossils



Fig. 5.31. General view of the succession in the old quarries south of Petarnitsa. Two surfaces are clearly visible: the upper wash-out surface of the Kailaka Fm. (green line); and the marlstone layer marking the MPBE (red line)

The samples from the lower portions of the section (the Kailaka Fm organogenic limestones) reveal poorly preserved nannoflora, referred to the Upper Cretaceous (Maastrichtian).

Several samples from the lower, middle and upper parts of the first limestone bank contain abundant and diverse nannofossil associations, typical for the Selandian zone NP5 – *Fasciculithus tympaniformis*, *Lithoptychius ulii*, *Neochiastozygus perfectus*, *Heliolithus cantabriae*, *Sphenolithus primus* and *Bomololithus elegans* (Fig. 5.30).

The thorough analysis of several samples from the thin marly layer between the two limestone banks indicates that they belong to the nannofossil zone NP6. They contain abundant *Heliolithus kleinpellii*, the first occurrence (FO) of which marks the boundary between the zones NP5 and NP6. Presumably this marly layer between the limestone banks embodies the Middle Paleocene Biotic Event (MPBE). The event has been identified worldwide and is interpreted as an abrupt climatic warming – Bralower et al., 2002; Zachos et al., 2004; Bernaola et al., 2007.

The samples from the uppermost parts of the section contain similar associations, characteristic of zone NP6 (Fig. 5.30).

Stratigraphic range. The Paleogene portion of the section encompasses parts of Selandian and the base of Thanetian, zones NP5 and NP6.

Pleven-Kailaka

The section is located in Kachitsa Quarry, south-east of Pleven, just above the hotel in Kailaka Park. The

exposed portion in the quarry is around 40 m thick, 15 m of which represent the organogenic limestones of the Kailaka Fm (Upper Cretaceous) and the overlying 25 m – the sandy limestones of the Komarevo Fm (approx. 20 m) and the clayey and silty marls of the Avren Fm (approx. 5 m).

A small section displaying the uppermost parts of the Komarevo Fm and its boundary with the overlying Avren Fm is observed in the vicinity of the Touristic centre, close to the public entrance of Kailaka Park. A section exposed above the cave at the Kailaka site, was described by Dachev (1967, 1975).

Everywhere in Central northern Bulgaria, the Kailaka Fm is represented by white to creamy organogenic limestones. These are solid, massive, thick-bedded and contain abundant remains of macrofauna – mainly bivalves, gastropods and echinoids. Above these is a sharp parallel unconformity at the base of a packet of clastic limestones (approximately 1.5 m thick) – calcarenites. Up section, an indistinct boundary and a 0.2 – 0.4 m thick bed of sandy limestones and calcareous sandstones, enriched in glauconite is present. They pass upwards into thin-bedded, grey to creamy colored indurated clayey limestones, enriched (at some levels) with flint nodules and concretions. These sediments belong to the Komarevo Fm.

The uppermost levels in the quarry expose 5-8 m of beige to light-grey colored clayey and silty marls, enriched in glauconite at the base. These are referred to the Avren Fm.

Biostratigraphy. Biostratigraphic subdivision of the section is shown in Fig. 5.32. The nannoflora found in the organogenic limestones of the Kailaka Fm (Maas-

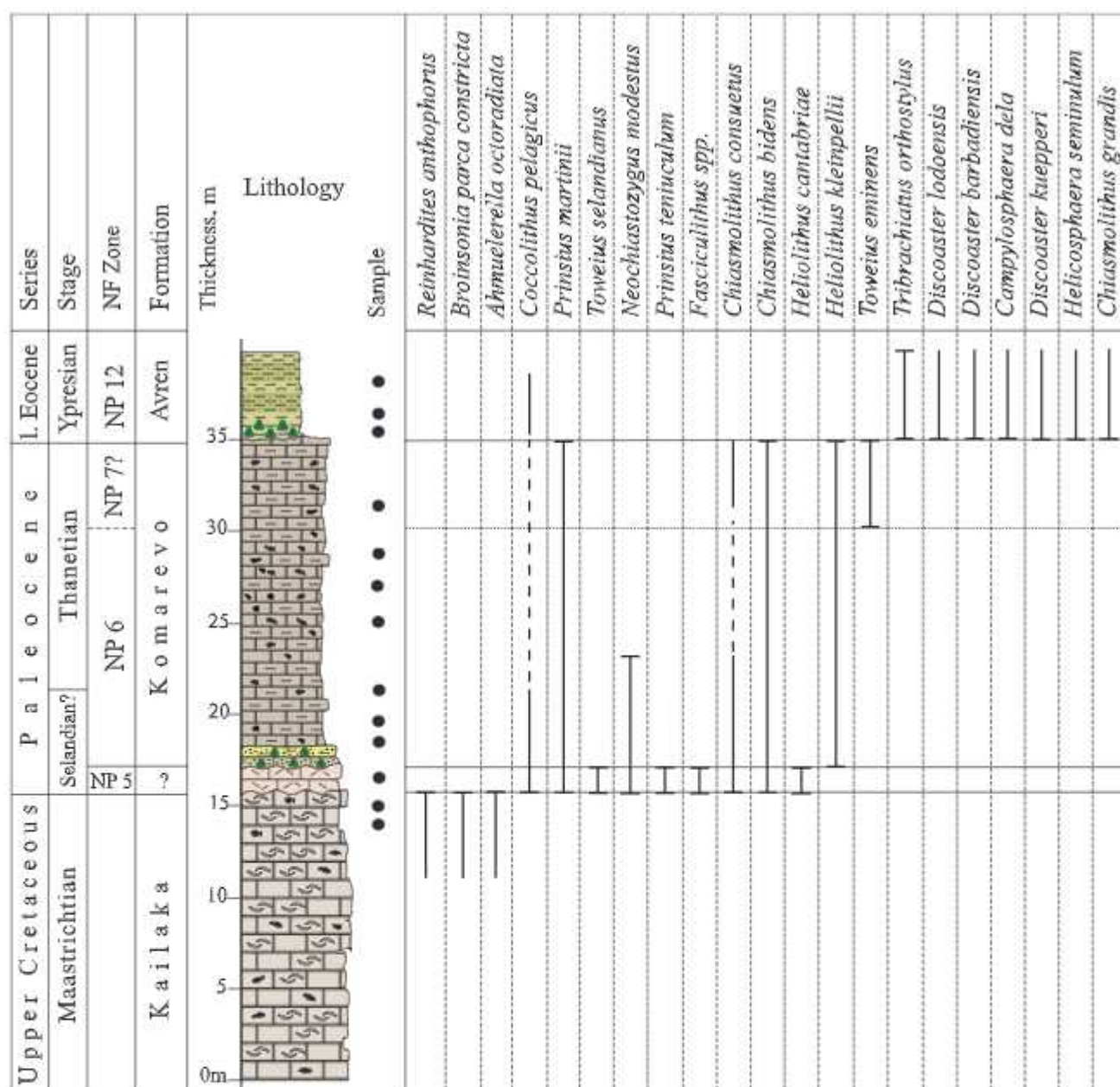


Fig. 5.32. Biostratigraphic subdivision of the section south of Pleven, in the quarry near the hotel and in Kailaka Park, by calcareous nannofossils

trichian part of the section) is rare and poorly preserved, with reworked Campanian and Maastrichtian species. It is worth noting that reworked Campanian species are also often observed in the overlying Paleocene sediments.

Immediately above the organogenic limestones, in the clastic limestone sample (calcarenite), the species *Toweius selandianus*, *Chiasmolithus consuetus*, *Heliolithus cantabriae* and *Prinsius tenuiculum* are identified, indicating the presence of Selandian Stage – zone NP5 in the base of the Paleocene Series in this section. Considering the fact that the lower and upper boundaries of the clastic limestones are unconformities, this body may not be assigned to the Komarevo

Fm and therefore should be traced and interpreted as a separate lithostratigraphic unit.

The nannofloristic content in the Komarevo Fm is characterised by low species diversity and poor preservation. The identified nannofossil assemblage is consistent with a Thanetian age, zone NP6. The species *Heliolithus klempellii* is observed in all analysed samples of this Formation. There is no reliable data to confirm the presence of nannofossil zone NP7, since the zonal index species *Discoaster mohleri* has not been recorded.

The nannofossil content in the marls of the uppermost portions of the section, assigned to the Avren Fm, is

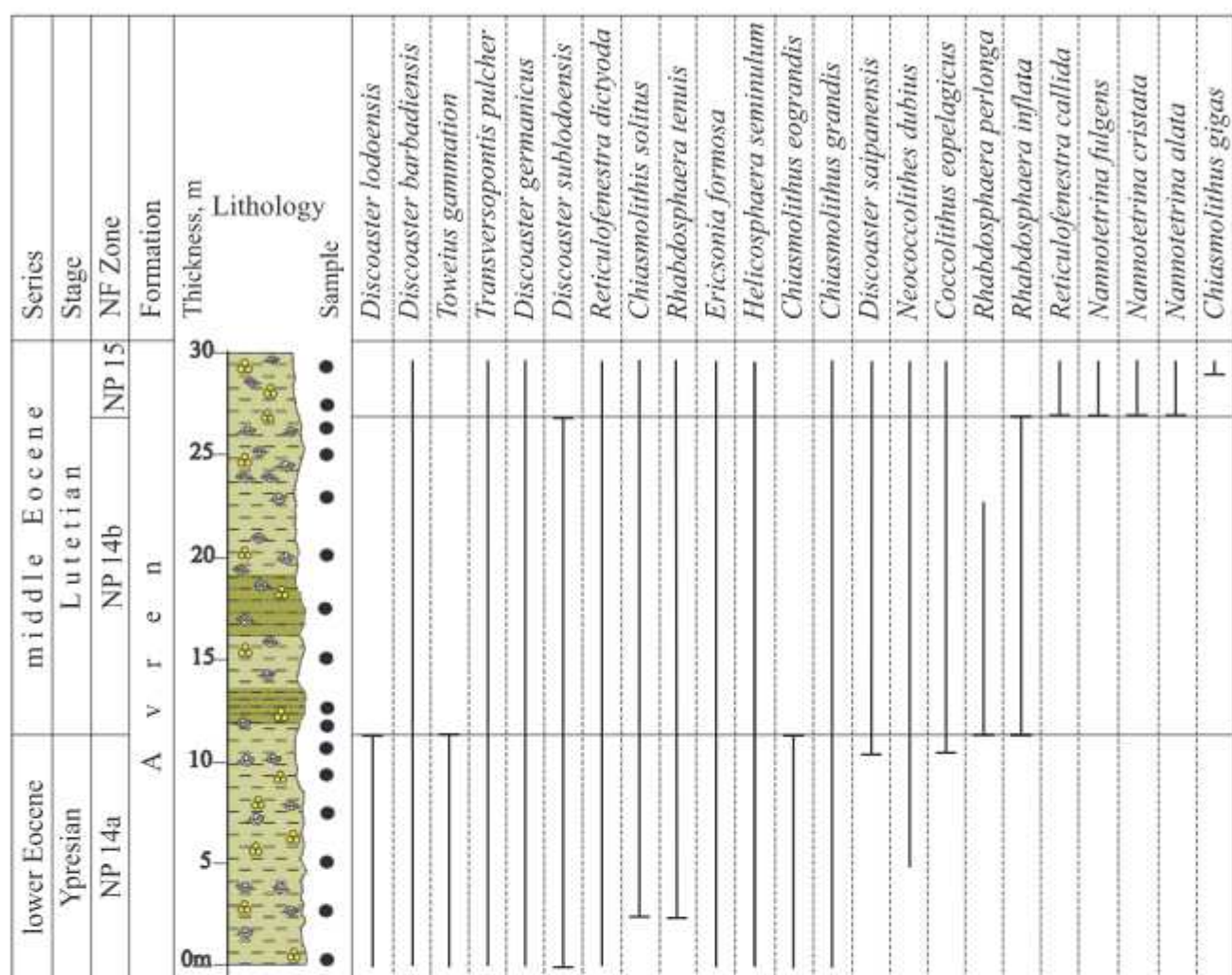


Fig. 5.33. Biostratigraphic subdivision of the section near Yasen village, Plevan District, in the large quarry near the bridge across the Vit River, by calcareous nannofossils

rather abundant and diverse. The documented assemblage is rich and diversified, comprising the species *Discoaster lodoensis*, *D. kuepperi*, *D. barbadiensis*, *D. mirus*, *Tribrachiatus orthostylus*, *Helicosphaera seminulum*, *H. lophota*, *Lophodolichus nascens*, *Campylosphaera dela*, *Toweius gammation* and *Chiasmolithus grandis*. It corresponds to the lower Eocene – Ypresian Stage, nannofossil zone NP12 (Fig. 5.32).

Stratigraphic range. The Paleocene portion of the section probably encompasses parts of the Selandian Stage, zones NP5 and NP6, as well as the lowermost parts of the Thanetian Stage, zone NP6. The lower Eocene portion (Avren Fm) includes the middle parts of the Ypresian Stage, zone NP12.

Yasen

The section is located in the large marlstone quarry, east of Yasen village, Plevan District, close to the bridge on the Vit River.

Around 30 m of massive to indistinctly bedded marlstones are exposed, silty and sandy in particular levels. These are solid and compact, grey-bluish or dark-grey on fresh surfaces losing color where weathered. They contain coalified plant remains, pyrite concretions as well as nodules and imprints of macrofauna – mainly mollusks. They are assigned to the Avren Fm (Filipov et al., 1995c).

Biostratigraphy. The section at the quarry has been sampled at 2–3 m resolution and all samples contain rich, perfectly preserved nannofossil associations. The subdivision of the section is presented in Fig. 5.33. The first 12 m at the base of the quarry are referred to the zone NP14a differentiated on the concurrent occurrence of *Discoaster sublodoensis* and *Chiasmolithus eograndis*. The occurrence of the first species (FO) defines the lower boundary, and the extinction of the second (LO) – its upper boundary.

Similar stratigraphic levels of the Avren Fm (NP14a) are indicated in the adjacent section at Tarnene village.

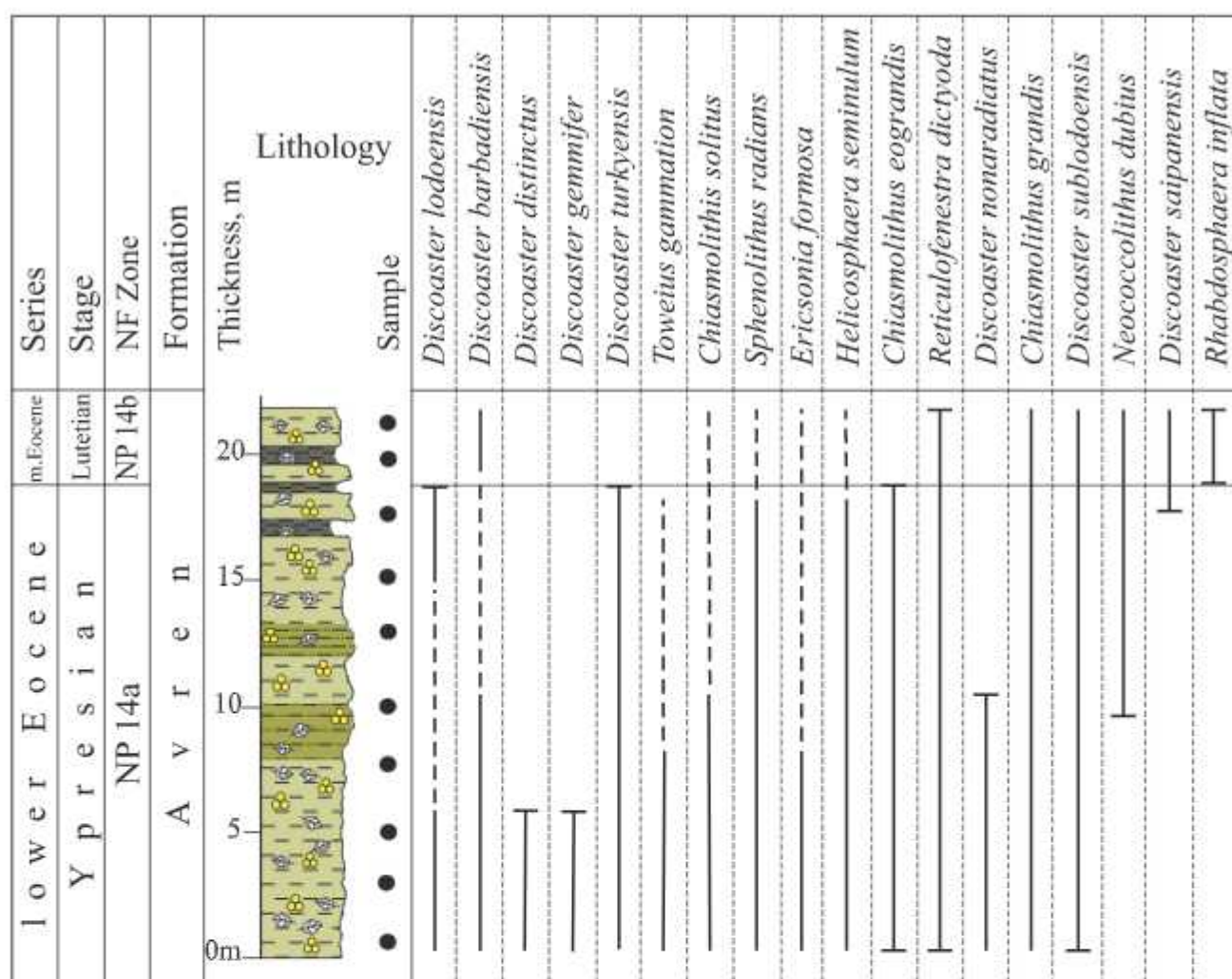


Fig. 5.34. Biostratigraphic subdivision of the section near Bivolare village, Pleven District, by calcareous nannofossils

The middle and upper parts of the section are assigned to the zone NP14b based on the total range of the species *Rhabdosphaera inflata* (abundant in all samples). The zone is located at the base of the middle Eocene, Lutetian Stage. Therefore, the section encompasses the lower/middle Eocene boundary (Ypresian/Lutetian Stage) drawn only on biostratigraphic criteria. The section is monotonous and the lithology of the sediments does not change substantially at the boundary.

The uppermost several metres are assigned to the next zone in the middle Eocene, NP15. The boundary between zones NP14b and NP15 is traced by the extinction (LO) of *Rhabdosphaera inflata* and *Discoaster subloboensis* as well as by the appearance (FO) of a number of species of genus *Nannotetrina* – *fulgens*, *cristata* and *alata* (Fig. 5.33).

Stratigraphic range. Uppermost parts of lower Eocene (Ypresian), zone NP14a to the lower parts of middle Eocene (Lutetian), zone NP15.

Bivolare

The section is observed on the right bank of Vit River, on the hill slope north of the village, close to the gypsy quarter.

Here, the marly sediments of the Avren Fm are exposed, in a similar manner to the previous section at Yasen. They are light-grey to light-beige and creamy in color. The uppermost levels are built of clayey marlstones and calcareous clays, besides the calcareous component containing mainly nannofossil skeletons. The total thickness of the exposed sequence is around 20 m.

Biostratigraphy. The section has been carefully sampled to pinpoint the position of the lower/middle Eocene boundary (between zones NP14a and NP14b). The biostratigraphic subdivision of the section is shown on Fig. 5.34. The outcropping sediments contain abundant and diverse fossil nannoflora, typical of the uppermost level of the lower Eocene and the base



Fig. 5.35. General view of the type section of the Bozhuritsa Fm in the old quarry SW of Bozhuritsa, Pleven District, on the right bank of the Vit River

of the middle Eocene. Two subzones of NP14 zone are recognised – NP14a (uppermost parts of the Ypresian) and NP14b (lowermost parts of the Lutetian); the lower/middle Eocene boundary is drawn between them. Biostratigraphically the boundary is traced by the last occurrences (LOs) of *Discoaster lodoensis*, *Chiasmolithus eograndis* and *Discoaster turkyensis* as well as by the FO of *Rhabdosphaera inflata*. The last bioevent was preceded by an earlier appearance of *Discoaster saipanensis* in this section. In the Yasen section these two species appear simultaneously and mark the lower boundary of subzone NP14b.

A nannofossil association, characteristic for the subzone NP14b is registered in the uppermost portions of the section, with abundant specimens of *Rhabdosphaera inflata*, along with *Chiasmolithus grandis*, *Reticulofenestra dictyoda*, *Discoaster sublodoensis* and *D. saipanensis*. Here, as in the Yasen section, the biostratigraphic data support the presence of a continuous transition between the lower and middle Eocene.

Stratigraphic range. Uppermost parts of the lower Eocene (Ypresian Stage), subzone NP14a to the lowermost parts of the middle Eocene (Lutetian Stage), subzone NP14b.

Bozhuritsa

The section is located on the right bank of Vit River, south-west of Bozhuritsa village, Pleven District. It is traced in the old quarry and the road cut on the dirt road along the river to the hill slope.

The section was studied and described by Dachev (1967, 1975) designating it as type section of the

Bozhuritsa Fm. The Komarevo, Bozhuritsa, “Beloslav” and Avren Fms are exposed (Fig. 5.35).

The uppermost levels of the Komarevo Fm are exposed on the right bank of the Vit River, east of the bridge at the entrance to the village (Fig. 5.36) and are represented by alternating light-beige poorly lithified silty limestones and marlstones with rare chert nodules.

The boundary between the Komarevo and Bozhuritsa Fms was not observed. Well exposed, however, are the grey-colored marls with flint nodules of the Bozhuritsa Fm, around 20 m thick. The flint nodules are particularly abundant in the lower levels (approximately the first 10 m). Upwards, these become sporadic and almost disappear. The clastic component in the marlstones visibly increases in the uppermost levels (the last 3 m) and these turn into silty to sandy marls, even to typical mixed rocks (hyporocks). Increased saturation of glauconite and ferruginous hy-



Fig. 5.36. Upper portion of the Komarevo Fm at the entrance to Bozhuritsa village, Pleven District



Fig. 5.37. Sharp lithological boundary between the Bozhuritsa Fm below (mixed hypo-rocks) and the “Beloslav” Fm above (*Ostrea*-level, with yellow tape) in the Bozhuritsa section, Pleven District

droxide concretions is also observed in the last metres of the Bozhuritsa Fm. An horizon containing round and elongated ferruginous concretions is located exactly 1.2-1.3 m below the *Ostrea* level.

The *Ostrea* layer is bounded by a sharp basal boundary. This shelly bed contains numerous valves of the bivalve mollusk *Ostrea* in a glauconite-sandy matrix (the so called “*Ostrea* level”, “shelly marker” etc.). The bed also contains some rounded clasts (5-10 cm in size) of volcanic and metamorphic rocks. The glauconite content is very high, giving the bed a dark-green color. The *Ostrea* level is 8-10 cm thick (Fig. 5.37).

Up section, the *Ostrea* level is overlaid by glauconitic sandstones and calcareous-glauconitic marls, 0.5-0.6 m thick. These are weakly cemented and poorly consolidated, gradually passing into glauconitic marls, light-beige to greenish, about 1 m thick. The calcareous-sandy sediments with glauconite and the *Ostrea* level are assigned to the “Beloslav” Fm (Fig. 5.37) (Stoykova & Ivanov, 2004b, 2005).

Above them, through a gradual transition, light-grey to whitish thin-bedded siltstones and clayey marlstones occur, referred to the Avren Fm. These occupy the uppermost portions of the section and the exposed thickness is around 10 m. The cover of the section consists of loess sediments (2-3 m in thickness), preserved only in some of the old quarries in the south-west end of the village.

Biostratigraphy. The section in the quarry has been sampled regularly at 1-2 m resolution, and all samples contain rich, perfectly preserved nannofossil associations. In order to identify the chronology of the different events around the Paleocene/Eocene boundary,

the sampling resolution has been increased to 5 cm intervals in the uppermost parts of the Bozhuritsa Fm near its boundary with the *Ostrea* level (above and below it). Abrupt impoverishment, in terms of the preservation of nannofossils, is observed only within or around the ferruginous hydroxide-rich interval, 1.2 m below the *Ostrea* horizon.

The subdivision of the section is shown in Fig. 5.38. A total of 78 species have been identified, but the figure displays only the ranges of some key stratigraphic taxa.

The lowermost levels of the sequence correspond to the NP7 zone, since *Discoaster mohleri*, *Fasciculithus tympaniformis* and *Chiasmolithus bidens* co-occur there.

The sediments of the lower and middle parts of the Bozhuritsa Fm contain an abundant association, characteristic of nannofossil zone NP8. In addition to the index species *Helicolithus riedelii* it comprises also *Discoaster drieri*, *Helicolithus cantabrigiae*, *H. universus*, *Bomolitus elegans* and many more. A bioevent of potentially high stratigraphic value is observed in the middle part of this zone – the first occurrence of the species *Discoaster protomultiradiatus* Wei, 1998 (Fig. 5.38). The FO of this species is tracked in nearly all sections of the upper Paleocene (Thanetian Stage) in Bulgaria and might be a useful biohorizon for a more detailed subdivision of the zone. The upper parts of NP8 zone display also a specific group of representatives of the genus *Fasciculithus* – *tonii* and *shaubii* (the so-called “*Fasciculithus richardi* group” – Agnini et al., 2014).

The lower boundary of NP9 zone is traced by the first occurrence and abundant development of *Discoaster*

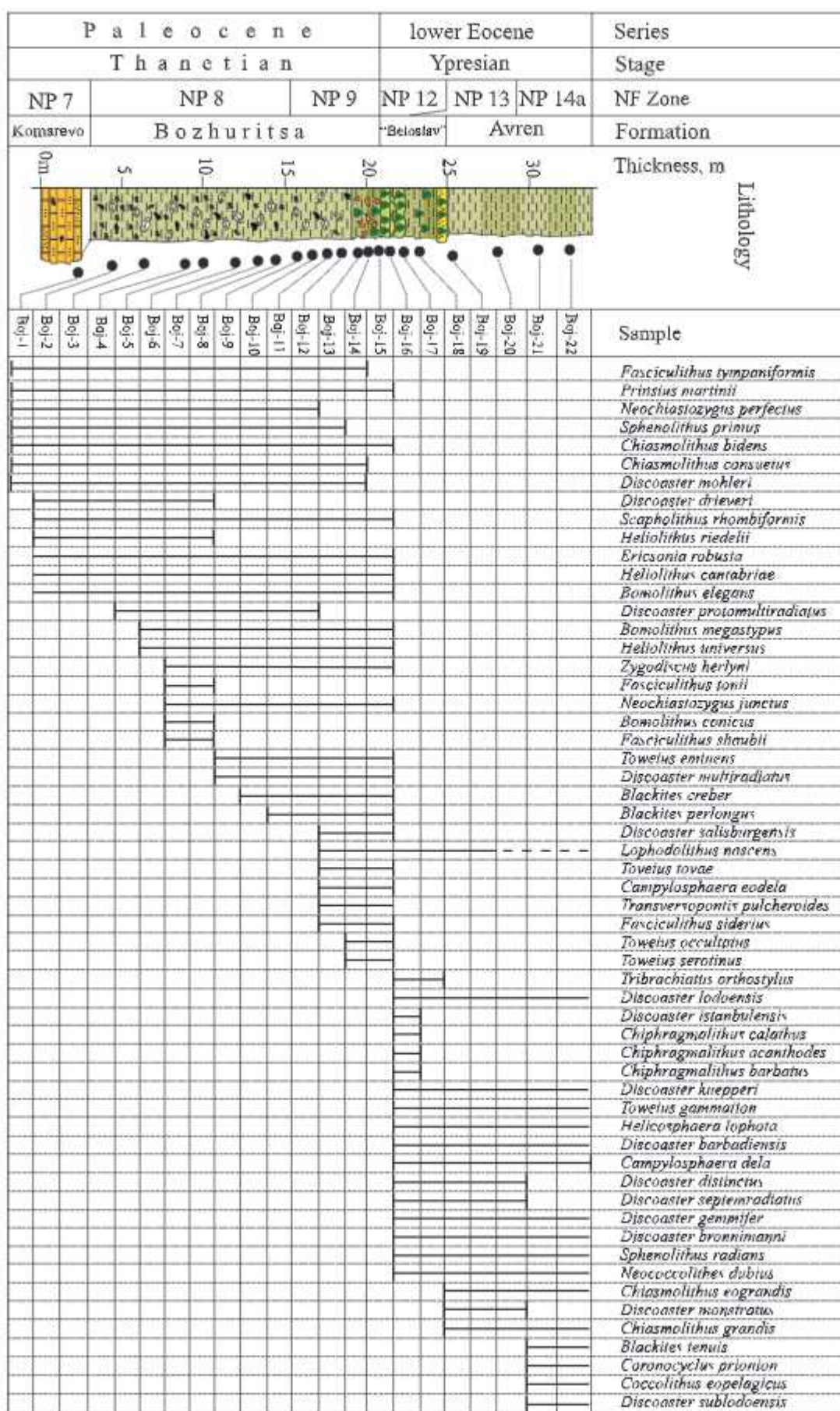


Fig. 5.38. Biostratigraphic subdivision of the section near Bozhuritsa village, Pleven District, by calcareous nannofossils



Fig. 5.39. Upper portions of the Bozhuritsa Fm, consisting of mixed hypo-rocks in the section at Riben village, Pleven District

multiradiatus. Representatives of the rhabdoliths – genus *Blackites* (*creber* and *perlongus*) also appear with this species and are common. It should be noted that these are not observed anywhere in the lower levels of the Paleocene section. Their initial occurrence and evolutionary origin took place within this zone (NP9), later becoming common components in lower Eocene associations.

The evolutionary appearance of several new species is recorded in the upper parts of NP9 zone – *Campylosphaera eodola*, *Lophodolichus nascens*, *Transversopontis pulcheroides*, *Fasciculithus siderius* and *Discoaster salisburgensis* have their FOs. These bioevents may also be successfully used for more detailed subdivision of the zone.

The Bozhuritsa section displays one of the most complete sedimentary records of NP9 zone in Central northern Bulgaria, comparable with the one at Kladorub section.

The uppermost part of NP9 zone (Thanetian) is truncated by NP12 zone (the *Ostrea* level). There is a sharp unconformity at the base of the Eocene here. A very rich and abundant association consisting of

Discoaster lodoensis, *D. kuepperi*, *D. istanbulensis*, *D. distinctus*, *D. septemradiatus*, *Tribachiatus orthostylus* and other species confirms the lower Eocene NP12 zone. Representatives of the rare genus *Chiphragmalithus*: *C. calathus*, *C. barbatus* and *C. acanthodes*, are identified only in this section. The genus is known with its short range in the middle of NP12 zone (Fig. 5.38).

The boundary between zones NP12/NP13 is marked by the LO of *Tribachiatus orthostylus*. Moreover, it is worth noting that the zonal association of NP13 includes also the rare *Discoaster monstratus* besides the commonly observed species.

The lower boundary of NP14a zone is fixed by the FO of *Discoaster sublodoensis*. It is present in the upper portion of the Avren Fm marls where *Discoaster lodoensis*, *Blackites tenuis* and *Coronocyclus prionion* co-occur with the zonal index species.

The sediments of the zone NP14a (Avren Fm) are covered by loess, therefore these are the highest preserved levels of the marine sequence in this section.

Stratigraphic range. The section encompasses the entire Thanetian Stage, zones NP7 to NP9 and the upper parts of the Ypresian Stage, zones NP12 to subzone NP14a. A stratigraphic gap is documented between the Paleocene and lower Eocene strata and corresponds to the zones NP10 and NP11.

Riben

The section is located in the old clay quarry, 150 m north-east of the centre of Riben village, Pleven District. The succession is traced from the entry point of the quarry along its right slope.

The Komarevo, Bozhuritsa, “Beloslav” and Avren Fms are exposed, topped by loess sediments, 2-4 m thick.

At the base of the section, along the pathway to the quarry, the uppermost portions of the sandy-silty limestones of the Komarevo Fm are exposed. They are covered by white to whitish colored thin-bedded marls with calcareous nodules and flint concretions (ranging from 1 to 15 cm in size), assigned to the Bozhuritsa Fm. The contact between the two formations is poorly exposed.

The upper parts of the Bozhuritsa Fm (the upper 7-8 m, Fig. 5.39) are represented by thin-bedded mixed sandy-silty-clayey rocks. They are beige, light-grey to rusty-brown and orange, colored by the abundant ferruginous oxides and hydroxide concretions (Fig. 5.40).



Fig. 5.40. Rusty-brown and orange colored hypo-rocks, containing Fe-hydroxide nodules in the topmost parts of the Bozhuritsa Fm in the section at Riben village, Pleven District

These are topped by a relatively compact, more calcareous marlstone bed, approximately 10-15 cm thick.

The latter is overlain (via sharp contact) by sandstones of high glauconite content and silty marls, dark-green in color (Fig. 5.41, "Beloslav" Fm). The highest concentration of glauconite is noted in the basal 15-20 cm, gradually decreasing upwards. Abundant remains of nummulitids, shell debris and well preserved bivalve shells are commonly encountered at the base of these sediments.

Up section are beige to grey, weakly glauconitic marls, 2-2.5 m thick. A concentration of shells of *Ostrea* and small nummulitids is recorded some 0.5 m from the base of the marls. The "Ostrea level" in this section is relatively thin (10 cm) and the shells are not highly concentrated.

The upper portions of the section are composed of beige to grey clayey marls (Avren Fm), over 5 m thick. Tracing of the normal stratigraphical succession is hampered by large fallen blocks, broken from higher levels as a result of active slumps in the quarry.

Biostratigraphy. The subdivision of the section in the Riben quarry is based on extensive high-resolution sampling, especially within the Paleocene/Eocene boundary interval (5 to 10 cm resolution). The results from the isotope geochemical study are presented in chapter 8, "Global Events".

The calcareous nannoplankton biostratigraphy is shown in Fig. 5.42. The sandy limestones of the Komarevo Fm are assigned to Thanetian NP6 and NP7 zones, the boundary between them is drawn by the FO of *Discoaster mohleri*. Similar to the section at Bozhuritsa, the Bozhuritsa Fm corresponds to NP8 and NP9 zones, that are based on abundant typical nannofossil associations. The nannofossils are very well preserved and with high diversity of species (over 70 species registered), except for one interval in the uppermost part where ferruginous oxide and hydroxide levels are extensive (between -3.2 and -2.0 m below the sharp boundary with the glauconitic marls of the "Beloslav" Fm).

The boundaries between the zones NP7 and NP8 and NP8 and NP9 are drawn by the first occurrences of the index species *Heliolithus riedelii* and *Discoaster multiradiatus*. Clearly fixed are also the bioevents of FO of *Discoaster protomultiradiatus* in the middle of NP8 zone and the FO of *Campylosphaera eodola*, *Transversopontis pulcheroides* and *Discoaster salisburgensis* in the upper half of NP9 zone (Fig. 5.42).

The unique feature of this section is its completeness around the Paleocene/Eocene boundary; the

Fig. 5.41. The sharp lithological boundary between the Bozhuritsa Fm and glauconitic marls of the "Beloslav" Fm in the section at Riben village, Pleven District



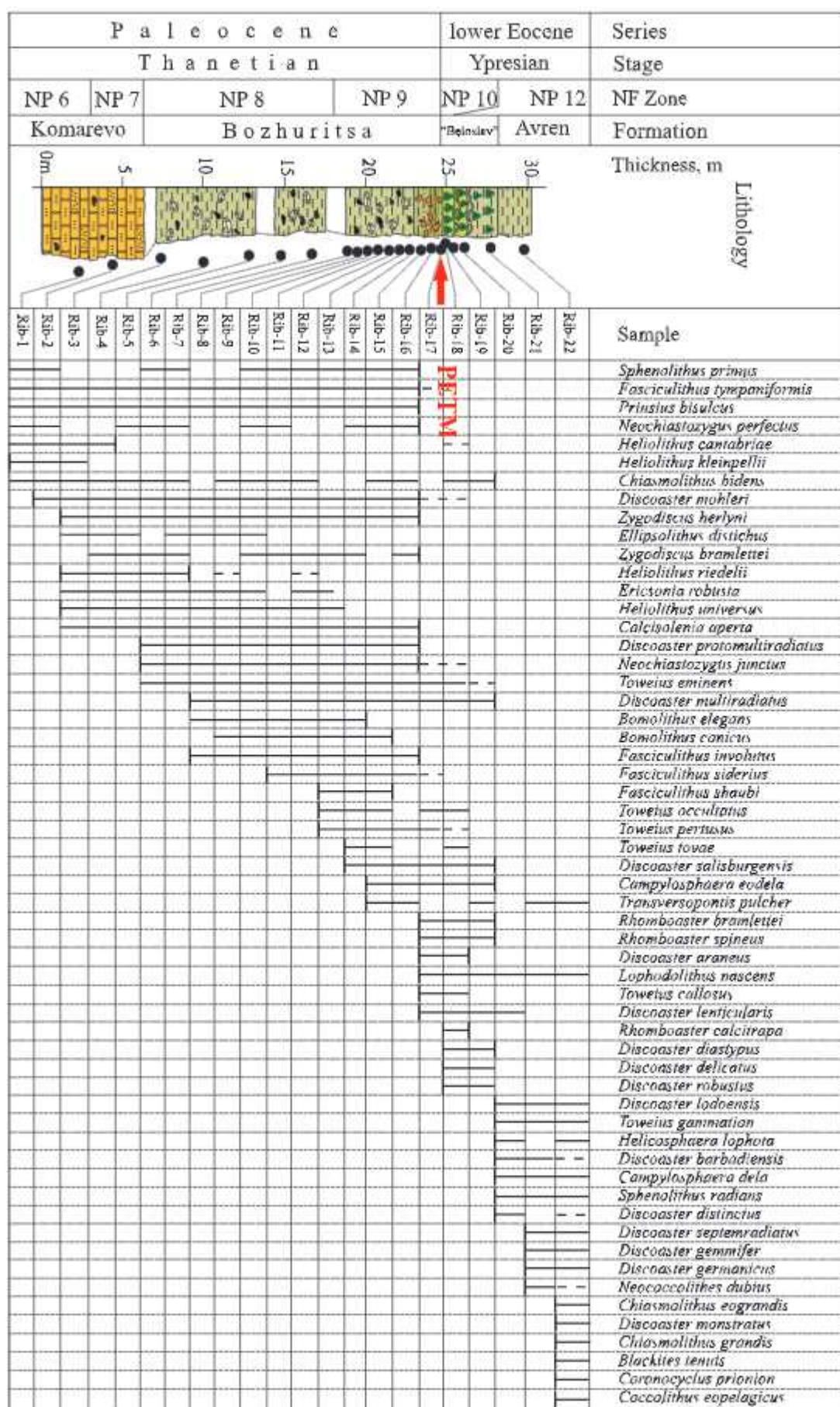


Fig. 5.42. Biostratigraphic subdivision of the section near Riben village, Plevan District, by calcareous nannofossils

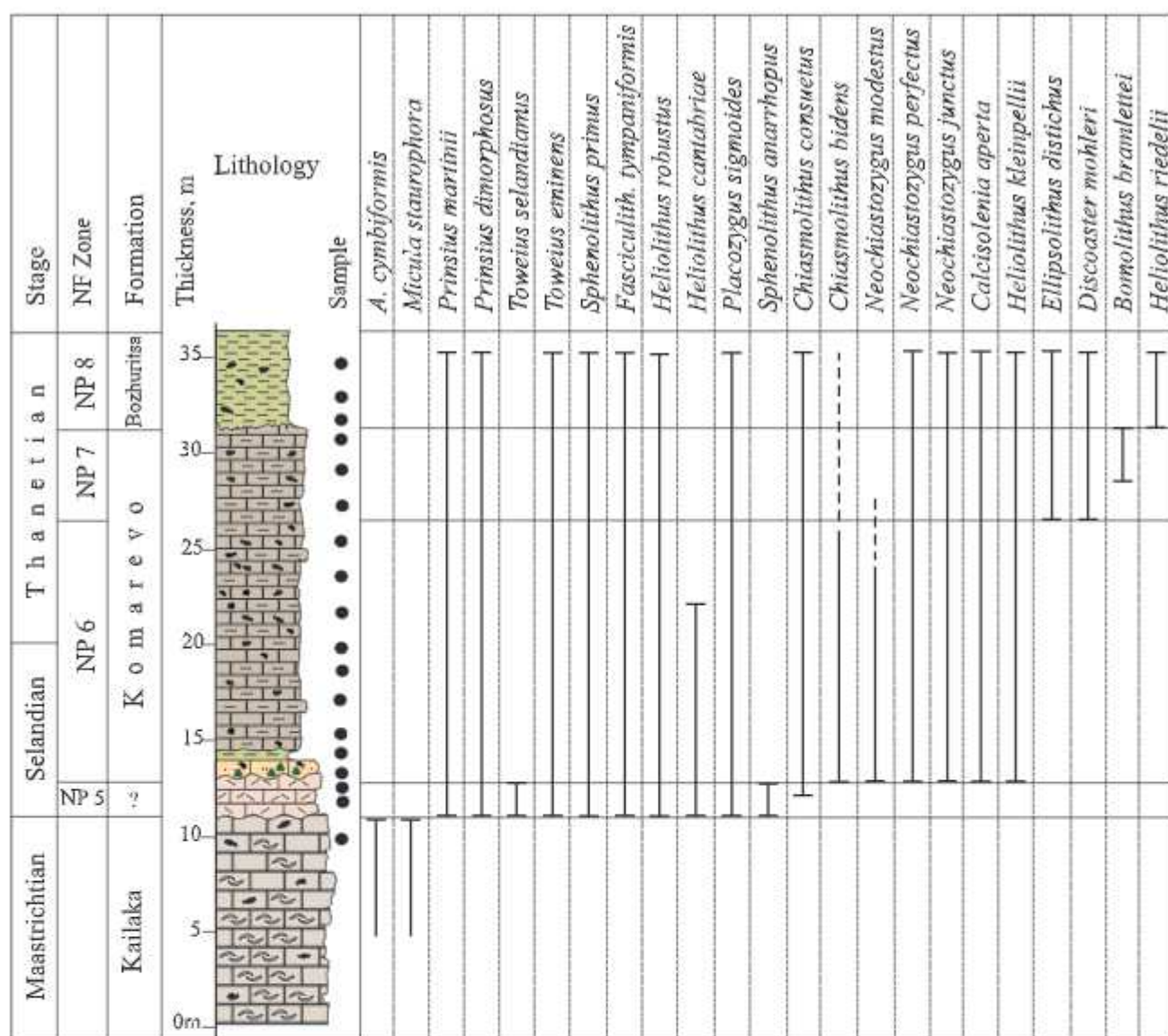


Fig. 5.43. Biostratigraphic subdivision of the section near Komarevo village, Pleven District, by calcareous nannofossils

sediments of the uppermost Paleocene NP9 zone and the lowermost Eocene NP10 zone record a continuous deposition. The discovery of a nannofossil association characteristic of the uppermost portions of NP9 zone, consisting of *Campylosphaera eodola*, *Transversopontis pulcheroides* and *Discoaster salisburgensis*, supports this statement. On the other hand, the lowermost portions of NP10 zone (the glauconitic level) are proved by the identification of *Rhomboaster bramlettei*, *R. spineus* and *Discoaster araneus*. The last three species are assumed to mark the Paleocene-Eocene thermal maximum interval and have been located precisely in this section in Bulgaria (Stoykova & Ivanov, 2005; Stoykova et al., 2005b, 2006). The nannofossil association of NP10 zone includes the species *Rhomboaster bramlettei*, *R. spineus*, *R. calcitrata*, *Discoaster delicatus*, *D. diastypus*, *D. medius* and *D. robustus*. The lack of the important markers *Rhomboaster contortus* and

Tribachiatus orthostylus, occurring higher in NP10 zone indicates, that only the lower part of the zone is developed in the Riben section. The *Ostrea* level, referred to NP12 zone, overlays unconformably with a basal washout. The NP12 zone is proved by abundant associations, dominated by *Discoaster lodoensis*, *D. barbadiensis* and *Neococcolithes dubius* (Fig. 5.42).

Stratigraphic range. The section encompasses the entire Thanetian Stage, zones NP6 to NP9, the base of the Ypresian Stage (lower parts of NP10) and the middle parts of Ypresian Stage, zone NP12. The hiatus spans the time equivalent of NP10 and NP11 zones.

Komarevo

The section is located on the right bank of Vit River near Komarevo village, Pleven District, some 500 m north of the river bridge.

It has been studied by Dachev (1975) who designated it as type section of the Komarevo Formation. The Kailaka, Komarevo and Bozhuritsa Fms are exposed here.

The base of the section consists of over 10 m of creamy to white massive organogenic and bioconstructed limestones, referred to the Kailaka Fm (Upper Cretaceous, Maastrichtian). These contain numerous fossils – bivalve shells, gastropods, echinoids, etc. The upper surface of the Kailaka Fm is uneven, with signs of washout/scouring. It is presumably karstified, as the overlying sediments are seen to fill erosional pockets.

The Kailaka Fm is overlain by creamy to whitish colored clastic limestones, around 2.2 m thick. Above these a sharp boundary marks the base of 0.4 m of thick grey-greenish silty to sandy limestones with chert nodules and irregularly distributed patches of glauconite. These gradually pass into light-grey to creamy, softer clayey limestones, with some horizons strongly silicified. The silicification is usually developed around organism remains – algae, Si-sponges, bryozoa, etc. Upwards, the limestones become purer and the chert concretions less common. The total thickness of the limestones of the Komarevo Fm is 20 m.

Grey-white to whitish colored thin-bedded marls, around 5 m thick with rare flint nodules are referred to the Bozhuritsa Fm. These marls have a sharp basal contact with the underlying Komarevo Fm (Dachev, 1975).

Biostratigraphy. The subdivision of the section is shown on Fig. 5.43. In this locality, as at the Plev-

en-Kailaka quarry, the Selandian Stage, NP5 zone, has been documented for the first time at the base of the Paleocene section, in a lithobody represented by clastic limestones (Fig. 5.43). A rich nannofossil association, documenting NP5 zone has been identified – *Fasciculithus tympaniformis*, *Toweius selandianus*, *T. eminens*, *Heliolithus cantabriae*, *H. robustus* and *Sphenolithus anarrhopus*.

The boundary between NP5 and NP6 zones is traced by the FO of *Heliolithus kleinpellii* at the base of the sandy limestones with glauconite (Komarevo Fm). It has a sharp lithological boundary and marks a short-term break in sedimentation. The nannofossil association of NP6 zone is rich and diverse, very well preserved – over 20 species are documented. Its boundary with the overlying NP7 zone is traced by the FO of the index species *Discoaster mohleri*. This zone is 3-4 m thick and occupies the uppermost levels of the Komarevo Fm.

The NP8 zone is evidenced in the marls with cherty concretions of the Bozhuritsa Fm by the presence of the index species *Heliolithus riedelii* along with other typical taxa (Fig. 5.43).

The species *Discoaster multiradiatus*, *Fasciculithus involutus*, *F. richardii*, *F. siderius*, *Heliolithus universus* and *Neochiastozygus junctus* were recovered from higher levels of the Bozhuritsa Fm marls, in a section a little to the north – along the gully between Kreta and Komarevo villages (Fig. 5.44). They are characteristic of NP9 zone and prove the presence of the upper part of the Thanetian Stage within the



Fig. 5.44. Section in the gully between the villages of Kreta and Komarevo, Pleven District; Komarevo and Bozhuritsa Fms



Fig. 5.45. General view of the section near Kreta in the old quarry SW of village, Pleven District; Kailaka and Komarevo Fms

framework of the Bozhuritsa Fm in this area.

Stratigraphic range. The Paleocene portion of the section comprises parts of the Selandian (NP5 and NP6 zones) as well as the entire Thanetian (NP6, NP7 – Komarevo Fm; NP8 and NP9 zones – Bozhuritsa Fm). The latter zone is present in the ravine between Komarevo and Kreta.

Kreta

The section is situated on the right bank of Vit River near Kreta village, Pleven District, in the old quarries south-west of the village, along the dirt road (Fig. 5.45).

A sedimentary sequence around 25 m thick is exposed, the lower 13 m of which are assigned to the Upper

Cretaceous (Upper Masstrichtian) and the upper 12 m – to the Paleocene (Selandian and Thanetian). The organogenic bioclastic limestones of the Kailaka Fm at the base of the section are built entirely of thick shells of large bivalves (Fig. 5.46).

Upwards, they are overlain (through an unclear boundary) by a 1 m bed of massive, clastic grained limestones, strongly fractured and karstified. Its upper surface is uneven, with deeply penetrating pockets, filled with fine clayey material from the overlying sediments (Fig. 5.47). At several places in the quarry this bed is overlain by a thin (2-5 cm thickness), dark-green to dark-brown colored clayey bed. Upwards it passes into a bed of glauconitic marls, traced everywhere, 0.45 m thick. Above are 3 m of alternating grey to beige marls and clayey limestones (Fig. 5.48), passing upwards into grey clayey limestones



Fig. 5.46. Accumulation of thick-shelled bivalves in the Kailaka Fm – the basal part of the section near Kreta, Pleven District



Fig. 5.47. Clastic limestone with uneven upper surface and deep penetrating karstic pockets, filled with clay materials in the base of the Paleocene section near Kreta, Pleven District



Fig. 5.48. Alternating glauconitic marls and marlstone-clayey limestones in the basal part of the Komarevo Fm in the section near Kreta, Plevan District

with flint concretions and nodules. The sediments described in this paragraph, resting above the karstified surface, are referred to the Komarevo Fm.

Biostratigraphy. The section has been sampled several times increasing the number of samples taken near the boundaries of the lithobodies. Abundant nan-

nofossil associations have been identified in both the soft chalky Maastrichtian limestones and the marly and clayey-carbonate Paleocene sediments. The identified associations justified subdivision into several nannofossil zones – CC 25b *Lithraphidites quadratus* and CC 25c *Micula murus* in the Upper Maastrichtian, NP5 and NP6 in Selandian and Thanetian (Fig. 5.49).

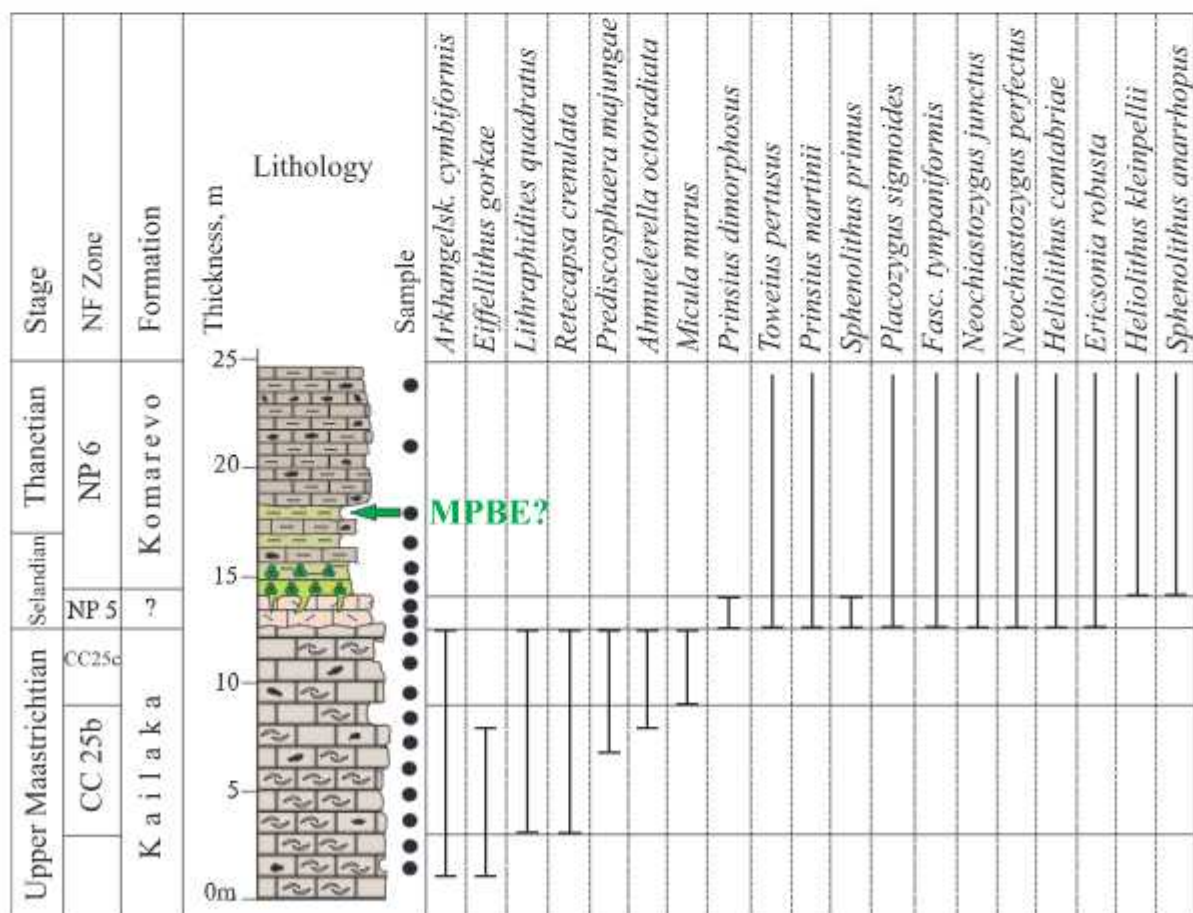


Fig. 5.49. Biostratigraphic subdivision of the section near Kreta village, Plevan District, by calcareous nannofossils



Fig. 5.50. General view of the section near Somovit village, Pleven District, along the railway line to the "Petrol" Company

The documenting of zones CC25b *Lithraphidites quadratus* and CC25c *Micula murus* in the Upper Maastrichtian is based on the FO of the index species for these zones. The species *Micula prinsii* has not been observed in the topmost part of the Kailaka Fm, therefore there is no data to confirm the presence of the uppermost Maastrichtian zone in this section.

The Paleocene section starts with zone NP5, evidenced in the basal 1 m thick clastic limestone bed that yielded *Fasciculithus tympaniformis*, *Neochiastozygus perfectus*, *Heliolithus cantabriae*, *Sphenolithus primus* and *Toweius pertusus*.

The FO of the species *Heliolithus kleinpellii* in the clayey layer and the glauconitic marls fixes the lower boundary of NP6 zone. This zone reveals relatively diverse and well preserved nannofossil associations, consisting of common *Gomphiolithus magnicordis*, *Lithoptychius billii*, *Fasciculithus tympaniformis*, *Placozygus sigmoides*, *Toweius pertusus* and *Chiasmolithus consuetus*.

The break in sedimentation between the Upper Cretaceous and Paleocene spans the uppermost Maastrichtian (zone *Micula prinsii*) and Danian Stage (NP1 to NP4 zones).

Stratigraphic range. The Paleogene part of the section encompasses only portions of the Selandian and Thanetian Stages, NP5 and NP6 zones (Fig. 5.49).

Somovit

The section is exposed along the bank of the Danube River, at Somovit village, on the route along the railway to the base of "Petrol" Company.



Fig. 5.51. Shell bed in the upper portion of the detrital limestones that have a sharp uneven upper boundary with glauconitic marls in the section near Somovit village, Pleven District

The sedimentary succession in the section is rather similar to the one outcropping at Kreta village. The essential difference concerns the thickness of the unit of poorly bedded detrital and clastic limestones, that exhibits its greatest thickness here – around 3-3.5 m (Fig. 5.50). Its uppermost portions are occupied by a shelly layer (10-25 cm thick). Above it, with an uneven washout boundary, the glauconitic marls and clayey limestones with cherts of the Komarevo Fm are deposited (Fig. 5.51).

Biostratigraphy. The subdivision of the section by nannofossils is shown on Fig. 5.52. The nannoflora in the organogenic limestones of the Kailaka Formation (Maastrichtian portion of the section) is rare and poorly preserved.

Quite the opposite applies to the overlying clastic limestones and calcarenites. These are soft, chalky sediments, containing diversified, abundant and perfectly preserved nannoflora. The most common species are *Fasciculithus tympaniformis*, *Prinsius martinii*, *Sphenolithus primus*, *Heliolithus cantabriae*, *Chiasmolithus bidens*, *Neochiastozygus perfectus*, *Toweius pertusus*, *T. eminens* and *T. tovae*. This association corresponds to nannofossil zone NP5 (Selandian Stage, lower part).

The boundary between NP5/NP6 zones is marked by the FO of *Heliolithus kleinpellii* in the glauconitic marls. The species *Heliolithus cantabriae*, *Toweius pertusus*, *T. eminens*, *Prinsius martinii*, *Sphenolithus primus* and *Chiasmolithus consuetus* continue their abundant occurrence in NP6 zone as well. The uppermost levels of the section remain within NP6 zone.

Stratigraphic range. The Paleogene part of the sec-

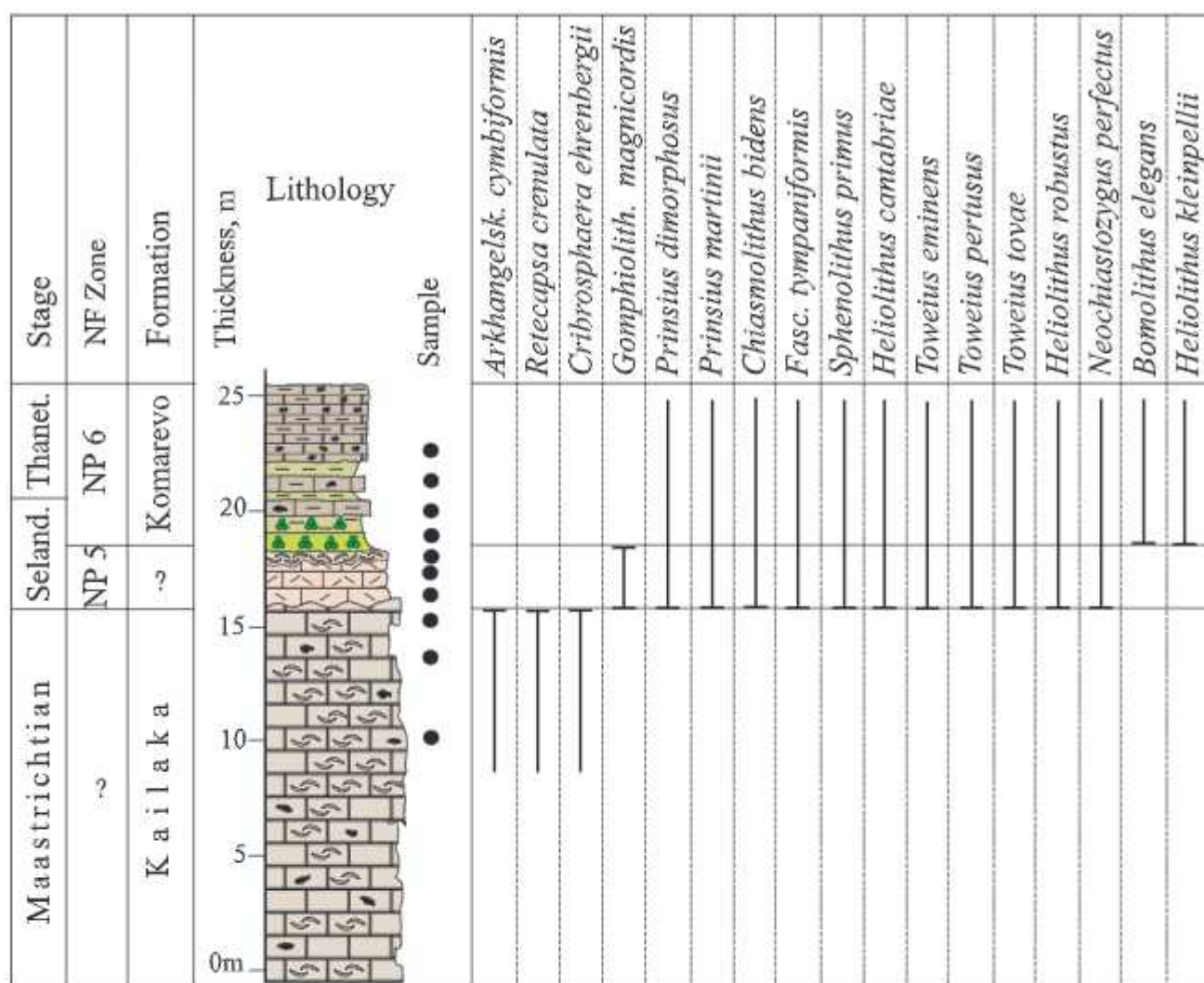


Fig. 5.52. Biostratigraphic subdivision of the section near Somovit village, Pleven District, by calcareous nannofossils

tion is consistent with portions of the Selandian and Thanetian Stages, NP5 and NP6 zones (Fig. 5.52).

The detailed biostratigraphic subdivision by nannoplankton of the Paleogene sediments in the studied sections allow reliable comparison and correlation. Figure 5.53 illustrates the correlation and shows the lithostratigraphic units (formations), the biostratigraphic units (identified zones by calcareous nannoplankton) and the chronostratigraphic subdivisions (stages) in the Paleocene-lower Eocene interval in Central northern Bulgaria (Danian, Selandian, Thanetian and Ypresian Stages).

5.4. Central Fore-Balkan and Balkan

Paleogene sediments are of limited distribution in the Central Fore-Balkan and Balkan, developed mainly in three regions – Tarnovo, Gabrovo and Sliven.

In the Tarnovo region, only the lower Eocene sedi-

ments, distributed exclusively in the central part of the Balvan Syncline are exposed – between the villages of Balvan and Sheremetiya (Hrishev, 1993). These are represented by the Shemshevo and Avren Fms. Larger outcrops are observed in the Gabrovo region encompassing both Paleocene and lower Eocene rocks (Tzankov, 1995a). Limited outcrops are located in the Elena-Tvarditsa part of the Balkan (Kanchev & Nikolov, 1995) and much larger outcrops in the Sliven Stara Planina (Sliven Balkan) (Kanchev, 1995d).

Veliko Tarnovo-Ledenik

The section starts 500 m west of the roundabout at the exit of Veliko Tarnovo. The exposure is in the road cutting on the right-side, along the highway to Sofia and up to Ledenik village.

Massive, light-beige colored, fine-grained sandstones and sandy limestones, alternating with thin beds and interbeds of siltstones and clayey marlstones are exposed. In places, the sandstones are very solid, mas-

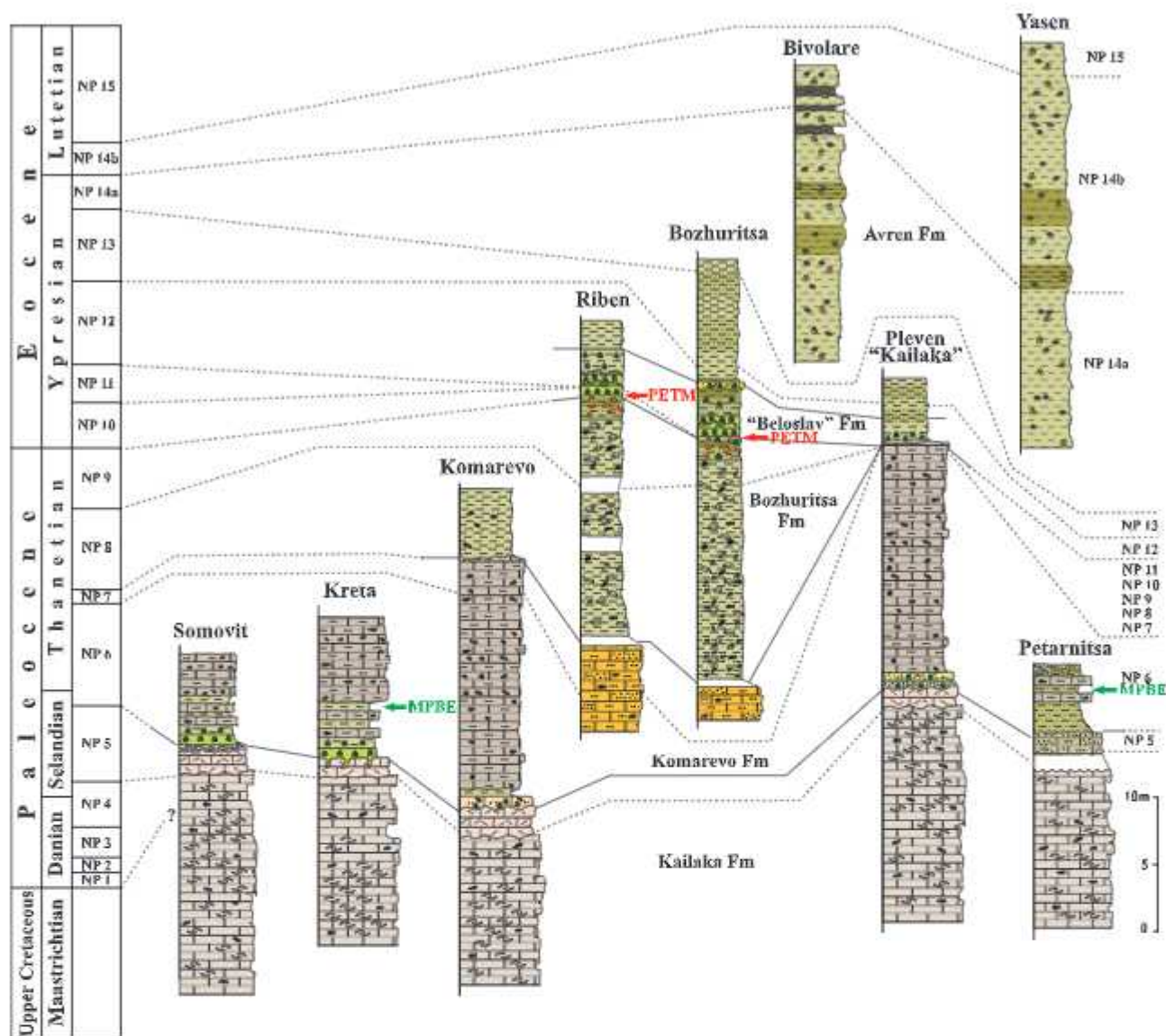


Fig. 5.53. Litho-, bio- and chronostratigraphic correlation of the Paleogene sediments in the studied sections in the central parts of the Moesian Platform by calcareous nannofossils (after Stoykova & Ivanov, 2004b)

sive, enriched packed with glauconite grains. These are assigned to the Shemshevo Fm (Aladjova-Hrischeva, 1988a).

Resting with a sharp basal boundary on these, are beige colored marlstones with a clastic component varying from sand to clay. They outcrop along the left bank of the Yantra River on the road from Pushevo to Shemshevo. These marlstones, referred to the Avren Fm, are well exposed even within Veliko Tarnovo town, in excavations for construction works opposite the OMV gas station.

Biostratigraphy. The subdivision of the section by calcareous nannoplankton is displayed in Fig. 5.54. The nannoflora obtained from the Shemshevo Fm sandstones is quite rare, relatively poorly diversified and poorly preserved, thus hampering identification

of the species. The associations of the Avren Fm marlstones are much richer and well preserved.

lower Eocene sediments, referred to NP10? zone, are distinguished at the base of the Paleogene sequence in this section. The recovered association is species poor and poorly preserved. However, some important species, characterizing NP10 zone have been found – *Tribrachiatus* cf. *contortus* (with a short range, only in the middle and upper parts of NP10), *Discoaster diastypus* and *D. salisburgensis*. The lower boundary of NP11 zone is fixed by the FO of *Tribrachiatus orthostylus*, whereas *Ericsonia formosa*, *Toweius gammaton* and *Sphenolithus anarrhopus* have their appearance within the zone. The uppermost portions of NP11 zone are proved at the base of the Avren Fm by the last occurrence (LO; extinction) of *Tribrachiatus orthostylus*. The Shemshevo Fm –

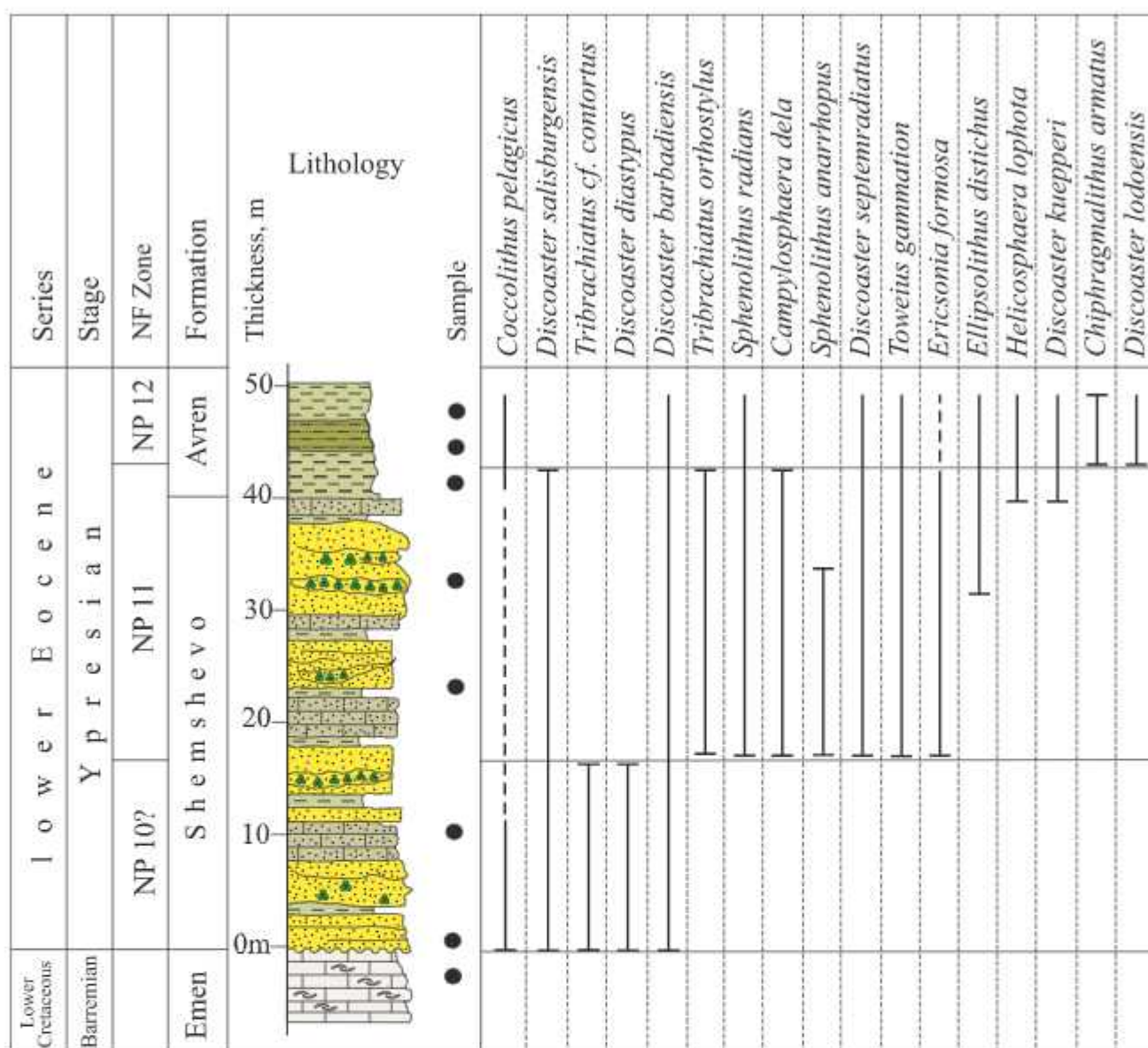


Fig. 5.54. Biostratigraphic subdivision of the Veliko Tarnovo – Ledenik section by calcareous nannofossils

Avren Fm boundary is lithologically sharp and probably reflects a short-term break in sedimentation that may not be detectable by biostratigraphy.

The lower boundary of NP12 zone is traced by the appearance of *Discoaster lodoensis* at 3 m above the base of the Avren Fm. *Chiphragmalithus armatus*, short-ranging in NP12 zone only, is also recorded with the former species.

Stratigraphic range. The section encompasses the lower parts of the lower Eocene, Ypresian Stage, NP10? – 11 zones and a small portion of NP12 zone (Fig. 5.54).

R-1hg Gabrovo

The section is described based on core and cuttings

recovered from water well R-1hg Gabrovo, drilled in 1995 in Gabrovo town by Geological Exploration Company, Pleven. The data has not been published before now.

From the top to the bottom the well penetrates Eocene, Paleocene, Upper Cretaceous and Lower Cretaceous sediments. The subdivision is shown in Fig. 5.55. Based on the description of the rocks from core intervals, the alternating sandstones, siltstones and marls are assigned to the Lukovit (Boynovtsi?) Fm, the creamy-white medium-grained sandstones – to the Iztochnik Fm, and the white organogenic limestones – to the Kailaka Fm (Fig. 5.55).

Biostratigraphy. Biostratigraphic analysis of calcareous nannoplankton allowed separation of one zone in the Paleocene (NP5, Selandian) and one zone in the

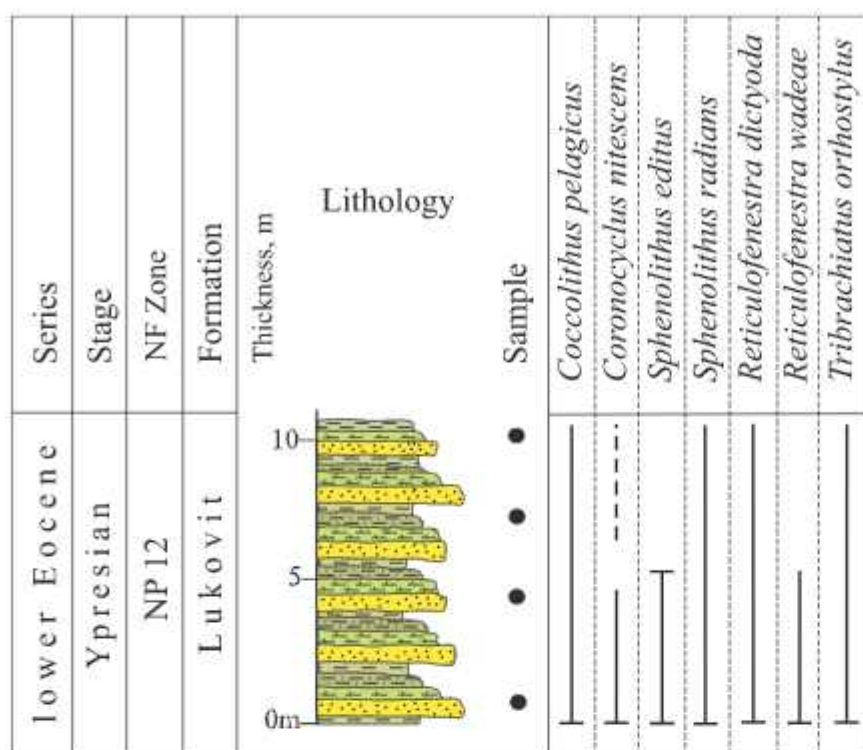


Fig. 5.56. Biostratigraphic subdivision of the section near Vrabtsite village, Gabrovo District, by calcareous nannofossils

lower Eocene (NP12, Ypresian). The vertical distribution of the identified species is presented in Fig. 5.55.

The nannofossil associations of the marl-clayey rhythms of the Lukovit Fm appear to be the best preserved and the richest in species. The nannoflora in the Iztochnik Fm sandstones as well as in the Maastrichtian organogenic limestones of the Kailaka Fm is rare and poorly preserved (Fig. 5.55).

The interval between 55.00 m and 72.00 m is assigned to the Selandian NP5 zone, based on the co-occurrence of *Fasciculithus tympaniformis*, *Heliolithus* cf. *cantabrigiae*, *Sphenolithus primus* and *Toweius pertusus*.

The interval between 20.00 m and 55.00 m is referred to NP12 zone, since core and cuttings samples revealed abundant and characteristic species for this zone's nannoplankton association. It comprises *Chiphragmalithus calathus*, *C. acanthodes*, *Discoaster lodoensis* and *Tribrachiatus orthostylus* (Fig. 5.55).

No data are available in the first 20 m of the well section, but presumably they also belong to the lower Eocene.

Stratigraphic range. The Paleogene portion of the well section includes the lower Eocene, Ypresian, NP12 zone and middle Paleocene, Selandian, NP5 zone (Fig. 5.55).

Vrabtsite

The section is located 1.5 km north of Vrabtsite village, Gabrovo District, and 2 km west of Tranito village. It is represented by a 10 m thick sequence in the road cutting outcrop on the road to Debel dyal village, at the fork in the road to Vrabtsite village.

The outcrop is a thin-rhythmic turbiditic alternation of sandstones, siltstones, silty marls and clayey marls, which, according to the geological map of Bulgaria, correspond to the Lukovit Fm. Samples have been taken at each 2.5-3 m – from the clayey part of the rhythms.

Biostratigraphy. The results from the biostratigraphic study of the nannofossils and the subdivision of the section are shown in Fig. 5.56. The species diversity is relatively low, whereas the preservation ranges from poor to moderate. Just a few species are taxonomically identified – *Sphenolithus editus*, *Sphenolithus radians*, *Reticulofenestra wadeae* and *Tribrachiatus orthostylus*. This implies an age assignment to the NP12 nannofossil zone.

Stratigraphic range. Lower Eocene, Ypresian Stage, NP12 zone (Fig. 5.56).

Iztochnik

The section is located in the south-eastern end of Iztochnik village and is a small outcrop on the gorge slope, along a dirt road.

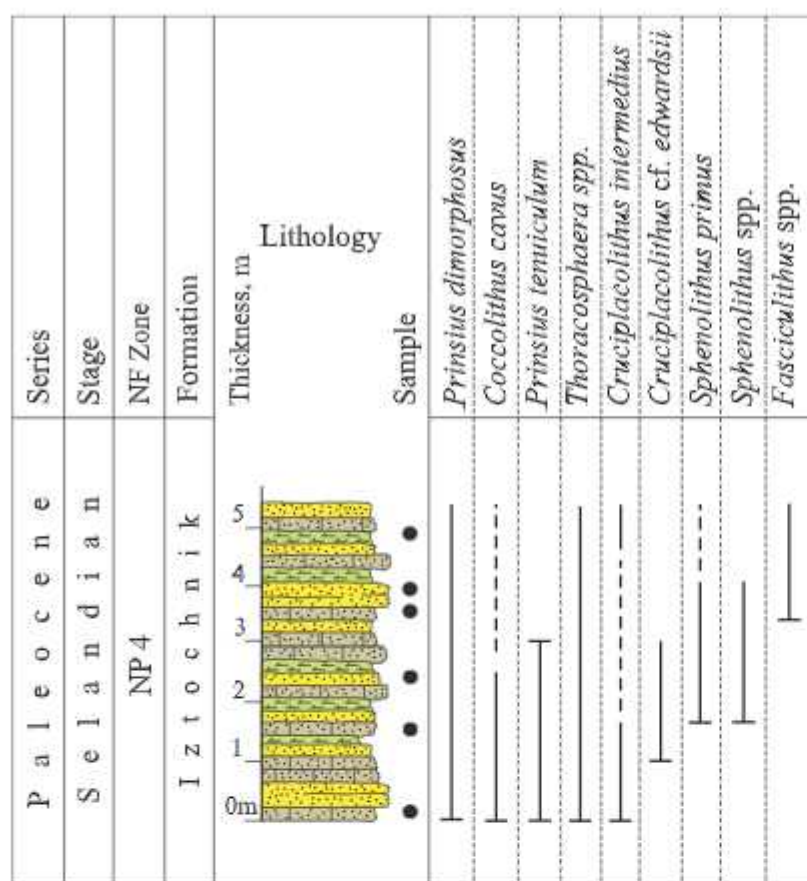


Fig. 5.57. Biostratigraphic subdivision of the section near Iztochnik village, Gabrovo District, by calcareous nannofossils

The section was studied and described by Aladjova-Hrischeva et al. (1991) who designated it as type section of the Iztochnik Formation. Their study did not provide any new paleontological data and the sediments are assumed to be Thanetian in age, based on mollusk data by Belmustakov and Jolkichev (1965). The present study substantially corrects the age of this Formation.

The section comprises about 5 m of grey-yellowish to whitish sandstones and sandy limestones, occasionally passing into siltstones and clayey limestones. These are referred to the Iztochnik Fm.

Biostratigraphy. Detailed sampling has been carried out at 1 m intervals, and the results of the nannofossil study are shown in Fig. 5.57. The nannofossil association is not species rich but is informative. The following species have been identified – *Sphenolithus primus*, *Prinsius dimorphosus*, *P. tenuiculum*, *Cruciplacolithus* cf. *edwardsii* and *Fasciculithus* spp. This association clearly indicates the upper part of NP4 zone, due to the co-occurrence of *Sphenolithus primus* with the first representatives of *Fasciculithus* – *Fasciculithus* spp. in the upper portion of the zone immediately before the FO of *Fasciculithus tympaniformis* and the massive radiation of the first large group of fasciculiths.

Stratigraphic range. Middle Paleocene – Selandian, uppermost part of zone NP4 (Fig. 5.57).

Zhaltesh – Yaseni

This section includes two localities, where the thin-rhythmic turbidite sediments of the Lukovit Fm crop out (Fig. 5.58). The first locality is situated approximately 500 m east of Zhaltesh village and the section is traced in the road cutting on the highway to Tryavna town. At the large (almost 180°) turn on the road, the thin-rhythmic turbidite sediments of the Lukovit Fm are perfectly exposed. The alternating sediments are sandstones, siltstones and clayey marls. The fine-grained portion of the rhythms was sampled for nannofossils.

The second locality is situated on the road between Zhaltesh and Iztochnik villages, precisely at the road fork to Yaseni village. The outcrop reveals thin-rhythmic sediments, composed of alternating weakly cemented sandstones, siltstones, silty marls and clays. The higher parts of the sequence are represented by clayey and silty marls, with sandstone interbeds (10 cm thick).

Biostratigraphy. A poorly preserved nannofossil association was recovered, represented by *Discoaster lodoensis*, *D. barbadiensis*, *Helicosphaera seminulum*, *Ericsonia formosa*, *Chiasmolithus eograndis* and *C. grandis*. It proves the occurrence of nannofossil zones NP12-13 (Fig. 5.58). The poor association makes the

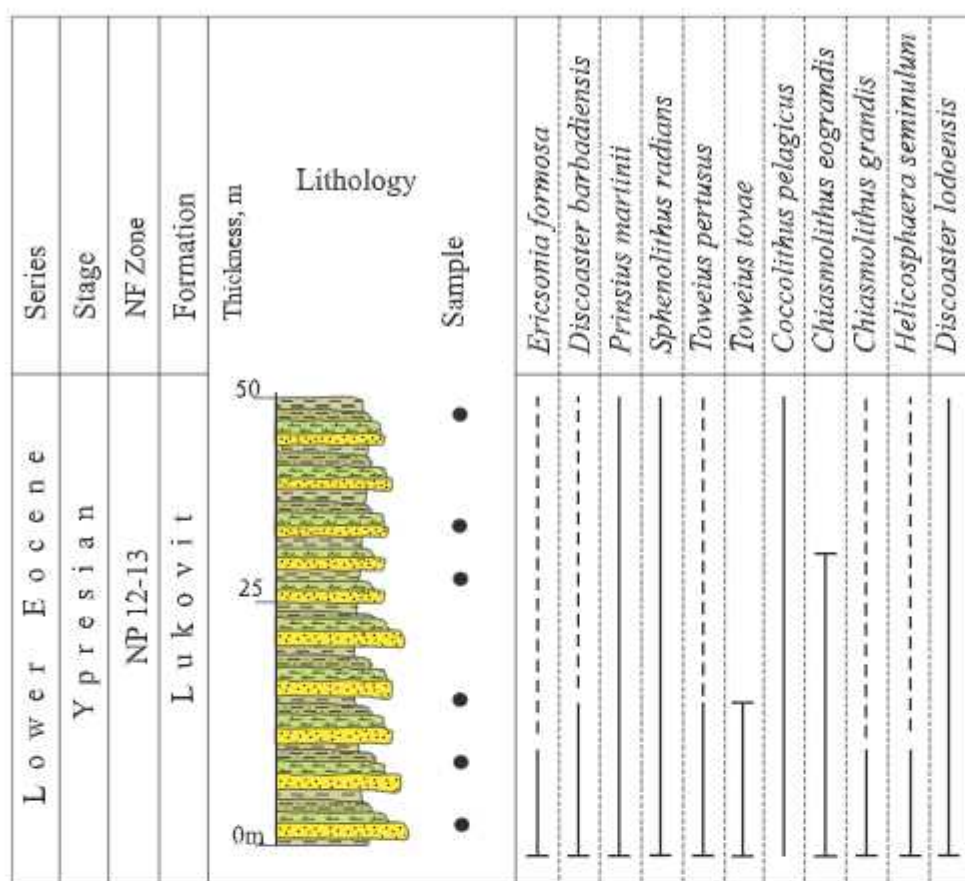


Fig. 5.58. Biostratigraphic subdivision of the section near Zhaltesh – Yaseni villages, Gabrovo District, by calcareous nannofossils

accurate definition of the zone impossible. The absence of *Tribrachiatus orthostylus* in the association rather suggests NP13 zone, but the lack (not discovered) of a certain species may not serve as a reliable proof for assignment to a specific biostratigraphic zone.

Stratigraphic range. Lower Eocene – Ypresian Stage, NP12-13 zones (Fig. 5.58).

Belitsa

The section is located some 3-4 km west-north-west of Belitsa village, Gabrovo District and is traced, with some interruptions, along the Belitsa-Tryavna road.

A thin-rhythmic alternation of sandstones, siltstones and marls assigned to the Lukovit Fm occupies the base of the sequence. At around 3.2 km west of Belitsa village, a coarse-grained clastic packet (approximate thickness of 10 m) of gravels, conglomerates and sandstones occurs. The conglomerates are built up of large clasts of boulder size with clayey-marly matrix. The clasts are composed of metamorphic, volcanic and sedimentary rocks.

The upper portion of the section is composed of thin-rhythmic turbidites. Above these sediments is a sharp lithological boundary at the base of poorly sorted,

polygenetic, boulder-sized conglomerates. The conglomeratic clasts include various rocks; gneisses, volcanic rocks, micritic limestones, marls, shales. These sediments are referred to the Staropatitsa Fm (Tzankov, 1995a).

Biostratigraphy. The calcareous nannoplankton subdivision of the section is synthesized on Fig. 5.59. Not particularly diversified in species, but characteristic associations have been determined in the rhythmic sediments of the Lukovit Fm. They are poorly to moderately preserved. No nannofossils have been encountered in the Staropatitsa Fm conglomerates and gravels in the upper portions of the section.

The concomitant occurrence of *Discoaster lodoensis*, *D. kuepperi*, *D. binodosus* and *Chiasmolithus eograndis* implies an early Eocene age, NP12-13 zones (Fig. 5.59). It is possible that the lower 20 m of the section belongs to NP11 zone, since *Discoaster lodoensis* occurs for the first time over 20 m up section. However, the poor preservation of the nannofossils hinders the precise pinpointing of this event. Therefore, there are no firm biostratigraphic proofs justifying the presence of NP11 zone in the Belitsa section.

Stratigraphic range. Lower Eocene – Ypresian Stage, NP12-13 zones (Fig. 5.59).

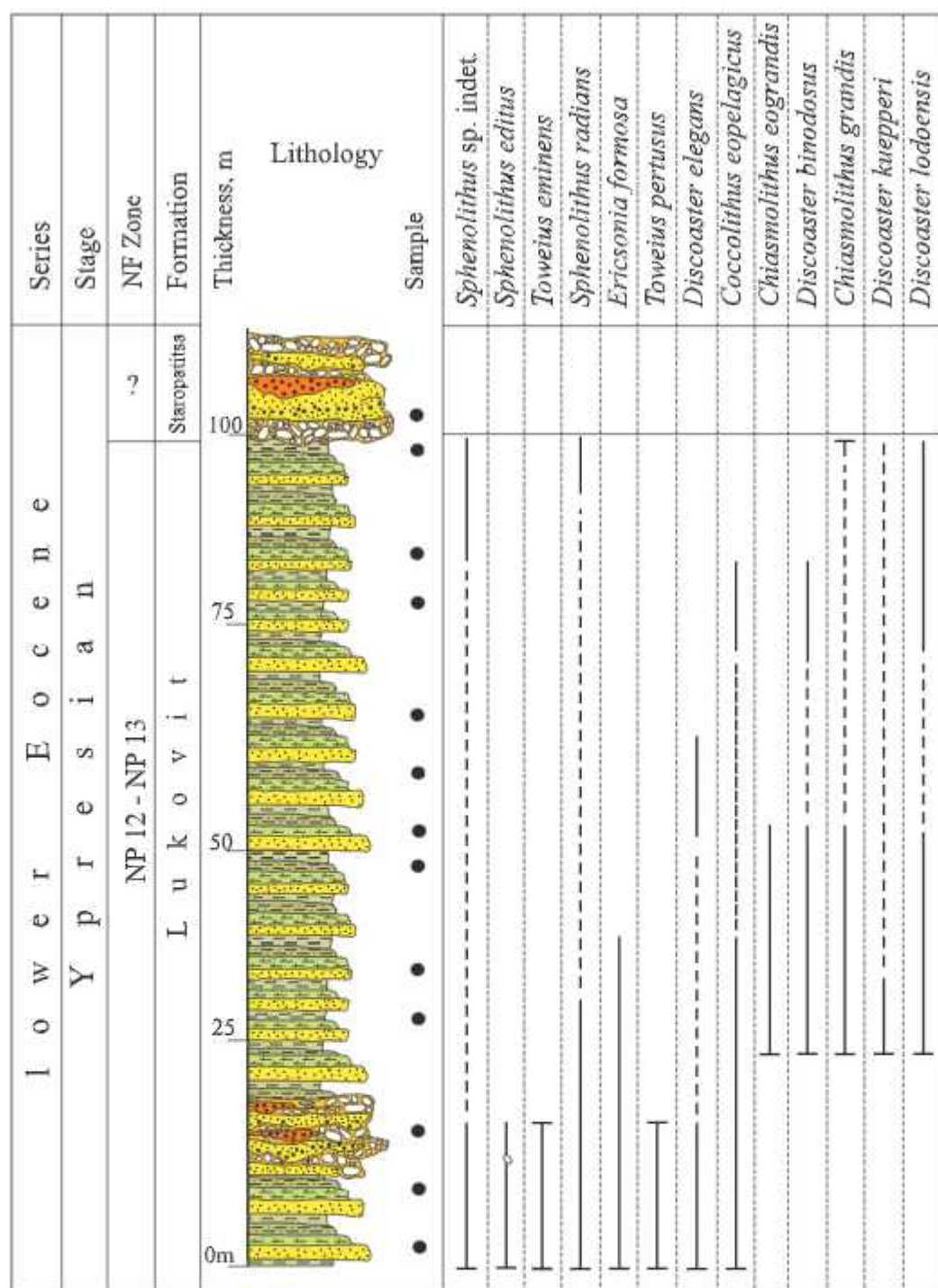


Fig. 5.59. Biostratigraphic subdivision of the section near Belitsa village, Tryavna area, by calcareous nannofossils

Mishemorkov han

The section starts 1 km south of Mishemorkov han village, Veliko Tarnovo District, in the outcrop along the dirt road to Ivanovtsi village and ends at the northern end of the village, by the village road sign. This road is known as "Republic Pass". The total thickness of the exposed sequence is around 40 m.

The lower portions of the section are represented by alternating dark- to light-grey, medium- to thin-bed-

ded clayey limestones and marls. The terrigenous admixtures (siltstones) are subordinate in volume. Occasionally, resistant beds of micritic limestones occur. In places the limestones are nodular, boudinated (with undulating ripple-like bed surfaces).

The clastic component gradually increases in the middle and upper portions, where alternating limestones, more massive beds of sandy limestones, siltstones and marls are exposed.

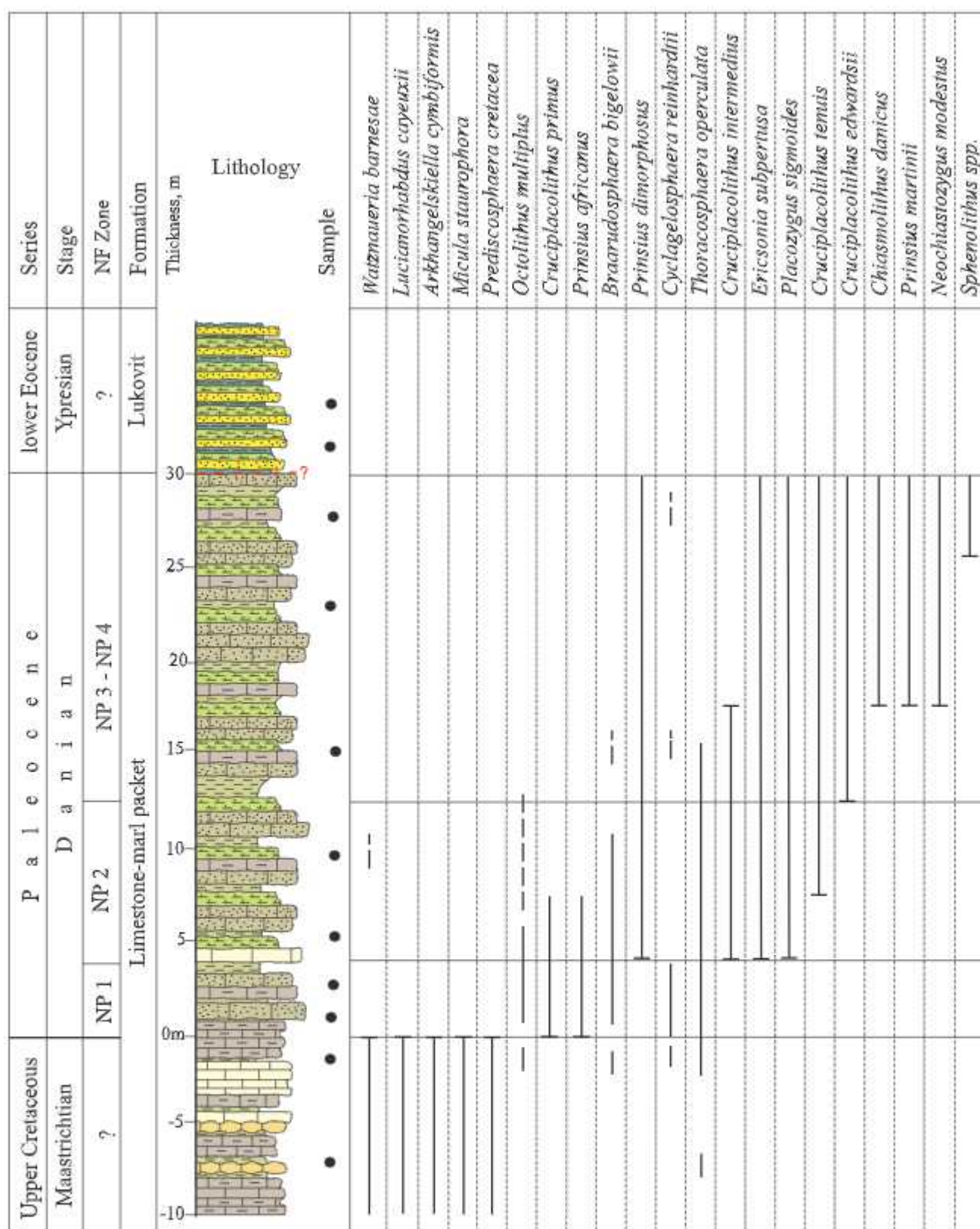


Fig. 5.60. Biostratigraphic subdivision of the section near Mishemorkov han, Veliko Tarnovo District, by calcareous nannofossils

The uppermost parts of the section outcrop at the northern end of the village (near the road sign, indicating the village's name), where thin-bedded alternating sandstones, siltstones and marls occur, referred to the Lukovit Fm (probably with a tectonic contact

fault, over the carbonate-marly sequence).

Biostratigraphy. The subdivision of the section by calcareous nannoplankton is shown in Fig. 5.60. The hard, resistant, dark-grey colored micritic limestones

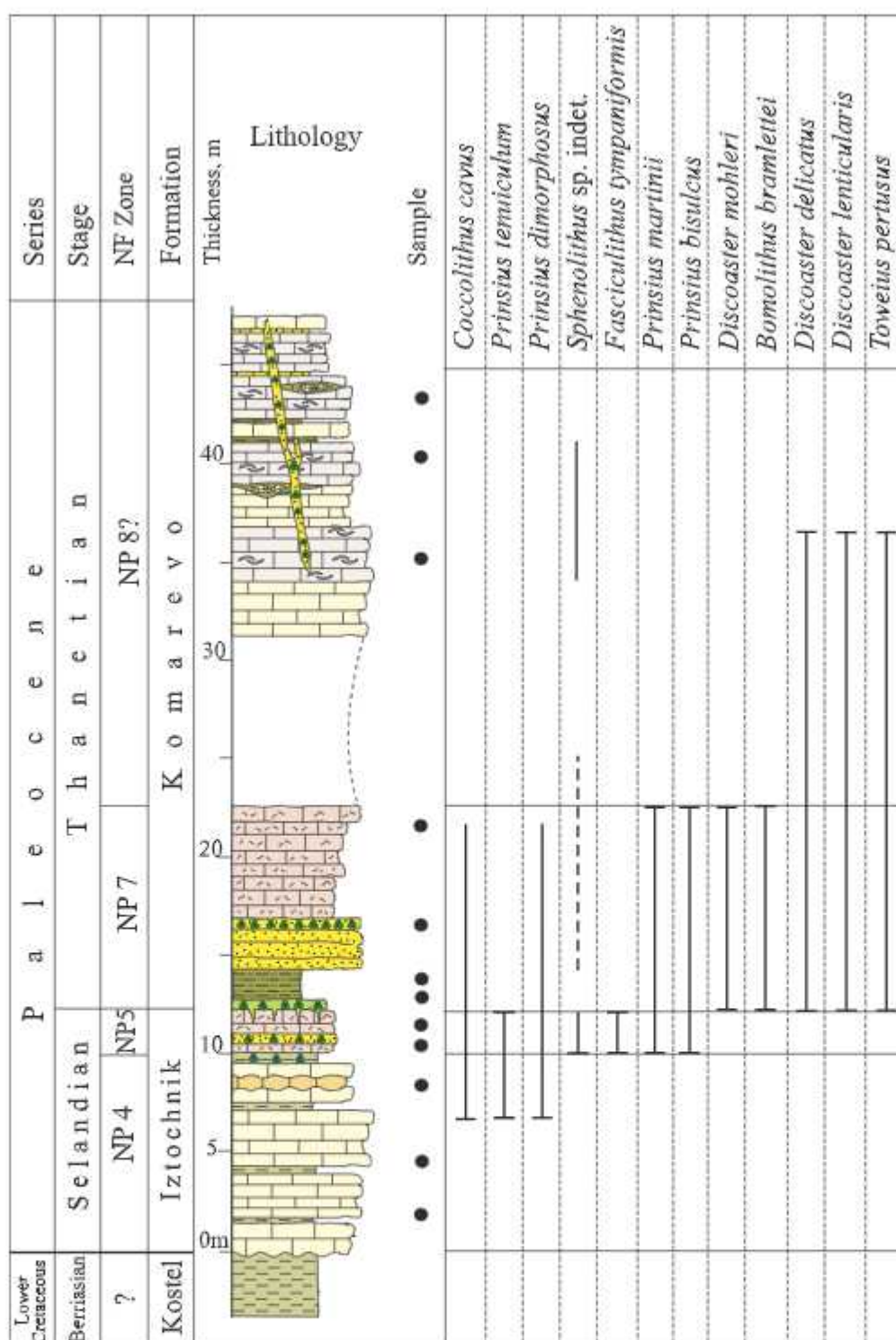


Fig. 5.61. Biostratigraphic subdivision of the section near Drenta village, Elena area, by calcareous nannofossils

at the base of the section contain rare, poorly preserved nannoflora. The identified association consists of several dissolution-resistant species, that indicate in general a Maastrichtian Stage: *Arkhangelskiella cymbiformis*, *Micula decussata*, *Watznaueria barnesiae* and *Prediscoaster cretacea*.

Upwards, the light-beige marly interbeds reveal an association characteristic of the lowermost Paleocene NP1

zone, comprising the species *Cruciplacolithus primus*, *Prinsius africanus*, *Thoracosphaera operculata*, *Octolithus multiplus* and *Braarudosphaera bigelowii*. The Cretaceous/Tertiary boundary (and consequently the boundary clay layer) has not been accurately located, due to the complicated tectonics and the lack of good outcrops in the boundary interval.

The lower boundary of NP2 zone is traced by the FOs

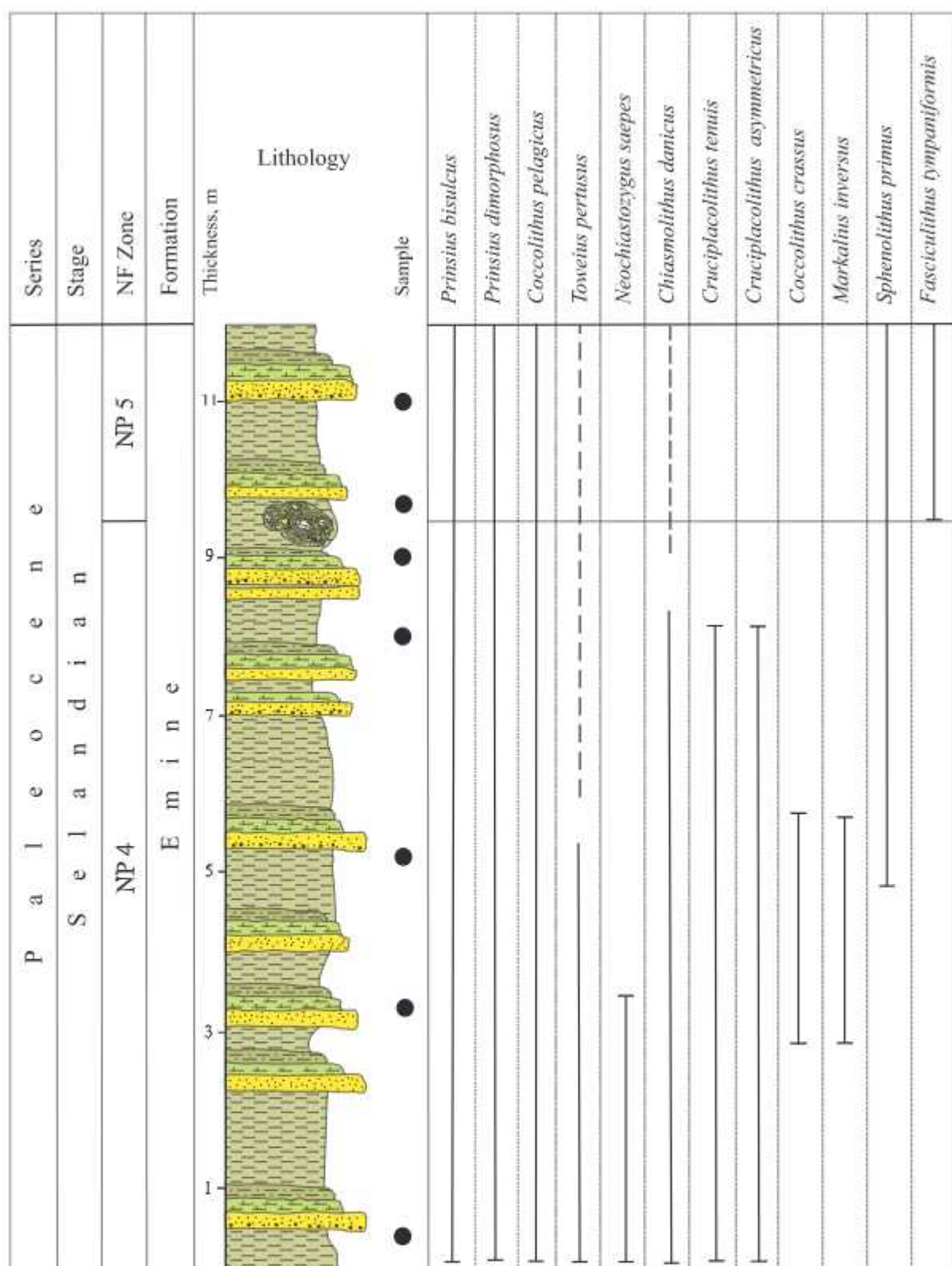


Fig. 5.62. Biostratigraphic subdivision of the section near "Tabelite" Holiday Village, Sliven District, by calcareous nannofossils

of *Cruciplacolithus intermedius*, concomitantly with *Prinsius dimorphosus* and *Ericsonia subpertusa*.

The boundary between NP2/NP3 zones is drawn at the FO of *Cruciplacolithus edwardsii*. The position of

the lower boundary of NP4 zone is not precisely fixed, since the recovered associations lack stratigraphically important species. It is clear, however, that the upper parts of NP4 zone are developed in the uppermost portions of the carbonate-marl formation, since rep-



Fig. 5.63. General view of the section near Kipilovo village, Sliven District – outcrop of the Gebesh Fm

representatives of the genus *Sphenolithus* – *Sphenolithus* spp. have been recorded and these have their FO in the upper half of NP4 zone.

The samples from the turbiditic flyschoid sediments in the uppermost part of the section, assigned to the Lukovit Fm, were barren of nannoplankton.

Stratigraphic range. Upper Cretaceous (Maastrichtian?) – lower Paleocene (Danian Stage), zones NP1 to NP4 (Fig. 5.60).

Drenta

The section is located at the eastern end of Drenta village, Elena region, near the old limestone pits. It begins at the scarp on the sharp turn of the road and is followed on the slope and in the old limestone quarries, ending some 50 m above the school.

The section has been studied by Nikolov et al. (1998) and Peybernès et al. (2004), and these authors were the first to publish paleontological proofs on the presence of older, Selandian sediments below the Thanetian. A detailed historical review on the studies of the limestones at Drenta is presented in the article of Nikolov et al. (1998).

The base of the outcrop exhibits grey clayey marls, related to the Kostel Fm (Lower Cretaceous, Berriasian). These are overlain by a sharp washout unconformity and approximately 12 m of light-beige to white colored limestones with rare clayey interbeds. In the upper 2.5 m, the limestones become detritic, with thin interbeds of glauconitic sandstones and siltstones, 2-3 cm thick, where calcareous nannoplankton has been recovered. These sediments are assigned to the Iztochnik Fm, although they closely resemble the detritic limestone of the unnamed lithobody, occur-

ring at the base of the Paleogene profile in Central northern Bulgaria.

A lithological boundary that marks an unconformity follows then – glauconitic marls with calcareous nodules (0.5 m thickness). Their lower boundary is uneven, with penetrations into the underlying bed. The terrigenous component in these varies from clayey-sandy to gravel size (large quartz grains). Upwards, they pass into silty and sandy marls and fine- to medium-grained sandstones. Then follows 0.1-0.2 m of glauconitic sandstone with cross bedding and limestone intraclasts. The lower part of the outcrop is topped by 5-6 m of detritic limestones with numerous calcite veins.

Fine- to medium-grained, beige to white colored, massive bedded crystalline limestones follow a 10 m covered interval. They contain remains of gastropods, colonial corals and algae. In the upper part, between limestone layers, thin interbeds of clayey-sandy sediment contain lens-like interbeds of limestone intraclasts in sandy-clayey matrix. An almost vertical sedimentary dike filled with glauconitic sandstones cross-cuts the limestones (Fig. 5.61). These sediments are assigned to the Komarevo Fm.

Biostratigraphy. The section has been closely sampled for nannoplankton. However, the lowermost and uppermost portions are barren or contain poorly preserved non-characteristic species. The most productive sediments for nannofossils appear to be the glauconitic marls and detrital limestones, where characteristic associations have been recovered. The biostratigraphic subdivision of the section is shown in Fig. 5.61. Selandian and Thanetian Stages have been identified, with a break in sedimentation between (NP6 zone is missing).

No nannoflora is detected in the lowermost portions of the section, but presumably these belong to the Selandian as well. The nannofossil zone NP4 is represented by a poor and non-characteristic association (Fig. 5.61). The lower boundary of NP5 zone is fixed at the FO of the index species *Fasciculithus tympaniformis* in the first sample from the detritic limestones. The zone is 2 m thick.

A relatively rich and diverse nannofossil association, comprising *Bomolithus bramlettei*, *Discoaster mohleri*, *D. delicatus*, *D. lenticularis* and *Toweius pertusus* is identified in the sample from the glauconitic marls, immediately above a sharp washout boundary. It represents the Thanetian NP7 zone. The uppermost portions of the limestones likely correspond to the next, upper zone NP8, but for the present this suggestion is not supported by any paleontological evidence.

Stratigraphic range. Middle Paleocene, Selandian, NP4 and NP5 zones for the lower limestones, and upper Paleocene, Thanetian, NP7 and NP8? zones for the middle and upper part of the section (Fig. 5.61).

Tabelite

The section is located in the ridge areas of Stara Planina Mountains (Balkan). It starts 1 km south of Tabelite Holiday Village, in the road cut on the Sliven-Stara reka road (Vratnik Pass). The section ends on the northern side of the Balkan, some 1.5 km west-north-west of Tabelite.

A medium-bedded turbidite sequence of sandstones, siltstones and clayey marls, typical of the Emine Fm is exposed. An olistostrome body of lens-like shape "flowing" among the turbidites is observed in the upper part of the section. Olistostromes occur quite often at different stratigraphic levels (Campanian-Paleocene) within the Emine Fm in the Sliven area.

Biostratigraphy. The turbiditic sediments have been sampled at intervals approximating to every 2 m and the results of the nannofossil study are shown in Fig. 5.62. The identified associations correspond to the

upper parts of nannofossil zone NP4 and the base of NP5 zone (Selandian Stage). The co-occurrence of *Sphenolithus primus* and *Prinsius bisulcus* indicates the upper part of NP4 zone. The lower boundary of NP5 zone is traced by the FO of *Fasciculithus tympaniformis* in the sample taken immediately above the olistostrome (fig. 5.62).

Stratigraphic range. Middle Paleocene – Selandian Stage, upper part of NP4 zone and lower part of NP5 zone (Fig. 5.62).

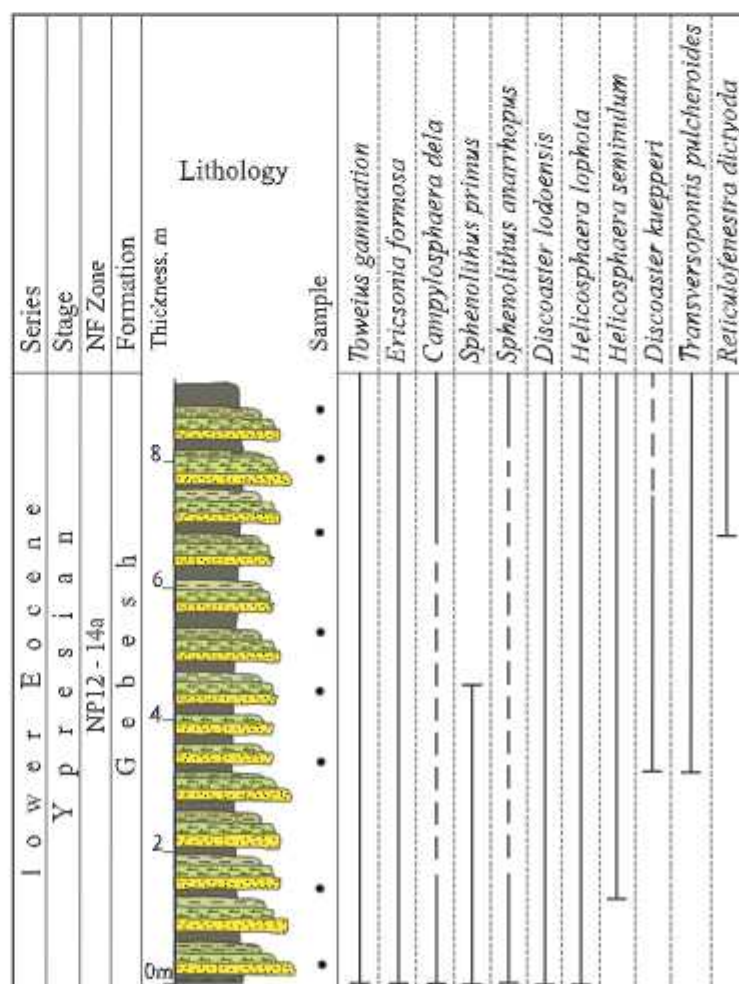
Kipilovo

This section consists of a large outcrop of thin-bedded rhythmic turbidite alternations, located on the Stara reka – Kipilovo road, 1.5 km after the road fork to Kipilovo (Fig. 5.63). The thickness is around 10 m.

The sediments are quite similar lithologically to the Gebesh Fm that mostly outcrops in the coastal part of the East Balkan and therefore they are assigned to this lithostratigraphic unit.

Biostratigraphy. The outcrop has been sampled in detail and the results are shown on Fig. 5.64. The analy-

Fig. 5.64. Biostratigraphic subdivision of the section near Kipilovo village, Sliven District, by calcareous nannofossils



Then a sharp lithological boundary is followed by a packet of thin-bedded clayey marls and clays. These are light-beige, of varying carbonate content, 20 m thick. Occasional lenses and thin beds (10–30 cm) of limestone with rare chert concretions occur. These sediments are assigned to the Emine Fm by analogy with the sediments of the neighbouring Ichera-Gradets section, located 5–6 km south of Zheravna.

The upper part of the section is built of white to yellowish massive hard thick-bedded sandstones, containing quartz grains and sandy-calcareous cement. They cover the marls with a sharp boundary and are referred to the thick-bedded sandstone formation which is broadly distributed in the entire East Balkan zone.

Biostratigraphy. The subdivision of the section by calcareous nannoplankton is synthesized on Fig. 5.65. An association with a low species and poor preservation is identified in the hard micritic limestones with chert of the Vetrila Fm. The occurrence of *Lithraphidites quadratus* proves the attribution to the Upper Maastrichtian.

The clayey marls have been sampled during several field campaigns, thus facilitating an increased sampling density for certain intervals. The nannofossil associations are not particularly diverse, but indicative of age. A continuous succession of nannofossil zones NP1 to NP3 in the Danian Stage is indicated (Fig. 5.65).

Zone NP1 is identified in the first 2.5 m of the marls and is characterised by the co-occurrence of *Cruciplacolithus primus*, *Neobiscutum romeinii* and the frequent occurrence of *Thoracosphaera operculata*, *Braarudosphaera bigelowii* and *Placozygus sigmoides* in the association. The lower boundary of NP2 zone is set by the FO of *Cruciplacolithus intermedius*, accompanied by the first *Prinsius dimorphosus* and *Coccolithus cavus*. The thickness of this zone is 7 m. The lower boundary of NP3 zone is traced by the FO of *Cruciplacolithus edwardsii* along with FO of *Prinsius martinii*.

No nannofossils were found in the samples from the thick-bedded sandstone formation in the upper part of the section, but likewise they may be assigned to the Selandian Stage by analogy with the nearby section.

Stratigraphic range. Nannofossils prove the sequence ranges from the Upper Maastrichtian, CC25b – lower Paleocene, Danian, NP1 – NP3 zones (Fig. 5.65).

Ichera-Gradets

The section is traced as a continuous succession along the road between Ichera and Gradets villages,

Sliven District. It is the continuation of a well-exposed Upper Cretaceous section (Emine Fm) on the Sliven-Ichera road that was sampled in detail and proved the presence of the Campanian and Maastrichtian Stages.

The section described here starts 2 km east of Ichera and ends at the northern end of Gradets, where the road reaches the highway to Kotel.

Irregular-bedded turbiditic alternations of gravels to pebble-conglomerates, marls and grey colored medium-bedded micritic limestones are exposed (Fig. 5.66). The conglomerates and gravels are polygenetic, with clasts of sandstones, limestones, volcanic and metamorphic rocks. Three large packets of limestone beds are present. Upwards, the alternation becomes more regularly rhythmic and thin-bedded, including sandstones, limestones and marls as the latter dominate. These sediments are included in the Emine Fm.

In the upper part of the section, thick beds and packets of hard sandstones (5–6 m thick) develop. These are interbedded within thin-bedded rhythmic turbidite alternations, followed again by another packet of sandstone, until thick-bedded sandstones dominate the succession (Fig. 5.66). No limestone interbeds are present in these sandstones. These sediments are referred to the thick-bedded sandstone formation. This formation displays impressive outcrops with spectacular sedimentary structures within the sandstones along the road between Gradets and Neykovo villages, about 2 km north of the featured section. Their total thickness exceeds 100–150 m.

Biostratigraphy. Because of the significant thickness of the described sequence, the turbiditic sediments have been sampled at intervals of 15–20 m, and the thick-bedded sandstones – at 50 m. The results of the nannofossil studies and the biostratigraphic subdivision of the section are displayed on Fig. 5.66. A continuous succession from the Upper Cretaceous to the lower Eocene is present, that by its completeness is comparable to the sequence outcropping on the Black Sea coast north of Emine Cape.

The lower parts of the section are referred to the Maastrichtian zone *Micula murus*, based on a nannofossil association comprising *Micula murus*, numerous *Micula decussata*, *Arkhangelskiella cymbiformis*, *Eiffellithus turrisseiffelii*, *Prediscosphaera ponticula*, *Microrhabdulus attenuatus*. The association was extracted from the marlstone interbeds between the packets of gravels and limestone beds (Fig. 5.66). The uppermost Maastrichtian zone *Micula prinsii* is not documented, likely due to its small thickness and the large sampling interval.

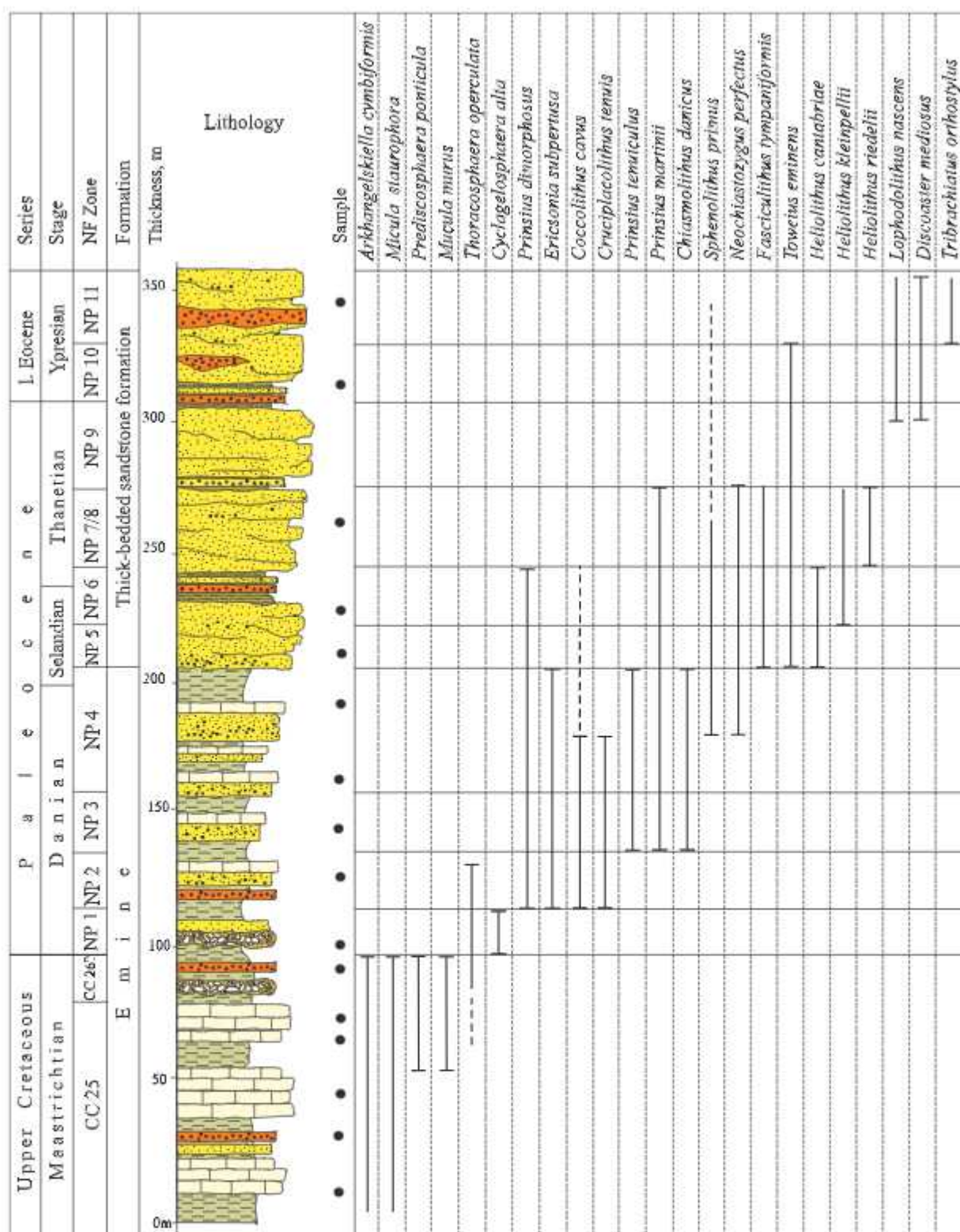


Fig. 5.66. Biostratigraphic subdivision of the section between the villages Ichera and Gradets, Sliven District, by calcareous nannofossils

The lowermost Paleocene NP1 zone is evidenced by the identification of the species *Cyclagelosphaera alta* along with *Thoracosphaera operculata* in the marls above the last debris packet (Fig.5.66). The thickness of the zone is not precisely measured, but is probably around 10 m.

The boundary between NP1 and NP2 zones is indicated by the FO of *Cruciplacolithus tenuis* as well as by the occurrence of the common and abundant *Prinsius africanus*, *Prinsius dimorphosus*, *Ericsonia subpertusa* and *Coccolithus cavus*.

The lower boundary of NP3 zone is traced by the FO of *Chiasmolithus danicus*.

The NP3/NP4 boundary is not precisely fixed, since the NP4 zonal index species *Ellipsolithus macellus* is not detected in the associations. The upper part of NP4 zone is firmly proved by the first co-occurrence of the important stratigraphic markers *Sphenolithus primus* and *Neochiastozygus perfectus* in the uppermost levels of the Emine Fm.

The lower boundary of NP5 zone is traced by the FO of *Fasciculithus tympaniformis* in the lower level of the thick-bedded sandstone formation and concomitant occurrence of *Heliolithus cantabriae* and *Toweius eminens*.

The FO of *Heliolithus kleinpeltii* in a clayey bed between two thick sandstone packets marks the lower boundary of NP6 zone, as well as being a marker for the Mid-Paleocene Biotic Event (MPBE). The sample shows exceptional species diversity and perfect preservation of the nannoflora. Several reworked Upper Cretaceous (Campanian) species were also identified.

The FO of *Heliolithus riedelii* in the marls between the two sandstone packs justifies the presence of NP8 zone.

The lower boundary of NP9 zone is conditionally marked by the last occurrence (LO) of *Heliolithus riedelii*, since the sediments are rather coarse-grained and unidentifiable fragments of nannofossils are observed. Its upper part, however, is indicated by the first concomitant occurrence (FO) of the species *Lophodolichus nascens* and *Discoaster mediosus* – events assigned to the upper part of NP9 zone.

The Paleocene/Eocene boundary (NP9/NP10) falls in a packet of gravels and conglomerates within the Thick-bedded sandstone formation.

The uppermost part of the sequence belongs to the lower Eocene with NP10 and NP11 zones present. The NP10/NP11 boundary is drawn by the FO of the species *Tribrachiatus orthostylus*. The identified nannofossil associations from the claystone interbeds between the thick sandstone beds are abundant, diverse and very well preserved. Numerous reworked Campanian species such as *Uniplanarius sissinghii*, *U. gothicum*, *Reinhardtites levis* and *Retecapsa crenulata* also show the same state of preservation.

Stratigraphic range. The proven range of the sequence encompasses the Upper Maastrichtian – lower Eocene (Ypresian), CC25c – NP11 zones (Fig. 5.66).

Marash

The section is located approximately 1.5 km north of Petoluchkata junction, Sliven District, on the road to Kotel. It is traced as a continuous succession in the river bed of the Marash River (Fig. 5.67) and the left cutting along the road (Fig. 5.68). It begins where the right gorge joins the Marash River and finishes at two thick turbiditic beds that are 1.5–2 m thick (Fig. 5.69).

The section was studied and published on during studies on the Cretaceous/Tertiary boundary in Bulgaria (Stoykova et al., 2000; Stoykova & Ivanov, 2004a). The total thickness of the studied sequence is 107 m; the lower 50 m is Upper Cretaceous and the overlying 57 m lower Paleocene (Danian).

Rhythmic alternations of clays, silty marls, siltstones



Fig. 5.67. General view of the section along Marash River valley, along the road Petoluchkata – Kotel, Sliven District – thin-bedded turbidites of the Emine Fm are exposed

Fig. 5.68. Section along the Petoluchkata – Kotel road, Sliven District – thin-bedded turbidites of the Emine Fm are exposed



and clayey limestones referred to the Emine Fm are exposed (Fig. 5.68). The Cretaceous-Paleogene boundary passes immediately above sample Ms-134, at the base of a dark-grey to black clayey bed (Fig. 5.70). An increase in thickness of the turbidite rhythms is observed in the upper part of the section, where the sandstone beds become 1.5-2 m thick (Fig. 5.69).

The thick-bedded sandstone formation overlies the Emine Fm close to the large bend of the Marash River, north of the bridge. All samples from the sandstones were barren of nannofossils.

Biostratigraphy. Sampling positions and nannofossil biostratigraphy of the section are shown in Fig. 5.71. A continuous succession of zones within the K/T boundary interval has been proved: CC25b, CC25c and CC26 zones in the Upper Maastrichtian and NP1, NP2 and NP3 in the Danian have been documented.

The taxonomic analyses of the nannoflora indicates the occurrence of more than 47 species of calcareous nannofossils.

Most of the Maastrichtian samples contained abundant, well preserved associations. Nannofossils are better preserved and of higher diversity in the samples below the K/T boundary, exhibiting a clear "Tethyan" affinity. This is supported by the occurrence of *Micula murus*, *Micula prinsii* and *Ceratholithoides kamptneri*.

Zones CC25b, CC25c and CC26 have been distinguished in the Upper Maastrichtian by the FOs of species *Lithraphidites quadratus*, *Micula murus* and *Micula prinsii*, respectively.

The Cretaceous/Tertiary boundary is marked by mass extinction of the Cretaceous species. Nannoplankton



Fig. 5.69. Uppermost portion of the Marash section along the Petoluchkata – Kotel road – thick turbidites

associations at the K/T boundary and the first several metres of the Paleocene are rare and poorly preserved. Upward sequence, species diversity slowly and gradually recovers to pre-K/T boundary levels, although of changed composition.

The K/T boundary is sedimentologically marked by a dark-grey to black clayey layer (Fig. 5.70). The FO of *Cyclagelosphaera alta*, indicating the lower boundary of NP1 zone, has been identified in the sample immediately above the clayey layer (Ms-135). The first 3 m above the K/T boundary shows substantial impoverishment in species diversity of the nannofossil associations. Rare fragments of specimens that are strongly recrystallised and also specimens with secondary overgrowth, mainly Cretaceous, are recorded. Also recorded are representatives of "survivor species" *Thoracosphaera operculata*, *Thoracosphaera saxea* and *Cyclagelosphaera reinhardtii*. No pentalites have been detected. The species *Braarudosphaera bigelowii* is absent below as well as above the K/T boundary. The successive FOs of a number of new species is documented within NP1 zone which is 17 m thick in this section (Fig. 5.71): *Neobiscutum romeinii*, *Neocrepidolithus dirimosus*, *Futyania petalosa*, *Cruciplacolithus primus* and *Prinsius tenuiculum*.

The lower boundary of NP2 zone is traced by the FO of *Cruciplacolithus intermedius*, concomitant with *Prinsius dimorphosus*. *Coccolithus cavus*, *Cruciplacolithus tenuis*, *C. asymmetricus* and *Ericsonia subpertusa* successively occur in this zone. The thickness of the zone in this section is 25 m.

The NP2/NP3 boundary is fixed at the FO of *Chiasmolithus danicus* in sample Ms-21. The species diversity continues to increase in this zone and reworked Cretaceous species are rarely encountered.

Prinsius martinii and *Neochiastozygus modestus* first occur in NP3 zone, quickly becoming the most abundant species, dominating the associations in the zone. The thickness of the zone exceeds 20 m.

Stratigraphic range. The sequence is Upper Maastichtian CC25b – lower Paleocene (Danian), NP3 zones (Fig. 5.71).

Interesting results have been obtained from the analysis of samples from 2 separate outcrops during field work for the "Geology of Bulgaria" project; Krastets railway station and Stanchov han. These are discussed below.

Krastets railway station

Thin-bedded dark-grey marls and clayey limestones crop out in the road cut on the Plachkovtsi-Krastets road and may be assigned to the limestone-marl formation (analogous to the Mishemorkov han section). The abundant nannoplankton association consists of the following species: *Cruciplacolithus primus*, *C. intermedius*, *Ericsonia subpertusa*, *Prinsius africanus*, *P. dimorphosus*, *Thoracosphaera saxea*, *T. operculata* and *Neocrepidolithus* spp. The association is characteristic of the uppermost part of NP1 zone and the base of NP2 zone, i.e. it indicates the lowermost part of the Danian Stage in that area.

Stanchov han

Here an abundant association, comprising *Sphenolithus editus*, *S. radians*, *Toweius occultatus* etc., characteristic of the lower Eocene NP12 zone is documented. The outcrop in Stanchov han village consists of thin-rhythmic turbiditic alternations of sandstones, siltstones and marls of the Lukovit Fm.



Fig. 5.70. The position of the K/T boundary (red line), marked by a dark grey clayey layer in the Marash section

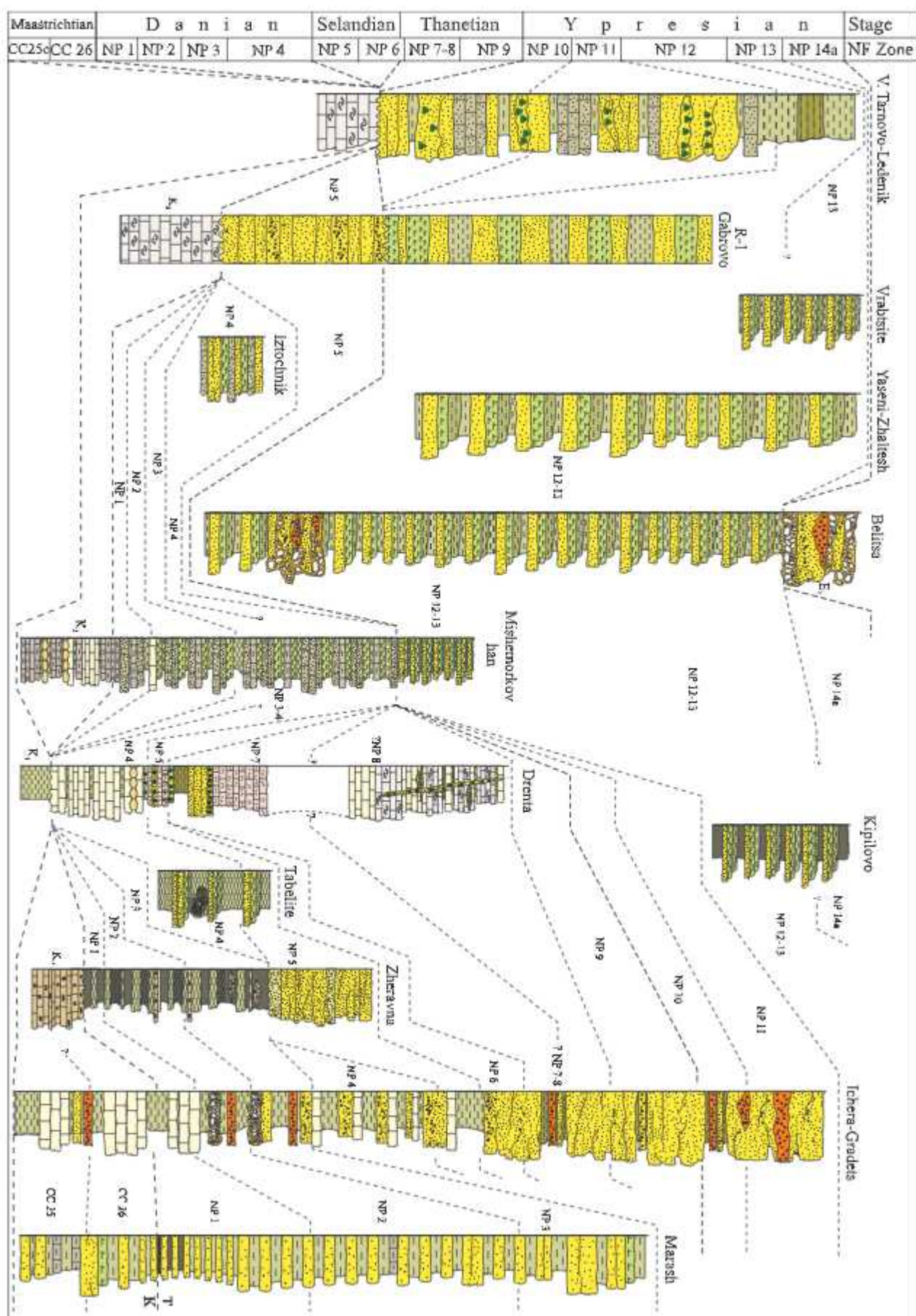


Fig. 5.72. Correlation of Paleogene sediments in the Central Fore-Balkan and Central Balkan by calcareous nannofossils

More intriguing results have been obtained from another outcrop, located 1 km north of Stanchov han, along the road to Svirtsu hamlet. A monotonous thick marly-clayey sequence dominated by light-beige colored thin-bedded silty marls and calcareous clays is exposed. An exceptionally abundant and diversified association of over 20 nannofossil species is identified, consisting of *Fasciculolithus tympaniformis*, *Lithopterychius ulii*, *L. jani*, *L. billii*, *Chiasmolithus danicus*, *C. bidens*, *Coccolithus pelagicus*, *Heliolithus cantabrigiae*, *Prinsius martini*, *P. dimorphosus*, *Sphenolithus primus*, *Ericsonia subpertusa*, *Ellipsolithus distichus* and *Markalius inversus*. The association characterizes NP5 zone of the Selandian Stage (middle Paleocene).

The studied sections from the Central Fore-Balkan and Balkan represent a unique geological archive, recording the dynamics in the development of the marine basin – lithological and faunistic/floristic successions in the area during Paleocene and early Eocene time. Explaining these by means of detailed calcareous nannoplankton biostratigraphy has allowed reliable correlations, displayed on Fig. 5.72.

5.5. East Fore-Balkan and Balkan

Paleogene sediments are of wide distribution, cropping out in vast areas within the East Fore-Balkan and Balkan, also known as the Luda Kamchia Zone (Fig. 5.73). Paleocene and lower Eocene sediments are mainly developed, while middle and upper Eocene as well as Oligocene sediments have a significantly restricted distribution.

Esen

The section is located in the northern end of Esen village, Burgas District (6 km north of Sungurlare), near the water pump station.

A 30 m thick sequence is exposed, with the lower and middle parts (around 22 m) built of rhythmic turbidites of the Emine Fm, while the upper part is represented by the thick-bedded sandstone formation. The turbidites consist of sandy and/or clastic limestones, siltstones and marls. Almost all of the characteristic types of turbiditic structures are perfectly displayed; graded bedding, lamination, convoluted bedding (particularly common in the siltstones), etc. Current directions are indicated by flute casts (sole marks filled with sediment) made by clasts and fossils on the base of bedding surfaces. The fine-grained portions of the rhythms (the marlstones) have been sampled for nannoplankton.

The thick-bedded sandstone formation above is represented by thick sandstones beds (from several metres to 10-15 m thick) with thin intercalations of siltstones and silty and clayey marls. No nannofossils have been detected.

Biostratigraphy. The biostratigraphic subdivision of the section by nannoplankton is presented on Fig. 5.74. All samples from Emine Formation exhibit abundant, well preserved nannofossil associations. Reworked Upper Cretaceous species are also commonly observed – *Broinsonia parva constricta*, *Lucianorhabdus cayeuxii* and *Arkhangelskiella cymbiformis*.

The presence of nannofossil zone NP5 is proved by the co-occurrence of *Chiasmolithus bidens* and *Neochiastozygus perfectus*, recorded in the first sample from the base of the section.

The rare species *Cyclagelosphaera prima* has its FO in the middle of NP5 zone, as do *Heliolithus cantabrigiae*, *Bomolithus elegans* and *Chiasmolithus consuetus*.

The samples from the silty interbeds of the thick-bedded sandstone formation do not contain nannoflora.

Stratigraphic range. Middle Paleocene – Selandian Stage, NP5 zone for the turbiditic sediments of the Emine Fm (Fig. 5.74).

Podvis

The section is located in the western end of the village of Podvis, Burgas District. It is traced from the western entrance of the village along the hill slope to the gully between two small peaks.

The base of the sequence comprises thin-bedded limestones with interbedded thin-bedded marlstones. The limestones contain numerous chert nodules. These strata are assigned to the Vetrila Fm (Fig. 5.75) which contains many folds and faults here.

There follows a rapid transition to over 30 m of thin-bedded rhythmic alternations of marls, sandy limestones and purer limestones, assigned to the Emine Fm.

Thick beds (over 20-30 m) of sandstones, alternating with thinner marlstone interbeds occur at the top of the succession above a sharp boundary. These represent the thick-bedded sandstone formation.

Biostratigraphy. The results of nannofossil study and the biostratigraphic subdivision of the section are presented in Fig. 5.75. A continuous sequence from the Upper Cretaceous to the middle Paleocene is devel-

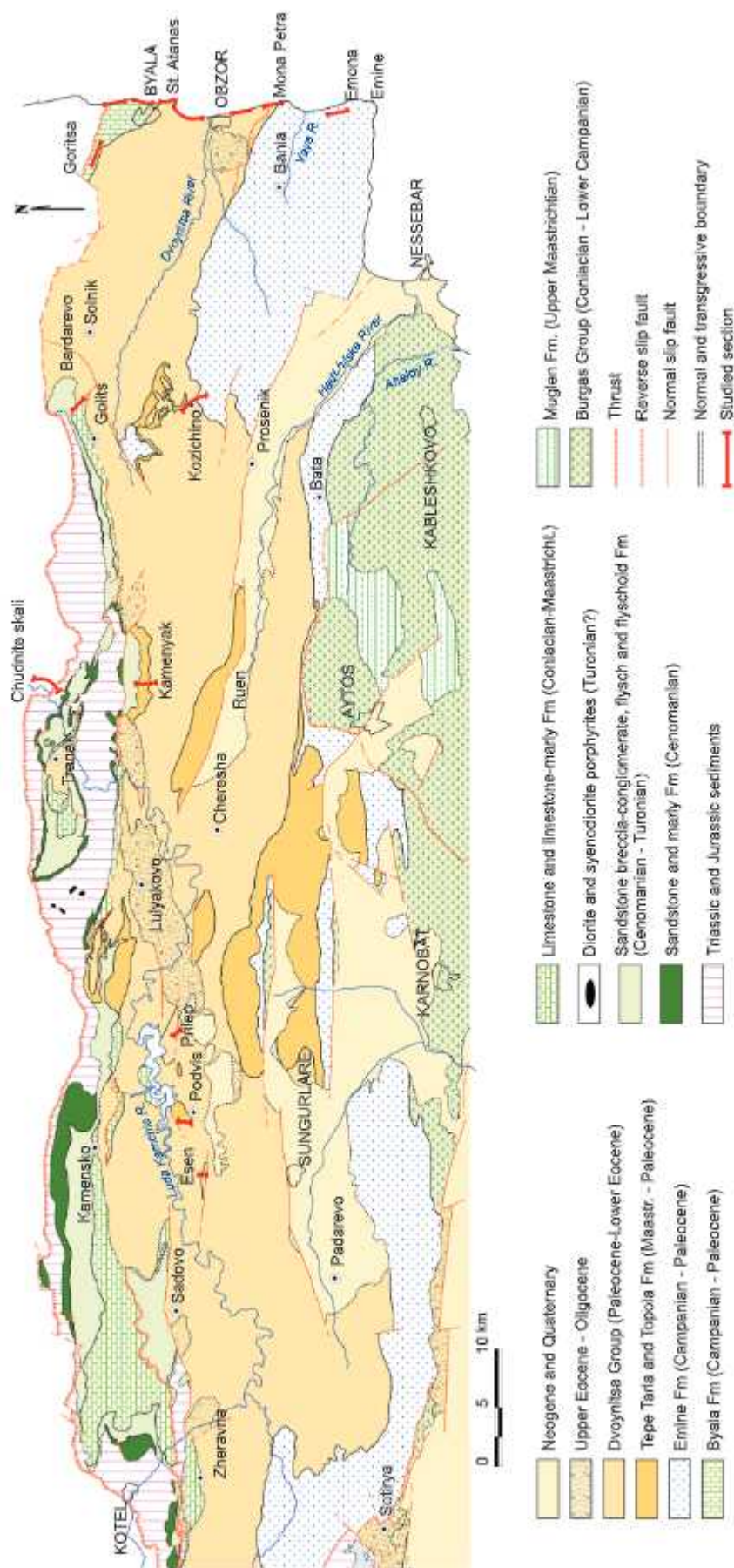


Fig. 5.73. Exposures of the Paleogene sediments within the East Fore-Balkan and Balkan (Luda Kamchia Zone)

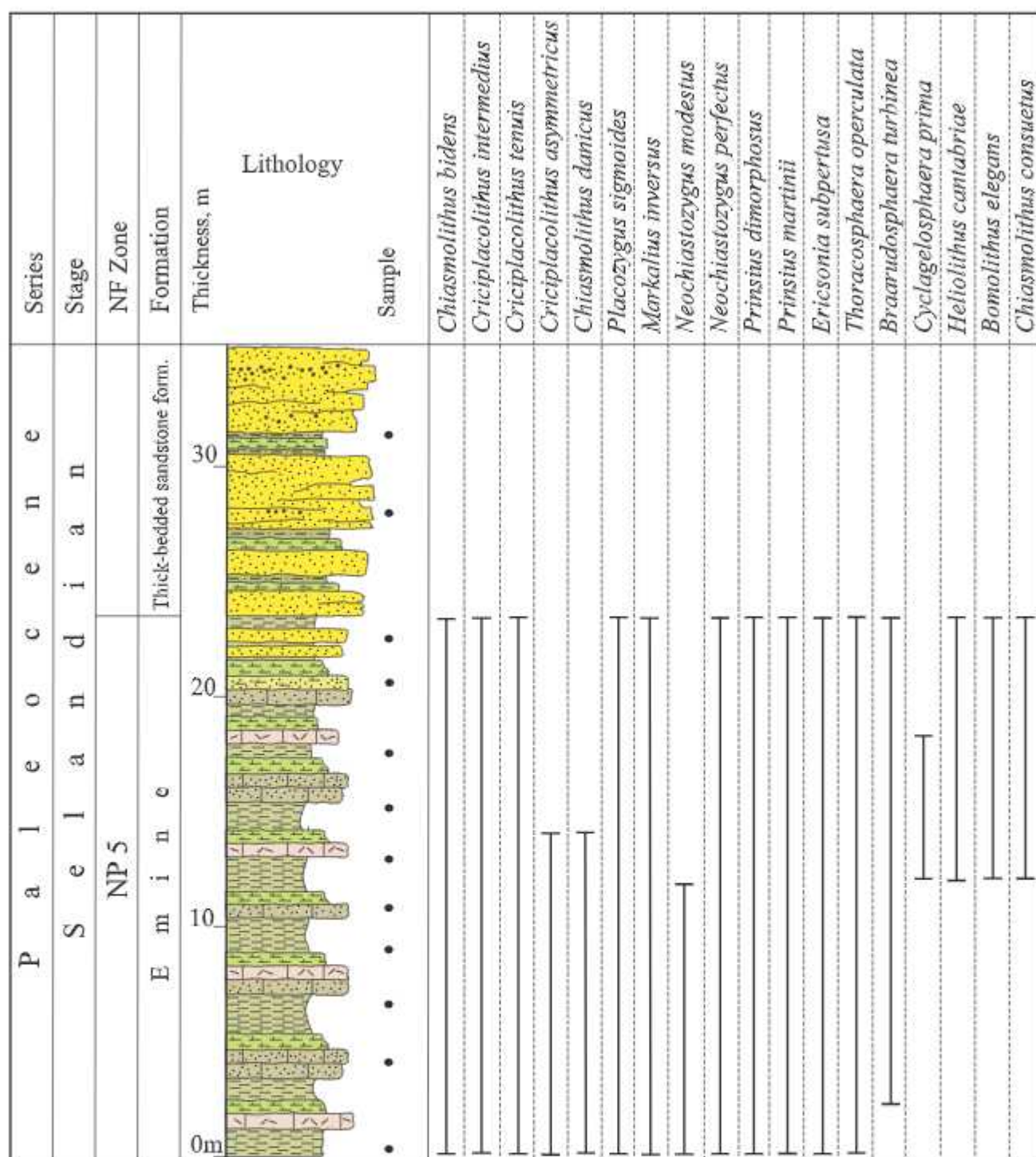


Fig. 5.74. Biostratigraphic subdivision of the section near Esen village, Burgas District, by calcareous nannofossils

oped, including the Maastrichtian, Danian and Selandian Stages. The K/T boundary is not precisely fixed due to intensive tectonics manifested in the thin-bedded limestones of the Vetrila Fm. Low abundance, but age-diagnostic nannofossil associations have been identified. The best preserved and most diverse assemblages were recovered from the clayey portion of the Emine Fm rhythms.

The base of the section is supposedly Upper Maas-

trichtian, but the rare and poorly preserved nannoflora from this part hampers the identification of a specific zone (Fig. 5.75).

Cyclagelosphaera alta, along with reworked Cretaceous species, is identified in the upper levels of the Vetrila Fm, in the thin marlstone interbeds within the cherty limestones. The FO of this species marks the lower boundary of NP1 zone at the base of the Danian Stage.

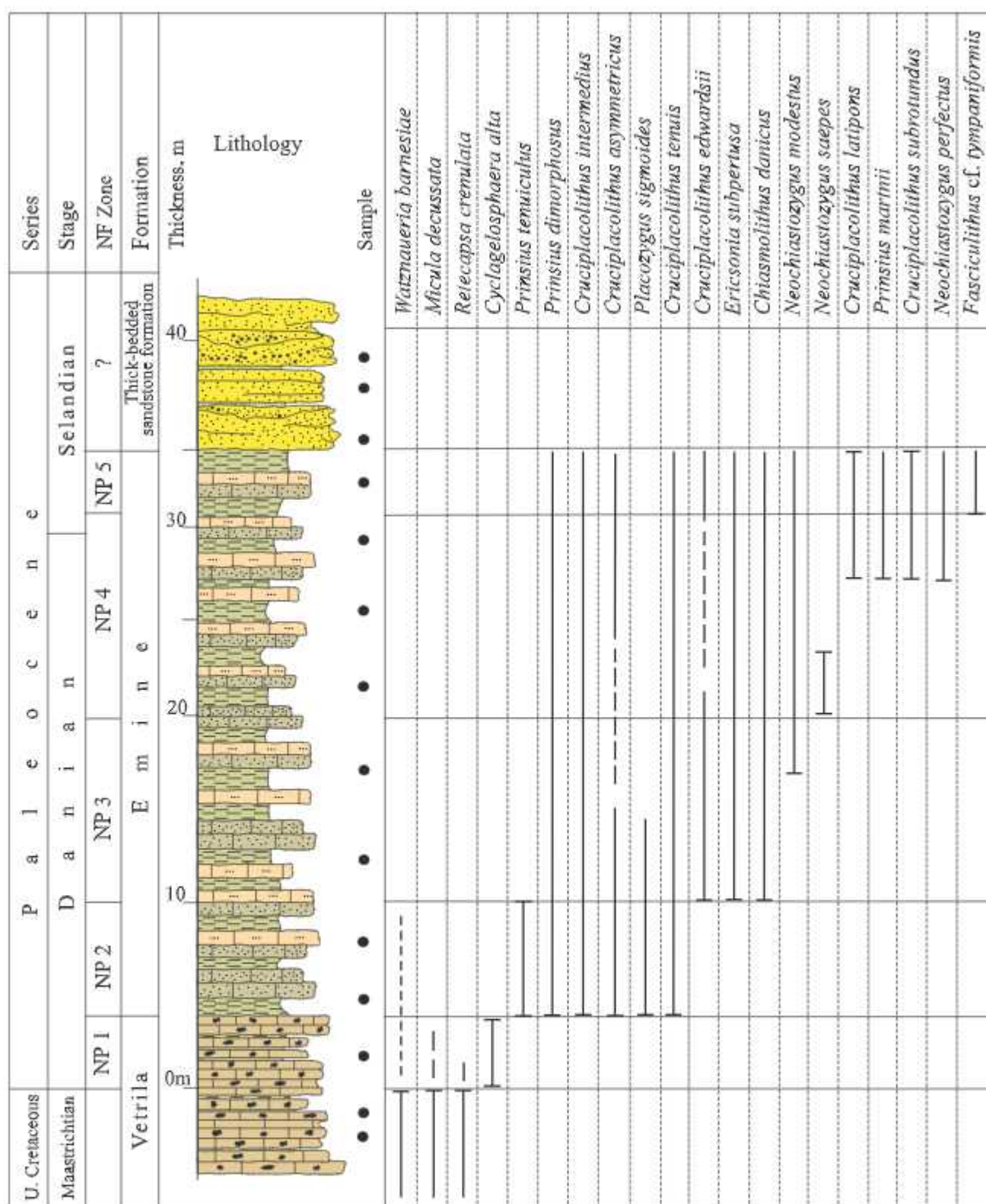


Fig. 5.75. Biostratigraphic subdivision of the section near Podvis village, Burgas District, by calcareous nannofossils

The lower boundary of NP2 zone is traced by the FO of *Cruciplacolithus intermedius*. The zone is represented by a relatively richer association, identified at the base of the thin-bedded rhythmic turbidite sequence of the Emine Fm. It comprises *Prinsius dimorphosus*, *P. africanus*, *Cruciplacolithus asymmetricus*, *C. tenuis*

and *Placozygus sigmoides* (Fig. 5.75).

The NP2/NP3 boundary is placed by the FO of *Cruciplacolithus edwardsii*. The lower boundary of NP4 is traced conditionally by the occurrence of *Neochiastozygus saepes*, since the index species

Ellipsolithus macellus has not been detected (Fig. 5.75). A specific association, that includes *Cruciplacolithus latipons* and *C. subrotundus* is detected in the upper part of NP4 zone and the base of NP5 zone. Both taxa have a short range only in the uppermost part of NP4 and the lowermost part of NP5, therefore appearing to be excellent markers for this stratigraphic interval.

The lower boundary of NP5 zone is traced by the FO of *Fasciculithus* cf. *tympaniformis* in the uppermost part of the Emine Fm, immediately below the boundary with the thick-bedded sandstone formation (Fig. 5.75). All samples from the thick-bedded sandstone formation in this section are barren of nannofossils.

Stratigraphic range. Upper Cretaceous, Maastrichtian Stage – lower and middle Paleocene, Danian and Selandian Stages, zones NP1 – NP5 (Fig. 5.75).

Prilep

An identical section to the one at Podvis is observed at the northern end of Prilep village, Burgas District, situated 4–5 km east of Podvis. Thin-bedded limestones (Vetrila Fm) and thin-rhythmic turbiditic sediments of the Emine Fm are exposed. Poorly preserved nannofossils, indicating the presence of NP3 – NP4 zones are identified in samples from the Emine Fm.

Ruen – Snyagovo

The section starts north of Ruen village, 0.5 km north of the road fork to Snyagovo and Dobra polyana villages, and is traced in the road cutting on the Ruen – Snyagovo road.

Rhythmically alternating limestones, sandy limestones, siltstones and marlstones are displayed. In the higher portions, the limestones become clastic – calcarenites to gravels, with extraclasts. These sediments were wrongly assigned to the Tepe-Tarla Fm on the geological map (Kanchev, 1995b). Here we consider them as corresponding to the Emine Fm (Fig. 5.76).

Above them, through a fast lithological transition, an alternation of hard, light-beige colored thick-bedded limestones with cherts and thin marly interbeds occurs. These sediments correspond to the Tepe-Tarla Fm. Though difficult to estimate, their thickness is in the range of 100 m. Limestone quarries have exploited these sediments. In one magnificent quarry exposure, located south of Dobra polyana, a 0.5–0.6 m thick bed of conglomerates is present among the limestone beds. The conglomerates are polygenetic, poorly sorted, containing coalified plant debris.

The uppermost part of the section is exposed 1.2

km SSW of Snyagovo village, along the road cut. Above the thick-bedded limestones of the Tepe-Tarla Fm (probably through a tectonic boundary – reverse fault), coarse-clastic sediments occur, corresponding to the thick-bedded sandstone formation. At their base they are represented by several beds of gravel and relatively thick beds of conglomerate. The latter are polygenetic, unsorted, with large clasts (0.2–0.3 m) of semi-rounded limestone with flint, rounded small flint clasts and rounded pebbles of marl in a sandy matrix. The conglomerates alternate with thin interbeds of siltstone and silty marl.

Biostratigraphy. The nannoflora in the clayey marls of the Emine Fm in the lower part of the section is exceptionally abundant, diverse, and very well preserved. The opposite is true for the nannofossils in the thick-bedded limestones of the Tepe-Tarla Fm being rare, of low diversity and poorly preserved. Better associations are registered in the thin marly interbeds between the thick limestone banks in the upper portion of this Formation. It is worth noting that nannofossils are discovered at the base of the thick-bedded sandstone formation. The marl interbeds below and above the basal conglomerates contain a moderately abundant, but characteristic nannofossil association.

The subdivision of the section by nannoplankton is shown on Fig. 5.76. The uppermost part of the Maastrichtian Stage is proved by an extraordinarily diverse and perfectly preserved association of zone CC26 *Micula prinsii*. It comprises over 20 species, among which are *Micula prinsii*, *Prediscosphaera grandis*, *P. majungae*, *P. stoveri*, abundant *Thoracosphaera operculata*, *Arkhangelskiella paucipunctata*, *A. cymbiformis*, *Retecapsa crenulata* and *Eiffellithus turrisseiffelii*. The K/T boundary is not precisely pinpointed, but it is clear that the sequence is continuous, supported by the occurrence of the lowermost Danian zone – NP1.

Zone NP1 is characterised by an association dominated by “survivor” species *Thoracosphaera operculata*, *Markalius inversus* and *Cyclagelosphaera reinhardtii* as well as reworked (?) or surviving Cretaceous species *Eiffellithus turrisseiffelii*, *Retecapsa crenulata*, *Microrhabdulus attenuatus*, *Micula decussata*, *Watznaueria barnesiae* and *Prediscosphaera cretacea*. The newly evolving species in this zone are *Cyclagelosphaera alta* and *Cruciplacolithus primus*.

The lower boundary of NP2 zone is traced by the FO of *Cruciplacolithus intermedius*. Considerably more new species appear within this zone: *Prinsius dimorphosus*, *P. africanus*, *Ericsonia subpertusa*, *Cruciplacolithus tenuis* and *Coccolithus cavus* (Fig. 5.76).

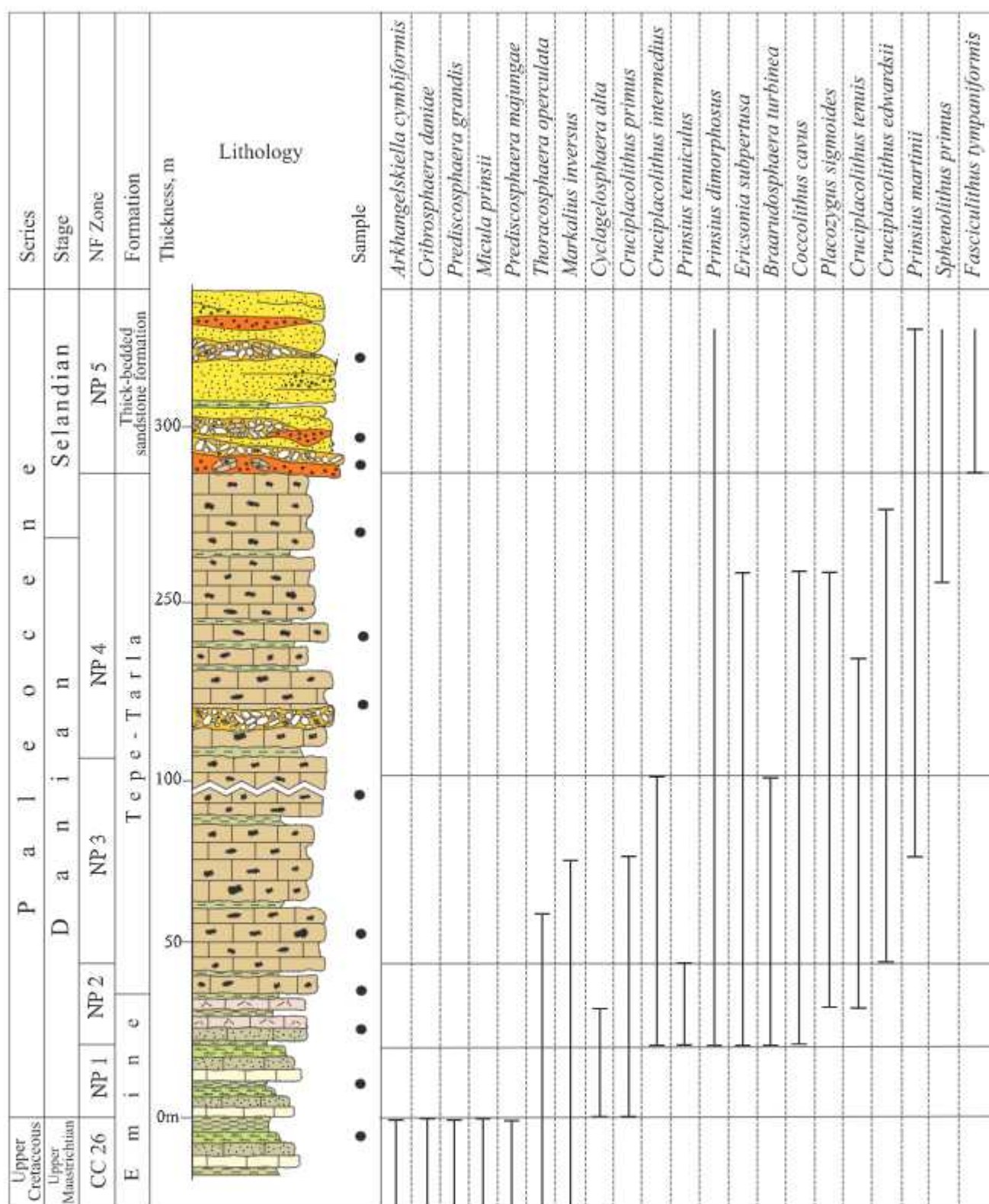


Fig. 5.76. Biostratigraphic subdivision of the section near Ruen-Snyagovo villages, Burgas District, by calcareous nannofossils

The lower boundary of NP3 zone is marked by the appearance of the species *Cruciplacolithus edwardsii*. The lower boundary of NP4 zone is traced conditionally – due to the poor and non-characteristic associations in the thick-bedded limestones of the Tepe-Tarla Fm.

Marly interbeds at the base of the thick-bedded sandstones reveal a particular nannofossil association, which corresponds to NP5 zone in the Selandian. This interpretation is supported by the concomitant occurrence of *Fasciculithus tympaniformis*, *Sphenolithus primus* and *Prinsius dimorphosus*.



Fig. 5.77. Section near the village of Kamenyak, Burgas District – outcrops along the roadcut of the road across the Tepe-Tarla hill

Stratigraphic range. The section encompasses an interval from the uppermost Maastrichtian, CC26 zone to the middle Paleocene, Danian and Selandian, NP1 – NP5 zones (Fig. 5.76).

Kamenyak

The section starts 250 m NE of Kamenyak village, Burgas area, and is traced along the southern slope of Tepe-Tarla hill, in the scarp of the new road cutting on Tepe-Tarla hill in a south-north direction (Fig. 5.77). The road was constructed in 2005, linking Kamenyak (to the south) with the villages of Snezha and Zaymchevo (to the north).

Pink to light-grey colored, thick-bedded solid limestones with flint concretions and siliceous layers are referred to the Tepe-Tarla Fm (Fig. 5.78). The exposed thickness is in the range of several tens of metres. These sediments were described by Kockel (1927, p. 364) as “...coarse-grained limestone – very characteristic, the beds of decimeters thickness, regularly bedded, no marl content, pink to grey-pink in colour, slightly sandy. Its thickness is only between 20 to 50 m”.

Similar to the Ruen-Snyagovo section, coarse-clastic sediments overlay the limestones with a sharp tectonic boundary (Fig. 5.79). They are represented by poorly sorted polygenetic conglomerates and breccia-conglomerates at the base, 40-50 m thick. Upwards, these are overlain by thick-bedded sandstones with thin siltstone interbeds (thick-bedded sandstone formation). Large clasts (0.1-0.5 m) of rounded or semi-rounded Upper Cretaceous sedimentary rocks (limestones, marls and chert concretions) are observed in the conglomerates and breccia-conglomerates (Fig. 5.80).

Biostratigraphy. Calcareous nannofossils are quite



Fig. 5.78. Section near the village of Kamenyak, Burgas District – exposures of the Tepe-Tarla Fm (thick-bedded limestone with cherts)

rare and poorly preserved in the massive limestones with flint. They are found in the very thin marly layers between the limestone banks. Slightly richer and better preserved are the nannofossils from the clayey-marly interbeds in the lower conglomerates. The biostratigraphy and subdivision of the section are displayed on Fig. 5.81.

The lowermost exposed levels of the Tepe-Tarla Fm limestones contain an association consisting of *Cyclagelosphaera alta*, *Prinsius dimorphosus* and *Coccolithus cavus*. It is interpreted as indicating NP2 nannofossil zone.

Small-sized Prinsiaceae and *Coccolithus cavus*, along with *Braarudosphaera bigelowii* are recovered in the samples from the middle and upper parts of the limestones. These levels are referred conditionally to NP3 – NP4? zone, since the poor association is not definitive for precise zonal assignment.

NP5 zone nannoflora has been determined at the base of the conglomerates. It includes species with their first occurrence (FO) in this zone: *Chiasmolithus consuetus*, *Neocrepidolithus neocrassus*, *Toweius pertusus* and *Fasciculithus* spp. The samples taken from the uppermost levels of the section were barren, containing no nannofossils.

Stratigraphic range. The range is lower and middle Paleocene, Danian and Selandian Stages, NP2 – NP5 zones (Fig. 5.81).

Chudnite skali

The section is located 10 km south of Dalgopol village and is traced along the cliff on both sides of the Provaida-Aytos road (Fig. 5.82).



Fig. 5.79. Section near the village of Kamenyak, Burgas District – tectonic contact between the Tepe-Tarla Fm (left) and coarse-clastic sediments at the base of the thick-bedded sandstone formation (right)



Fig. 5.80. Section near the village of Kamenyak, Burgas District – large clasts (0.1 – 0.5 m in size) of rounded or semi-rounded Upper Cretaceous sedimentary rocks in Selandian conglomerates and breccia-conglomerates of the thick-bedded sandstone formation

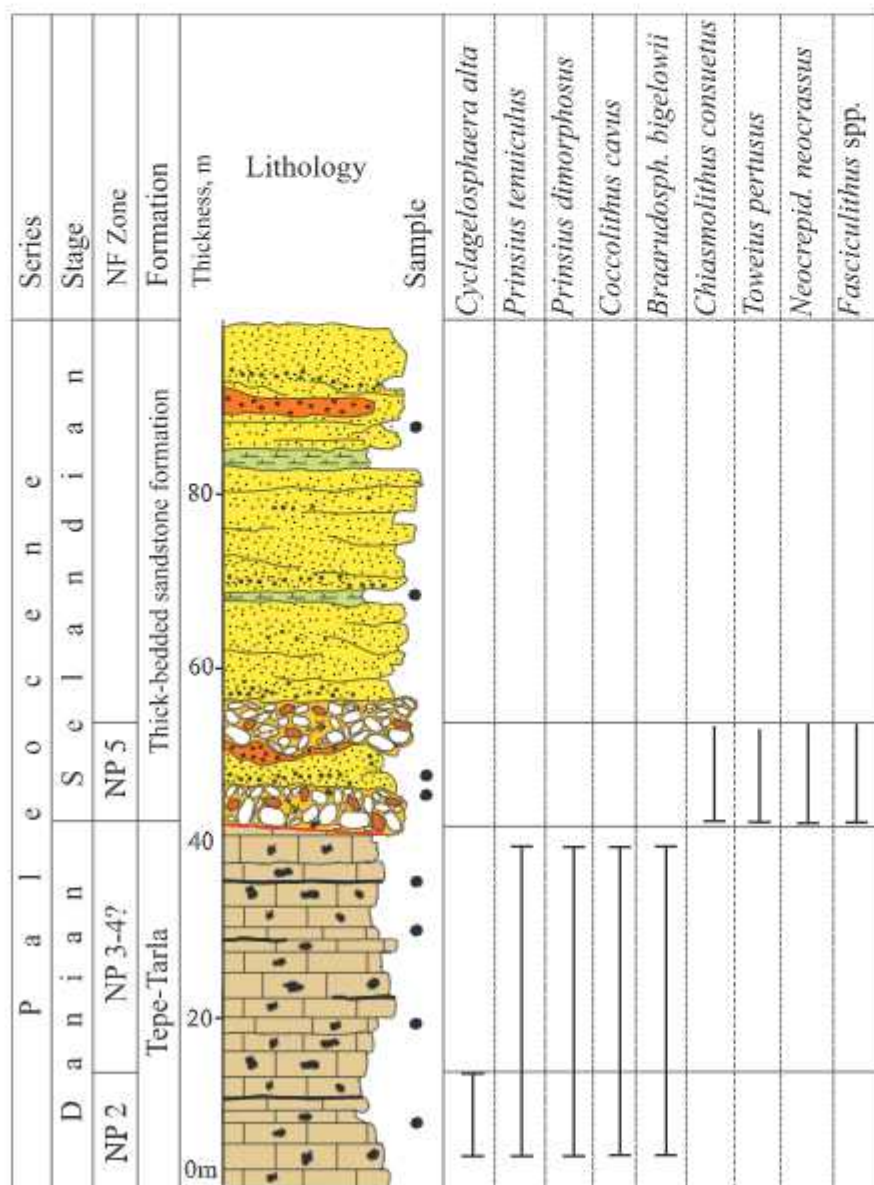


Fig. 5.81. Biostratigraphic subdivision of the section near Kamenyak village, Burgas District, by calcareous nannofossils



Fig. 5.82. General view of the Chudnite skali section – lower portion of the sedimentary succession at the tunnels

It starts immediately south of the bridge on Tsonevo Dam, along the dirt road to the old quarries (Fig. 5.83) and ends at the northern entrance to Dobromir village. A 200 m thick succession, encompassing sediments from the Upper Cretaceous to the middle Eocene, is exposed. Different parts of this section have been studied by Jolkichev (1989), Vangelov and Sinnyovsky (2000) and Peybernès et al. (2004).

The base of the section is built up of light-grey, thick-bedded to indistinctly bedded silty limestones,

referred to the Asparuhovo Fm (Jolkichev, 1989). These are covered by light-grey, thin- to medium-bedded nodular limestones with chert concretions and lenses that have a sharp basal lithological boundary (Fig. 5.83). The concretions and lenses are abundant along the road between the first and second tunnel (Fig. 5.84). The higher levels reveal clear clinofolds, prograding southwards, that are covered by parallel bedded limestones (Fig. 5.85). These sediments are referred to the “Mezdra” Fm due to their lithological characteristics.



Fig. 5.83. Lower portion of the Chudnite skali section – the sharp boundary between the limestones of the Asparuhovo Fm and the overlying nodular limestones of the “Mezdra” Fm



Fig. 5.84. Cherty concretions and lenses in the "Mezdra" Fm between the first and the second tunnel

Up section, these are overlain by medium- to thick-bedded clastic limestones, creamy to whitish, that contain abundant biotritus and algal skeletons. The detritus is composed of shell fragments – echinoids, bivalves and benthic foraminifera, as well as quartz grains (10-15%). These rocks are classified as skeleton wackestones, packstones and grainstones and are assigned to the "Kailaka" Fm. Clearly expressed clinoforms are observed in these rocks, too, around 10 m thick. This sequence is magnificently exposed in the big old quarry (Fig. 5.86).

The uppermost portions of the quarry are built by ~30 m sandy and detritic limestones – calcarenites to sandstones, with abundant red algae skeletons (the so-called *Lithothamnium* limestones) and large benthic foraminifera. They lie unconformably over "Kailaka"



Fig. 5.85. Clinoforms in the "Mezdra" Fm, prograding to the south, after the second tunnel

clastic limestones and are assigned to the Komarevo Fm. The boundary is very distinct, wash-out "hard ground" type, and is marked by a 3 cm glauconite level with phosphorite concretions (Fig. 5.87).

The upper parts of the section are traced in road-side exposures, following the bridge (its southern end). The Komarevo Fm limestones are overlain by sands and sandstones of the Beloslav/Dikilitash Fms through a sharp washout boundary. They are represented by yellowish to white colored, weakly cemented quartz sandstones and loose sands, massive to indistinctly bedded (Fig. 5.88). These are fine-grained, well sorted, enriched with glauconite in some levels. Better cemented beds are observed where the sandstones form vertical columns, similar to the Dikilitash Pobiti kamani (stone columns) (Fig. 5.89).



Fig. 5.86. Clinoforms in the "Kailaka" Fm, prograding to the south-southeast, in the big old limestone quarry



Fig. 5.87. Wash-out boundary "hard ground", between the "Kailaka" and overlying Komarevo Fm, marked by a glauconitic level with phosphoritic concretions (red arrow)



Fig. 5.88. Weakly cemented quartz sandstones and loose sands of the Beloslav/Dikilitash Fms



Fig. 5.89. Firmly cemented sandstones with vertical structures into the Beloslav/Dikilitash Fms

The sandstones are overlain by dark-green, dark-grey and reddish colored calcareous claystones and marlstones. The upper part consists of alternating siltstones and thin-bedded sandstone interbeds. The total thickness of these sediments, referred to the Avren Fm, is around 30 m.

The Avren marls are overlain with sharp transgressive boundary and angular unconformity by coarse-clastic sediments (Fig. 5.90). These begin with breccia-conglomerate, around 2-3 m thick, with elongated tile-arranged clasts from the underlying green claystones, 25-30 cm in size (Fig. 5.91). Up section, it turns into clast supported conglomerate with well-rounded clasts of sedimentary and volcanic rocks and then into coarse-grained sandstones (Fig. 5.92). These sediments are assigned to the Obzor Fm (the so-called

“exotic conglomerate”). Nannofossils have been discovered for the first time in these sediments, which allows their age determination.

Biostratigraphy. Chudnite skali is a unique section among all others described, since it demonstrates (with several short breaks of sedimentation) the whole succession from the Upper Maastrichtian to the middle Eocene. Calcareous nannoplankton recovered throughout the entire section facilitated its biostratigraphic subdivision (Fig. 5.93). The richest and best preserved associations are recorded in the upper portions of the section – within the Komarevo, Beloslav and Avren Fms.

An age diagnostic, but low abundance association is identified at the base of the section, in the Asparuhovo



Fig. 5.90. Sharp and transgressive angular unconformity at the base of the Obzor conglomerates overlying the Avren marls



Fig. 5.91. Basal breccia-conglomerate (Obzor Fm) with elongated tile-like clasts derived from the underlying green clays (Avren Fm)

Fm limestones, indicating the upper Maastrichtian zone CC25c *Micula murus*. The last Maastrichtian zone CC26 *Micula prinsii* and the first Danian NP1 zone were not detected. This probably reflects a break in sedimentation (non-deposition), corresponding to the sharp boundary between the Asparuhovo and "Mezdra" Fms.

The nannoflora in the nodular limestones with chert is very rare and poorly preserved. Usually, poorly preserved Prinsiaea are observed, though *Prinsius dimorphosus* is undoubtedly documented. Therefore, the presence of NP2-NP3 zone may be assumed in the section. The lower boundary of NP4 zone is conditionally traced due to rare finds and a lack of stratigraphically important species. The middle and upper parts of the zone, however, are clearly evidenced by the recovery of *Sphenolithus primus* and *Neochiastozygus perfectus* in the upper part of the "Mezdra" Fm.

The lower boundary of NP5 zone is traced by the FO of *Fasciculithus tympaniformis* in the lower portion of the Kailaka Fm clastic limestones. The FO of *Heliolithus kleinpellii* is noted in the upper portion of the Kailaka limestones, thus marking the lower boundary of NP6 zone (Fig. 5.93).

The hiatus, marked by a hard ground and glauconitic level between the Kailaka and Komarevo Fms, spans part of NP6 zone and whole NP7 zone.

The lower boundary of NP8 zone is traced by the FO of *Heliolithus riedelii* in the glauconitic marls at the base of the Komarevo Fm. The zone equates to the entire thickness of the Komarevo Fm at Chudnite skali.

The next stratigraphic gap, marked by the sharp boundary between the Komarevo Fm limestones and Beloslav Fm sandstones encompasses a part of NP8 zone and the entire NP9 zone, which is supported by the identification of *Rhomboaster bramlettei* in a clayey interbed at the base of the Beloslav Fm. The occurrence of this species indicates the lower boundary of NP10 zone.

The lower boundary of NP11 zone is drawn by the FO of *Tribrachiatus orthostylus* recovered from the glauconitic levels in the upper part of the Beloslav/Dikilitash Fms (Fig. 5.93).

The lower boundary of NP12 zone is perfectly marked by the first and abundant occurrence of *Discoaster lodoensis* at the base of the calcareous claystones of the Avren Fm. The determination of *Discoaster turkyensis* and *D. mirus* in the upper part is indicative of the presence of NP13 zone and its lower boundary is marked by the extinction of *Tribrachiatus orthostylus*.

The lower boundary of NP14a zone is fixed by the FO of the species *Discoaster subloboensis* in the highest levels of the Avren Fm, 2 m below the boundary (transgressive angular unconformity) with the conglomerates of the overlying Obzor Fm.

Poorly preserved, but paleontologically identifiable characteristic species are distinguished in the first metres of the Obzor Fm, in the silty-clayey interbeds among the sandstone beds: *Dictyococcites scrippsae*, *Helicosphaera salebrosa*, *Reticulofenestra* spp. Their co-occurrence defines the NP16-NP18 interval, i.e. middle Eocene to base of upper Eocene.

The acquired biostratigraphic data indicates that the so-called "Illyrian unconformity" (Illyrian tectonic phase) is likely manifested in this section, between the Avren and Obzor Fms.

Stratigraphic range. The section covers the upper parts of the Maastrichtian Stage (Asparuhovo Fm, CC25c zone), the middle and upper portions of Danian Stage ("Mezdra" Fm, NP2-3 and NP4 zones), the entire Selandian Stage ("Kailaka" Fm, NP5-NP6 zones), the middle part of the Thanetian (Komarevo Fm, NP8 zone), the entire Ypresian Stage (Beloslav/Dikilitash and Avren Fms, NP10-14a zones) and the upper part of the middle Eocene – Lutetian Stage, (Obzor Fm, NP16-18 zones).

Bardarevo

The section is located in the ravine west of Bardarevo village, Varna District, and crosses the Golitsa hill from the north southwards (Fig. 5.94). It is traced from the high parts of the ravine down to the Solnik-Golitsa road, ending south of this road with the last outcrops in the river bed by the village cemetery.



Fig. 5.92. Clast-supported conglomerate with rounded clasts of sedimentary and volcanic rocks, gradually passing to coarse grained sandstones (Obzor Fm)



Fig. 5.94. General view of the middle part of the succession in the section west of Bardarevo village – Sveti Atanas Fm

A coarse-clastic sequence is exposed at Bardarevo with no analogue in the region of the East Fore-Balkan. It occurs with sharp unconformity over Upper Cretaceous (Turonian) limestones and is covered, through gradual lithological transition, by sandstones of the Sveti Atanas Fm. Here it is informally called the Bardarevo Member of the Sveti Atanas Fm, however, it needs to be traced and formally nominated according to the requirements of the Stratigraphic Code of Bulgaria. The Bardarevo Member is represented by megabreccias with floating blocks, ranging in size from several centimetres to 2-3 m, in clayey to

silty matrix (Fig. 5.95). Conglomerates, gravels and breccia-conglomerates are observed at different levels. Clasts consist of micritic limestones, red-coloured dolomites (Triassic?), grey clayey limestones, quartzites and quartzitic sandstones (Jurassic?), volcanic rocks (Upper Cretaceous), reefal limestones and sandstones. Moreover, no clear bedding was noted – the clasts are chaotically disposed and the sediments may be interpreted as deposited by debris flows. To the north of the Solnik-Golitsa road, in the upper part of the section, gradual lithological transition to the Sveti Atanas Fm sandstones was observed.

South of the Solnik-Golitsa road, the uppermost parts of the section are tectonically complicated and a large block of Byala Fm (thin alternation of marls and clayey limestones) over 20 m thick, appears to be inserted (slumped?) among the sandstones of the Sveti Atanas Fm (Fig. 5.97).

Biostratigraphy. Calcareous nannofossils are relatively rare in the matrix of the breccias and conglomerates. Low abundance but characteristic associations are recorded for five samples (Fig. 5.96). The presence of *Fasciculithus tympaniformis*, *F. spp.*, *Coccolithus cavus* and *Prinsius dimorphosus* indicate that the coarse-clastic sediments are upper Paleocene, Thanetian, NP8-9? zone. Paleontological evidence on the age of this coarse-clastic breccia-conglomerate unit, named here the Bardarevo Member of the Sveti Atanas Fm, were obtained for the first time in this study.



Fig. 5.95. Bardarevo Member – megabreccia with clasts (several cm up to 2-3 m in size), floating in clayey-silty matrix

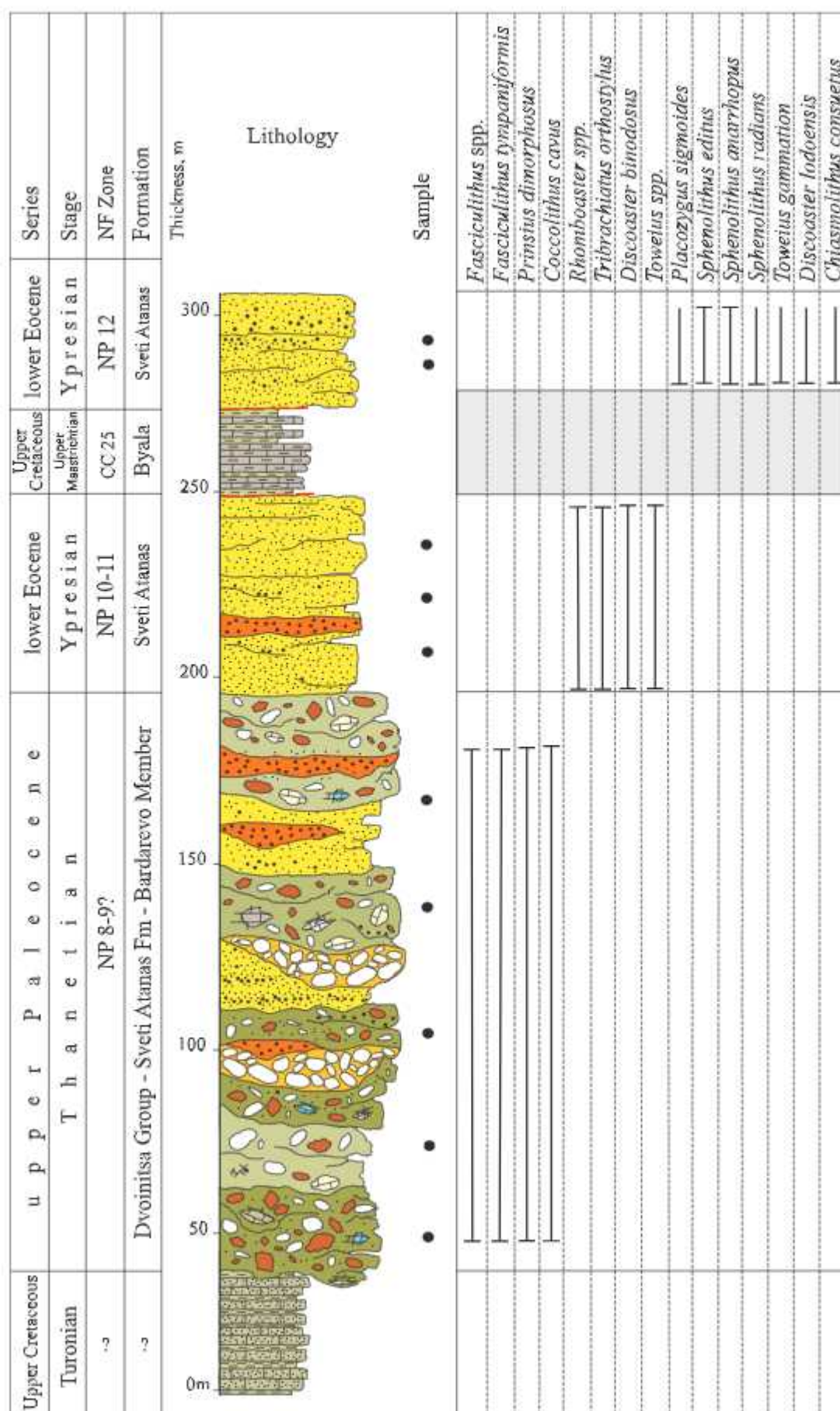


Fig. 5.96. Biostratigraphic subdivision of the section near Bardarevo by calcareous nannofossils



Fig. 5.97. Large block (> 20 m in size) of Byala Fm, inserted (slipped) into the sandstone of Sveti Atanas Fm

Rhomboaster spp., *Discoaster binodosus* and *Tribra-chiatus orthostylus* have their co-occurrence in the overlying sandstones of the Sveti Atanas Fm. This association corresponds to the lower Eocene, NP10-11 zone.

Slightly richer and better preserved associations are recovered from the uppermost portions of the succession, above the inserted block of the Byala Fm. These contain *Discoaster lodoensis*, *Toweius gammation* and *Sphenolithus radians*, indicative for NP12 nanofossil zone (Fig. 5.96).

Stratigraphic range. The range of the section is upper Paleocene, Thanetian stage, NP8-9 zone – lower Eocene, Ypresian Stage, NP12 zone (Fig. 5.96).

Kozichino

The section starts in the gully south of Kozichino village, Burgas District, where the most complete lower parts of the sequence crop out (Fig. 5.98). Its upper parts are exposed along the ravine north of the village (Fig. 5.102).



Fig. 5.98. Section near the village of Kozichino, Burgas District – lower parts of the succession in the ravine south of the village



Fig. 5.99. Fine-grained thin rhythmic turbidites in the uppermost part of the Kozichino Fm



Fig. 5.100. The boundary between the Eminë Fm and the overlying Kozichino Fm in the ravine south of the village; boundary in lower half of photograph

The outcrops around Kozichino have been explored by Savov et al. (1956f) and Kanchev (1995a), during various stages of geological mapping. The section was studied also by Stancheva (1961) and Vangelov & Sinnyovsky (2001). The exposure of the K/T boundary in the ravine south of Kozichino has been proclaimed a protected geotope by Sinnyovsky (2003).

Lithologically, the section is built up by thin-bedded rhythmic turbidites of the Eminë Fm succeeded by coarse-clastic sediments of the Kozichino Fm. The topmost part is represented by the thick-bedded sandstone formation.



Fig. 5.101. 2-m thick bed of calcareous sandstones at the base of the Kozichino Fm in the ravine south of the village

The base of the succession reveals a thin-bedded rhythmic alternation of sandstones and marls, referred to the Eminë Fm. Sinnyovsky (2007) distinguished three Upper Maastrichtian zones – CC25b *Lithraphidites quadratus*, CC25c *Micula murus* and CC26 *Micula prinsii*, accurately locating the K/T boundary. The latter is marked by a 4 cm dark colored clayey layer, occurring in the uppermost part of the Eminë Fm. The boundary between the Eminë and Kozichino Fms is beautifully exposed in the gully south of the village (Fig. 5.100). It is lithologically sharp, reflecting probably a short-term break of sedimentation and change in the depositional environment.



Fig. 5.102. Section near the village of Kozichino, Burgas District – upper parts of the succession in the ravine north of the village



Fig. 5.103. Left – cross stratification in the sandstones and gravels of the Kozichino Fm in the ravine north of the village; Right – grey limestone beds with cherty concretions within the Kozichino Fm in the ravine south of the village

The basal part of the Kozichino Fm comprises a bed of calcareous sandstone, 2 m thick (Fig. 5.101), overlain by light-grey limestones with flint concretions.

The main portion of the section is composed of alternations between thick-bedded medium- to coarse-grained sandstones, passing into gravels and pebble conglomerates. Cross bedding is locally observed (Fig. 5.103). This part of the sequence is best exposed along the ravine north of the village. Beds of grey limestones – fine-grained or micritic, with or without chert concretions, are observed at different levels here (Fig. 5.103). In the upper parts of the Kozichino Fm, a packet of medium-bedded limestones with abundant flint

nodules occurs. The topmost part of the section consists of fine-grained thin-rhythmic turbidites that represent a gradual lithological transition to the overlying thick-bedded sandstone formation (Fig. 5.99, 5.104).

Biostratigraphy. The nannofossil assemblage from the base of the section (marls of the Emine Fm) is exceptionally abundant and diverse, perfectly preserved. It is not described here since it represents associations of the Upper Maastrichtian – *Micula murus* and *Micula prinsii* zones. Distinctive, although not abundant associations, have been recorded in the coarse-clastic sediments of the Kozichino Fm and particularly in the limestone and marlstone-clayey interbeds.



Fig. 5.104. Gradual lithological transition between the Kozichino Fm and the overlying thick-bedded sandstone formation

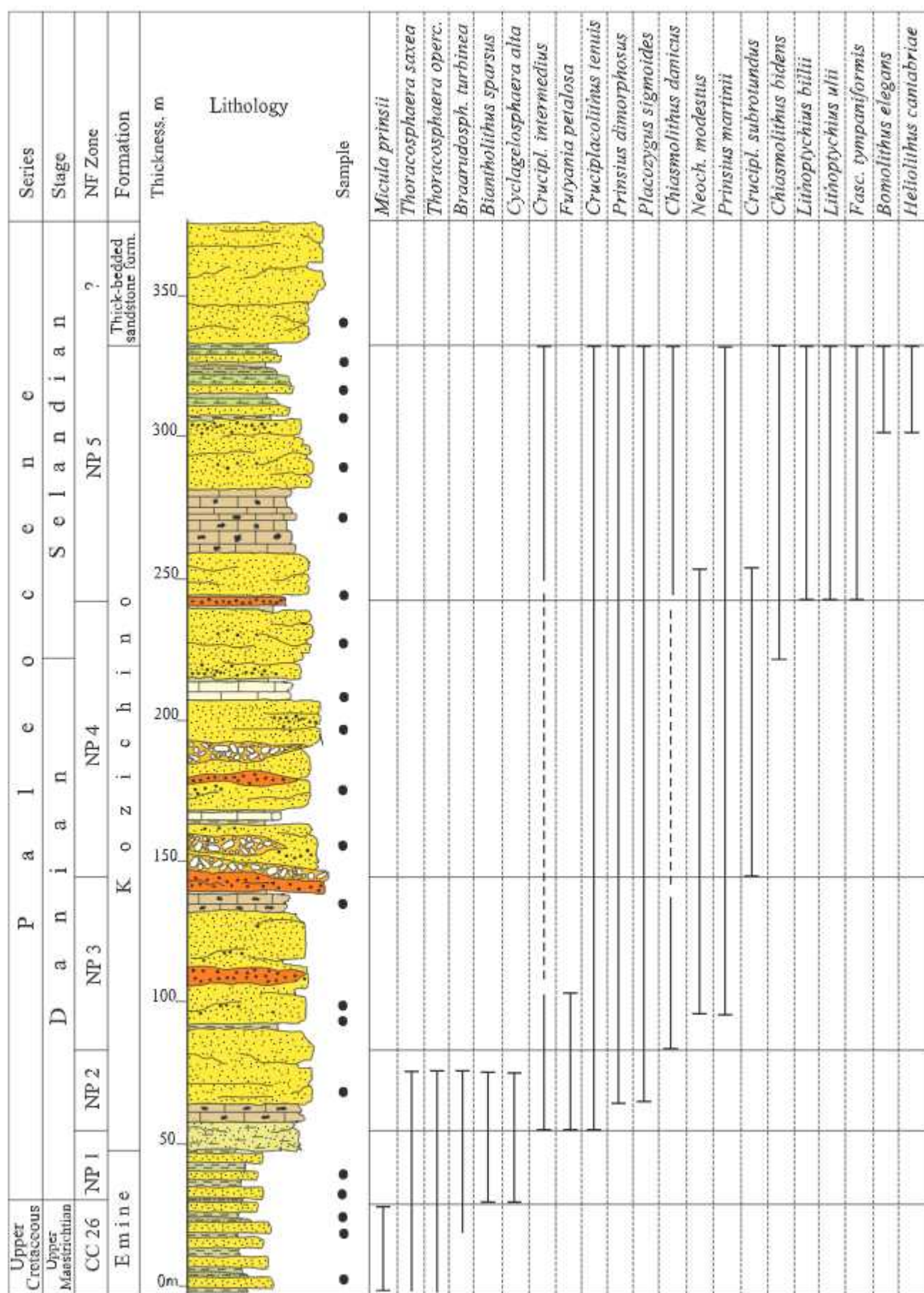


Fig. 5.105. Biostratigraphic subdivision of the section near Kozichino by calcareous nannofossils

The biostratigraphic subdivision of the section is shown on Fig. 5.105. The identified associations correspond to five nannofossil zones – four in the Danian (NP1 to NP4) and one in the Selandian (NP5).

The last Maastrichtian zone *Micula prinsii* is documented by a distinctive and diverse nannofossil association, comprising *Micula prinsii*, among others.

The Cretaceous/Tertiary boundary is marked by a 4 cm dark coloured marlstone layer, situated in the uppermost part of the Emine Fm (Sinnyovsky, 2003). Immediately above it, within the lower parts of NP1 zone, the nannofossil associations become rather impoverished. Nevertheless, the characteristic species *Cyclagelosphaera alta* and *Biantholithus sparsus*, as well as representatives of abundant “survivor” species *Thoracosphaera operculata*, *T. saxeae* and *Braarudosphaera bigelowii* have been identified (Fig. 5.105).

The lower boundary of zone NP2 is traced by the FO of *Cruciplacolithus intermedius*. The FOs of *Coccolithus cavus*, *Futyania petalosa*, *Cruciplacolithus tenuis*, *Prinsius dimorphosus* and *Placozygus sigmoides* are also marked in this zone.

The lower boundary of NP3 zone is set by the FO of *Chiasmolithus danicus*. Moreover, the FOs of *Neochiastozygus modestus* and *Prinsius martinii* are noted in this zone as well.

The lower boundary of NP4 zone is drawn conditionally by the FO of *Cruciplacolithus subrotundus* (due to the absence of the index species *Ellipsolithus macellus*).

The lower boundary of NP5 zone is fixed by the FO of *Fasciculithus tympaniformis* at the base of the packet of thin-rhythmic fine-grained turbidites (Fig. 5.105). It is characterized by a rich association, dominated by representatives of the genus *Fasciculithus* – *F. tympaniformis*, *F. spp.*, *Lithoptychius billii*, *L. ulii*. *Bomolithus elegans* and *Heliolithus cantabriae* are also present, however in the upper part of the zone.

No nannofossils have been recovered from the samples in the thick-bedded sandstone formation.

Stratigraphic range. The full range of the section is Upper Cretaceous (Upper Maastrichtian, CC26 zone) – middle Paleocene (Selandian, NP5 zone).

Emona

The section starts 1.5 km north of Emona village and is traced in the road cut along the dirt road between Emona and Irakli.

It was investigated for the first time as a continuous section across the Cretaceous/Tertiary boundary by Sinnyovsky and Stoykova (1995). Subsequently Stoykova and Ivanov (2002a, b; 2004a) published a detailed nannofossil biostratigraphy, as well as sequence stratigraphy subdivision of the section. Sinnyovsky (2004a) performed nannofossil zonation and clarified the stratigraphic range of the Emine Fm, studying it in 5 sections located around Cape Emine and Emona village.

Thin-bedded rhythmic turbiditic alternations of calcareous sandstones, siltstones, silty marls, clayey marls and calcareous clays, referred to the Emine Fm crop out. The finest-grained and thinnest-bedded rhythmic portion of the turbidites is located in the K/T boundary interval. Thin layers of limestones and calcareous clays, entirely built of nannofossil skeletons are observed here. The quantity of the clastic component increases at the base of the section as well as in its upper part – manifested by increasing thickness of the sandstone beds in the rhythms (Fig. 5.106). The sediments revealed in this section are interpreted as deposited in the deepest axial parts of the basin (basin plain – Stoykova & Ivanov, 2002a, b; 2004a).

Biostratigraphy. The section has been sampled in detail with analysis of nannofossil composition in 33 samples – 16 in the Upper Maastrichtian and 17 in the Danian Stage (Fig. 5.106). The nannoflora in the limestones and the marly-clayey portions of the rhythms in the Emine Fm is extremely abundant and diverse, excellently preserved. Fifty-nine (59) species of calcareous nannofossils have been determined (Fig. 5.106). The continuous sequence of nannofossil zones from the Upper Maastrichtian to the Lower Danian, including CC 25b, CC25c, CC26, NP1, NP2 and NP3 zones has been documented.

The Upper Maastrichtian nannofossil zone CC26 *Micula prinsii* is evidenced by a rich and abundant association. Its lower boundary is set by the occurrence of the index species *Micula prinsii*. *Nephrolithus frequens* and *Ceratolithoides kamptneri* considered essential for the correlation, are observed as well in the section. The measured thickness of the zone is 27 m.

The K/T boundary is established at the base of a light-grey layer of calcareous claystone (sample E-12). The FOs of *Cyclagelosphaera alta* and *Biantholithus sparsus* are detected at this level. The associations of NP1 zone are dominated by abundant *Thoracosphaera operculata*, *T. saxeae* and *Braarudosphaera bigelowii*. The FOs of species *Neocrepidolithus dirimosus* (+0.6 m), *Neobiscutum romeinii* (+4.0 m), *Cruciplacolithus primus* (+8.7 m) are precisely pinpointed in the frame of this zone.

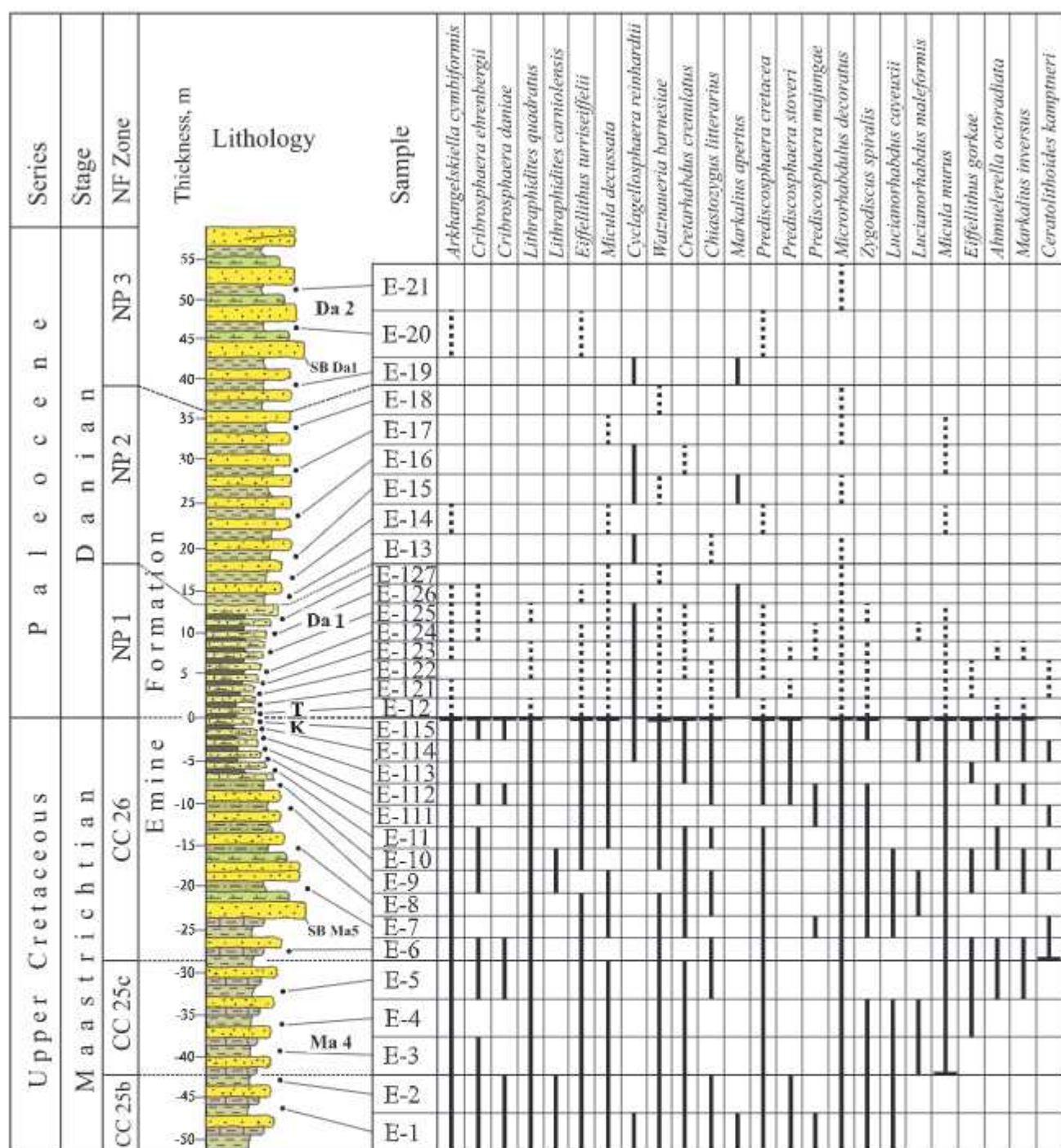


Fig. 5.106. Biostratigraphic subdivision of the section near Emona, Burgas District, by calcareous nannofossils

The lower boundary of NP2 zone is traced by the FO of *Cruciplacolithus tenuis* in sample E-13 (Fig. 5.106). The occurrence of *Cruciplacolithus asymmetricus* and *Coccolithus cavus* is documented within the zone.

The lower boundary of NP3 zone is set by the FO of *Chiasmolithus danicus* in sample E-19 (Fig. 5.106) followed by FOs of *Prinsius martinii*, *P. bisulcus* and *Neochiasiozygus modestus*. The section at Emona demonstrates a continuous succession across the K/T boundary, deposited in a deep water environment.

This is supported by both the facies of the sediments (thin-rhythmic turbidites from the outer part of the fan) and the completeness of the biostratigraphic record. Besides, the thickness of the individual biostratigraphic zones is significantly greater – about 4 times greater than the ones in the shelf margin sections.

Stratigraphic range. The range of the section is Upper Cretaceous (Upper Maastrichtian, CC25 zone) – lower Paleocene (Danian Stage, NP3 zone, Fig. 5.106).

<i>Nephrolithus frequens</i>	<i>Micula primii</i>	<i>Vagalapilla matalosa</i>	<i>Prediscosphaera grandis</i>	<i>Zeughabdus embergeri</i>	<i>Thoracosphaera operculata</i>	<i>Thoracosphaera saxea</i>	<i>Braarudosphaera bigelowii</i>	<i>Lucinorhabdus arcuatus</i>	<i>Watznaueria biporta</i>	<i>Micrantholithus obtusus</i>	<i>Calcalites obscurus</i>	<i>Eifellithus eximius</i>	<i>Prediscosphaera spinosa</i>	<i>Kamptnerius magnificus</i>	<i>Ocotolithus multiplex</i>	<i>Braarudosphaera turbinea</i>	<i>Cyclagelosphaera alta</i>	<i>Biantholithus sparsus</i>	<i>Neorepidolithus dirimosus</i>	<i>Neorepidolithus neocrassus</i>	<i>Braarudosphaera discula</i>	<i>Neobiscutum rometini</i>	<i>Zeughabdus signoides</i>	<i>Cruciplacolithus primus</i>	<i>Cruciplacolithus intermedius</i>	<i>Prinsius dimorphus</i>	<i>Neorepidolithus fossus</i>	<i>Cruciplacolithus tenuis</i>	<i>Cruciplacolithus asymmetricus</i>	<i>Coccolithus cavius</i>	<i>Chiasmolithus danicus</i>	<i>Prinsius martinii</i>	<i>Prinsius bisulcus</i>	<i>Neochiastozygus modestus</i>	Samples
																																			E-21
																																			E-20
																																			E-19
																																			E-18
																																			E-17
																																			E-16
																																			E-15
																																			E-14
																																			E-13
																																			E-127
																																			E-126
																																			E-125
																																			E-124
																																			E-123
																																			E-122
																																			E-121
																																			E-12
																																			E-115
																																			E-114
																																			E-113
																																			E-112
																																			E-111
																																			E-11
																																			E-10
																																			E-9
																																			E-8
																																			E-7
																																			E-6
																																			E-5
																																			E-4
																																			E-3
																																			E-2
																																			E-1

Mona Petra

The section starts 50 m south of Mona Petra Cape and is traced to the north along the coast. It ends at the southern entrance of Obzor Beach, Burgas District.

The base of the section is represented by thin-rhythmic turbiditic alternations of gravels, sandstones, siltstones and silty marls, referred to the Emine Fm. It crops out south of the Mona Petra dislocation (fault) along which the flysch sediments of the Emine Fm are thrust onto the overturned southern limb of the

Obzor Syncline composed of sandstones of the Sveti Atanas Fm (Figs. 5.107-5.108). Most likely the displacement amplitude is insignificant.

Excellent outcrops of coarse-grained sandstones with typical spheroidal weathering (assigned to the Sveti Atanas Fm) are observed at Mona Petra Cape (Fig. 5.109). Moreover, gravel beds and lenses of pebble conglomerates are also noted. The extraclasts of clayey limestones and marls, possibly from the Byala Fm, located to the north, occur as a very characteristic component (Fig. 5.110).

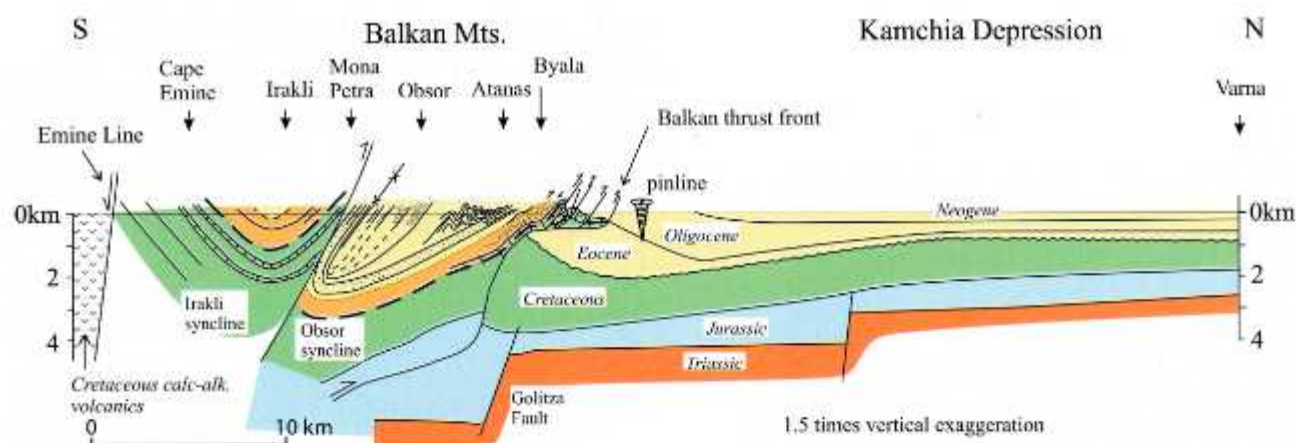


Fig. 5.107. Structural cross-section (S – N) between Emine Cape and Varna (after Sinclair et al., 1997)

In the lower parts of the section the coarse-grained sandstones alternate with clayey sands and thin marly interbeds (Fig. 5.109). In the upper parts, large-scale cross bedding with erosional lower bed surfaces are noted.

Biostratigraphy. The results of the nannofossil investigation and the biostratigraphic subdivision of the section are shown in Fig. 5.111. The lowermost

parts of the section representing the uppermost stratigraphic levels of the Emine Fm, comprise abundant nannoflora, referred to the Thanetian NP8 zone. It is proved by the co-occurrence of *Heliolithus riedelii*, *Fasciculithus mitreus*, *F. tympaniformis* and *Neochiastozygus junctus*.

The lower boundary of NP9 zone is fixed by the FO of *Discoaster multiradiatus*. The following taxa



Fig. 5.108. Mona Petra dislocation – the Emine Fm turbidites are faulted and thrust over the overturned southern limb of the Obzor Syncline



Fig. 5.109. Thick-bedded coarse-grained sandstones with spheroidal weathering alternating with thin clayey interbeds, Sveti Atanas Fm at Mona Petra Cape



Fig. 5.110. Extraclasts of clayey limestone within thick-bedded coarse-grained sandstones with spheroidal weathering, Sveti Atanas Fm at Mona Petra Cape

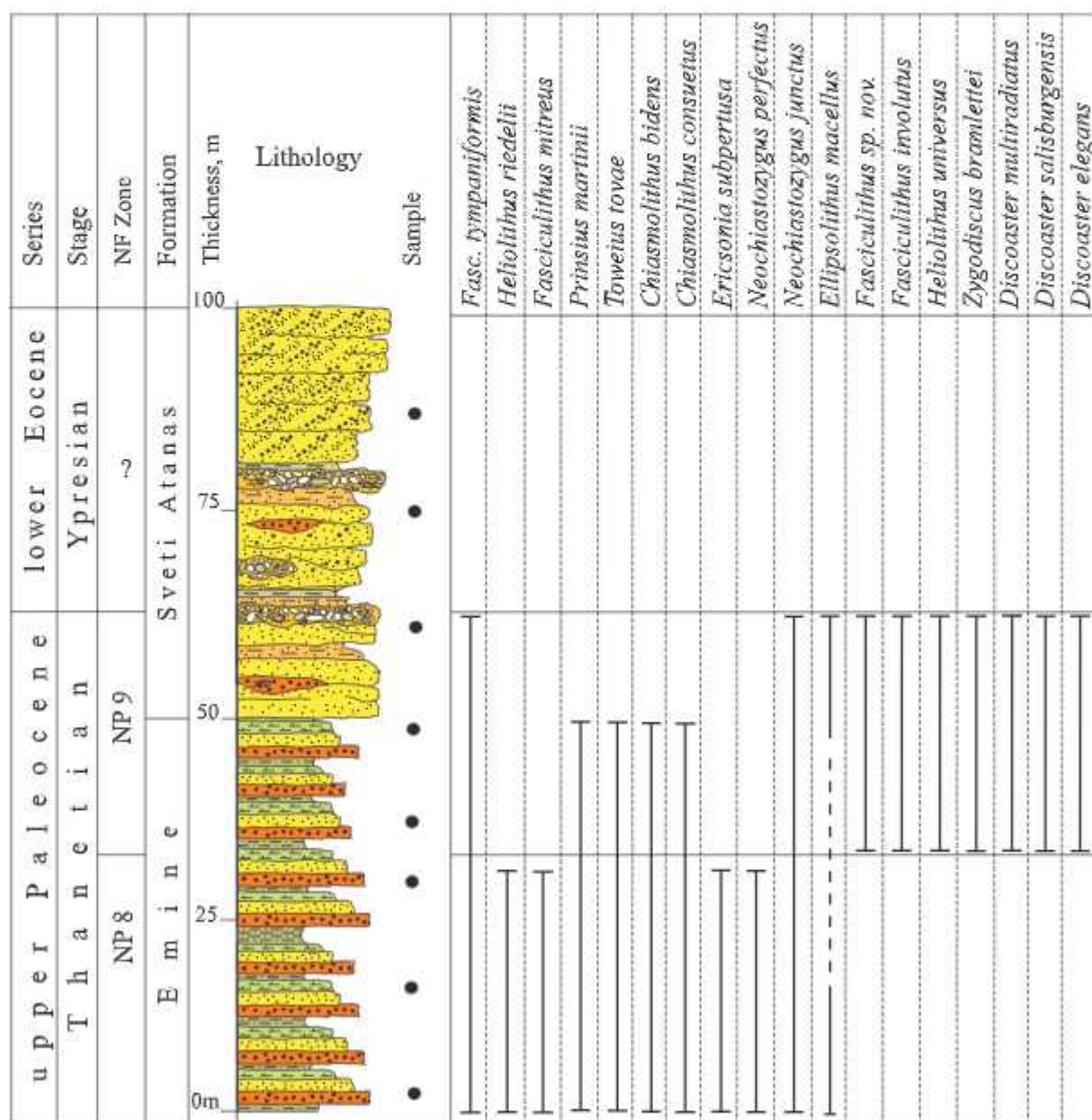


Fig. 5.111. Biostratigraphic subdivision of the section near Mona Petra, Burgas District, by calcareous nannofossils

are also present in this zone: *Discoaster elegans*, *D. salisburgensis*, *Fasciculithus fenestrellatus*, *Zygodiscus bramlettei* and *Heliolithus universus*.

No nannofossils have been recovered from the matrix of the coarse-grained sandstones of the Sveti Atanas Fm, but only in the clasts of clayey limestones, which proves their origin from the Byala Fm limestones.

Stratigraphic range. The range of the section is upper Paleocene (Thanetian Stage, NP8 and NP9 zones) – lower Eocene (Ypresian Stage, zone ?, Fig. 5.111).

Obzor-Meshelika

The section is traced along the coastline from the southern entrance of the beach in Obzor, Meshelika locality, to the north, reaching the central entrance point of the beach. This is the type section of the Meshelika Member of the Gebesh Fm.

A part of the section south of Obzor has been studied by Aladjova-Hrischeva (1985) who identified a shallow-water foraminiferal fauna – nummulites and assilins – in the olistostromes. When describing the Dvyonitsa Fm, Juranov and Pimpirev (1989) also mentioned the olistostromes south of Obzor.



Fig. 5.112. Obzor – Meshelika section, Burgas District – chaotically distributed blocks, floating in silty matrix – Meshelika Member of the Gebesh Fm

Thick indistinctly poorly-bedded siltstones, silty and clayey marls are exposed. Large blocks (2-3 m) of various sedimentary and volcanic rocks float chaotically in them: thin-bedded rhythmic turbidites, large slabs of limestone with nummulitids and clayey limestones and marls (Fig. 5.112-5.114). Smaller rounded sandstone clasts (to several centimetres across), quartzitic pebbles and volcanics (Late Cretaceous in age – from the Srednogorie region, Fig. 5.113) are also present. The conglomeratic blocks and lenses are developed at several levels in the sequence – at least 4 or 5 levels have been noted. The limestone and coarse-grained sandstone beds contain abundant shallow-water fauna: nummulitids, gastropods, echinoids and bivalves, irregularly dispersed among bioterritic and clayey matrix. The actual thickness of the section is difficult to measure but is in the range of 250-300 m.

It is assumed that these sediments have been formed at



Fig. 5.113. Obzor – Meshelika section, Burgas District – clasts of rounded sandstone, quartz cobbles and Upper Cretaceous volcanic rocks



Fig. 5.114. Obzor – Meshelika section, Burgas District – clasts of limestone with nummulitids, clayey limestone and marl

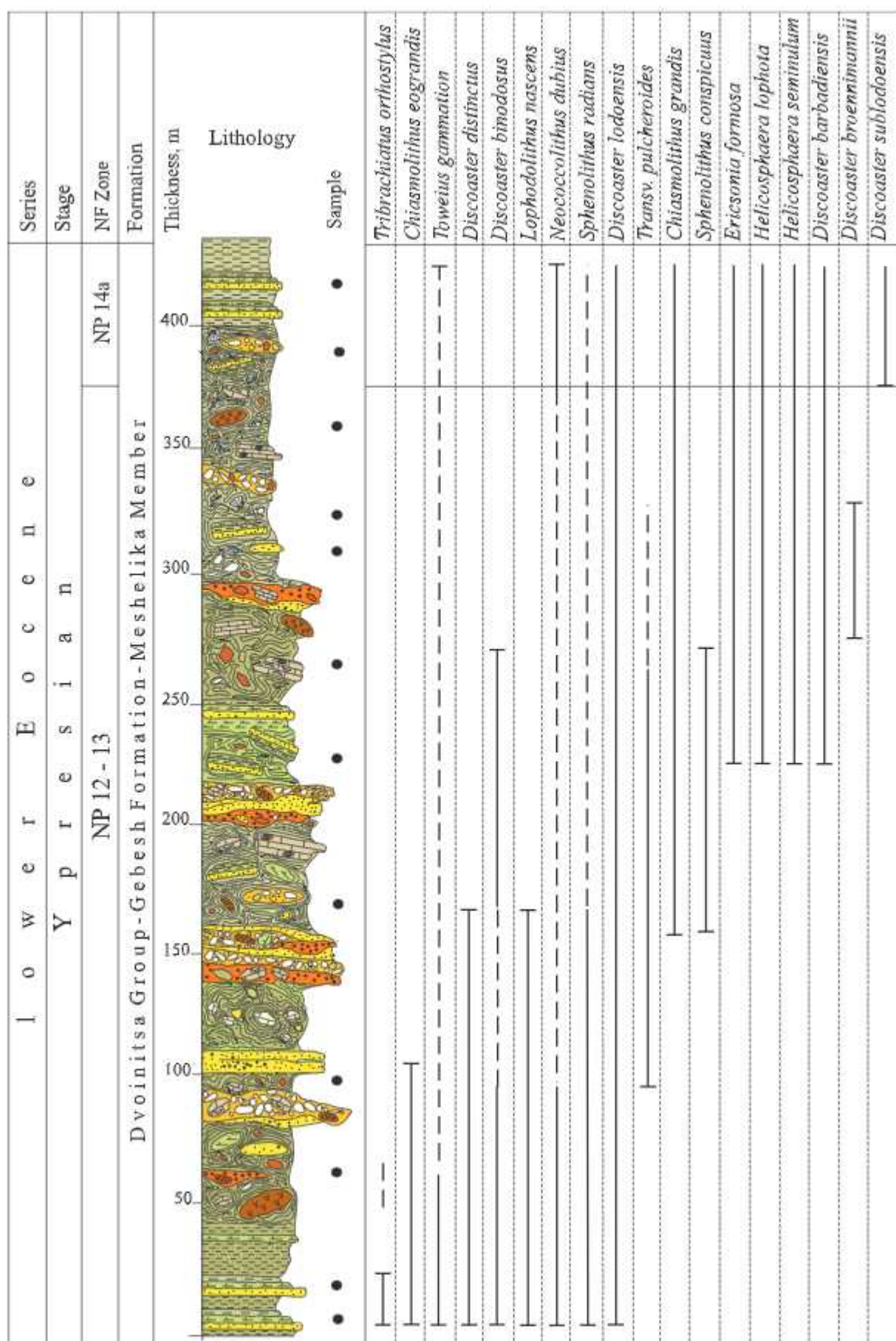


Fig. 5.115. Biostratigraphic subdivision of the Obzor – Meshelika section, Burgas District, by calcareous nannofossils



Fig. 5.116. Sveti Atanas section – light beige, grey-greenish and pinkish marls of the variegated marl-clayey formation, building the base of the succession



Fig. 5.117. Sveti Atanas section – silty and sandy marls with thin intercalations of sands and detrital sandstones, enriched in Fe-hydroxides – a transition to the Sveti Atanas Fm

the foot of the basin slope as a result of deposition of massive debris flows and slumps. The shallow-water sediments, chaotically floating in them, have resulted from destabilization of the already consolidated sediments at the margin of the carbonate platform to the north. Volcanic rocks from the Srednogorie region form a minor component of the clasts; these have a provenance from the south.

Biostratigraphy. Calcareous nannoplankton have been identified in both the matrix of the coarse-clastic sediments (silty and clayey marls) and the chaotically jumbled clasts. Considering the latter, it may be quite certainly concluded where the source material for the debris flows has come from, namely thin-bedded rhythmic turbidites (Gebesh Fm, the clasts are aged NP12-13), limestones with nummulitids (Dikilitash-Aladan Fm, the clasts are aged NP12-14a) and clayey limestones and marls (Byala Fm, the clasts are aged NP3-4).

The major thickness of the succession is referred

to the lower Eocene NP12-13 zones. The identified association includes species occurring in both zones; *Discoaster lodoensis*, *Sphenolithus radians*, *Helicosphaera lophota* and *Toweius gammation*. The only taxon exhibiting a shorter range in NP13 zone is *Discoaster broemmimannii*, identified in the upper parts. However, it could not be used for precisely locating the NP12/NP13 boundary.

The highest parts of the section are assigned to the nannofossil zone NP14a. Its lower boundary is clearly fixed by the FO of *Discoaster sublodoensis*, detected in the last two samples.

Stratigraphic range. Upper parts of the lower Eocene (Ypresian Stage), nannofossil zones NP12-13 to NP14a (Fig. 5.115).

Sveti Atanas

The section starts at the southern end of Byala beach (Shelborun locality), and is traced along the shoreline



Fig. 5.118. Sveti Atanas section – gravels and pebble conglomerates at the base of massive thick sandstone packets



Fig. 5.119. Rhythmic alternation of sandstone, siltstone, marl and clay – so-called "Gebesh facies"

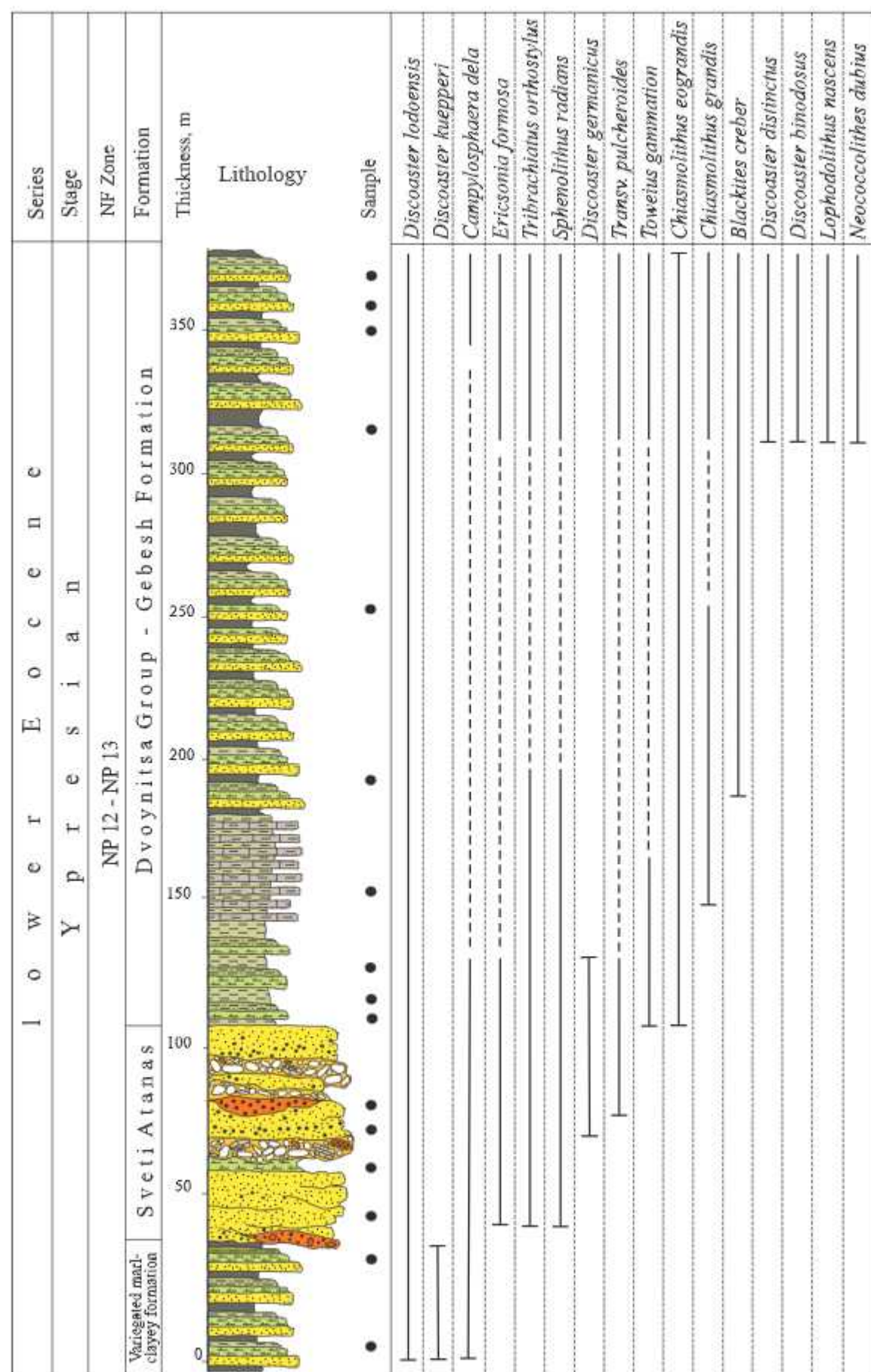


Fig. 5.120. Biostratigraphic subdivision of the section at Sveti Atanas Cape, Burgas District, by calcareous nannofossils



Fig. 5.121. Sveti Atanas section – rhythmic alternation of sandstone, siltstone, marl and clay – Gebesh Fm

to Cape Sveti Atanas and south of it, to the large hotel complex Sol Luna Bay (former Luna Camping), north of Obzor.

The upper parts of the section (located between Sveti Atanas Cape and Sol Luna Bay) are described as the type section of Dvoynitsa Fm by Juranov and Pimpirev (1989).

The base of the sequence exposed at the southern end of Byala Beach (Shelborun) is occupied by a thin-bedded rhythmic alternation of light-beige, grey-greenish and pink colored marlstones, clays and calcareous clays (Fig. 5.116), referred to the variegated marl-clayey formation. Up section, the marlstones pass to silty and sandy marls, with thin interbeds of sands and detritic sandstones, enriched with ferruginous hydroxides (Fig. 5.117). This represents a rapid lithological transition to the overlying sandstones of the Sveti Atanas Fm (Dvoynitsa Group).

The lower part of the section is composed of thick-bedded, coarse- to medium-grained amalgamated sandstones (approximately 100 m thick). They are poorly sorted, as quartz grains and clayey matrix prevail. Beds (0.5-1.0 m thick) of gravels and pebble conglomerates and breccias are usually seen at the base of the massive sandstone packets (Fig. 5.118). They contain many rounded clasts of volcanic rocks as well as angular clasts derived from the Byala Fm. Spheroidal (ball-shaped) weathering has been ob-

served. Thin interbeds of siltstones and silty marls rich in plant debris are present among the sandstone beds and packets.

Alternating siltstones and silty and clayey marls overlie the last sandstone packet on the southern side of Sveti Atanas Cape (outcrops in the hill near Chaika Restaurant). It is about 20 m thick, comprising abundant nannofossils finds. These are overlain by 24 m of thin-bedded rhythmic alternations of grey clayey limestones and marls; some beds are dark-brown to black in color.

The middle and upper parts of the section are composed of magnificently expressed thin- to medium-bedded (10-40 cm) rhythmic alternations of sandstones, siltstones, marls and clays (Fig. 5.119, 5.121) – the so-called “Gebesh facies” (Pollak, 1933). The lower bed surfaces of the sandstones display sole marks (paleotransport direction to the south-east), bioturbation, ichnofossils, etc. typical of turbidites. The described sequence is over 200 m thick and is assigned to the Gebesh Fm (Dvoynitsa Group).

Biostratigraphy. Calcareous nannofossils are recorded throughout the whole succession, in the fine-grained sediments – marls, calcareous clays and clayey limestones. The abundance and preservation state of the nannofossils varies from poorly preserved and rare (Sveti Atanas Fm) to abundant and very well preserved (the clays of the variegated marl-clayey formation and the clayey portion of the rhythms of the Gebesh Fm). The biostratigraphy is shown on Fig. 5.120. The identified associations correspond to the lower Eocene NP12-13 zones as the two zones could not be separated due to lack of characteristic species. The concomitant occurrence of *Disocaster lodoensis* and *Tribrachiatus orthostylus* in all analysed samples implies NP12 zone to be more plausible. On the other hand, these are turbidites and reworking is very common (it is the rule rather than the exception), therefore *Tribrachiatus orthostylus* might have been reworked in the upper part of NP13 zone.

Stratigraphic range. Middle parts of lower Eocene (Ypresian Stage), nannofossil zones NP12-13 (Fig. 5.120).

Byala 2b

The section is located in the northern end of the beach in Byala, Varna District. It starts some 0.8 km north of the central entrance of the beach, at around 30 m north of the large tectonic fault (Fig. 5.122) and is traced along the shoreline cliff, south of the last thick limestone bank (Fig. 5.126). This section reveals the most complete sedimentary succession, outcropping in the Byala region.

The region of Byala shows evidence of intense tectonics and the section has been studied in 5 separate blocks that were further accurately correlated and tied, using biostratigraphy and cyclostratigraphy (Fig. 5.124).

The Byala 2b section has attracted a remarkable amount of attention from many Bulgarian and foreign researchers in the last 30 years, after the Cretaceous/Tertiary boundary clay layer (Fig. 5.123) was discovered and proved for the first time in Bulgaria (Stoykova & Ivanov, 1992).

A series of studies, discussing the biostratigraphy of the boundary interval were published (Stoykova & Ivanov, 1992, 2002a; Ivanov, 1993b; Ivanov & Stoykova, 1994; Rögl et al., 1996; Stoykova & Ivanov, 2004a). In addition, many studies have been carried out on other aspects of the K/T boundary: cyclic and event stratigraphy (Preisinger, 1994; Sinnyovsky, 2001a; Stoykova & Ivanov, 2002b; Adatte et al., 2002; Preisinger et al., 2002; Dinarès-Turell et al., 2006, 2010, 2012); bioevents of the boundary (Ivanov & Stoykova, 1994, 1995; Stoykova et al., 2000; Stoykova & Ivanov, 2002a, 2004a); mineralogy and geochemistry (Preisinger et al., 1993a, b; Kostov & Tsankarska, 1997; Adatte et al., 2002); and magnetostratigraphy (Preisinger et al., 1993a, 2002; Dinarès-Turell et al., 2006, 2010, 2012, 2013a).

Rhythmic alternation of limestones and marls (thickness of the beds varying between 0.1 and 0.5 m), intercalated with thicker marlstone packets (several



Fig. 5.123. Boundary black clay layer at Byala 2b section

tens of metres thick) are perfectly exposed. On fresh surfaces the rocks are colored grey to light-grey and on weathered ones almost white. The marls are whitish, indistinctly bedded, massive or thin-layered. The limestones are white to light-grey, solid and medium-bedded. The limestone-marl ratio differs with stratigraphic level. The marls prevail in the Upper Maastrichtian portion of the section (Fig. 5.125), while the clayey limestones dominate in the middle part of the Danian Stage (Fig. 5.126).

The K/T boundary is lithologically marked by a dark-brown to black clayey layer, 2-4 cm thick. It is used as



Fig. 5.122. General view of the lower part of the succession in the Byala 2b section. The position of the K/T boundary is marked by red line

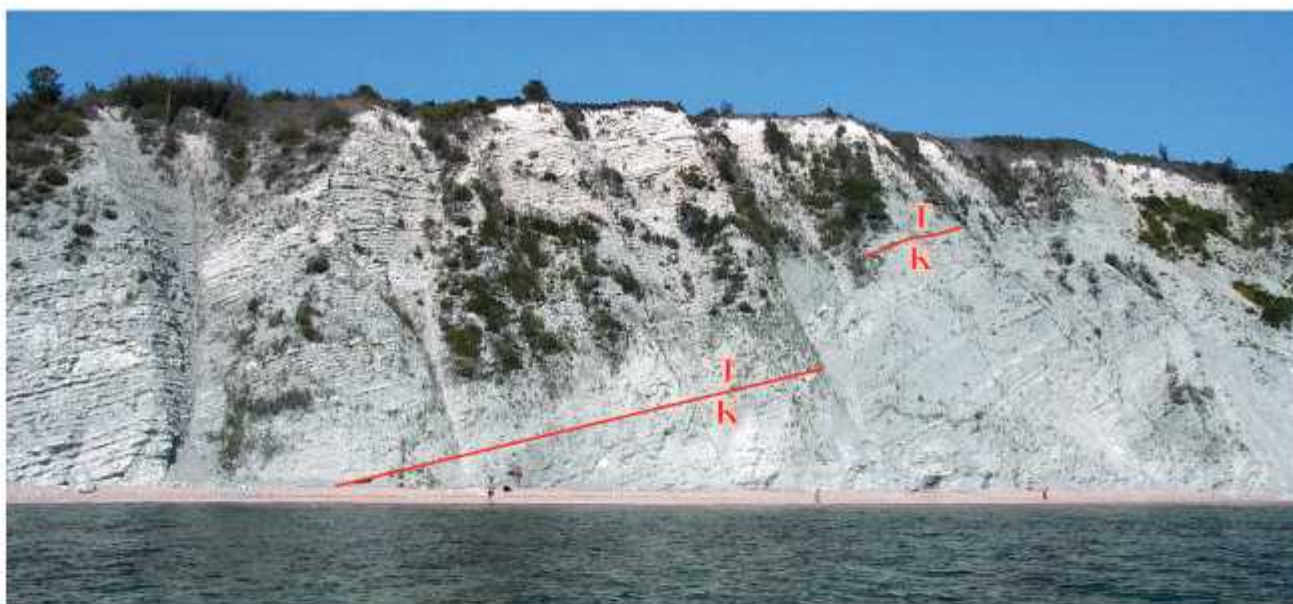


Fig. 5.125. Byala 2b section – general view, with marked position of the K/T boundary (red line)

an anchor point for the section and is designated as 0 m, whereas the levels above and below are indicated by (+m) and (-m), respectively. The base of the clayey layer (the lowermost 5 mm) contains increased content of iridium, cobalt and nickel, as the iridium peak reaches 6.1 ppb (Preisinger et al., 1993a).

The Paleocene part of the sequence magnificently demonstrates orbitally forced precession and eccentricity cyclicity (Milankovitch cyclicity). The precession cycle includes a couplet of marl/limestone beds, its thickness varying from 15 to 45 cm and the average periodicity is ~ 21 kyr. The eccentricity cycle appears as a group of 4-6 couplets, the thickness ranges from 0.6 to 2.0 m with average periodicity of ~ 100 kyr. More details on recently developed cyclostratigraphy of the section are presented herein in Chapter

8 “Global Events” (Dinarès-Turell et al., 2006, 2010, 2012, 2013a, b; 2014).

Biostratigraphy. The biostratigraphic subdivision of the section by calcareous nannoplankton is synthesized in Fig. 5.127. The nannofloristic associations are diversified – more than 100 species have been determined; however, the preservation varies from poor (near the K/T boundary) to moderate (in the Upper Maastrichtian and Upper Danian).

Zones CC25c *Micula murus* and CC26 *Micula prinsii* documented by rich nannofossil associations, are evidenced in the Upper Maastrichtian. The lower boundary of CC26 zone is traced by the FO of *Micula prinsii* in sample B2b-8 at -17 m below the K/T boundary.



Fig. 5.126. Byala 2b section – general view of the Paleocene (Danian) portion of the succession, with beautifully expressed orbital cyclicity. The last prominent limestone bank marks the top of this section

The nannofossil assemblage in the clayey layer, marking the K/T boundary is rather poor in species. Rare fragments of the „survivor“ species *Thoracosphaera operculata* and *Braarudosphaera bigelowii* are encountered.

The first occurrence of the species *Cyclagelosphaera alta* and *Biantholithus sparsus* is noted immediately above the clayey layer, at the base of the first Danian NP1 zone. Successive FOs of *Cruciplacolithus primus* (+1.80 m), *Futyania petalosa* (+2.00 m) and *Neobiscutum romeinii* (+4.20 m) are documented within this zone.

The lower boundary of NP2 zone is drawn by the FO of *Crucioplacolithus intermedius* at +5.00 m above

the K/T boundary. The zone is around 8 m thick, with a number of newly appearing species identified: *Cruciplacolithus tenuis*, *Coccolithus cavus*, *Prinsius dimorphosus*, *Cruciplacolithus asymmetricus* and *Ericsonia subpervetus* (Fig. 5.127).

The lower boundary of NP3 zone is fixed by the FO of *Cruciplacolithus edwardsii* at +13.00 m above the K/T boundary. The precise thickness of the zone could not be calculated because the highest located samples in the studied block remain within NP3 zone; in any case it exceeds 28 m. The FOs of *Prinsius martini*, *Chiasmolithus danicus* and *Neochiastozygus modestus* are present in this zone. It is worth noting that the FOs of *Neochiastozygus eosaepe*, *N. saepe* and *N. imbrici* are recorded in the uppermost part of

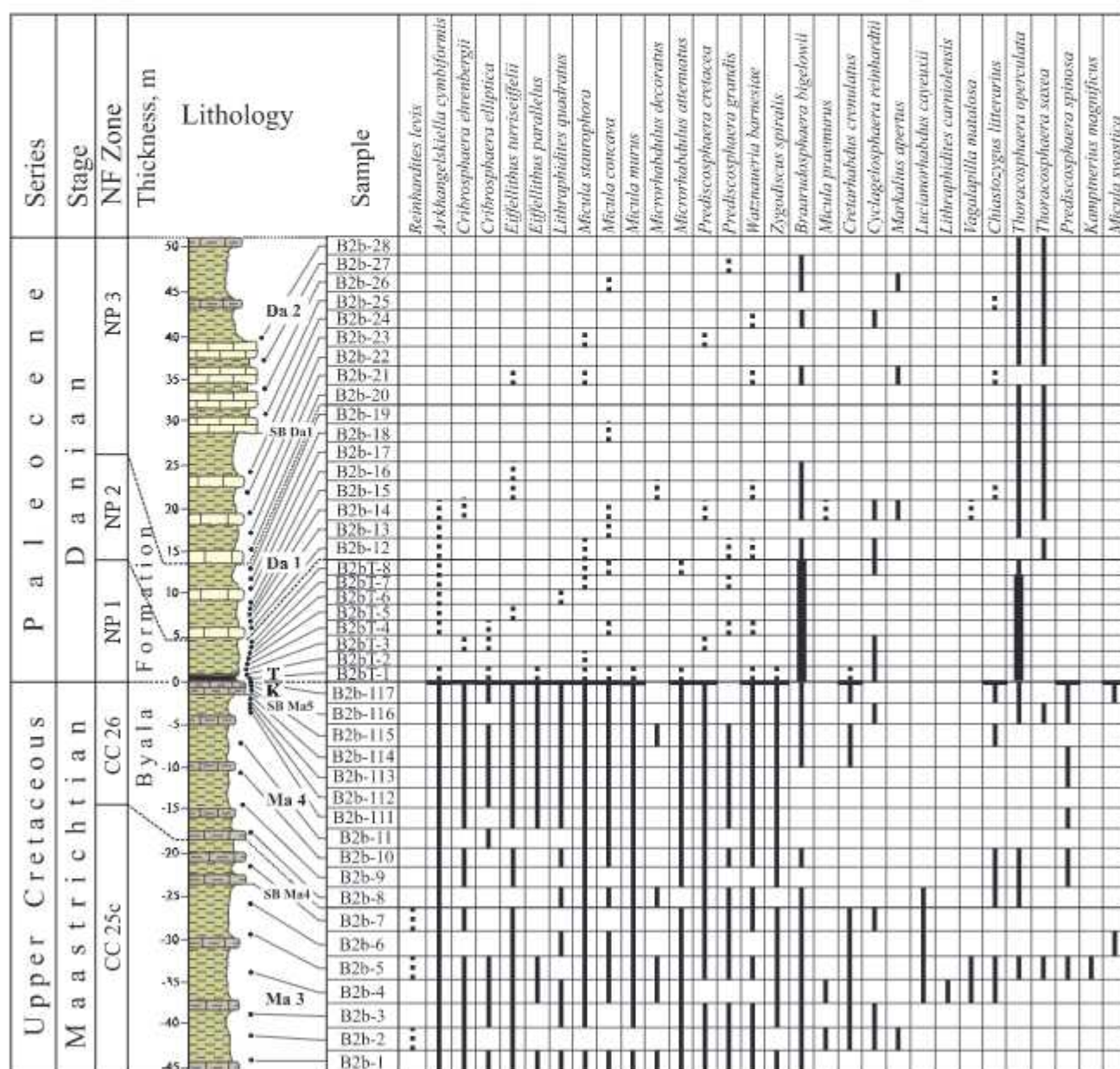


Fig. 5.127. Biostratigraphic subdivision of the Byala 2b section, Varna District, by calcareous nannofossils (after Stoykova & Ivanov, 2004a)

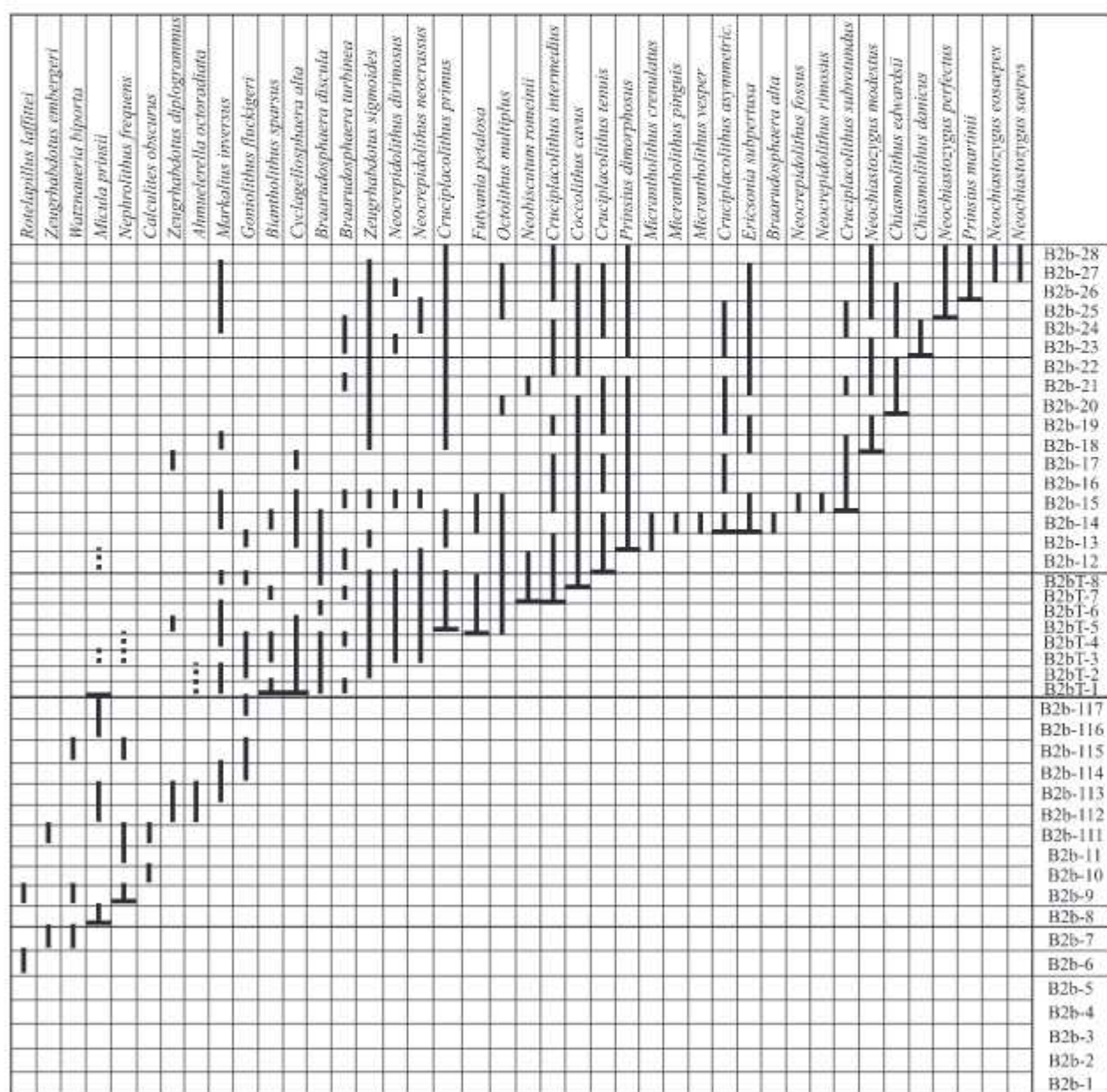
the zone, slightly below the boundary with the next NP4 zone.

The lower boundary of NP4 zone is traced by the FO of the index *Ellipsolithus macellus*. This species is relatively rarely seen in the associations due to its delicate morphology; it may be identified only in very well-preserved associations. In the absence of the index, the appearance of *Neochiastozygus eosaepe*, *N. saepe* and *N. imbrici* may be successfully used for approximation of the NP3/NP4 boundary. In the middle part of zone NP4, the FO of the representatives of the genus *Sphenolithus* – *Sphenolithus* spp. and *Sphenolithus primus* occur. The first occurrence and common development of species of the genus *Fasciculithus*, as well as

the occurrence of *Neochiastozygus perfectus* and *Chiasmolithus bidens* have also been identified in the upper part of the zone, several metres below the boundary with NP5 zone.

The lower boundary of NP5 zone is fixed by the FO of *Fasciculithus tympaniformis* immediately above the last thick limestone bank (Figs. 5.126, 5.130). The continuation of the succession above this bank, including NP5 to NP9 zones, is described below as *Byala 4* section.

Stratigraphic range. The section encompasses the uninterrupted sedimentary sequence from the Upper Maastrichtian (zones CC25c, CC26) to the Upper Danian, NP1 to NP4 zones (Fig. 5.127).



Byala 4 (upper part)

The section, herein designated as Byala 4, includes the upper part of the sequence exposed at Byala and represents a continuation of the Byala 2b section.

It starts above the last thick limestone bank of the Byala 2b section, at the northern end of the beach, and can be traced in almost continuous exposures along the beach (Fig. 5.128). The section has been studied and published on by Stoykova and Ivanov (2006a, b).

In the uppermost parts of the Byala Fm (the last 12–15 m) a substantial change of lithology is registered – a sharp drop of the carbonate content and domination of marlstones and clays. Limestone-marl cycles (periodites), although not very clear, are observed in the lower and middle parts of this interval. The uppermost 4 m are built of grey-greenish clayey marls and greenish clays with rare rusty-brown inclusions or interbeds. This succession is preserved in a wedge-shaped block immediately below the thrust surface, where Upper Cretaceous sediments are uplifted and thrust over the Paleocene (Fig. 5.129).

The sharp lithological change from predominantly carbonate sedimentation in the Danian to marly-clayey in the Selandian and Thanetian is interpreted as a result of global climatic and eustatic events during the middle and late Paleocene. These events have



Fig. 5.128. Byala 4 section – exposure of the claystone and marls above the last prominent limestone bank (Selandian, NP6 zone). Black stick = 1 m

been recently discovered and identified in a number of hemipelagic sections in West Europe, as well as in the Pacific and Atlantic Ocean (Bernaola et al., 2006b, 2007).

Biostratigraphy. All samples contain exceptionally abundant, diverse and well preserved nannofossil associations. Biostratigraphic analysis of all identified taxa indicates a complete normal succession of nannofossil zones from NP5 to the uppermost parts of NP9 (Fig. 5.130).

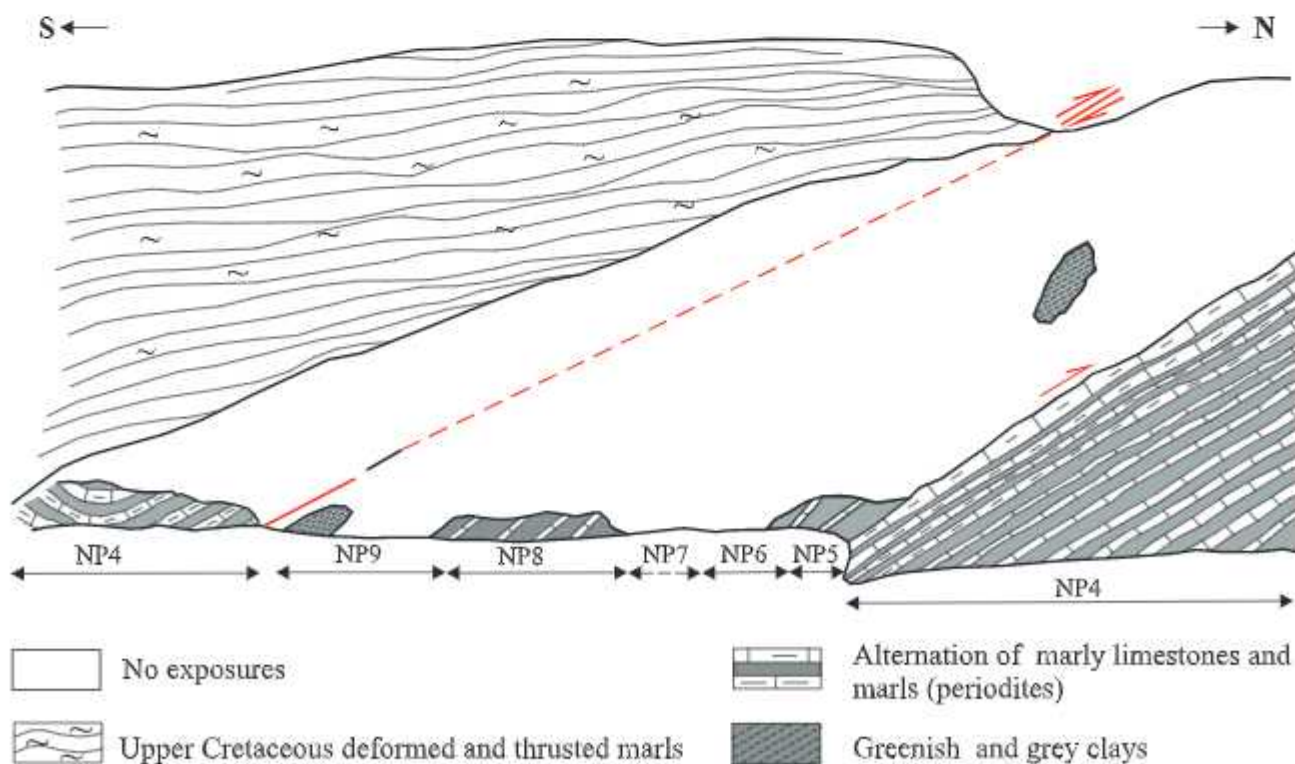


Fig. 5.129. Byala 4 section – sketch of the wedge-shaped block with undisturbed stratigraphic succession below the fault surface (after Stoykova & Ivanov, 2006a)

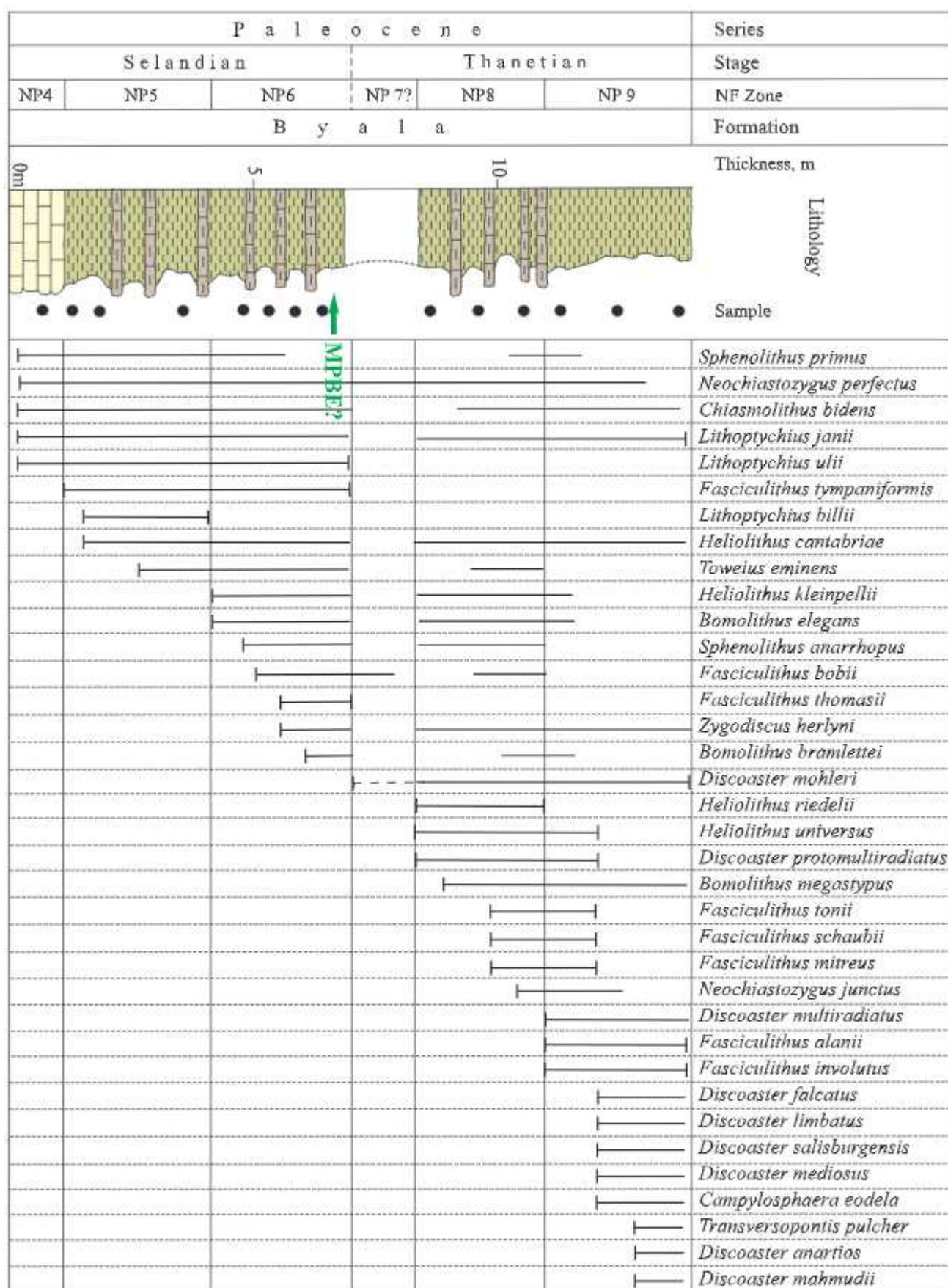


Fig. 5.130. Biostratigraphic subdivision of the Byala 4 section, Varna District, by calcareous nannofossils (after Stoykova & Ivanov, 2006a, b)

The lower boundary of NP5 zone is marked by the FO of species *Fasciculithus tympaniformis*, detected within the first centimetres of the marly-clayey interval, located above the thick limestone bank. The FO of two stratigraphically important species – *Neochiastozygus perfectus* and *Chiasmolithus bidens* is fixed in the uppermost parts of the zone NP4, just below the NP4/NP5 boundary. Rapid bloom and domination of species of the genus *Lithoptychius* – *L. ulii*, *L. janii*, *L. billii* and *Fasciculithus tympaniformis* is characteristic of the nannofossil association of NP5 zone. The lower part of the zone reveals the FO of a species of the genus *Heliolithus* – *H. cantabriae*. The first occurrence of *Toweius eminens* is observed in the middle part. The thickness of the zone is in the range of 2–3 m, and is probably tectonically reduced by faulting.

The lower boundary of zone NP6 is marked by the appearance of *Heliolithus kleinpellii* – an exceptionally clearly marked bioevent, as the index *H. kleinpellii* is detected in super abundance in the sediments (hundreds of specimens). A series of first occurrences of characteristic species such as *Bomolitus elegans*, *Sphenolithus anarrhopus*, *Zygodiscus herlyni* and *Bomolitus bramlettei* is noted within this zone.

There is a gap with no exposure, approximately 1–1.5 m thick (Fig. 5.129) that may correspond to the sediments of zone NP7. This suggestion is supported by the

fact that the NP7 index species *Discoaster mohleri* is identified in the first sample of the overlying zone NP8.

The lower boundary of zone NP8 is set by the FO of *Heliolithus riedelii* along with concomitant occurrence of *Discoaster protomultiradiatus*, *Heliolithus universus* and *Ericsonia robusta* that also appear for the first time here. The nannofossil association of the zone is dominated by representatives of the genus *Heliolithus* (*riedelii*, *universus*), *Fasciculithus* (*tonii*, *schaubii*, *mitreus*, *involutus*), *Toweius* (*eminens*, *pertusus*), as well as *Discoaster protomultiradiatus*.

The lower boundary of zone NP9 is fixed by the FO of *Discoaster multiradiatus*. Two nannofossil associations are clearly differentiated in lower and upper parts of the zone. *Discoaster multiradiatus* and *Discoaster protomultiradiatus* co-occur in the lower association, along with various species of *Fasciculithus* (*alanii*, *involutus*). The upper one is characterized by the FO and bloom of *Discoaster mediosus*, *D. falcatus*, *D. limbatus*, *D. salisburgensis*, *D. elegans*, *D. anartios*, *D. mahmudii*, *Campylosphaera eodola* and *Transversopontis pulcher*. The identification of both associations in the Byala section proves the completeness of NP9 zone. Its thickness is around 2 m.

Stratigraphic range. Selandian and Thanetian Stage of the Paleocene Series, proved by the full range of nannofossil zones from NP5 to NP9 (Fig. 5.130).

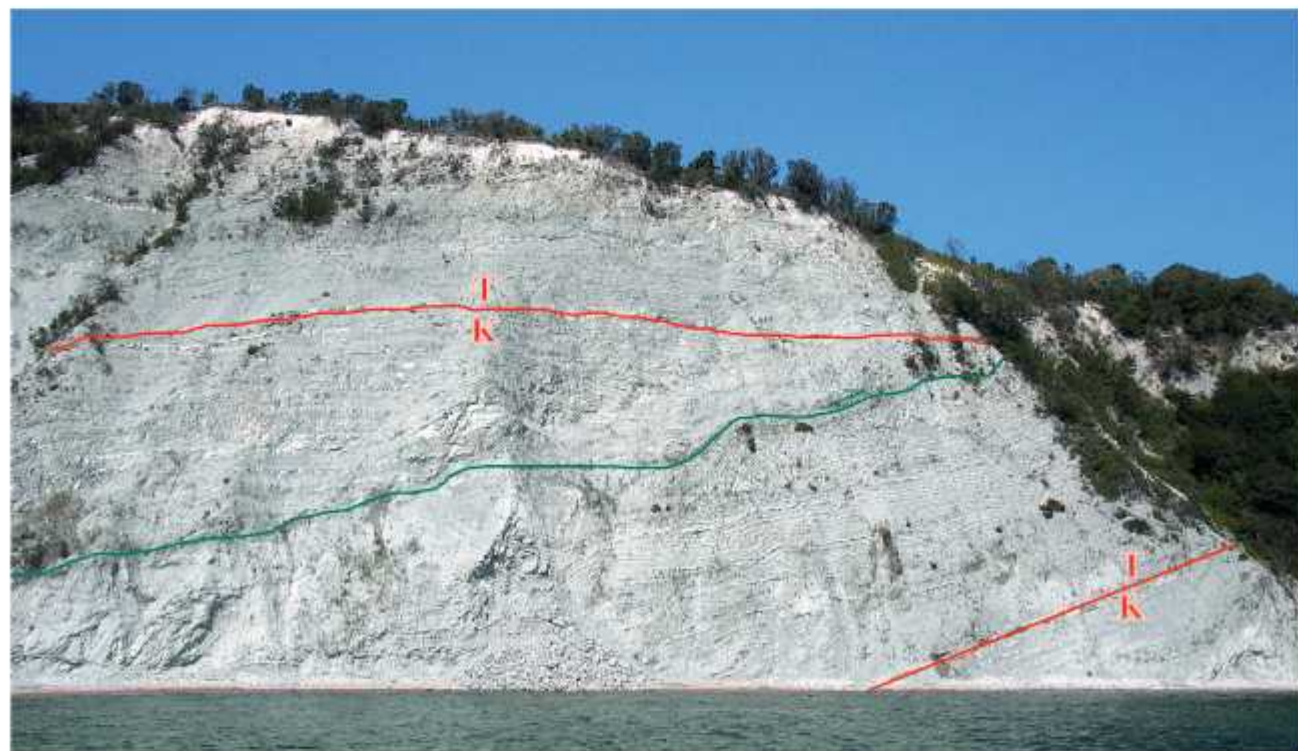


Fig. 5.131. General view of Byala 3 section – two large overthrust slices, with repetition of the K/T boundary interval and the boundary clay bed (marked with red line). Thrust plane marked with green line



Fig. 5.132. Clay bed 3 – 6 cm thick (between the red arrows), marking the K/T boundary in Byala 3 section

Byala 3

The section is located 2 km north of Byala and around 1.2 km north of the Byala 2b section, in a tectonically faulted block, with two slices, one thrust over the other (North-vergent thrusts), resulting in repetition of the K/T boundary interval section (Fig. 5.131).

This section was described by Ivanov and Stoykova (1994), Stoykova and Ivanov (2004a).

The boundary clay layer at this locality is thicker (3 to 6 cm, Fig. 5.132) and marls dominate in the boundary interval. The exposed succession is referred to the Upper Maastrichtian and Lower Danian.

Biostratigraphy. The sediments contain abundant and diverse, well preserved nannofossil associations. A total of 47 species have been documented that supports the biostratigraphic subdivision of the section. Zones CC25c and CC26 are present in the Upper Maastrichtian; respectively zones NP1, NP2 and a part of NP3 are determined in the Danian Stage (Fig. 5.133).

The co-occurrence of *Micula prinsii* and *Nephrolithus frequens* in sample B3-61 help trace the boundary between zones CC25c and CC26. Here *Micula prinsii* and *Nephrolithus frequens* occur more frequently than in Byala 2b section.

The K/T boundary is marked by a black clay layer of variable thickness – it becomes thinner or thicker, forming lenses (Fig. 5.132). The FO of *Biantholithus sparsus* and *Cyclagelosphaera alta* (+10 cm) is fixed immediately above the layer, followed by the FOs of *Neochiastozygus primitivus* (+60 cm) and

Crucioplacolithus primus (+1.60 m). This section also reveals abundant specimens of the “survivor” *Thoracosphaera operculata*, which is the most commonly seen species in NP1 zone.

The lower boundary of NP2 zone is traced by the FO of *Crucioplacolithus intermedius* (+5.20 m) and of NP3 zone – by the FO of *Crucioplacolithus edwardsii* (Fig. 5.133).

Stratigraphic range. The continuous sequence includes the interval from the Upper Maastrichtian (zones CC25c, CC 26) to the Lower Danian, zones NP1 to NP3 (Fig. 5.133).

Goritsa

The section is traced in the westernmost ravine at Goritsa village, Varna District. It has been studied and published on in relation to the K/T boundary and the parallel zonation of the Paleocene (Stoykova et al., 2004, 2005a).

A continuous sequence from the Upper Maastrichtian to the middle Paleocene, Selandian is exposed, around 65 m thick. The uppermost portions of the section are faulted – a slice of Upper Cretaceous (Maastrichtian) rocks is thrust over Selandian sediments. The K/T boundary is detected by nannofossils and is designated at the reference level of 0 m (Fig. 5.134).

This section of the Byala Fm slightly differs lithologically from the ones described along the coast near Byala by the fact that marlstones significantly predominate over clayey limestones. The clayey limestones here are thin-bedded, rare layers among thick packets of indistinctly bedded marls (Fig. 5.135).

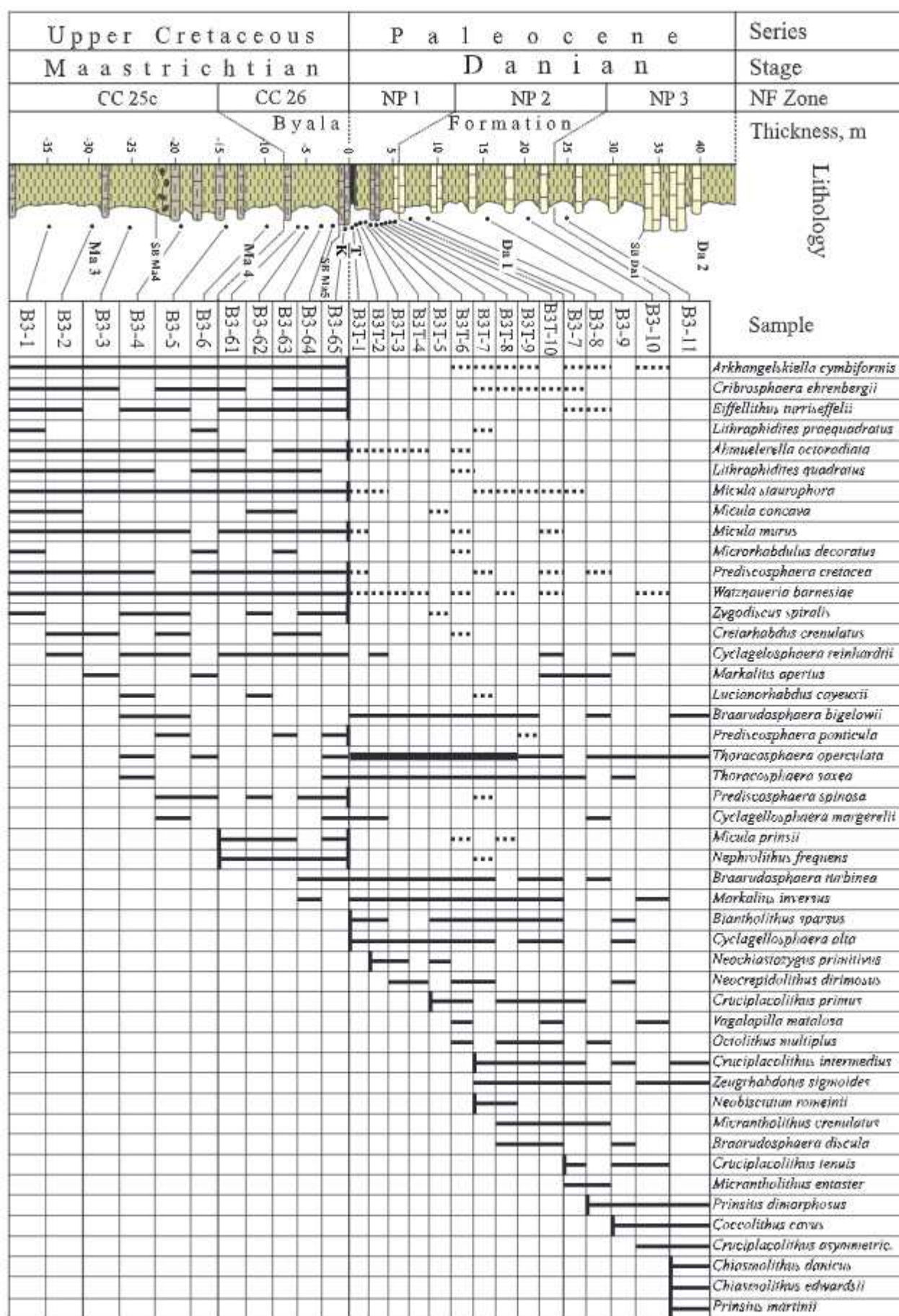


Fig. 5.133. Biostratigraphic subdivision of the Byala 3 section by calcareous nannofossils (after Stoykova & Ivanov, 2004a)

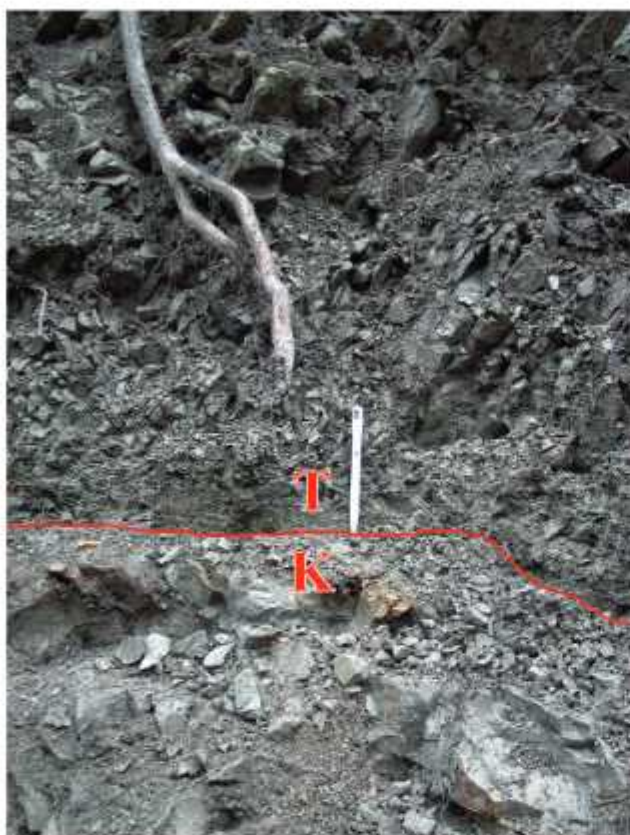


Fig. 5.134. Clay bed, marking the K/T boundary in the Goritsa section (marked with red line)

Biostratigraphy. Exceptionally rich, excellently preserved, abundant and diverse nannofossil associations are detected. Over 70 species are documented in the Upper Cretaceous alone. Species diversity sharply drops immediately above the K/T boundary as a result of the global event, but in the upper levels above NP1 zone it increases again and reaches high values in the Upper Danian and Selandian.

Zones CC25c and CC26 are recognized in the Upper Maastrichtian and the lower boundary of each zone is traced by the occurrence of their index species – *Micula murus* and *Micula prinsii*, respectively. Here the occurrence of *Nephrolithus frequens* precedes the FO of *Micula prinsii*, at around 10 m below the K/T boundary (Fig. 5.136).

The K/T boundary is lithologically expressed by a dark-grey clay layer, 2-3 cm thick (Fig. 5.134). The first occurrence of *Cyclagelosphaera alta* is detected just above this layer, marking the lower boundary of the first Danian zone NP1. The nannoflora in this zone is poor and rarely encountered, as *Thoracosphaera operculata* is the dominant species along with *Braarudosphaera bigelowii* and rare Cretaceous species. Although rare, *Neobiscutum romeinii* and *Cruciplacolithus primus* are observed as newly



Fig. 5.135. Two thin beds of clayey limestone within thick marlstone packet in the Goritsa section; lower limestone = base of NP3 zone, Byala Fm

occurring species in the zone.

The lower boundary of the NP2 zone is set by the FO of *Cruciplacolithus intermedius* at +2.0 m above the K/T boundary. A series of successive first occurrences of new species is recorded for this zone: *Prinsius africanus* (+2.0 m), *Futyania petalosa* (+4.0 m), *Prinsius dimorphosus* (+4.0 m), *Ericsonia subpertusa* (+5.0 m), *Cruciplacolithus tenuis* (+6.0 m), *Coccolithus cavus* (+8.0 m). The reworked (?) Cretaceous species gradually decrease in number and are observed even more rarely.

The lower boundary of NP3 zone is fixed by the first occurrence of *Cruciplacolithus edwardsii* at +14.0 m. At the base of this zone, a couplet of two beds of clayey limestone occur (Fig. 5.135). Accelerated speciation continues within the zone as *Chiasmolithus danicus*, *Prinsius martini* and *Neochiastozygus modestus* appear.

Due to the lack of NP4 index *Ellipsolithus macellus*, the lower boundary of the zone is traced by the FO of *Neochiastozygus eosaepe*, *N. saepe* and *N. imbricatus* in a sample taken at +27.0 m above the K/T boundary. The species *Neochiastozygus perfectus* appears and becomes abundant in the upper levels of this zone, im-

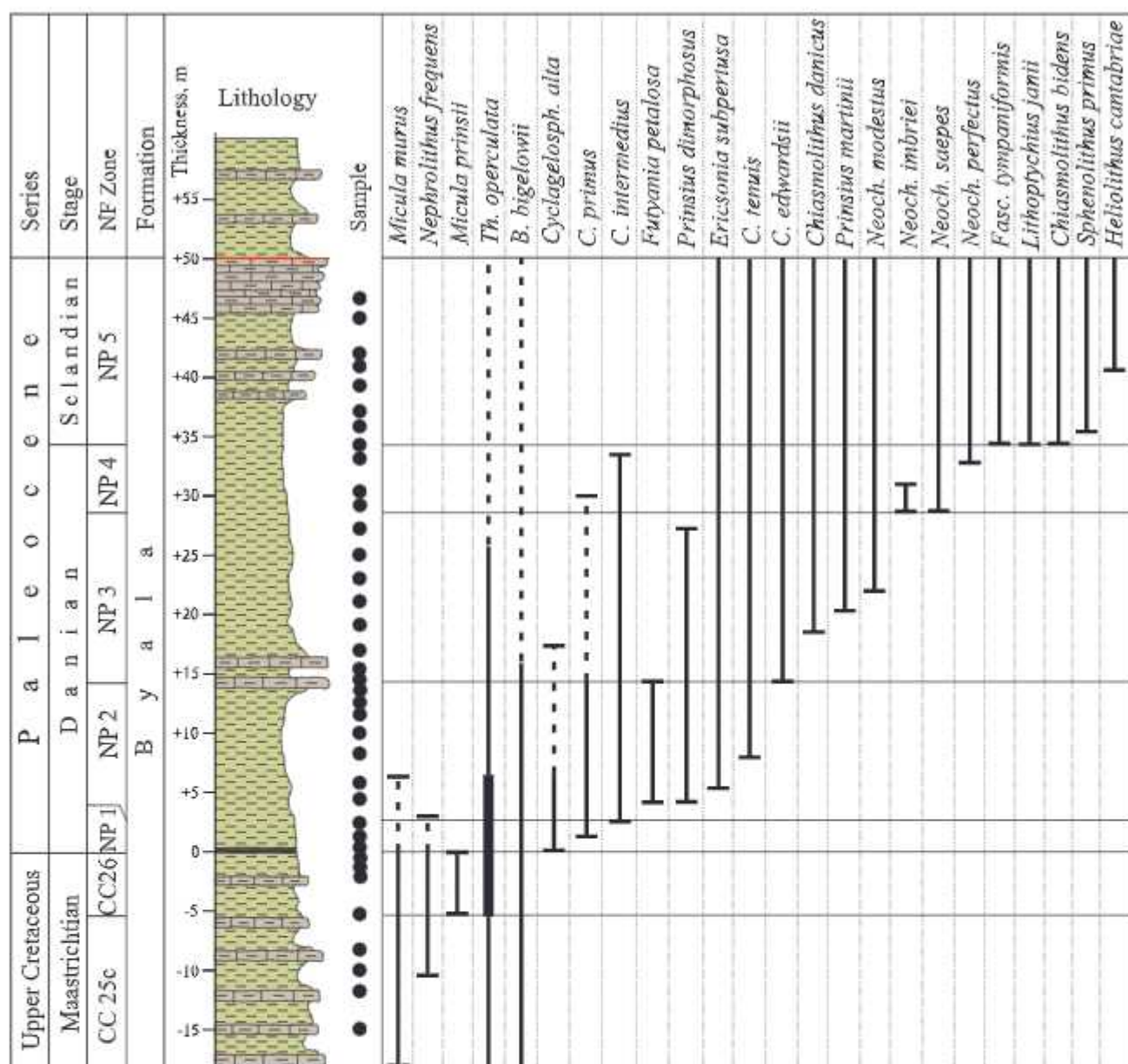


Fig. 5.136. Biostratigraphic subdivision of the Goritsa section, Varna District, by calcareous nannofossils (after Stoykova et al., 2004, 2005a)

mediately below its boundary with the next NP5 zone.

The lower boundary of NP5 zone is marked by the FO of *Fasciculithus tympaniformis* (at +34.0 m). In the base of the zone is a group of species of the genus *Lithopterychius* – *jani*, *billii* and *pileatus*, marking the onset of the second radiation of fasciculiths (sensu Bernaola et al., 2008). The first *Heliolithus* – *H. cantabrigiae* appears in the middle of the zone, at +41.0 m.

In general, the nannofossil associations in this section are significantly more diversified and abundant compared to the ones in the adjacent sections around Byala.

Stratigraphic range. A continuous sedimentary sequence encompasses the interval between the Upper

Maastrichtian (zones CC25c and CC26) and the middle Paleocene (Danian and Selandian Stages, NP1 – NP5 zones, Fig. 5.136).

C-30 Goritsa

This description includes only a part of the section, penetrated with core barrel by the structural well C-30 Goritsa in the interval between 100.0 m and 130.0 m depth. The well is located at 750 m north of Goritsa village, Varna District.

The well section and the planktonic foraminifera stratigraphy have been studied and published by Juranov (1983, 1984, 1989). The core samples for nannofossil content analysis (23 in number), have been provided

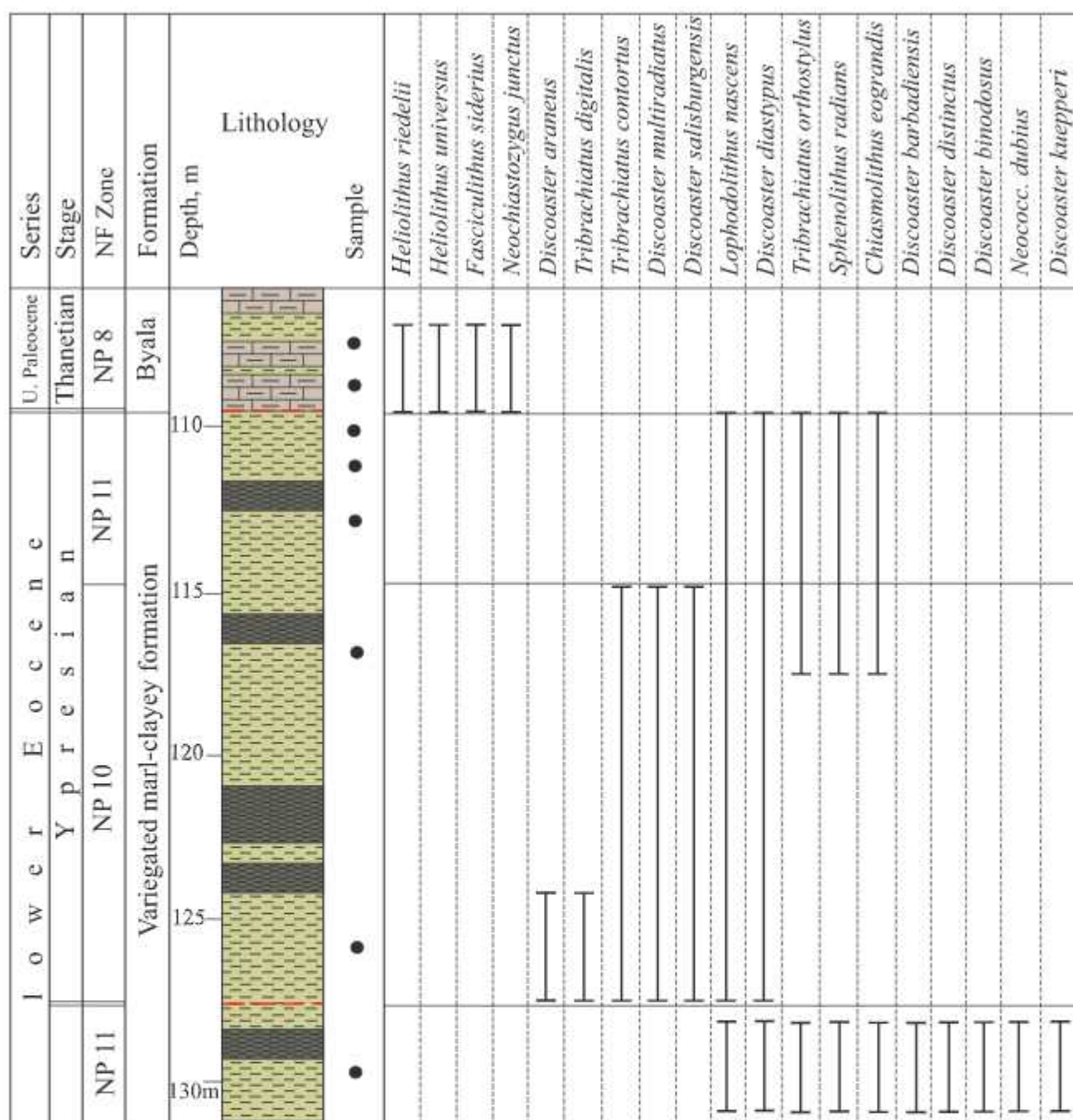


Fig. 5.137. Biostratigraphic subdivision of the well C-30 Goritsa by calcareous nannofossils

by my late colleague S. Juranov.

Since the well is located in a zone of intensive tectonics, it has penetrated several thrusts slices, some of them overturned (Juranov, 1983, 1984, 1989). Similar stratigraphic relationships (thrust slices and slide blocks) can also be identified in the natural outcrops in the gullies around Goritsa (Stoykova et al., 2004; Stoykova et al., 2005a).

From top to bottom, the well penetrated clayey limestones and marls of the Byala Fm and variegated marls and clays of the variegated marl-clayey formation.

Grey clayey limestones alternating with marls are penetrated in the interval 81.70 – 110.00 m. These are referred to the Byala Fm. Between 110.00 m and 130.00 m depth, the core consists of pink-grey, greenish to whitish clayey marls and claystones. The latter are indistinctly bedded, of massive structure and greasy texture. They are assigned to the variegated marl-clayey formation.

Biostratigraphy. The well section reveals very rich, diverse and abundant, perfectly preserved nannofossil associations. Over 40 species are documented in the Paleocene part of the section alone. The section is

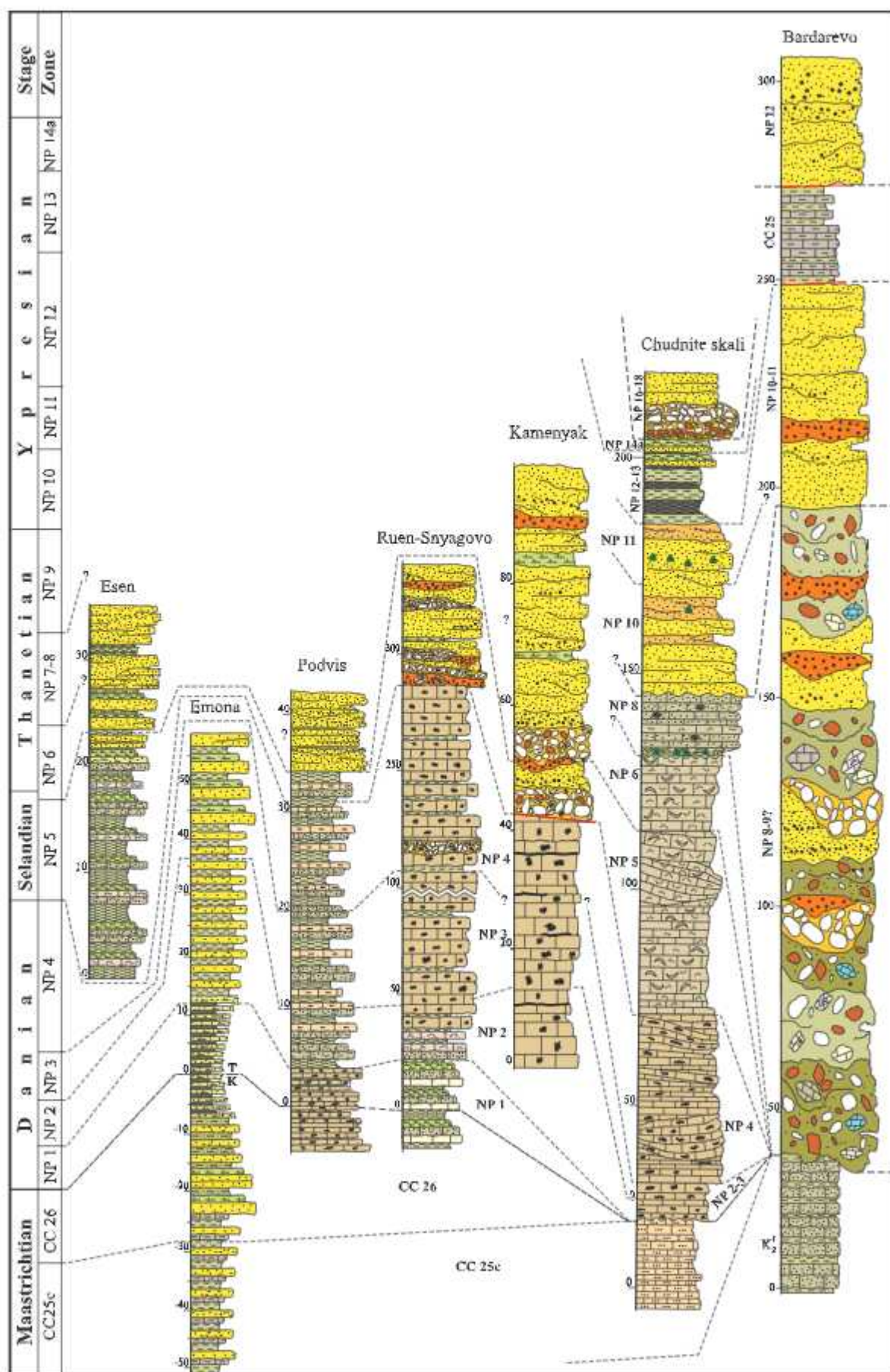
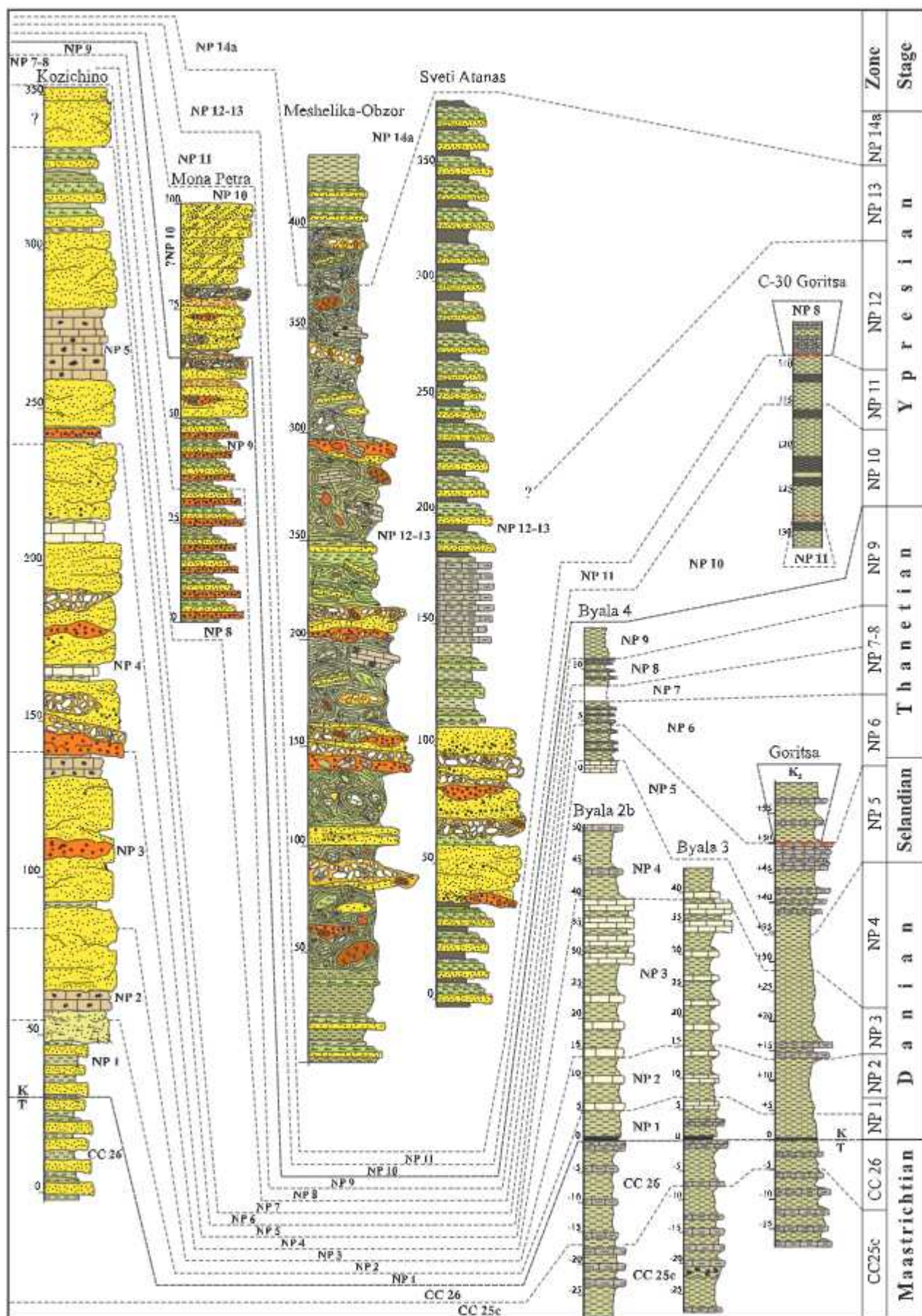


Fig. 5.138. Correlation of the studied sections in the Eastern Fore-Balkan and Eastern Balkan by calcareous nannofossils



considered unique by recording the lowermost stratigraphic levels of the lower Eocene in the area, which are poorly exposed in natural outcrops. This is due to the fact that the clayey marlstones breakdown rapidly into soil when weathered and are easily covered by vegetation. Areas prone to slipping and slumping result and therefore only isolated patches of bedrock are exposed.

The nannofossil subdivision of the section is shown in Fig. 5.137. The interval from 81.70 m to 110.00 m in the Byala Fm yields a very rich and diverse association, which corresponds to NP8 zone. It is defined by the presence of *Heliolithus riedelii*, whereas *Heliolithus universus*, *H. kleinpellii*, *H. robustus*, *Bomolitus megastypus*, *Fasciculithus thomasi*, *F. siderius*, *F. involutus*, *Discoaster splendidus*, *Toweius eminens* and *Calcisolenia aperta* are also recorded.

The Paleocene-Eocene boundary is a tectonic disturbance, at a depth of 110.00 m. Below it, in the interval 110.00 – 127.00 m, another slice of marls and claystones of the variegated marl-clayey formation is identified, where the normal succession of nannofossil zones NP10 and NP11 is evident (Fig. 5.137).

The existence of NP10 zone in the interval 115.00 – 127.00 m is based on the co-occurrence of *Tribrachiatus digitalis* and *Tribrachiatus contortus*, both having a very short range in the middle and upper parts of the zone. The FO of *Tribrachiatus orthostylus* is detected in the upper part of NP10.

The lower boundary of NP11 zone is drawn by the extinction (last occurrence; LO) of *Tribrachiatus contortus*. The zone is evidenced to be present at two levels: between 110 m and 115 m and below 127 m (Fig. 5.137). A series of concomitant FOs of species such as *Discoaster kuepperi*, *D. binodosus*, *Neococcolithes dubius* and *Chiasmolithus eograndis* is documented in the upper level of the zone (below 127 m).

The next tectonic disturbance within the sequence appears below the NP10 zone at a depth of 127 m, where the upper part of NP11 zone repeats.

Stratigraphic range. Upper Paleocene, Thanetian, NP8 zone and lowermost parts of lower Eocene, Ypresian, NP10-11 zones, in tectonically disturbed stratigraphic order.

The sections in the East Fore-Balkan and Balkan (Luda Kamchia Zone) reveal one of the most complete sedimentary and event records throughout Paleocene-early Eocene time within the territory of Bulgaria. Their detailed subdivision using calcareous nannofossils provides new stratigraphic information

and a number of new facts, which shed light on the geological evolution of the area. The age of the conglomerates near Bardarevo (Bardarevo Member) has been determined, the range of the thick-bedded sandstone formation revised, the "exotic conglomerate" (= Obzor Fm) – dated. It is worth noting that the majority of sections represent continuous sedimentary successions, deposited in the deep part of the basin or on the basin slope near the shelf margin. The section at Chudnite skali, where several breaks of sedimentation have been identified, is the only exception, due to its specific location in the basin – on the shelf margin.

Another specific feature of the studied sections is the intensive post-depositional tectonism affecting the sediments, resulting in frequent faulting, folding and thrusting, along with repetition of the section (thrust slices/faulted slices). The correlation of all studied sections is presented on Fig. 5.138.

5.6. Eastern parts of the Moesian Platform

Paleogene sediments are of relatively limited distribution in the eastern parts of the Moesian Platform, compared to the vast areas in the East Fore-Balkan and Balkan (Fig. 5.73). The main outcrops are concentrated along the margins of Varna, Provadia and Shumen plateaus, where Paleocene and lower Eocene sediments are developed. The gap in the sedimentary record (hiatus) between the Upper Cretaceous and Paleogene increases from south to the north, which is considered a regional trend.

Yankovo

The section is located 3 km north of Yankovo village, Shumen District, north of Golyamata kanara and Malkata kanara cliff (Fig. 5.139).

The Upper Cretaceous portion of the section has been studied by Sinnyovsky and Vangelov (2007), who defined it as holostratotype section of the Yankovo Fm (light-grey limestones with *Orbitoides*). Its range is uppermost Campanian – lower Maastrichtian.

The exposed thickness of the Eocene sediments does not exceed 15 m. The uppermost parts of the Upper Cretaceous are represented by massive, medium- to thick-bedded clastic limestones, referred to the Yankovo Fm. They are overlain, through sharp boundary (parallel unconformity), by grey clayey silts and sandy marls and clays. These are poorly bedded, with sandstone lenses with nummulitids in the upper part (Fig. 5.140). At various levels, the marls are enriched with glauconite. These sediments are assigned to the Krivnya Member of the Beloslav Fm.



Fig. 5.139. General view of the Yankovo section; Yankovo, Beloslav (Krivnya Mb) and Avren Fms

Up section, the clays and marls gradually turn lighter in color and become light-grey to whitish. Due to poor exposure, the boundary between the Krivnya Member and the overlying Avren Fm (grey clayey marls) was not observed. In adjacent sections this boundary represents a gradual lithological transition.

Biostratigraphy. The sediments contain abundant and diverse, well preserved associations with a total of 30 species of nannofossils identified in the Eocene portion of the section (on Fig. 5.140; not all species are plotted).

A rich nannofossil association is documented in the first sample from the Krivnya Member, taken immediately above the bank of clastic limestones of the Yankovo Fm (from the outcrop near the bridge on the road). The identification of *Tribrachiatulus contortus* along with *Campylosphaera eodela*, as well as *Discoaster diastypus* and *Toweius tovae* conclusively proves the rocks refer to the first zone of the lower Eocene – NP10 zone. Since *Tribrachiatulus contortus* has a very short range in the uppermost part of NP10 zone (NP10d – Monechi et al., 2000), the inference is that only these topmost parts of NP10 are developed in the section.

The lower boundary of NP11 zone is marked by

the last occurrence (extinction) of *Tribrachiatulus contortus* and the FOs of a number of new species as *Tribrachiatulus orthostylus* (near the NP10/NP11 boundary), *Sphenolithus editus*, *Discoaster pacificus*, *Toweius gammation*, *Campylosphaera dela* and *Ericsonia formosa*.

The lower boundary of NP12 zone is a clearly traced and easily identifiable biohorizon – the FO of *Discoaster lodoensis*. The FO of *Discoaster kuepperi* (uppermost portions of NP11 zone) has also been detected near that boundary. The marls of the Avren Fm yield *Chiphragmalithus calathus*, whose range is within the NP12 zone only.

Stratigraphic range. Lower Eocene, Ypresian Stage, upper parts of NP10 zone and NP11-NP12 zones (Fig. 5.140).

Sindel

The section is located immediately south of Sindel railway station, Varna region. It is traced along the western margin of the Avren Plateau, on the right bank of the Provadia River.

The section has been studied by Stoykova and Vangelov (1997) who characterized the lithological and

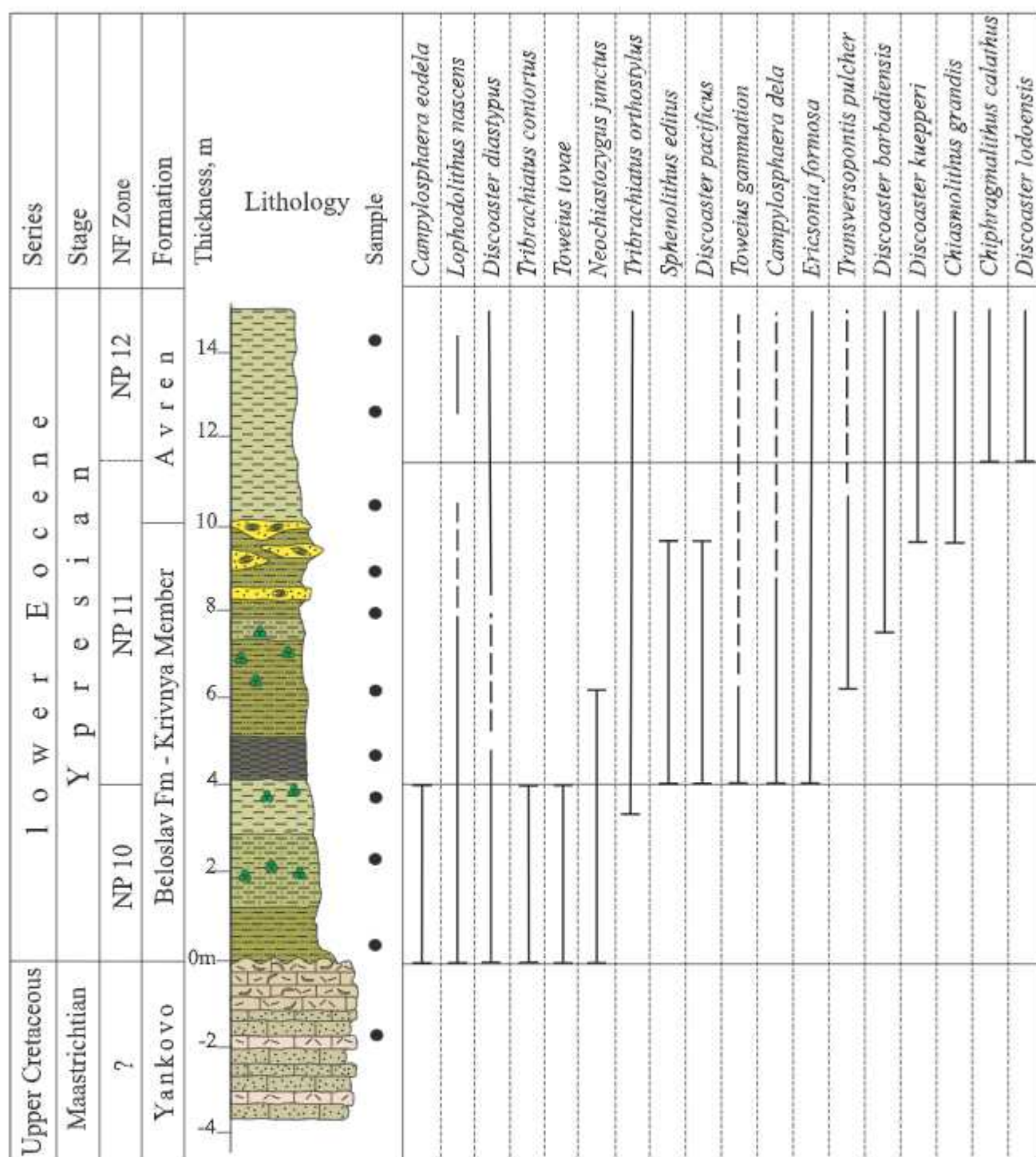


Fig. 5.140. Biostratigraphic subdivision of the Yankovo section, Varna District, by calcareous nannofossils

nannofossil sequences and estimated the duration of the gap between the Paleocene and Eocene.

At the base of the succession soft, chalky limestones with chert concretions (Shumen Fm, Upper Cretaceous) are overlain by creamy sandy limestones, rich in glauconite (Komarevo Fm, Paleogene). The boundary between the Shumen and Komarevo Fms is a sharp washout of "hard ground" type. The Komarevo limestones are thin-bedded, detritic and the clastic

component is mainly of bivalve shells. Moreover, irregularly dispersed flint nodules and fossil flora and fauna are present – sponges, bryozoa and mollusks are commonly observed. The measured thickness of the sediments is 4.5 m.

The upper boundary of the Komarevo Fm is also sharp and marks a break in sedimentation. The sandy limestones are overlain by whitish clayey and calcareous sands and weakly cemented sandstones with

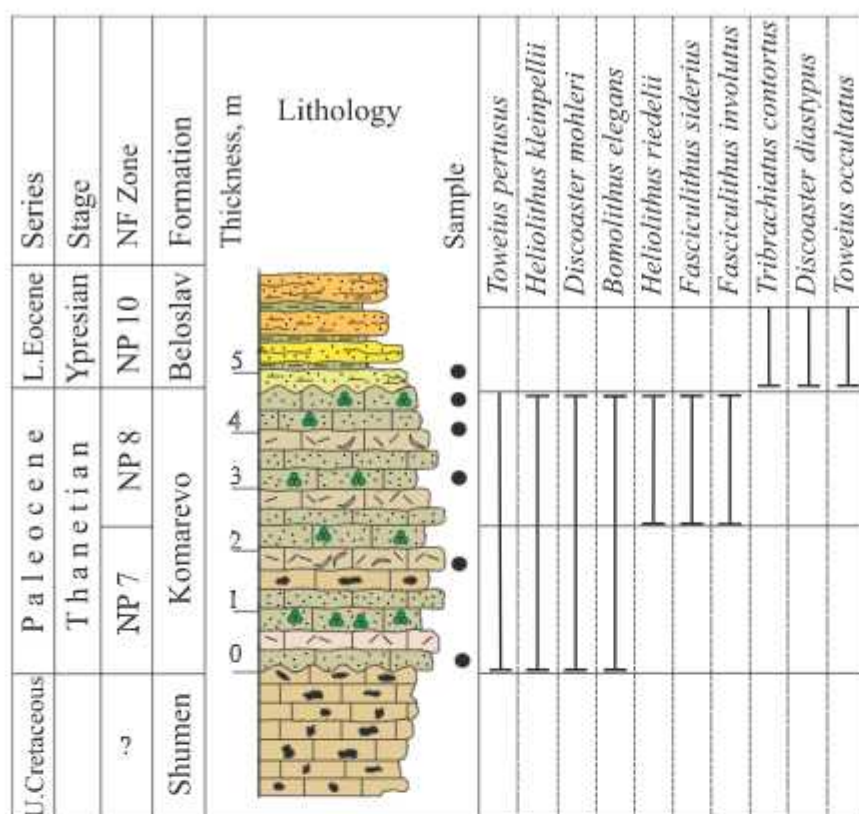


Fig. 5.141. Biostratigraphic subdivision of the Sindel section, Varna District, by calcareous nannofossils (after Stoykova & Vangelov, 1997)

intercalations of silty marls. They are referred to the Beloslav Fm. The exposed thickness is only several meters above the boundary with the Komarevo Fm, as the slope is covered with vegetation (total thickness of over 25 m).

Biostratigraphy. The associations are not rich, but age-characteristic and moderately well-preserved. The biostratigraphic subdivision of the section is shown in Fig. 5.141.

The sandy and detritic limestones of the Komarevo Fm document the presence of the Thanetian NP7 and NP8 zones. The concomitant occurrence of *Discoaster mohleri*, *Heliolithus kleinpellii* and *Bomolitus elegans* in the lower 2.5 m refers these sediments to nannofossil zone NP7.

The lower boundary of NP8 zone is traced by the FO of *Heliolithus riedelii*, while *Fasciculithus siderius* and *F. involutus* also have their FOs in the zone.

Tribrachiatus contortus and *Discoaster diastypus*, restricted to NP10 zone, are determined in the sample taken from the base of the Beloslav Fm, just above the sharp boundary.

The gap in sedimentation most likely encompasses some part of NP8 zone, the entire NP9 zone and part of NP10 zone.

Stratigraphic range. Upper Paleocene, Thanetian Stage, NP7-NP8 zones and lower Eocene, lower part of the Ypresian Stage, NP10 zone (Fig. 5.141).

Trastikovo

The section is located approximately 10 km south-east of Beloslav, east of Trastikovo railway station. The outcrop appears along the western margin of the Avren Plateau, as does the Sindel section (Fig. 5.142).

The section has been studied by Stoykova and Vangelov (1997). The sequence is similar to the Sindel section.

White, chalky limestones with flint nodules, referred to the Mezdra Fm (Upper Campanian) occur at the base of the succession. The upper boundary of the Formation is marked by washout and typical signs of a hard ground. The Mezdra Fm is overlain by thin- to medium-bedded detritic and sandy limestones 4.5 m thick, assigned to the Komarevo Fm. Locally they are strongly bioturbated and contain lenses and thin layers of shell debris, as well as irregularly dispersed glauconite grains. Phosphorite concretions, sponge spicules and quartz grains are commonly seen at the base (the basal 0.15-0.20 m).

Above them is another unconformity (washout) at the base of the Beloslav Fm. comprising fine-grained



Fig. 5.142. General view of the Trastikovo section; Mezdra, Komarevo and Beloslav Fms

clayey and calcareous sands and weakly cemented sandstones. Only the lower 10-15 m are exposed, while the upper parts of the slope are covered with vegetation.

Biostratigraphy. The subdivision of the section by calcareous nannoplankton is summarized in Fig. 5.143. Diverse and relatively well preserved nannofossil associations are documented.

The uppermost part of the Mezdra Fm is referred to the

Upper Campanian, based on the characteristic association, comprising *Uniplanarius trifidus*, *Reinhardtites levis*, *Broinsonia parca constricta*, etc.

The samples from the lowest two metres of the Komarevo Fm, immediately above the sharp boundary with the Mezdra Fm, correspond to Thanetian NP7 zone. Its lower boundary is marked by the FO of the species *Discoaster mohleri*. *Neochiastozygus perfectus*, *Prinsius dimorphosus* and *Heliolithus*

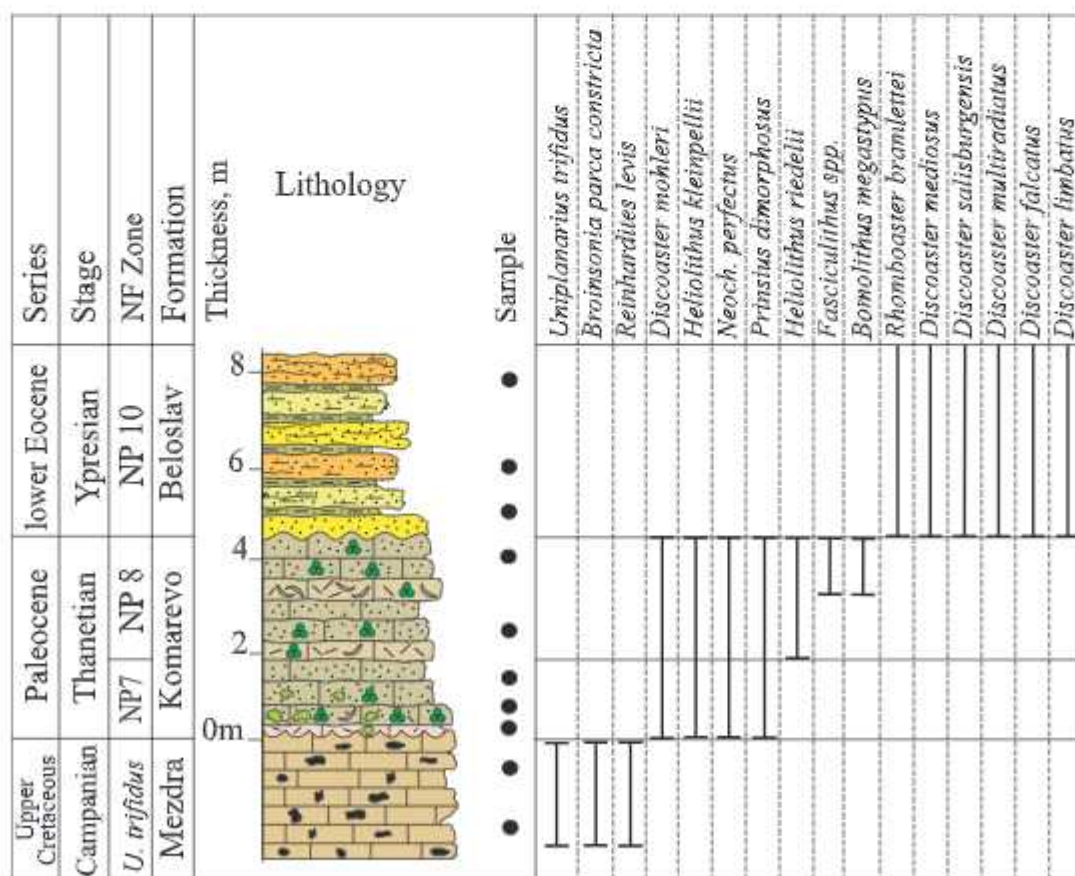


Fig. 5.143. Biostratigraphic subdivision of the Trastikovo section, Varna District, by calcareous nannofossils (after Stoykova & Vangelov, 1997)

kleinpellii are also present in this zone.

The lower boundary of NP8 zone is drawn by the FO of the index species *Heliolithus riedelii*, which is abundant in all samples from the middle to uppermost Komarevo Fm. Its range coincides with the range of NP8 zone. The thickness of the zone is 2.5 m.

The first metres of the clayey sands of the Beloslav Fm contain a rich and diversified association, indicating the presence of the lowermost NP10 zone of the lower Eocene (Ypresian Stage). This conclusion is based on the common occurrence of the species *Rhomboaster bramlettei*, *Discoaster falcatus*, *D. limbatus*, *D. medius*, *D. multiradiatus* and *D. salisburyensis*. Due to poor exposure, the thickness of the zone is not accurately known.

Stratigraphic range. Upper Paleocene, Thanetian Stage, NP7 – NP8 zones and lower Eocene, lower parts of Ypresian Stage, NP10 zone (Fig. 5.143).

Beloslav – South

The section starts at the south-western end and finishes at the south-eastern end of Beloslav town, Varna District. It is traced as continuous outcrops in the ravine near the Roma hamlet (Fig. 5.144). The uppermost portions are not well exposed in the ravine; therefore, the upper stratigraphic levels are best traced in the gully east of Beloslav (Fig. 5.145).

This is one of the key Paleogene sections in NE Bulgaria, representative for sedimentary sequences in the eastern parts of the Moesian Platform. It has been a subject of study by generations of geologists and while sparing the details, it is worth mentioning the classic works of Gochev (1926, 1933, 1937), Gellert

(1929), Mandev (1955), Belmustakov (1962, 1968) and Aladjova-Hrischeva (1984a, 1990, 1991). More recently, parallel biostratigraphic studies on three fossil groups have been conducted by Aladjova-Hrischeva et al. (1983), while Stoykova and Vangelov (1997) refined the range of the lithostratigraphic units using calcareous nannofossils. In the vicinity of Beloslav older rocks are also exposed – Lower and Upper Cretaceous sediments, cropping out west and south-west of Beloslav (Turonian-Lower Maastrichtian; Sinnyovsky, 2007).

Soft, chalky limestones with rare chert concretions, referred to the Mezdra Fm, occur at base of the section. Sinnyovsky (2007) identified the Lower Maastrichtian zone *Arkhangelskiella cymbiformis* in the uppermost 2 m of the limestones.

They are overlain by 5.2 m of thick- to thin-bedded sandy and clastic limestones, referred to the Komarevo Fm (Fig. 5.146). At their base is a sharp washout boundary; the basal sediments are 0.2-0.3 m of sandy limestones enriched with glauconite and phosphoritic concretions. Upwards, they gradually pass into calcarenites and mixed terrigenous-carbonate rocks, consisting of abundant red algae skeletons (*Lithothamnium* limestones), *Discocyclina* and mussel shells (*Ostrea*). The deposition of these sediments probably took place in a shallow-water, high-energy environment within the shelf zone.

The upper boundary of the Komarevo Fm is also sharp, reflecting a short-term break of sedimentation. Weakly cemented, medium- to fine-grained yellow sandstones and sands, very well sorted, belonging to the Beloslav Fm occur above. They are interbedded at several levels by beds of hard calcareous sandstones, 0.1-0.2 m thick (Fig. 5.144). White quartzitic sands



Fig. 5.144. Section at the SW end of Beloslav village, along the ravine; Beloslav Fm



Fig. 5.145. Section at the SE end of Beloslav village, along the ravine "Teterlika"; Dikilitash Fm exposed in foreground, limestone bank of the Aladan Fm at the top of the slope



Fig. 5.146. Section at the SW end of Beloslav village – exposures of the clastic limestones of the Komarevo Fm



Fig. 5.147. Section at the SE end of Beloslav village – exposure of the *Ostrea*-marker horizon in the upper part of the Beloslav Fm

are developed in the upper parts of the Formation, above which the so-called shell bed marker level is identified, rich in macrofossil shells, mainly bivalves (*Ostrea rarilamella* – Belmustakov, 1968) and nummulitids (Fig. 5.147). Above the *Ostrea* marker horizon is 2 m of grey to light-beige sandy and silty marls of the Krivnya Member. They contain nummulitid shells and abundant nannofossils. These sediments are also assumed to have been deposited at a shallow-water depth in a high-energy environment, in the littoral zone.

The upper boundary of the Beloslav Fm displays a rapid lithological transition to the overlying Dikilitash Fm and is exposed in the gully east of Beloslav (Fig. 5.145). The Dikilitash Fm is composed of white, fine-grained quartz sands with beds of well cemented calcareous sandstone in the shape of vertical pillars.

The uppermost parts of the section in the ravine south-east of Beloslav is topped by a 1-2 m thick hard limestone bank, built of numerous nummulitid shells (Aladan Fm, Fig. 5.145). The latter is overlain by marls of the Avren Fm, with a sharp lithological contact at their base.

Biostratigraphy. The sediments contain relatively diverse and well preserved nannofossil associations. In total, over 30 species have been determined, which resulted in the biostratigraphic subdivision of the section.

The uppermost part of the Mezdra Fm is assigned to the Lower Maastrichtian, zone A. *cymbiformis*, since *A. cymbiformis*, *A. confusa* and other long-ranging Upper Cretaceous species have been identified.

The presence of NP7 zone is proved at the base of the

Komarevo Fm (the lower 2.5 m) by the discovery of the index species *Discoaster mohleri*. The upper 2.7 m are assigned to the next NP8 zone, since *Heliolithus riedelii* is identified.

The samples taken from the lower and middle parts of the yellow clayey sands of the Beloslav Fm reveal an abundant and diversified association, including the species *Rhomboaster bramlettei*, *Discoaster mediusus*, *D. multiradiatus*, *Discoaster falcatus*, *D. lenticularis*, *D. diastypus*, *D. limbatus*, *D. salisburgensis* and *Toweius tovae*. The association corresponds to NP10 zone.

No nannofossils were recovered from a 6 to 7 m thick barren interval below the *Ostrea* shell bed that marks the top of the Beloslav Fm (Fig. 5.148).

The samples from the shell bed, as well as from the overlying silty marls of the Krivnya Member contain a relatively scarce, but characteristic nannoflora. The FO of *Discoaster lodoensis* identified in it implies the sediments are of NP12 zone age.

Furthermore, a similar poor association is recovered from the clayey interbeds of the Dikilitash Fm. The upper parts of this Formation could be conceivably assigned to the next NP13 zone; however, this may not be definitely confirmed. No bioevents place the lower boundary of NP13 zone, although *Discoaster bronnimanni*, a commonly occurring species in NP13 zone, has been detected.

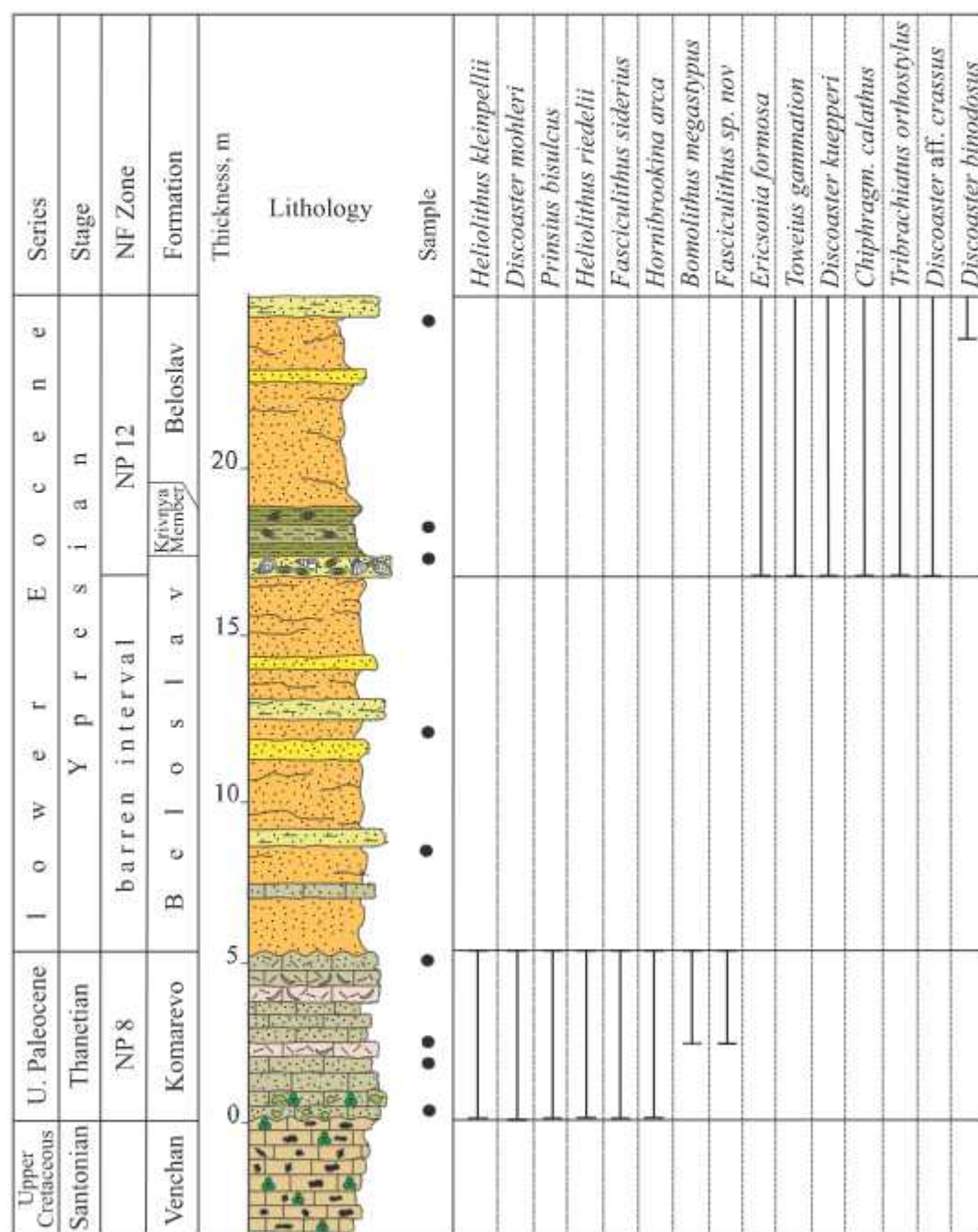
Stratigraphic range. The existence of NP7 and NP8 zones (Thanetian Stage) is established in the Komarevo Fm as well as NP10, NP12 and part of NP13 (Ypresian Stage) in the Beloslav and Dikilitash Fms (Fig. 5.148).

Beloslav – North

The section is located on the northern side of Beloslav Lake, around 1 km NNW of Beloslav. It occurs on the slope of Kanarata Hill. Although the section may show considerable resemblance to Beloslav – South, the description here focuses on the established essential differences in biostratigraphic and chronostratigraphic range of the units, as well as on the duration of the hiatuses (the breaks in the sedimentation). The section is of key importance in interpreting the geological development of the basin in the eastern parts of the Moesian Platform.

The section has been studied by Belmustakov (1962), who erroneously assigned the Danian to the Upper Cretaceous portion, and included lower Eocene sediments (the sandstones and sands of the Beloslav Fm) into the Thanetian Stage (Paleocene). Modern stratigraphic data on the succession were published by Stoykova and Vangelov (1997).

The base of the section is occupied by white chalky limestones with glauconite and dark coloured chert nodules, referred to the Venchan Fm (Jolkichev, 1988). They are overlain through a sharp boundary by creamy clastic limestones – sandy, detritic, and rich



in glauconite and phosphoritic concretions in the basal 5-10 cm. These are referred to the Komarevo Fm, around 5 m thick in this section.

Above the limestones, light-beige to whitish weakly cemented sandstones and sands (Beloslav Fm) occur. Single beds of firmly cemented calcareous sandstones and sandy limestones are present. The boundary between the Komarevo and Beloslav Fms is a sharp parallel unconformity, reflecting a break in sedimentation.

The upper part of the section contains the "shell marker bed" rich in *Ostrea* valves and fossil remains of nummulitids and echinoids. Above this marker bed, beige and greyish silty marls and siltstones occur, representing the Krivnya Member (around 2 m thick).

Biostratigraphy. Calcareous nannofossils are recorded only in the Komarevo Fm and the upper part of the Beloslav Fm. The abundance and preservation varies from medium to well preserved. The biostratigraphy of the section is plotted on Fig. 5.149. No nannofossils have been detected in a 10 m interval from the base of the Beloslav Fm to the "shell marker". This interval is denoted as a barren interval.

The entire thickness of the Komarevo Fm in the Beloslav-North section corresponds to the Thanetian Stage, zone NP8. All samples from the clastic limestones contain *Heliolithus riedelii* – the index-species of the zone. Moreover, other characteristic taxa are determined – *Fasciculithus siderius*, *F. sp. nov.*, *Hornobrookina arca* and *Bomolithus megastypus*.

The lower 10-12 m of the Beloslav Fm are defined as a barren interval due to the lack of nannofossils. It is similar to the barren interval in the Beloslav – South section.

Abundant and well preserved nannoflora, corresponding to Ypresian NP12 zone is identified in the samples from the *Ostrea* level and above. The zone is unambiguously documented by the concomitant occurrence of *Chiphragmalithus calathus*, *Discoaster kuepperi* and *Tribrachiatulus orthostylus* only within NP12 zone.

Stratigraphic range. The Komarevo Fm is dated as zone NP8, Thanetian Stage and the Beloslav Fm as zone NP12, Ypresian Stage.

Considering the biostratigraphy results of both sections near Beloslav, essential differences regarding the duration of hiatuses can be highlighted. Thus, the time gap in the Beloslav-South section between the Upper Cretaceous and the Paleocene includes the Upper Maastrichtian, Danian and Selandian (time equivalent

of NP1 to NP6 zones inclusive). In Beloslav-North the time gap is substantially longer – encompassing the entire Campanian, Maastrichtian, Danian, Selandian and the beginning of the Thanetian (zone NP7 inclusive).

A difference is also noted in the gap around the Paleocene-Eocene boundary, between the Komarevo and Beloslav Fms. In the Beloslav-South section it covers only the NP9 zone at the end of the Thanetian, whereas in the Beloslav-North section it comprises end-Thanetian and beginning of the Ypresian (NP9, NP10 zone and probably part of NP11). These differences are well-illustrated on the correlation scheme for the studied sections in the eastern part of the Moe-sian Platform (Fig. 5.150).

5.7. Black Sea offshore area

The first offshore wells in the Bulgarian Black Sea area were drilled in mid-1980s by the Oil and Gas company of the then existing Committee of Geology. These wells were Samotino-More, Samotino-East, R-79 Shkorpilovtsi, Elizavetino and Nanevo. Later, following the international bidding rounds and opening of the acreage to foreign companies in 1991, petroleum exploration in the Black Sea entered a new stage. In the period 1993-1996, a number of offshore wells were drilled by Union Pacific (Severna-1, 2), Texaco (with Enterprise Oil and OMV as partners in the Galata Block: Galata-1, Galata-2, Bogdanov-north, Epsilon) and British Gas (LA-IV/9 1-1, LA-IV/9 1-2, LA-IV/9 1-3). Of these wells only the first one, drilled in the Galata Block – Galata-1, made a commercial discovery of high quality gas.

A new phase in drilling began after 2004, when Galata natural gas field production started. Melrose Resources Plc., the operator of Galata field, drilled a number of exploration wells aimed at new discoveries: Galata-east, Bogdanov-east, Varna-west, Yuri Shimanov, Samotino-1, Samotino-2, Izgrev, Ropotamo and Obzor (Figs. 5.151, 5.152).

The text below discusses only the offshore wells that have penetrated Paleocene and/or lower Eocene sediments. Their location (marked with red star) is shown on Fig. 5.152.

Samotino-More

The well is located offshore Black Sea, around 30 km east of Byala town. It was drilled in 1985-1986 by the former Oil and Gas company with the Committee of Geology, using the Russian "Sivash" drilling rig.

Data on the stratigraphy of the section were first pub-

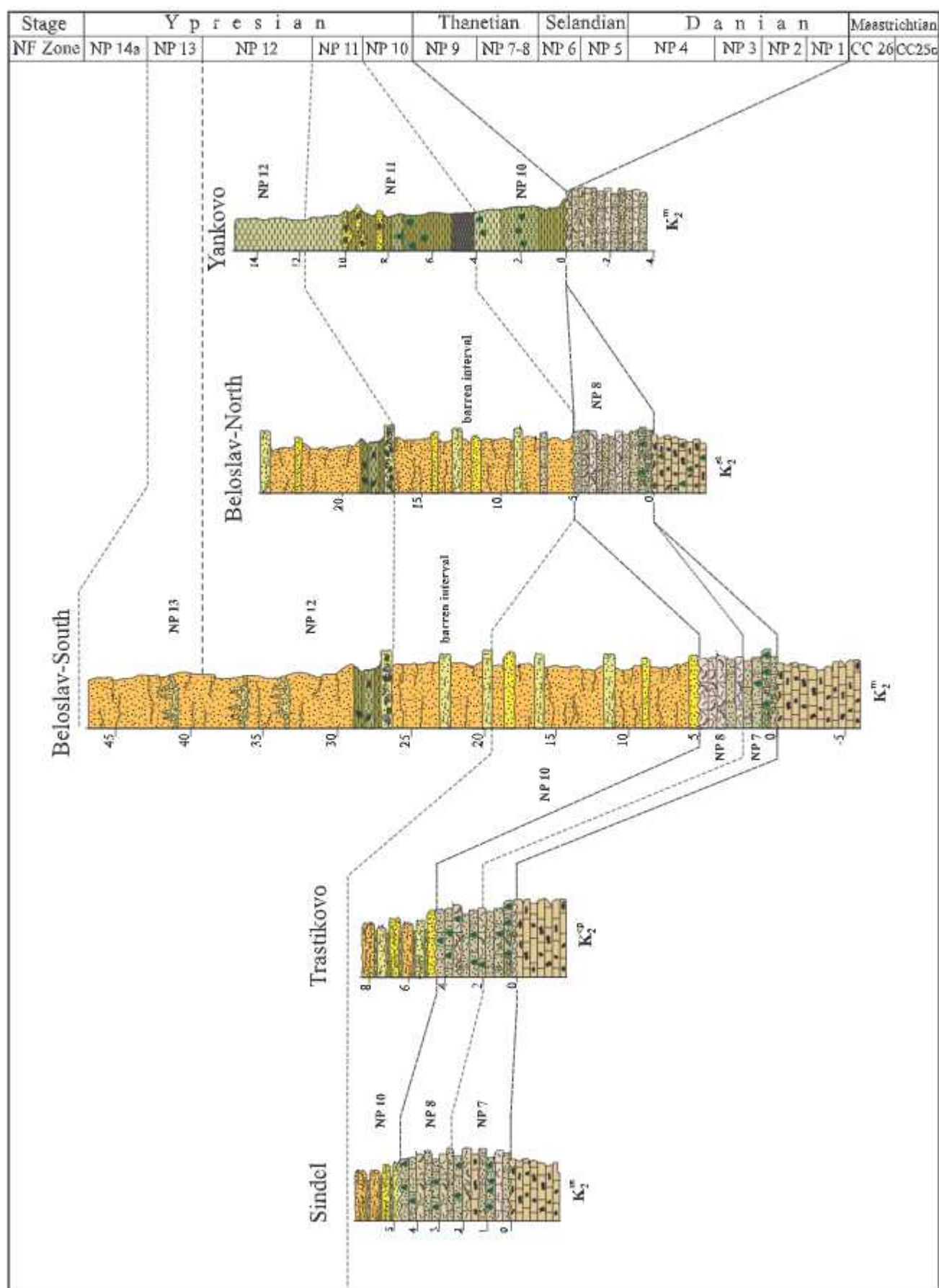


Fig. 5.150. Correlation of Paleogene sediments in the studied sections in the eastern parts of the Moesian Platform by calcareous nannofossils

lished by Juranov (1991) and later on by Stoykova (1994).

The well reached a total depth (TD) of 3648 m. The main portion of the drilled section includes Paleogene sediments and only below 3000 m depth, Upper Cretaceous (Cenomanian) rocks were encountered. A total of 28 core runs were made with relatively high percentage of core recovery. Detailed description of the lithology and nannofossil content in all core intervals was made by Stoykova (1994). The discussion here will focus only on the lower Eocene part of the section, in the interval 3175-3545 m.

Sandstones with thin siltstone-clayey interbeds enriched with plant debris are encountered in the interval 3175-3182 m. The sandstones are medium- to coarse-grained, massive. Some 100 m downwards, in the interval 3287-3290 m, dark-grey siltstones are penetrated. Due to lithological similarity, these sediments are conditionally referred to the Meshelika Member of the Gebesh Fm.

Turbidites represented by alternations of thin-bedded sandstones, siltstones and shales are recovered in the interval 3353-3361 m. They are assigned conditionally to the thin-rhythmic turbidites of the Gebesh Fm, outcropping onshore between Cape Sveti Atanas and Sol Luna Bay complex.

The interval between 3474 m and 3481 m penetrated light-grey medium-grained sandstones, interbedded with dark-grey silty marls and shales. The deepest penetrated interval of the lower Eocene section, from 3542 m to 3548 m, consists of dark-grey siltstones and clayey marls. The sandstones with marly interbeds are considered corresponding to the Sveti Atanas Fm sandstones, outcropping onshore.

In the two core intervals below these sediments (3605-3612 m and 3640-3648 m), the well penetrated dark-grey indistinctly bedded marls, alternating with light-grey limestones. This portion of the section is referred to the Upper Cretaceous – Cenomanian, based on abundant nannofossil finds.

Biostratigraphy. Calcareous nannofossils are encountered only in sediments of fine-grained lithology – marly and clayey interbeds at the base of the Sveti Atanas Fm, in the Gebesh Fm and the Meshelika Member (Fig. 5.153). Reworking of excellently preserved Upper Cretaceous and Paleocene species is extensive.

The Cenomanian age of the lowermost core intervals to the bottom-hole (3605-3612 m and 3640-3648 m) is proved by the common occurrence of the species

Corollithion kennedyi, *Eiffellithus turriseiffelii* and *Eprolithus floralis*.

Relatively poor, however, characteristic associations are documented at different levels in the lower Eocene section. The association determined at the base of Sveti Atanas Fm contains common *Discoaster lodoensis*, *D. binodosus*, *Chiphragmalithus armatus* and *Helicosphaera lophota*. It defines unambiguously the NP12 zone in the lower Eocene, since the genus *Chiphragmalithus* occurs only within this zone. The discovery of the stratigraphically important species *Discoaster lodoensis* in the lowermost and uppermost levels defines the maximum stratigraphic range as NP12 – NP14a zone.

Stratigraphic range. The Upper Cretaceous portion of the section is related to the Cenomanian Stage, while the lower Eocene one – to the middle and upper parts of the Ypresian Stage, NP12-14a zone (Fig. 5.153).

Galata-1

The well is located some 22 km east of the Kamchia River estuary, in the Black Sea offshore area. It was drilled in May-August 1993 by Texaco, Enterprise Oil and OMV as partners in the Galata Block (Texaco Exploration Offshore Bulgaria Ltd. as operator).

The TD reached by the well was 2580 m, with three core runs and the core recovery from the first run was 100% (Fig. 5.154). The well discovered the first commercial offshore natural gas field in the Bulgarian shelf.

Grey to whitish calcareous clays and marls, referred to the Avren Fm are penetrated in the interval 1020-1035 m.

They are underlain through sharp lithological boundary (parallel unconformity) by creamy-yellowish to whitish colored clastic limestones. The clastic component is represented mainly by shell debris, rare quartz grains are present. These sediments are referred to the Komarevo Fm (1035-1044.5 m).

Strongly mixed rocks are penetrated in the interval 1044.5-1059.9 m – calcarenites and clastic limestones with numerous large foraminifera shells – representatives of the genus *Orbitoides*. These are assigned to the Upper Cretaceous Dobrina Fm. Below 1059.9 m, grey massive to indistinctly bedded clayey limestones and chalky limestones are drilled, assigned to the Lower Cretaceous.

Biostratigraphy. Calcareous nannofossils are identified throughout the whole drilled section, but the most abundant are the associations in the calcareous clays

and marlstones of the Avren Fm (Fig. 5.155). As a rule, the nannofossils in the clastic limestones of the Komarevo Fm are rather rare and poorly preserved. Age-diagnostic nannofossil species are rarely encountered in the mixed rocks of the Dobrina Fm. The species *Micula murus*, zonal marker in the Upper Maastrichtian, is documented only in 3 samples (Fig. 5.155).

The nannofossil association from the interval 1035–1044.5 m is poor and non-characteristic and comprises long-ranging species in the upper Paleocene – *Prinsius bisulcus*, *Ericsonia subpertusa* and *Sphenolithus* spp. The association is referred conditionally to NP8-9 zone, by analogy with similar sediments, penetrated in the neighboring Galata-2 well.

The nannofossil associations of the lower and middle Eocene portion of the section are abundant and diversified, and allow differentiation of NP12-13 and NP14a zones within the Ypresian as well as of NP14b and NP15 zones in the lower part of the Lutetian.

Zone NP12-13 is documented by the co-occurrence of *Discoaster lodoensis* along with *Discoaster septemradiatus*, *Chiasmolithus consuetus* and *Chiasmolithus grandis*.

The lower boundary of NP14a zone is traced by the FO (= last downhole occurrence, LDO) of the index species *Discoaster sublodoensis* at 1027 m.

The lower and upper boundaries of NP14b zone are fixed respectively by the first and last occurrence of the species *Rhabdosphaera inflata* (its total stratigraphic range) in cutting samples at 1024–1025 m.

The lower and upper boundaries of NP15 zone are marked by the first and last occurrence of the genus *Nannotetrina* (*N. cristata*, *N. quadrata*) in the cuttings at 1020–1023 m.

Stratigraphic range. The Upper Cretaceous part of the section (Dobrina Fm) is referred to Upper Maastrichtian, zone *Micula murus*. The Paleocene portion (Komarevo Fm) is conditionally assigned to the Upper Thanetian, NP8-9 zone, and the lower Eocene portion (Avren Fm) – to the middle and upper parts of the Ypresian, NP12-14a zone (Fig. 5.155).

Galata-2

The well is located several km east of Galata-1 well, Black Sea offshore. It was drilled in September-Octo-



Fig. 5.151. Oil and gas exploration drilling by “Atwood Southern Cross” Drilling Rig in the Black Sea shelf, 2007

ber 1996 by Texaco in Galata Block as an exploration well.

It reached its TD of 1151 m, penetrating lower Eocene and Paleocene sediments, similar to the ones in Galata-1 well. Certain differences are noted only in the thicknesses of the formations and the biostratigraphic zones. The well section encompasses (from top to bottom) calcareous clays and marls of the Avren Fm, clastic limestones of the Komarevo Fm and detritic

limestones of the Dobrina Fm, the latter two being entirely cored.

Biostratigraphy. Calcareous nannofossils encountered in the well are relatively more common and rich, compared to Galata-1 well. The most abundant and diverse associations are revealed in the calcareous clays and marls of the Avren Fm (Fig. 5.156). Furthermore, substantially richer and better preserved associations are recovered from the clastic limestones

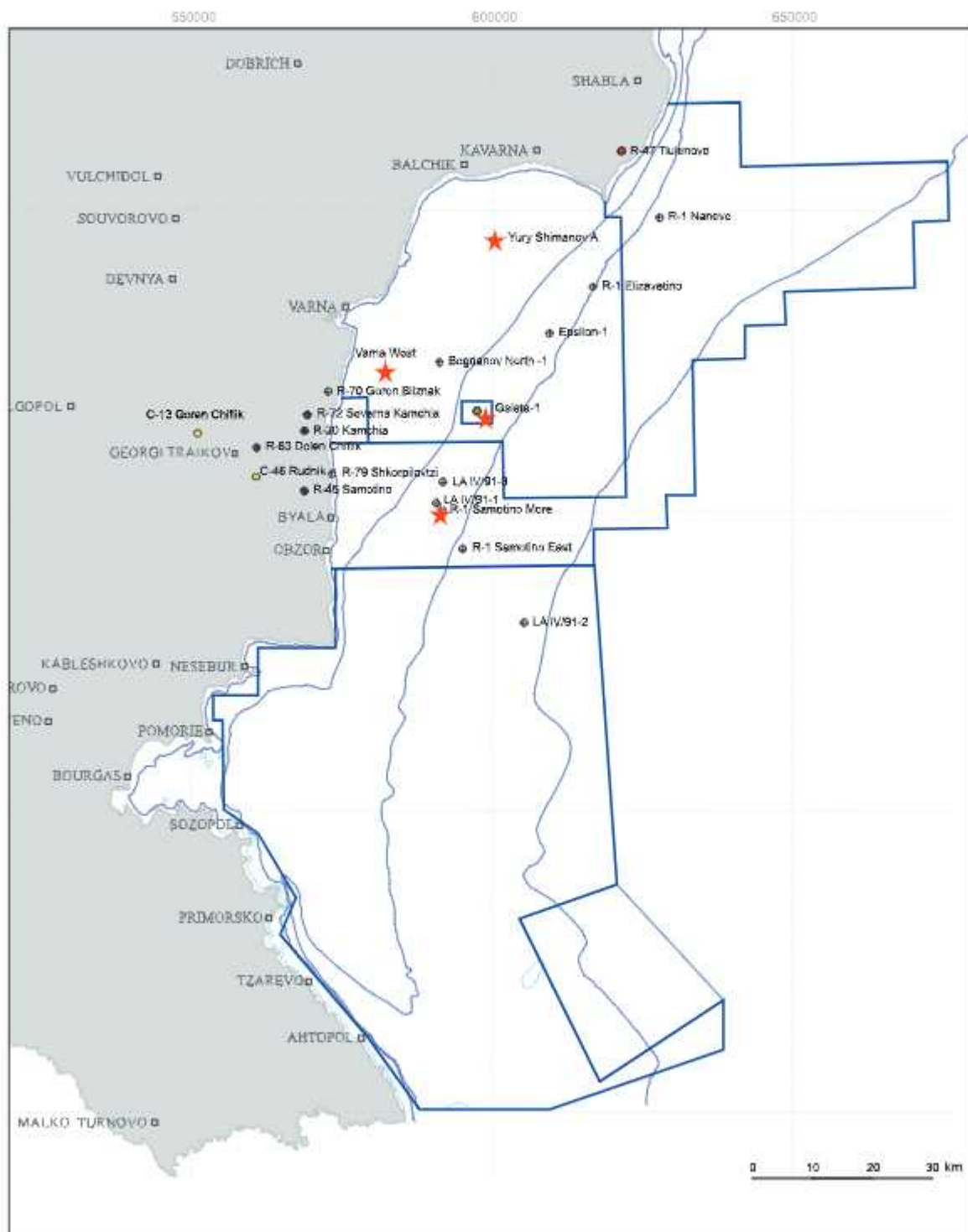


Fig. 5.152. Location of the wells drilled in the Black Sea shelf

with glauconite (Komarevo Fm). The limestones of the Dobrina Fm (like in Galata-1 well) contain rare and poorly preserved nannofossils.

The limestones from the interval 1050-1056 m revealed the species *Micula murus*, that implies a late Maastrichtian age.

An abundant nannofloristic association, comprising *Discoaster limbatus*, *D. falcatus*, *D. lenticularis* and *Fasciculithus* spp. are recorded in the clastic limestones with glauconite of the Komarevo Fm in the interval 1046-1050 m. The association defines NP8-9 zones in the upper parts of the Thanetian Stage.

Characteristic associations are determined in the calcareous clays and marls of the Avren Fm, thus proving normal continuous succession from nannofossil zone NP12 in the Ypresian stage to NP15 at the base of the lower Lutetian.

The lower boundary of NP12 zone is traced by the FO of *Discoaster lodoensis*. *Chiphragmalithus barbatus* and *Toweius callosus* occur with short ranges and are documented only in this zone.

The lower boundary of NP13 zone is not firmly traced due to the absence of the index *Tribrachiatus orthostylus* in the associations. However, numerous species restricted only to this zone are determined including *Discoaster bronnimanni* and *D. mirus*.

The lower boundary of NP14a zone is set by the appearance (LDO) of *Discoaster sublodoensis*, documented in cuttings at 1029 m and the lower boundary of NP14b zone respectively – by the occurrence (LDO) of *Rhabdosphaera inflata* at 1026 m.

Zone NP15 is also distinguished at the base of the middle Eocene by the identification of the characteristic taxa *Nannotetrina cristata*, *N. quadrata* and *Sphenolithus furcatholithoides*.

Stratigraphic range. The Upper Cretaceous portion of the section (Dobrina Fm) is referred to the Upper Maastrichtian, CC25c zone. The Paleocene part (Komarevo Fm) is conditionally assigned to the upper Thanetian, NP8-9 zone, and the lower Eocene portion (Avren Fm) – to the middle and upper parts of the Ypresian Stage, NP12-14a zone (Fig. 5.156). The middle Eocene portion corresponds to the lower part of Lutetian Stage, NP14b and NP15 zones.



Fig. 5.154. First core run and the recovered core from Galata-1 well – calcarenites and clastic limestones with large *Orbitoides* foraminifera shells

Varna-West

The well is located around 11 km south-east of Varna, offshore Black Sea. It was drilled as an exploration well in October 2004 by Melrose Resources in Galata Block.

The well reached TD of 1032 m, penetrating consecutively Neogene, upper Eocene and Paleocene sediments, ending in the Upper Cretaceous.

Dark-grey to grey-greenish silty clays with siltstones interbeds, referred to the Avren Fm, are penetrated in the interval 920-930 m. A sharp lithological boundary at the base of the Avren Fm marks a substantial stratigraphic gap.

Underneath (interval 930-940 m) are light-grey to whitish colored sandy clays. They alternate with firmly cemented light-beige colored silty marls and mixed rocks, and are referred to the Bozhuritsa Fm. The supposed depositional environment for these sediments is the internal part of the shelf, near the littoral zone.

White to creamy marls are penetrated in the interval 940-950 m, relatively brittle and crumbly, of variable carbonate content that are conditionally assigned to the Kailaka Fm.

Biostratigraphy. The biostratigraphic subdivision of the section is shown in Fig. 5.157. The presence of Maastrichtian Stage is documented by the co-occurrence of *Prediscosphaera cretacea*, *Retecapsa*

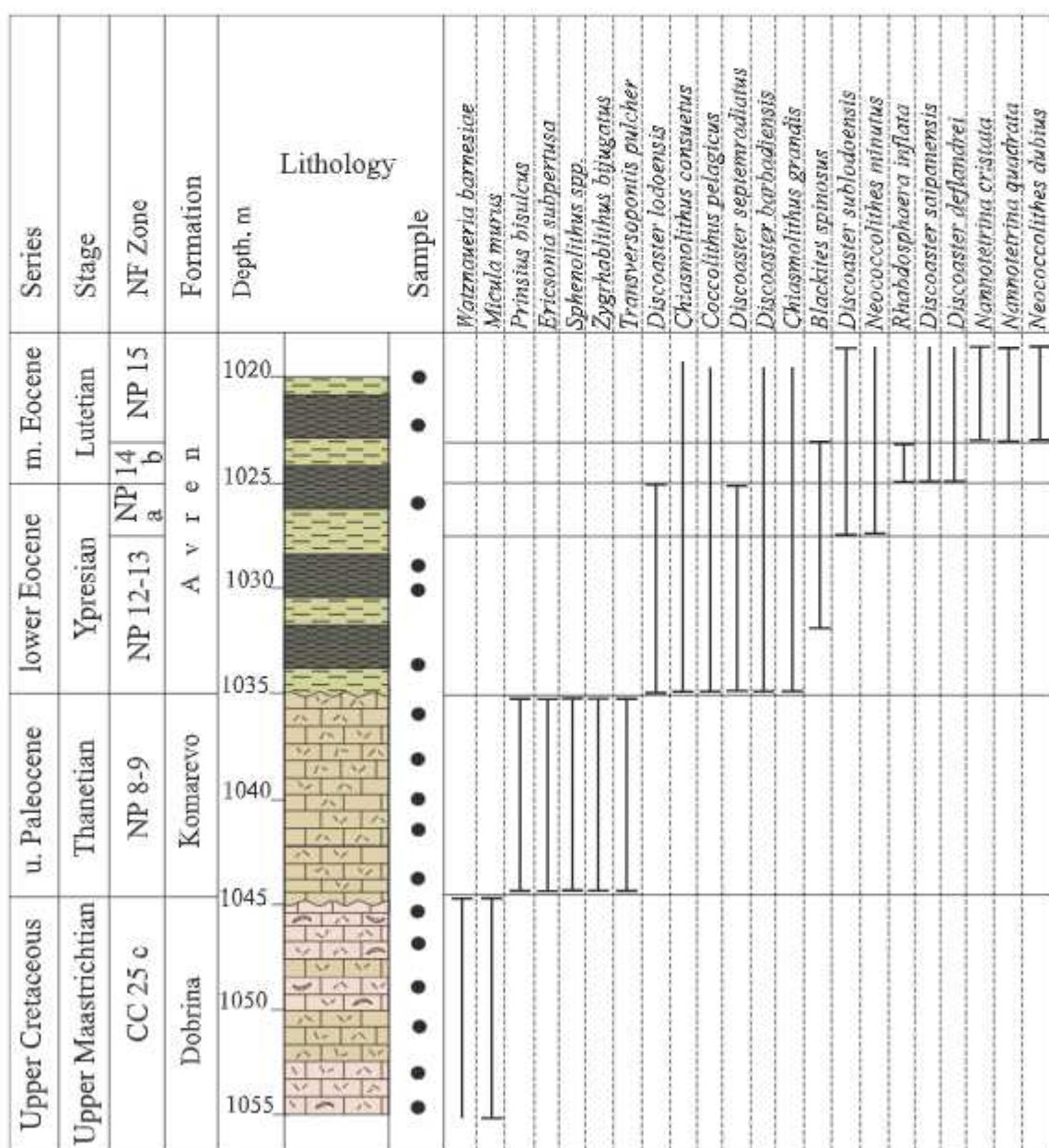


Fig. 5.155. Biostratigraphic subdivision of the Galata-1 well section by calcareous nannofossils

crenulata and *Ahmuelerella octoradiata* in core samples from interval 940-950 m.

Paleocene sediments are evidenced in interval 930-940 m. The recovered nannoflora corresponds to NP8 and lower part of NP9 zones in the Thanetian stage. Zone NP8 is represented by the typical association of common *Ericsonia robusta*, *Heliolithus kleinpellii*, *Fasciculithus tympaniformis*, etc. (Fig. 5.157). The lower boundary of NP9 zone is traced by the occurrence of the species *Discoaster multiradiatus* in cuttings at 932 m.

The sandy clays and marls of the Avren Fm (interval 920-930 m) revealed a particular association, comprising *Criboecentrum reticulatum*, *Reticulofenestra*

umbilica and *Dictyococcites bisectus*. The identified taxa co-occurred in NP18 zone only – Priabonian Stage, upper Eocene.

Stratigraphic range. Upper Cretaceous portion of the section (Kailaka Fm) is referred to the Upper Maastrichtian. Paleocene part (Bozhuritsa Fm) is related to the upper Thanetian, NP8 and NP9 zones. Avren Fm that covers the Paleocene in this well is dated as upper Eocene – Priabonian, NP18 zone (Fig. 5.157).

Yuri Shimanov

Located in the Black Sea area, some 28 km north-east of Varna, this well was drilled in 2004 by Mel-

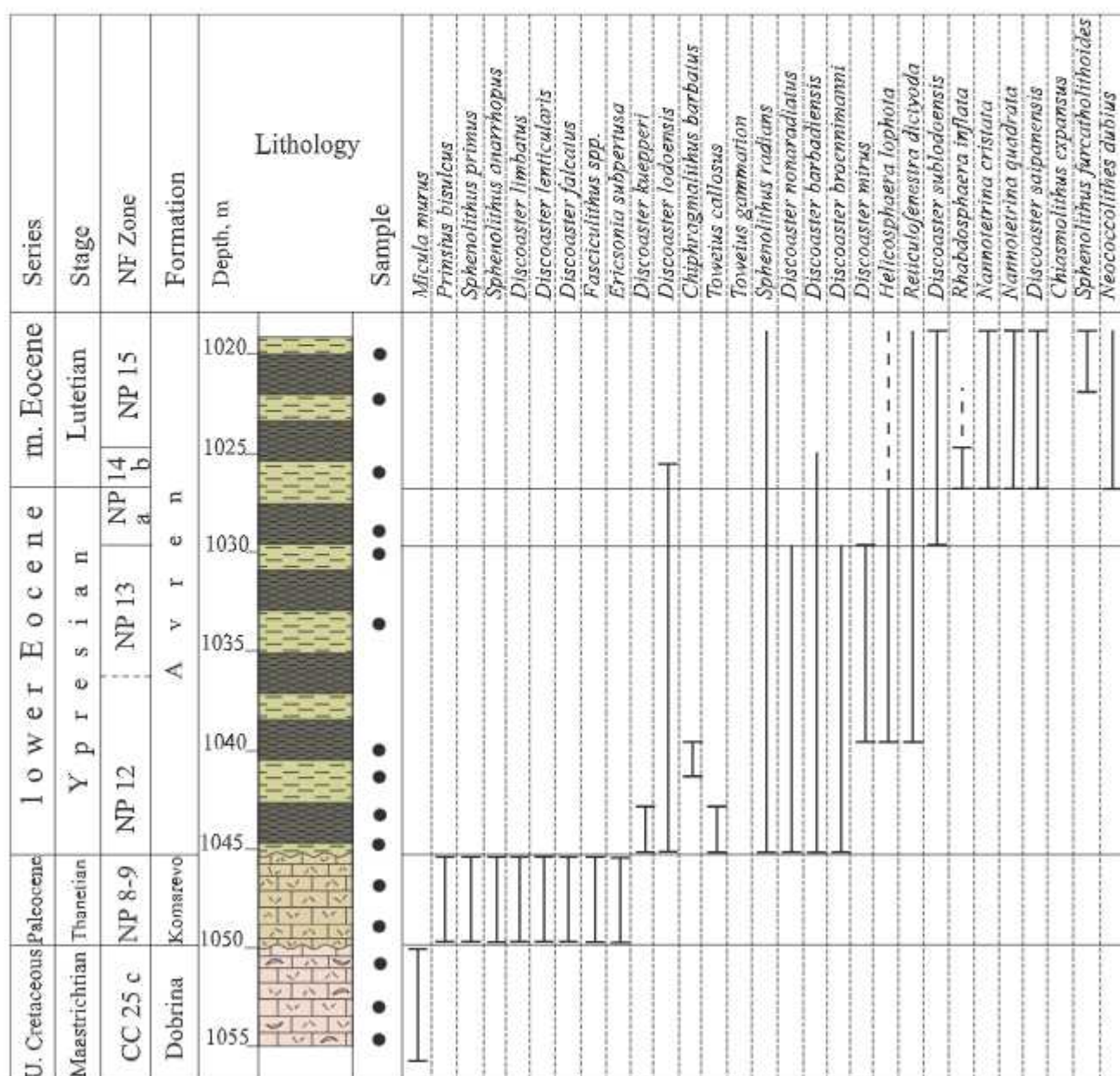


Fig. 5.156. Biostratigraphic subdivision of the Galata-2 well section, by calcareous nannofossils

rose Resources in the Galata Block as an exploration well.

It reached TD of 681 m as the main part of the section penetrated the Paleogene with bottom-hole in the Upper Cretaceous (Campanian Stage).

The well crossed a specific sequence of continuous sedimentation in the Paleocene-lower Eocene interval. The rocks of the sequence are referred to the Avren, Beloslav, Bozhuritsa and Komarevo Fms, respectively (Fig. 5.158).

The 590-616 m interval reveals greenish to grey clays of high carbonate content, compact, related to the Avren Fm.

Alternations of weakly cemented sandstones, sands and marls, enriched with glauconite, assigned to the Beloslav Fm are observed in the next interval from 616-623 m. The sands and sandstones are fine-grained and well sorted.

The interval 623-632 m consists of sandy marls, siltstones and weakly cemented sandstones, enriched with glauconite, assigned to the Bozhuritsa Fm.

The lower parts of the Paleocene section are penetrated in the interval 632-652 m. They are composed of alternating sandy limestones and marls, yellowish to light-grey, referred to the Komarevo Fm.

Upper Cretaceous sediments are penetrated in the

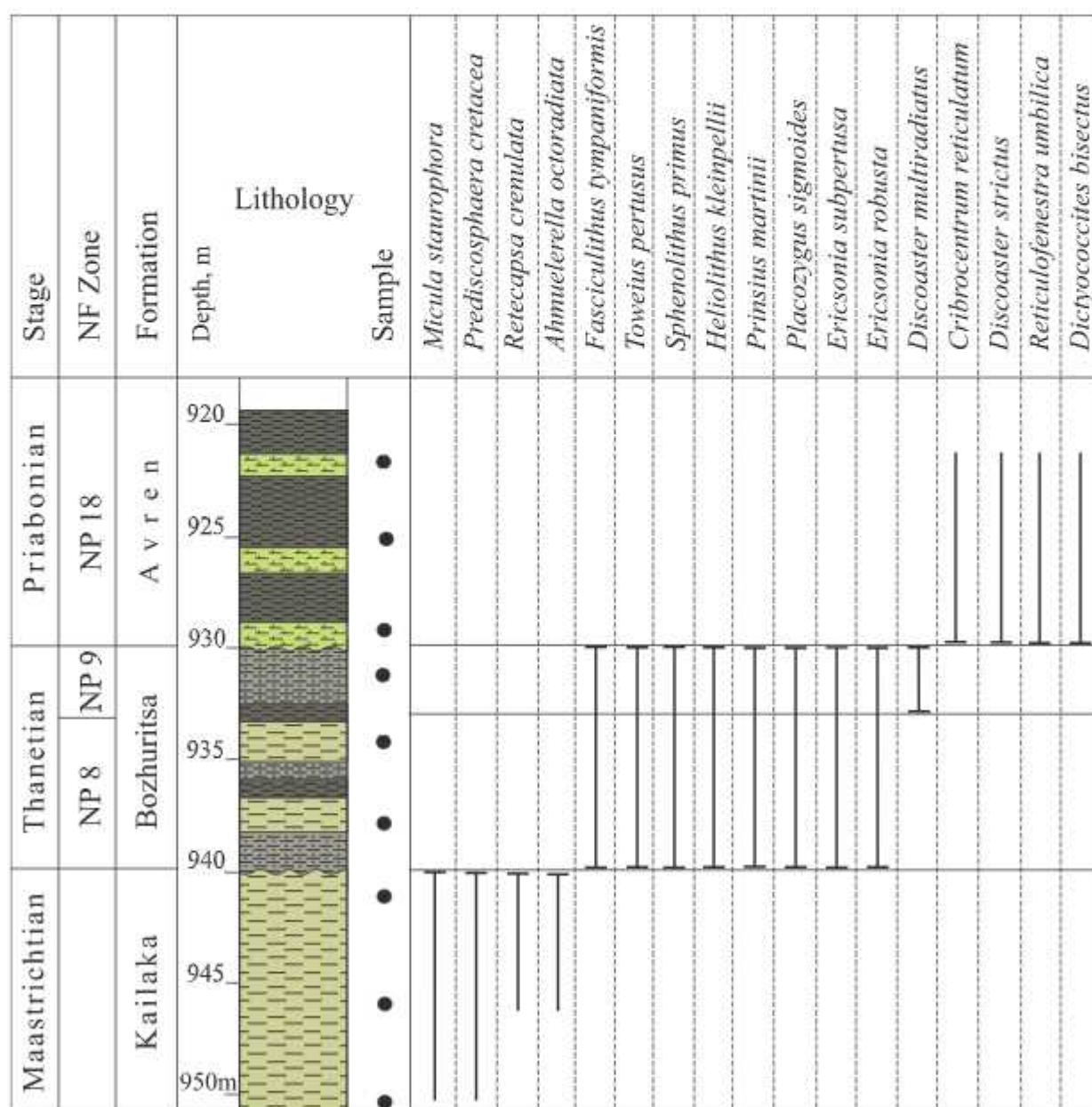


Fig. 5.157. Biostratigraphic subdivision of the Varna-West well section by calcareous nannofossils

deepest portions of the well section (652-681 m). They are represented by light-greenish marls and solid dolomitized limestones. These are not related to any known Upper Cretaceous lithostratigraphic units.

Biostratigraphy. Relatively abundant and diversified nannofloristic successions are documented in this well. The biostratigraphic subdivision is shown in Fig. 5.158. The results of most of the samples are based on core analysis.

The lower parts of the Campanian are proved by the occurrence of *Micula staurophora* and *Lithastrinus grillii* in samples from 652-662 m interval.

The Paleocene series, represented by the Thanetian

Stage, is documented between 623-652 m. The abundant association, that consists of *Heliolithus riedelii*, *Lithopterychius janii* and *Fasciculolithus* sp. nov. defines NP8 zone. The lower boundary of NP9 zone is traced by the FO of *Discoaster multiradiatus* in the core sample at 632 m.

The thorough analysis of the core material enables fixing the FOs of the important species *Campylosphaera eodela*, *Discoaster mediosus*, *D. salisburgensis* and *D. araneus* in the upper part of NP9 zone (626 m depth, Fig. 5.158). The latter species is considered an indicator for the carbon isotope excursion interval of the Paleocene-Eocene Thermal Maximum (Bybel & Self-Trail, 1995; Khan & Aubry, 2004; Agnini et al., 2014).

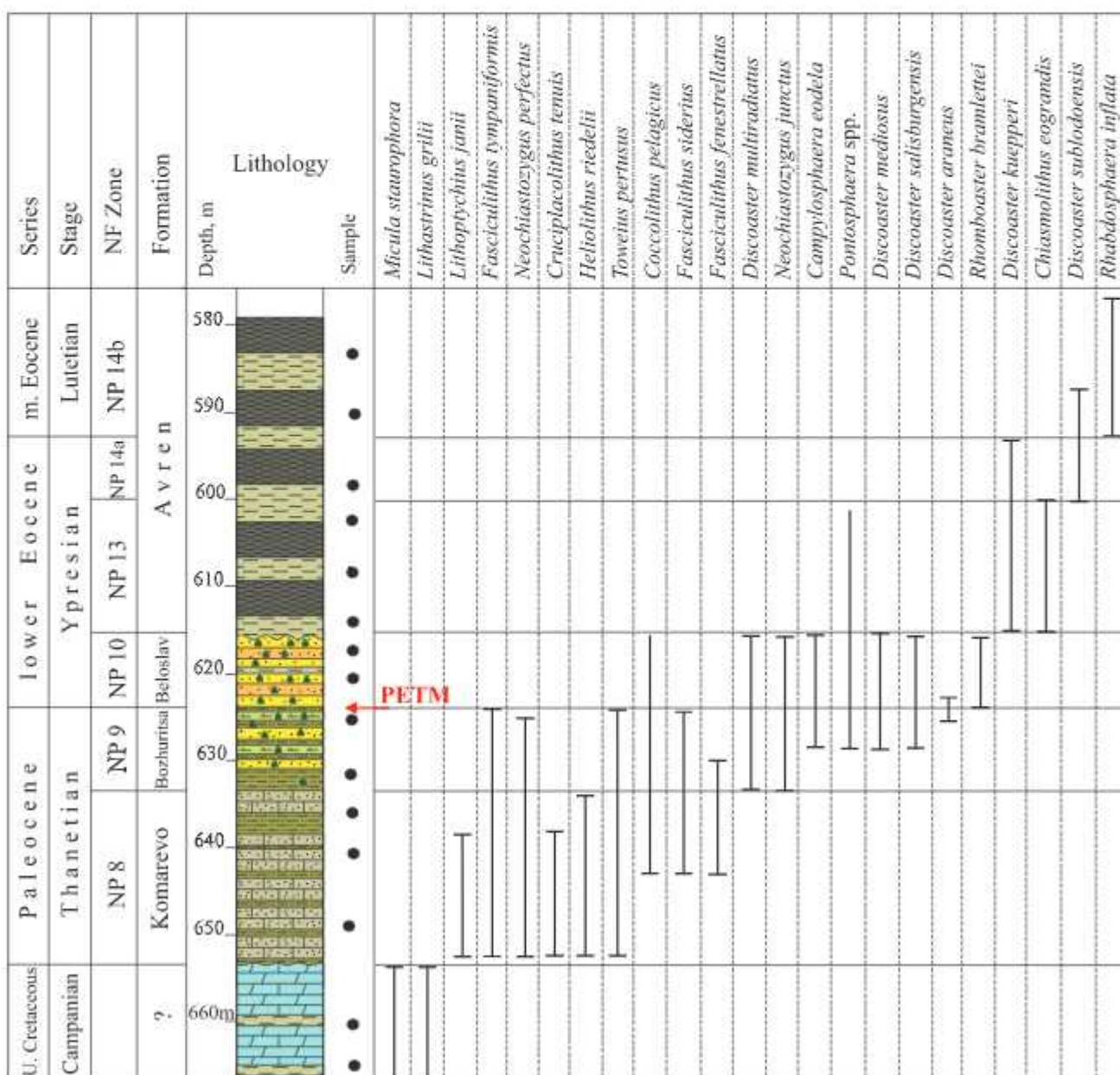


Fig. 5.158. Biostratigraphic subdivision of the Yuri Shimanov well section by calcareous nannofossils

The identification of *Rhomboaster bramlettei* in the core sample at 621-620 m confirms the presence of the lowermost levels of NP10 zone, i.e. no gap in sedimentation between NP9 and NP10 zones, respectively between the Paleocene and Eocene Series. Therefore, the well documents for the first time in the shelf, a gradual transition across the Paleocene-Eocene boundary and the event related to it – the PETM.

Ypresian NP13 and NP14a zones as well as the basal Lutetian NP14b zone are identified in the calcareous claystones and marls of the Avren Fm. The subdivision is based on the FOs of *Discoaster kuepperi*, *Discoaster sublodoensis* and *Rhabdosphaera inflata* (Fig. 5.158).

Stratigraphic range. The Upper Cretaceous part of the section is conditionally referred to the Lower Campanian. The Paleocene part (Komarevo and Bozhuritsa Fms) is upper Thanetian, NP8 and NP9 zone, whereas the base of the lower Eocene (Beloslav Fm) is lower Ypresian, NP10 zone. The middle and upper parts of the lower Eocene (Avren Fm) are assigned to NP13 – 14a zones (Fig. 5.158).

The correlation scheme of the studied offshore wells is shown on Fig. 5.159. It illustrates the general trend of thickness reduction from south to north for the Paleocene-lower Eocene sequences, as well as greater stratigraphic gaps (increase in duration) in the same direction.

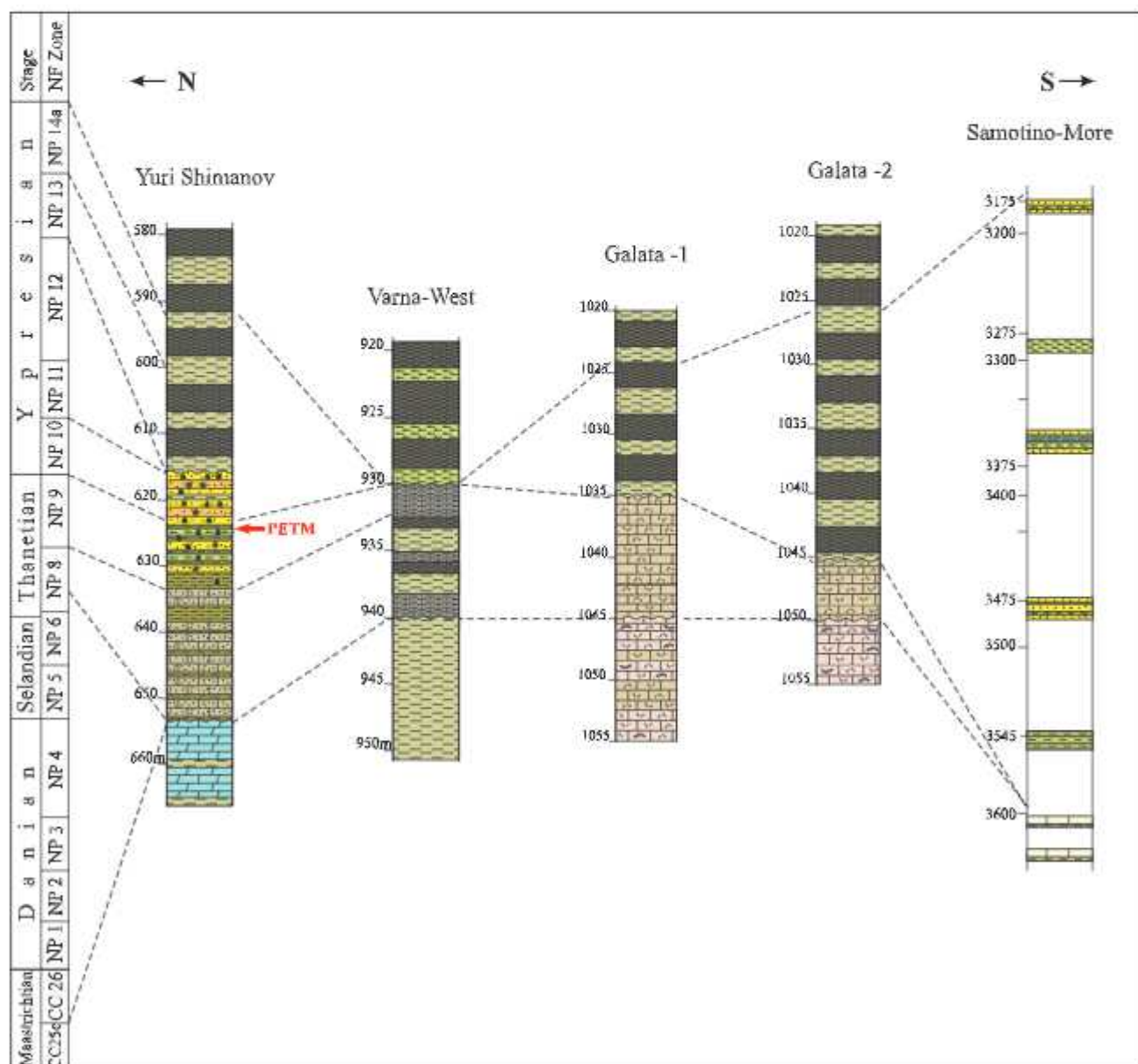


Fig. 5. 159. Correlation of Paleogene sediments in the studied well sections in the Black Sea shelf by calcareous nannofossils

Chapter 6

Biostratigraphy

6.1. Introduction

Paleogene nannofossil biostratigraphy has more than 60 years of history. Its fundamentals date back to the beginning of the 1960s of the twentieth century with the work of Brönnimann and Stradner (1960) who proposed the first formal nannofossil zones. Bramlette and Sullivan (1961) differentiated three biostratigraphic units in the Paleocene and lower Eocene in California (Lodo Formation) giving them preliminary zonal names. Hay (1964) made an attempt to create a zonal scheme, based on the evolution of the *Discoaster* group. Significant advances were made in the development of the zonation of the Paleocene and lower Eocene through Mohler & Hay's work (1967) (in Hay et al., 1967), where 7 interval zones in the Paleocene and 4 in the lower Eocene were defined for the first time, using biostratigraphic criteria. A major part of these zones was used by Martini (1971c) to construct his scheme.

The most comprehensive summary of zonal schemes for the Paleogene was presented at the Second Plankton Conference held in Rome in 1970. At this conference, the German researcher Erlend Martini proposed a standard zonal scheme based on nannofossils of the Tertiary and Quaternary (Martini, 1971c). This scheme was based on studies of land-based sections, located mostly in low- and mid-latitudes. During the decades that followed, Martini's scheme has been continuously verified, upgraded and proved, especially in its applicability in many different parts of the world. Nowadays it is assumed to be one of the basic biostratigraphic schemes for global correlation of Paleogene sediments (Fig. 6.1).

Another key zonal scheme using nannofossils is the one compiled by Okada and Burky (1980). It is based on studies of ocean sections in the low latitudes. A greater part of the studies under the Deep Sea Drilling Project (DSDP) and Ocean Drilling Program (ODP) programs, used this scheme for subdivision of oceanic, deep-water well sections (Fig. 6.1).

The two global schemes are precisely tied by means of parallel correlation with other microfossil groups such as planktonic foraminifera, as well as by using other independent methods.

The strong progress of the petroleum exploration in the North Sea in the 1980s and 1990s of the 20th century played the role of an impetus for elaboration of new nannofossil zonal schemes, that differ from the already proposed "standard global schemes" of Martini (1971c) and Okada and Burky (1980). Moreover, some specialized investigations showed that the ranges of a number of marker species in the North Sea differ from those in the standard zonal schemes due to biogeographic and climatic factors. The need for precise correlation of oil and gas reservoirs, as well as for steady horizontal drilling in production operations in the North Sea fields resulted in development of detailed, high-resolution biostratigraphic schemes for Paleocene sediments (van Heck & Prins, 1987; Varol, 1989 – Fig. 6.1).

I would like to emphasize that nannofossils are used as a correlation tool not only by the oil industry. Nannofossil zones draw the time frame, so necessary in magnetostratigraphic studies (Dinarès-Turell et al., 2003, 2006, 2007) and isotope chemostratigraphy (Sugarman et al., 1995; Bernaola et al., 2006a, 2007).

It should be outlined at the end of this review that nannofossil biostratigraphy turned out to be a key tool in the most dynamically developing branches of modern stratigraphy – sequence stratigraphy and cyclostratigraphy. The detailed subdivision of sedimentary sequences by nannofossils has a key role in developing regional sequence stratigraphic schemes and their correlation with the "global" sequence stratigraphic scale of the Paleogene.

6.2. Biostratigraphic zones

The Martini standard zonal scheme (1971c) has been used in this work as the main framework for biostratigraphic subdivision. It has been modified and updated with the newest data on the ranges of key taxa in order to fully comply with the nannofossil assemblages, identified in the Bulgarian sections. A graphical outline of the biozonation of the Paleogene is presented herein in two figures, the Paleocene (Fig. 6.2) and lower Eocene (Fig. 6.12), indicating the most important bioevents in each nannofossil zone (appearance and extinction of given species).

ciation is not of ultimate importance in defining the interval zones, the description of each zone includes the most common and characteristic species.

The three stages of the Paleocene Series comprise 9 "standard" nannofossil zones of the Martini scheme (1971c), traditionally numbered from 1 to 9 and alphabetically abbreviated "NP" (Nannoplankton Paleogene). Their boundaries, traced by important nannofossil biohorizons, are shown in Fig. 6.2.

The lower Eocene, corresponding to the Ypresian Stage, is divided into 4 nannofossil zones – from NP10 to NP14 (Fig. 6.12).

6.2.1. Upper Cretaceous – Maastrichtian Stage

Zone CC26 – *Micula prinsii*

Nomenclature. The zone was introduced for the first time by Perch-Nielsen (1985a) who proposed it as the uppermost subzone CC26b of the upper Maastrichtian in the low latitudes.

Its presence in Bulgaria was firstly demonstrated by Stoykova (in Stoykova & Ivanov, 1992) in the uppermost part of the Maastrichtian in the section at Byala.

Definition. Interval from the FO of *Micula prinsii* to the extinction of the Cretaceous species. Burnett (1998) further clarified the definition – as an interval from the FO of *Micula prinsii* to the extinction of „non-redeposited and non-surviving“ Cretaceous species.

Stratigraphic range. Uppermost Maastrichtian.

Remarks. The nannofossil association of this zone shows great species diversity. The number of species detected in the sections around Byala and in the Emine Formation exceeds 70 (Stoykova & Ivanov, 2004a). Granchovski (2019) reported more than 80 species determined in the Kladorub section, within UC20d^{TP} zone (= CC26). Some of the species characteristic for the zone are shown in Plate 6.1, Plate 6.2 and Plate 6.3: *Micula prinsii*, *M. murus*, *M. staurophora*, *M. swastica*, *Nephrolithus frequens*, *Predisco-sphaera majungae*, *P. cretacea*, *P. ponticula*, *P. grandis*, *Arkhangelskiella cymbiformis*, *A. confusa*, *Ceratolithoides aculeus*, *C. kamptneri*, *Eiffelolithus turrisseiffelii*, *E. parallelus*, *Cribrosphaerella ehrenbergii*, *Lithraphidites quadratus* and *Retecapsa crenulata*.

No occurrences of new species have been noted in the zone. Its upper boundary coincides with the Cretaceous/Tertiary boundary and is marked by the extinc-

tion of a huge percentage of the Cretaceous species (part of the K/T "mass extinction").

Distribution and correlations. The zone is identified in a great number of sections in low latitudes (the Tethyan area – southern parts of Europe and North Africa, Southern Asia and southern parts of North America). It corresponds to zone UC20d^{TP} of the Burnett zonal scheme (1998) and to the upper part of subzone P. *stoveri* in the Antarctic (Wei & Pospichal, 1991; Pospichal et al., 1992).

In Bulgaria the zone is identified in several sections where continuous transition across the Cretaceous/Tertiary boundary is proved (Stoykova & Ivanov, 1992, 2004a; Ivanov & Stoykova, 1994; Sinnyovsky & Stoykova, 1995; Sinnyovsky, 2003; Granchovski, 2019). The presence of the zone is the most substantial biostratigraphic criterion for indicating the completeness of the Cretaceous portion of the sedimentary succession.

In the West Fore-Balkan the zone covers the last 5 m of the Maastrichtian (Kladorub Formation) in Tsigan-ski dol, SE of Kladorub village (Sinnyovsky, 2004b; Granchovski, 2019).

In the East Balkan, in the region of Byala, where it has been detected for the first time in the country, the zone covers the uppermost 17 m of the Maastrichtian part of the Byala Formation (Ivanov & Stoykova, 1994; Dinarès-Turell et al., 2013; Stoykova et al., 2013).

In the Luda Kamchia area, the zone includes around 30 m of the Emine Formation in sections at Cape Emine near the St. Nikola chapel and along the road from Emona village to Irakli (Sinnyovsky & Stoykova, 1995; Sinnyovsky, 2004a). The same thickness of the zone is revealed in the section south of Kozichino village and at Cape Kochan, where the Cretaceous/Tertiary boundary is identified (Sinnyovsky, 2004a). Similar thicknesses of the zone are seen also in the Emine Formation sections in the Sliven region (Marash, Sedlarevo – Stoykova et al., 2000) and in the Aytos region (Ruen, Maglen, Dryankovets).

6.2.2. Paleocene Series – Danian Stage

Zone NP1 – *Biantholithus sparsus* (Fig. 6.3)

Nomenclature. The zone was proposed for the first time by Perch-Nielsen (1971). It is defined as an interval from the FO of *Biantholithus sparsus* to the FO of *Criciplacolithus tenuis*. The characteristic of the zone was supplemented by Romein (1979) who highlighted the extraordinary acme of *Thoracosphaera operculata*

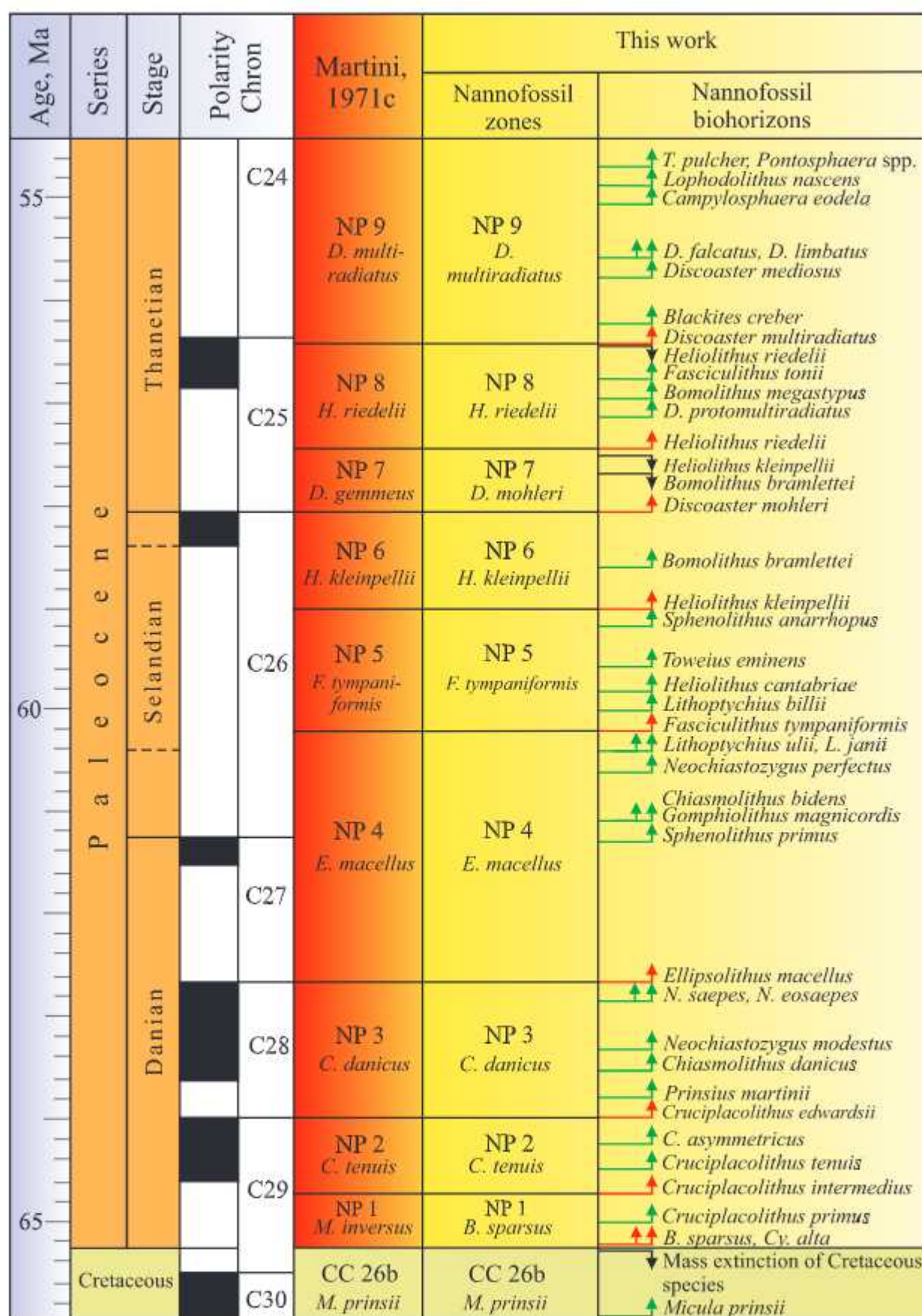


Fig. 6.2. Chronostratigraphic scheme (after Luterbacher et al., 2004) and biozonation of the Paleocene and lower Eocene, used in the present study (after Martini, 1971c with modifications). Key nannofossil biohorizons are also shown (red, green and black arrows)

and *Braarudosphaera bigelowii* in this zone. Later on, the criteria for setting the upper boundary of the zone was modified by Perch-Nielsen (1981a, 1985a).

The change in the original stratigraphic range of the zone follows the revisions of the taxonomic concept of the species *Cruciplacolithus tenuis* and, respectively, the change in drawing the upper boundary of the zone – not by the FO of *Cruciplacolithus tenuis* s. str., but by the appearance of the first “large” *Cruciplacolithus* specimens over 7 µm, corresponding to the species *Cruciplacolithus intermedius* (Perch-Nielsen, 1981a; 1985a).

In Bulgaria the zone has been documented for the first time by Stoykova at the base of the Paleocene (Danian Stage) in the section at Byala (in Stoykova & Ivanov, 1992; Ivanov & Stoykova, 1994).

Definition. Interval from the FO of *Biantholithus sparsus* to the FO of *Cruciplacolithus intermedius*.

Stratigraphic range. Lowermost Paleocene, lower part of the Danian. The time equivalent, corresponding to the zone is 375 Ka (Westerhold et al., 2008).

Remarks. The lower boundary of this zone coincides with the Cretaceous/Tertiary (K/T) boundary, marked by the mass extinction of “Cretaceous” species. A rich and diverse association of representatives of the genera *Micula*, *Eiffellithus*, *Retecapsa*, *Cribrosphaerella*, *Arkhangelskiella*, *Lithraphidites*, *Lucianorhabdus*, *Nephrolithus*, *Prediscosphaera*, *Microrhabdulus*, *Watznaueria* and *Ceratholithoides* in the uppermost parts of the Maastrichtian sharply decrease and became extinct at the K/T boundary. This was replaced

by a very poor association with rare *Thoracosphaera operculata* and *Braarudosphaera bigelowii* (the so-called “survivor” species), along with Cretaceous species, that are assumed to be reworked.

Immediately above the K/T boundary (the first centimetres above the boundary layer), the FOs of *Cyclagelosphaera alta* and *Biantholithus sparsus* are detected. In the deep-water sequences (sections of the Emine and Byala Formations), the middle part of the zone reveals the FO of *Neobiscutum romeinii*, along with *Futyania petalosa* and *Placozygus sigmoides* (Fig. 6.3). A bloom in abundance of the “survivor” species *Thoracosphaera operculata* and *Braarudosphaera bigelowii* is documented all through the zone.

A reliable bioevent in the middle part of the zone, distinguished in all studied sections, appears to be the FO of *Cruciplacolithus primus*. This event has high biostratigraphic potential and may be useful for a more detailed subdivision of the zone.

Representatives of the genus *Prinsius* – *P. tenuiculus* and *P. spp.* appear for the first time in the upper part of zone NP1, near the boundary with the overlying zone NP2. Due to their small size (2-3 µm) they are difficult to detect and may be easily overlooked.

The FO of *Cruciplacolithus intermedius* (larger than 7 µm) clearly marks the upper zonal boundary.

The behavior of the nannoplankton and the reaction of the nannoflora to the event at the K/T boundary is described in Chapter 8 “Global Events”.

The association of species characteristic of the zone

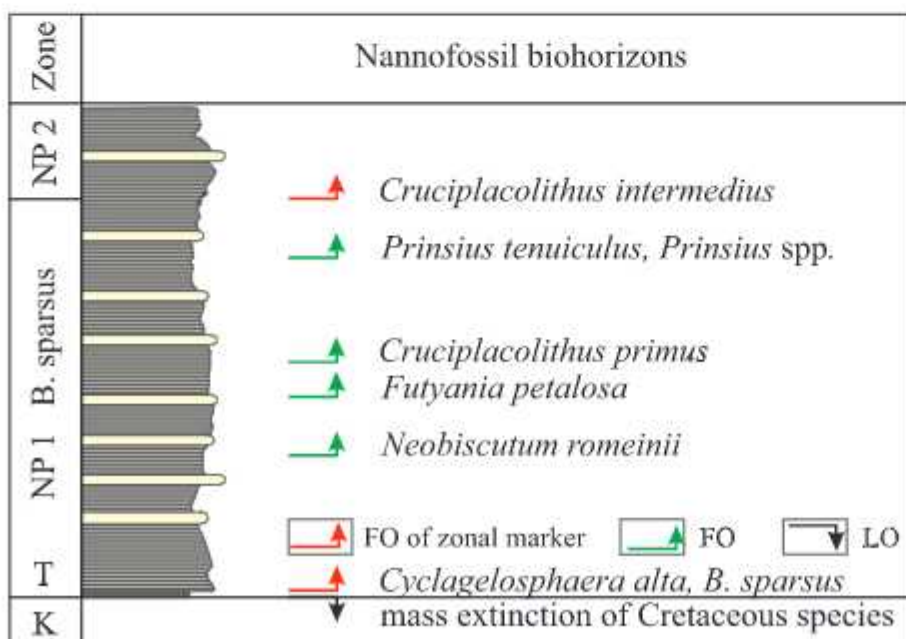
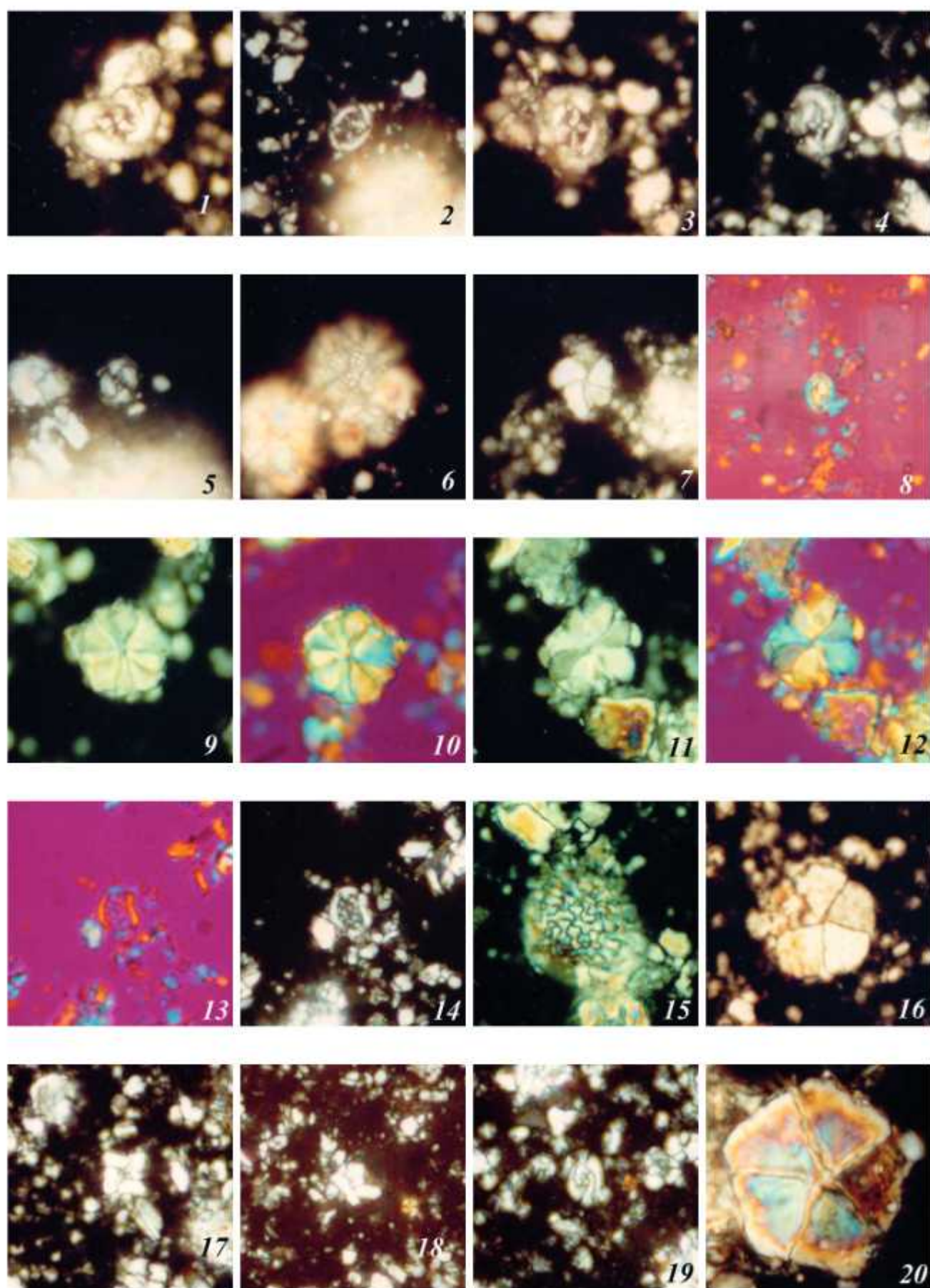


Fig. 6.3. Nannofossil biohorizons in the range of NP1 zone. Legend for color arrows as in Fig. 6.2



10 μm

includes (Plate 6.1-6.3): *Cyclagelosphaera alta*, *Biantholithus sparsus*, *Thoracosphaera operculata*, *T. saxea*, *Braarudosphaera bigelowii*, *B. discula*, *B. turbinea*, *Placozygus sigmoides*, *Markalius inversus*, *M. apertus*, *Neobiscutum romeinii*, *Futyania petalosa*, *Cruciplacolithus primus* and *Prinsius* spp.

Distribution and correlations. The zone is traced in a large number of sections, where continuous transition between the Cretaceous and Paleogene is documented, in both low and high latitudes (the Antarctic – Wei & Pospichal, 1991; Pospichal et al., 1992).

It corresponds to the sum of zones B. *sparsus* and C. *primus* of Romein (1979), zone CP1a of Okada and Burky (1980) as well as of zones B. *sparsus* and Placozygus *sigmoides* of van Heck and Prins (1987), zone NNTp1 and lower parts of NNTp2 of Varol (1989), and zone CNP1 – *Braarudosphaera bigelowii* Partial Range Zone of Agnini et al. (2014).

In Bulgaria, this zone is identified in sections where continuous transition across the Cretaceous/Tertiary boundary is proved (Stoykova & Ivanov, 1992, 2004a; Ivanov & Stoykova, 1994; Sinnyovsky & Stoykova, 1995; Sinnyovsky, 2003; 2004a, b).

In the region of Vidin, the zone encompasses some 2-3 m at the base of the Paleogene part of the sections at Kladorub village (Sinnyovsky, 2004b) and Rakovitsa. In the West Fore-Balkan (Mezdra region) the zone is around 5 m thick in Mezdra, Moravitsa and Lyuti dol sections.

In the vicinity of Byala and Goritsa, where it has been identified for the first time in the country, the zone includes the lowermost 5 m of the Danian Stage, immediately above the boundary clay layer (Stoykova & Ivanov, 1992, 2004a; Stoykova et al., 2005a). The zone displays the same thickness in the eastern part of the Central Balkan – in the sections at Mishemorkovhan, Zheravna and Ichera-Gradets.

The greatest thickness of the zone is observed in the sections of the Emine Formation turbidite sequences – Emona, Marash and Ruen-Snyagovo, where it ranges between 13 and 20 m.

Zone NP2 – *Cruciplacolithus tenuis* (Fig. 6.4)

Nomenclature. The zone was introduced for the first time by Mohler and Hay (1967) (in Hay et al., 1967) under the name “*Cruciplacolithus tenuis* zone”, and Martini (1971c) made substantial corrections in the range and definitive criteria for its upper boundary. The setting of the lower boundary follows the criteria proposed by Perch-Nielsen (1981a, 1985a – see the discussion above for zone NP1). According to the original definition by Mohler and Hay (1967) (in Hay et al., 1967), the zone is separated as an interval from the FO of *Cruciplacolithus tenuis* to the FO of *Fasciculithus tympaniformis*. Martini (1971c) revised its range and divided the original zone of Mohler and Hay (1967) into 3 zones – NP2, NP3 and NP4, following the FOs of *Cruciplacolithus tenuis* (NP2), *Chiasmolithus danicus* (NP3) and *Ellipsolithus macellus* (NP4), respectively.

Based on taxonomic revisions, Romein (1979) proved that a greater portion of the nannofossils described as *Chiasmolithus danicus* belong to the species *Cruciplacolithus edwardsii* – an opinion shared by almost all recent researchers (Perch-Nielsen, 1981a, 1985a; van Heck & Prins, 1987).

In Bulgaria the presence of zone NP2 was indicated by Sinnyovsky (1990) in the vicinity of Byala, but was characterized in detail by Stoykova (in Ivanov & Stoykova, 1994).

Definition. Interval from the FO of *Cruciplacolithus intermedius* to the FO of *Cruciplacolithus edwardsii*.

Stratigraphic range. Lower Paleocene, lower parts of Danian Stage. The time equivalent of the zone is 590 Ka (Westerhold et al., 2008).

Plate 6.1. Calcareous nannofossil species from the K/T boundary interval in Byala 2b section – CC26, NP1, NP2 and NP3 zones; cross-polarized light (XPL) and gypsum plate (GP). With “-” and “+” is noted the distance (m) below and above the K/T boundary

1 – *Chiasmolithus danicus*, zone NP3, +27.4 m; 2 – *Neochiastozygus saepes*, zone NP4, +35.30 m; 3 – *Cruciplacolithus tenuis*, zone NP3, +28.6m; 4 – *Cruciplacolithus tenuis*, zone NP2, +11.00 m; 5 – *Cruciplacolithus intermedius*, zone NP2, +5.20 m; 6 – *Futyania petalosa* coccosphere, zone NP2, +6.80 m; 7 – *Braarudosphaera turbinea*, zone NP3, +28.00 m; 8 – *Neobiscutum romeinii*, zone NP1, +1.80 m; 9-10 – *Biantholithus sparsus*, zone NP1, +0.03m; 11-12 *Biantholithus sparsus*, zone NP1, +0.06m; 13-14 – *Nephrolithus frequens*, zone CC 26, -0.09 m; 15 – *Thoracosphaera operculata*, zone NP1, +0.01 m; 16 – *Braarudosphaera bigelowii*, -0.03 m; 17 – *Micula murus*, zone CC 26, -4.25 m; 18 – *Micula prinsii*, zone CC 26, -0.04 m; 19 – *Zygodiscus spiralis*, zone CC 26, -0.03 m; 20 – *Braarudosphaera bigelowii*, zone CC 26, -4.25 m

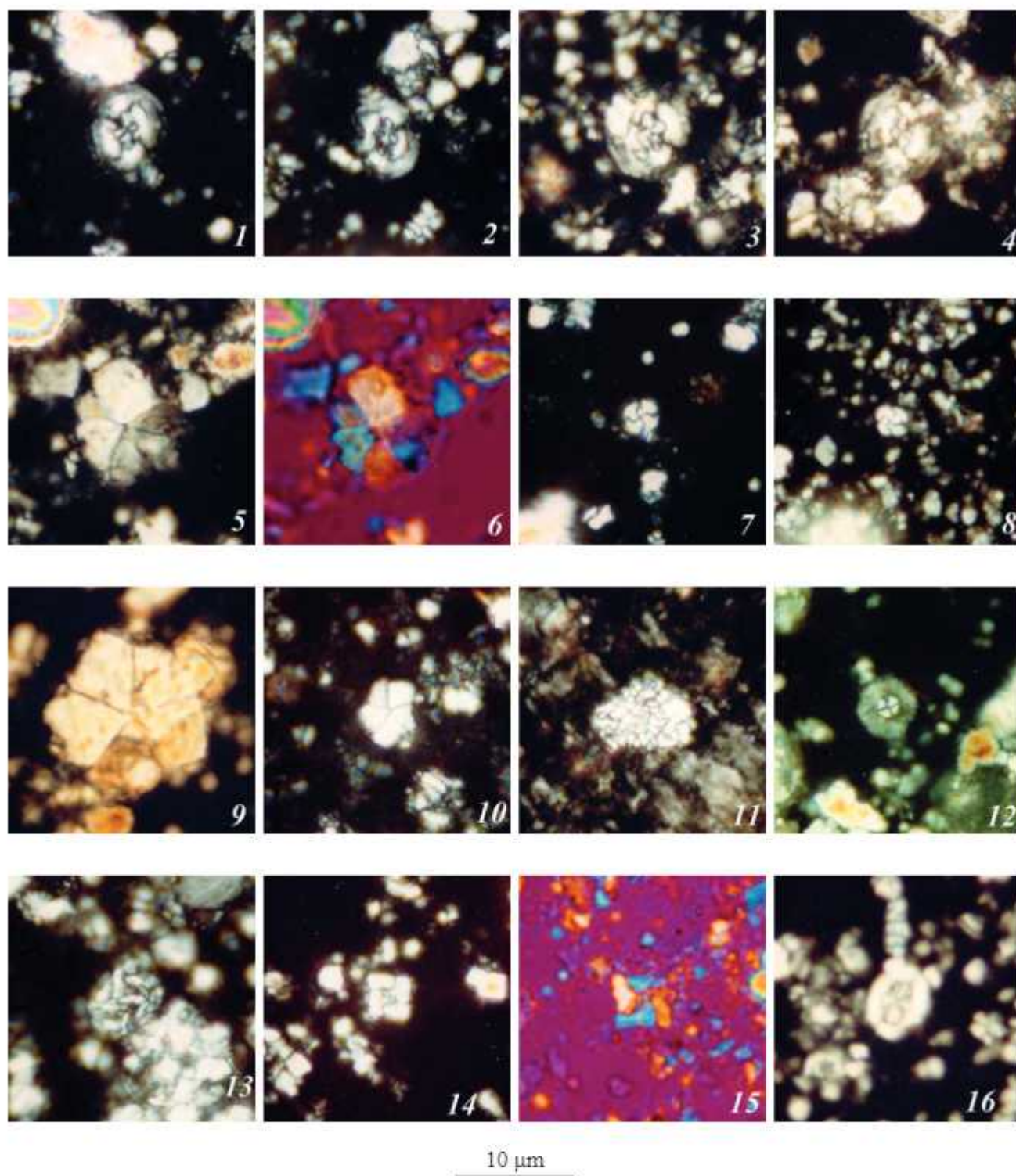


Plate 6.2. Calcareous nannofossil species from the K/T boundary interval in Byala 3 section – CC26, NP1, NP2 and NP3 zones; cross-polarized light (XPL) and gypsum plate (GP). With “-” and “+” is noted the distance (m) below and above the K/T boundary

1-2 – *Cruciplacolithus asymmetricus*, zone NP2, +7.50 m; 3 – *Cruciplacolithus intermedius*, zone NP2, +5.60 m; 4 – *Cruciplacolithus intermedius*, zone NP2, +6.07 m; 5-6 – *Biantholithus sparsus*, zone NP1, +3.00 m; 7 – *Cyclagelosphaera alta*, zone NP1, +0.97 m; 8 – *Cyclagelosphaera alta*, zone NP1, +0.10 m; 9 – *Braarudosphaera bigelowii*, zone CC26, -0.05 m; 10 – *Braarudosphaera turbinea*, zone NP1, +1.60 m; 11 – *Thoracosphaera operculata*, zone NP1, +0.03 m; 12 – *Markalius inversus*, zone NP1, +0.50 m; 13 – *Prediscosphaera grandis*, zone CC26, -0.02 m; 14 – *Micula swastica*, zone CC26, -0.02 m; 15 – *Micula murus*, zone CC26, -0.05 m; 16 – *Arkhangelskiella cymbiformis*, zone CC26, -1.30 m.

Remarks. The lower boundary of the zone is traced by the FO of the species *Cruciplacolithus intermedius*. The FO of *Prinsius dimorphosus* in the analyzed sections is usually detected around this boundary or slightly above it and often occurs in even poorly preserved associations. This species may serve as an approximation for tracing the lower boundary of the zone in cases when *Cruciplacolithus intermedius* is absent.

Representatives of genus *Coccolithus* – *C. cavus* and *C. subpertusus* appear for the first time in the lower part of the zone, along with the index species *Cruciplacolithus tenuis*.

Cruciplacolithus asymmetricus occurs in the upper part which is the evolutionary ancestor of *Cruciplacolithus edwardsii* (van Heck & Prins, 1987).

The association of species often seen in the zone includes: *Cruciplacolithus intermedius*, *C. tenuis*, *Prinsius dimorphosus*, *Placozygus sigmoides*, *Coccolithus cavus*, *C. subpertusus* and *Cruciplacolithus asymmetricus*.

The abundance of the “survivor” species *Thoracosphaera operculata* and *Braarudosphaera bigelowii* sharply decreases in this zone and they occur rarely.

Distribution and correlations. The zone is identified in low, middle and high latitudes – the Antarctic and the North Sea.

Zone NP2 corresponds to zone CP1b of Okada and Burky (1980), to the sum of several zones of Romein (1979) (upper parts of zone *C. primus*, zone *P. dimor-*

phosus and base of zone *C. tenuis*) as well as to zones *C. intermedius* and *C. asymmetricus* of van Heck and Prins (1987) and zone NNTp2 of Varol (1989), zone NA3 of Wei and Pospichal (1991), zone CNP2 and lower parts of CNP3 zone of Agnini et al., 2014 (Fig. 6.1).

In Bulgaria it is observed in sections in the Kula Zone and West Fore-Balkan (Mezdra) where its thickness varies from 7 to 10 m. In the Central Balkan the zone is observed in the sections at Mishemorkov han, Krastets railway station, Zheravna and Ichera-Gradets and is between 8 and 12 m thick. A similar thickness of the zone is present in the section near Byala and Goritsa (10-15 m). Its greatest thickness, however, is measured in the deep-water sections – at Marash and Emona – around 30 m (based on data by Sinnyovskiy, 2004a; at Emona the re-calculated thickness of the zone is 88 m).

Zone NP3 – *Chiasmolithus danicus* (Fig. 6.5)

Nomenclature. The zone was identified for the first time by Martini (1971c), describing it as an interval from the FO of *Chiasmolithus danicus* to the FO of *Ellipsolithus macellus*. Its features have been supplemented and clarified by Perch-Nielsen (1981a, 1985a) and van Heck and Prins (1987) based on detailed taxonomic revisions of the *Cruciplacolithus edwardsii* – *Chiasmolithus danicus* group.

In Bulgaria the zone was identified for the first time by Sinnyovskiy (1990) in the vicinity of Byala. Its detailed characteristics were discussed by Stoykova (in Ivanov & Stoykova, 1994).

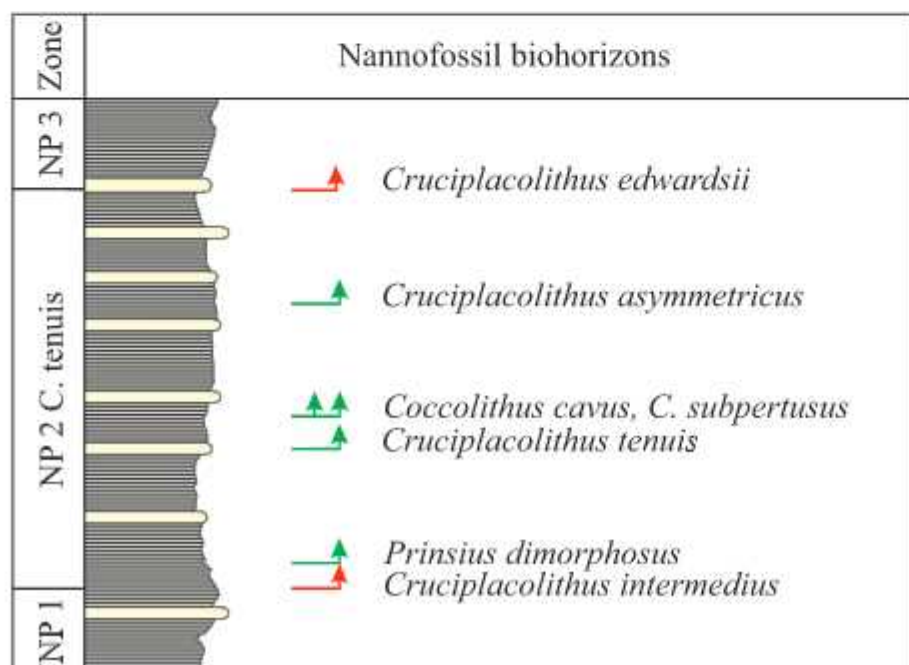


Fig. 6.4. Nannofossil biohorizons in the range of NP2 zone

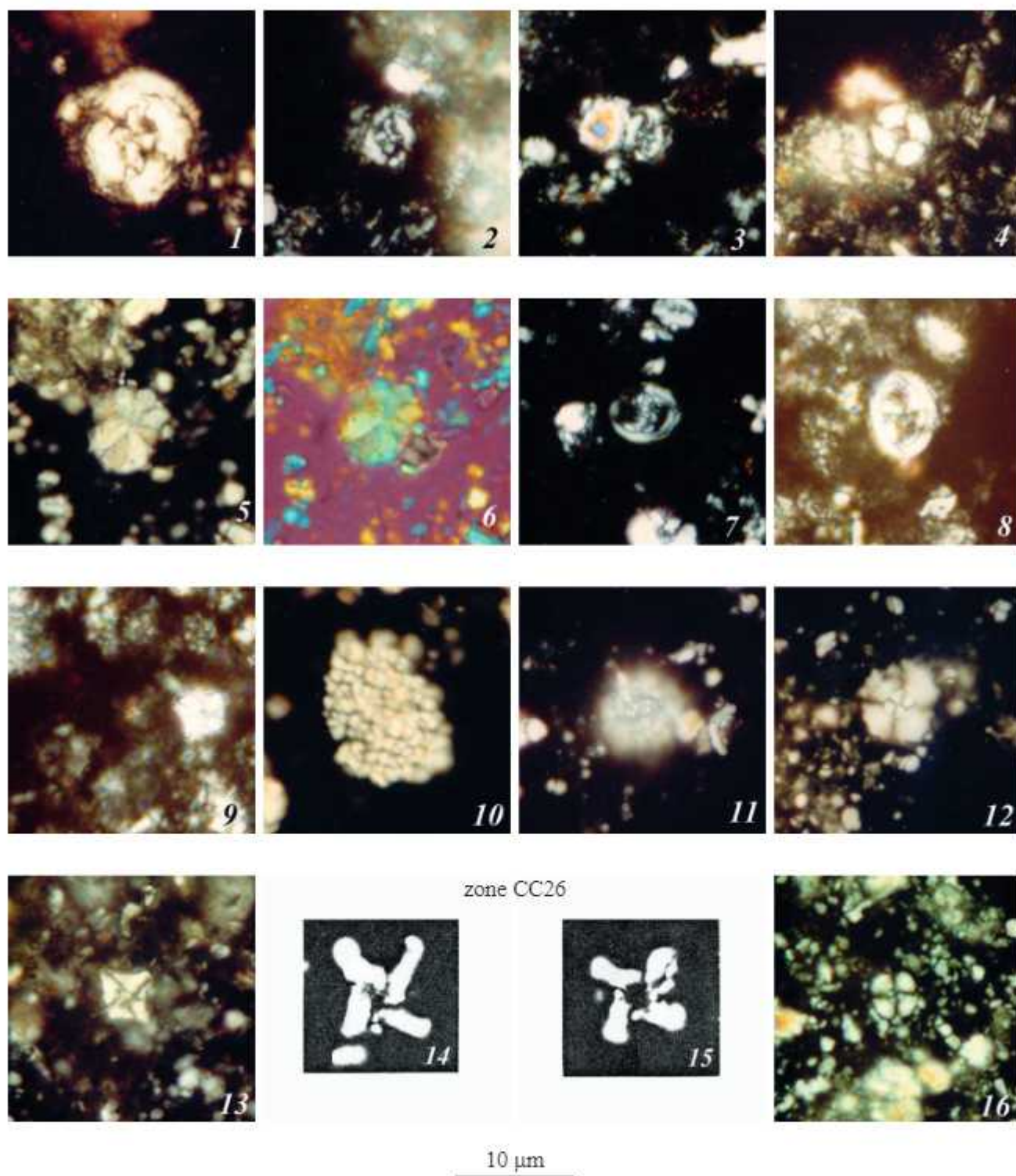


Plate 6.3. Calcareous nannofossil species from the K/T boundary interval in Marash and Emona sections – CC26, NP1 and NP2 zones. All photos with XPL except of 6 (GP). With “-” and “+” is noted the distance (m) below and above the K/T boundary

1 – *Crucioplacolithus tenuis*, zone NP2, +14.50 m; 2 – *Crucioplacolithus intermedius*, zone NP2, +6.40 m; 3 – *Crucioplacolithus* cf. *primus*, zone NP1, +2.10 m; 4 – *Ericsonia subpertusa*, zone NP2, +17.60 m; 5–6 – *Biantholithus sparsus*, zone NP1, +0.50 m; 7 – *Placozygus sigmoides*, zone NP 1, +0.97 m; 8 – *Placozygus sigmoides*, zone NP1, +1.80 m; 9 – *Micula* cf. *prinsii*, zone CC26, -0.6 m; 10 – *Thoracosphaera operculata*, +0.03 m; 11 – *Prinsius dimorphosus* coccosphere, zone NP2, +14.80 m; 12 – *Cyclagelosphaera reinhardtii*, zone NP1, +4.55 m; 13 – *Micula staurophora*, zone CC26, -2.50 m; 14–15 – *Micula prinsii*, zone CC26, -0.05 m; 16 – *Cyclagelosphaera margerellii*, zone CC26, -8.50 m.

Definition. Interval from the FO of *Cruciplacolithus edwardsii* to the FO of *Ellipsolithus macellus*.

Stratigraphic range. Lower Paleocene, upper Danian. The time equivalent of the zone is 1.8 Ma (Westerhold et al., 2008).

Remarks. The FO of the species *Cruciplacolithus edwardsii* is a clearly identifiable event in all of the studied sections. Concomitantly, or slightly higher-up, the commonly occurring and abundant species *Prinsius martini* appears. Its appearance could certainly serve as a reliable biostratigraphic horizon for fixing the lower boundary of the zone.

The successive FOs of the species *Chiasmolithus danicus* and *Neochiastozygus modestus* is noted in the middle of the zone (Fig. 6.5).

The association of species characteristic of the zone comprises (Plate 6.1; 6.2; 6.3): *Cruciplacolithus tenuis*, *C. asymmetricus*, *C. intermedius*, *C. edwardsii*, *Thoracosphaera operculata*, *Braarudosphaera bigelowii*, *Placozygus sigmoides*, *Chiasmolithus danicus*, *Prinsius martinii*, *P. tenuiculum*, *P. dimorphosus*, *Coccolithus cavus*, *Ericsonia subpertusa* and *Neochiastozygus modestus*.

A small, but very characteristic group of species of the genus *Neochiastozygus* – *N. eosaepe*, *N. saepe*, ($\pm$ *N. imbrici*) occurs in the uppermost part of the zone (Fig. 6.5). This event has a high biostratigraphic potential – it repeats in the majority of the studied sections in Bulgaria as well as in the high latitudes of the North Sea (Perch-Nielsen, 1979; van Heck & Prins,

1987). Therefore, it can reliably serve as a criterion for the approximate position of the upper boundary of the zone, considering the absence of the marker *Ellipsolithus macellus* in the associations.

The upper boundary of zone NP3 is fixed by the FO of the species *Ellipsolithus macellus*. This biohorizon is commented on in detail in the next zone.

Distribution and correlations. The zone is identified in the low and middle latitudes, as well as in the high latitudes in the northern hemisphere (the North Sea – Perch-Nielsen, 1979; van Heck & Prins, 1987). In the southern Atlantic, however, it may not be identified due to the absence of the zonal marker and discrepancies/differences in the levels of FO of other significant stratigraphic markers (Agnini et al., 2007a).

It corresponds to zone CP2 of Okada and Burky (1980), to zone C. *tenuis* of Romein (1979), to the sum of zones C. *danicus*, N. *modestus* and N. *saepes* of van Heck & Prins (1987), to zones NTP3, NTP4 and NTP5 of Varol (1989), to zone NA4 of Wei and Pospichal (1991), to parts of CNP3 and CNP4 zones of Agnini et al. (2014).

In Bulgaria the zone has been identified in the sections of the Kula zone (Kladorub) and the West Fore-Balkan (Mezdra-Moravitsa), where its thickness varies from 5 to 15 m. In the Central Balkan it is observed in the sections at Mishemorkov han, Zheravna and Ichera-Gradets, where it is several tens of metres thick. In the sections around Byala it is 28-30 m thick. In the flysch sections, the thickness of the zone reaches 60 m (Emona section – Sinnyovsky, 2004a).

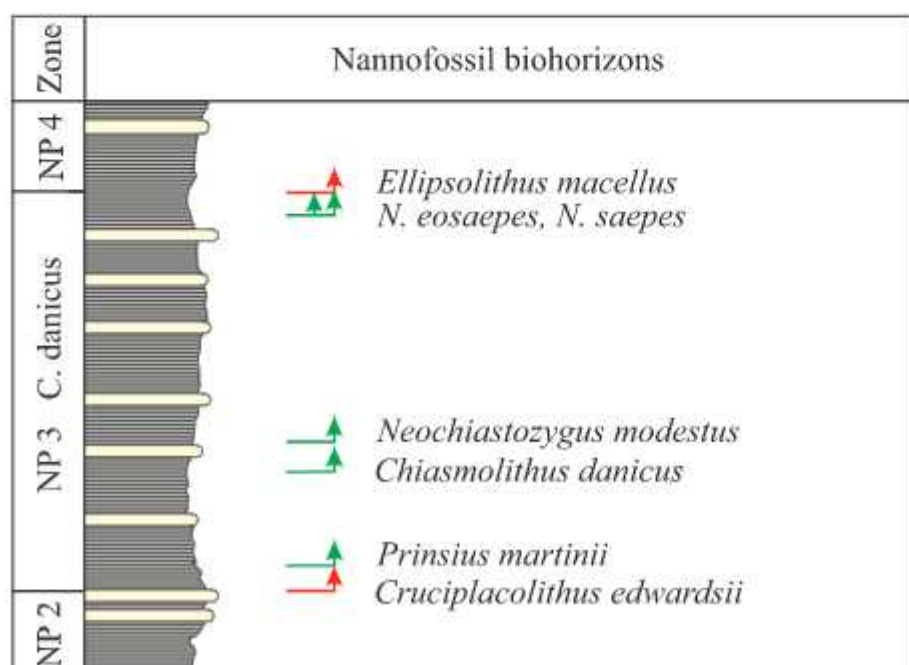


Fig. 6.5. Nannofossil biohorizons in the range of NP3 zone

Zone NP4 – *Ellipsolithus macellus* (Fig. 6.6)

Nomenclature. The zone was identified for the first time by Martini (1971c). In Bulgaria this zone was indicated by Stoykova (in Ivanov & Stoykova, 1994) in sections Byala 1 and Byala 2b.

Definition. Interval from the FO of *Ellipsolithus macellus* to the FO of *Fasciculithus tympaniformis*.

Stratigraphic range. Lower Paleocene, upper parts of the Danian Stage. The zone covers a relatively large chronostratigraphic range and is one of the longest in the Paleocene (around 2.3 Ma – Dinarès-Turell et al., 2003).

Remarks. The FO of the marker species *Ellipsolithus macellus* that defines the base of zone NP4 is a rather disputable biohorizon, discussed recently in a number of biostratigraphic analyses. It is assumed that it may not be used as a reliable biohorizon, since the identification of the species is strongly dependent on preservation conditions (often when dissolution occurs, the species with the most fragile skeletons are not preserved) and on differing paleoecological conditions, etc. It is rarely seen in most of the deep-water sections worldwide and the same applies in Bulgaria.

With *Ellipsolithus macellus* missing, the FO of species *Neochiastozygus eosaepes* and *N. saepes* can be justifiably used for approximate tracing of the lower boundary of the zone (Ivanov & Stoykova, 1994).

No bioevents of high biostratigraphic significance have been found in the lower part of the zone.

However, a series of events of FOs of genera and species with stratigraphic importance have been documented in the upper part (Fig. 6.6).

Representatives of the genera *Sphenolithus*, *Gomphiolithus*, *Lithoptychius* and *Heliolithus* displaying one of the most accelerated speciation rates among nannofossils by the end of the Paleocene are seen here.

The first species from these genera – *Gomphiolithus magnicordis* and *Sphenolithus primus*, appear at the base of the upper part of the zone (first radiation of fasciculiths). An important stratigraphic event is also the FO of *Chiasmolithus bidens*, nearly at the same level. The FO of *Neochiastozygus perfectus* – also a very strong biohorizon, is documented above it (Fig. 6.6).

The second radiation of the fasciculiths – the occurrence of *Lithoptychius ulii*, *L. jani*, *L. pileatus* (Fig. 6.6) is fixed in the uppermost part of the zone, immediately below the NP4/NP5 boundary. This event reveals high biostratigraphic correlation potential – it is identified in a number of deep-water successions and in Bulgaria – in the sections at Byala and Kladorub. Therefore, this event has been proposed as a criterion for setting the lower boundary of the Selandian Stage in the section at Zumaia (Dinarès-Turell et al., 2007; Bernaola et al., 2008). The section was formally approved as GSSP (Global Boundary Stratotype Section and Point) for the Danian, Selandian and Thanetian Stages during a meeting of the working group on Paleocene stratigraphy held on June 19-20, 2007 in Zumaia, Spain.

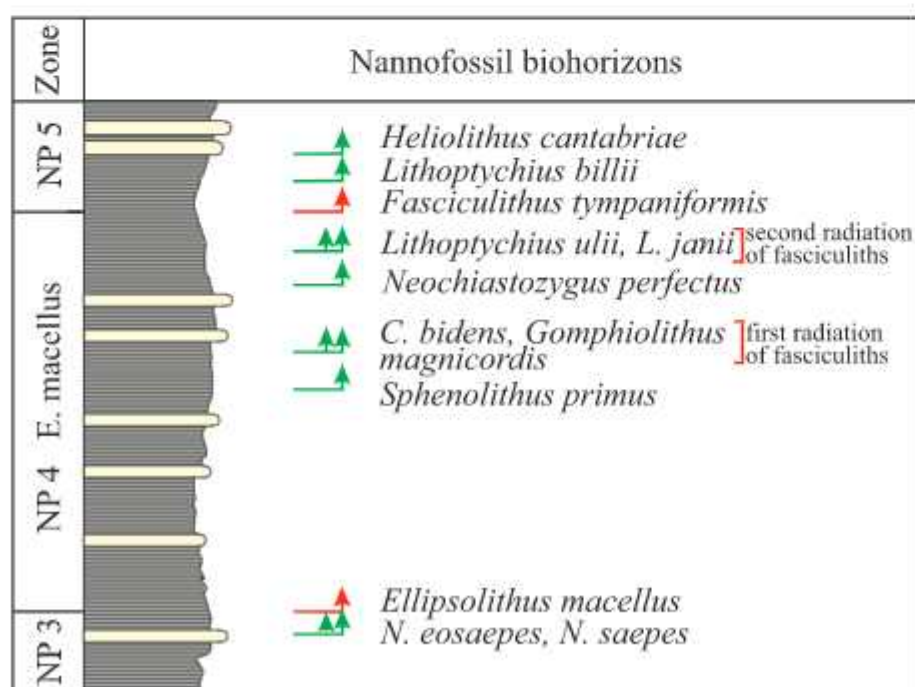


Fig. 6.6. Nannofossil biohorizons in the range of NP4 zone

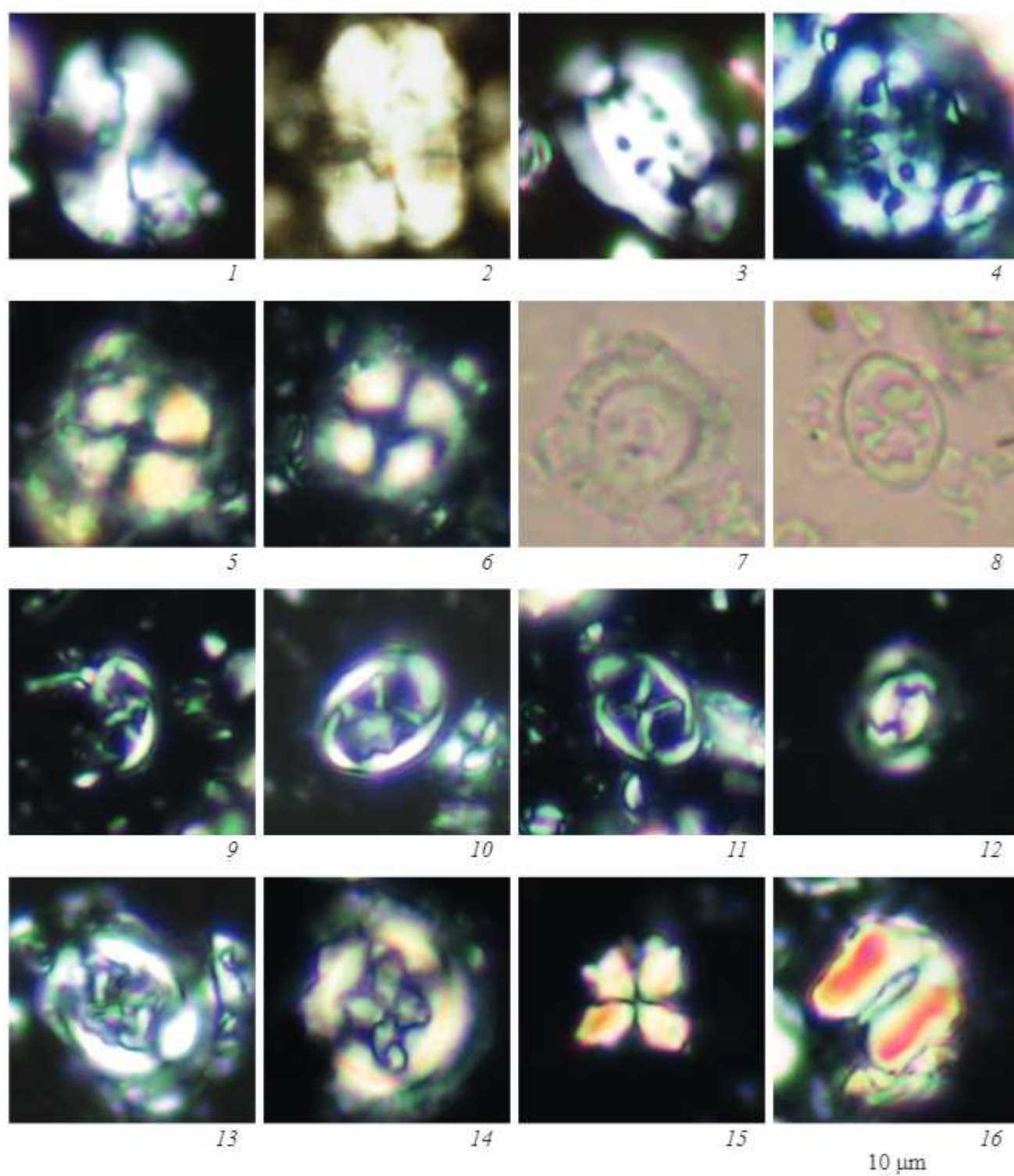


Plate 6.4. Calcareous nannofossil species from the NP4 zone in the sections at Byala and Kladorub. All photos with XPL, except of 7 and 8 – plane polarized light (PPL)

1-2 – *Ellipsolithus macellus*, section Byala 2b, samples BB1, BB77; 3-4 – *Ellipsolithus distichus*, 3 from section Byala 2b, sample BB78; 4 from section Kladorub, sample Krb21, +19.10 m; 5-7 – *Heliolithus cantabrias*, section Byala 1, sample B23; 8 – *Neochiastozygus perfectus*, section Byala 1, sample B21; 9 – *Neochiastozygus saepes*, section Byala 2b, sample BB79; 10-11 – *Neochiastozygus modestus*, Ibid.; 12 – *Prinsius martinii*, section Byala 2b, sample BB78; 13 – *Chiasmolithus danicus*, section Byala 2b, sample BB1; 14 – *Cruciplacolithus tenuis*, section Byala 2b, sample BB2; 15 – *Sphenolithus primus*, section Kladorub, sample Krb26, +28.65 m; 16 – *Lithopterychius ulii*, section Kladorub, sample Krb29, +34.60 m

The upper boundary of the zone is traced by the FO of *Fasciculithus tympaniformis*. The FOs of the species *Lithoptychius billii* and *Heliolithus cantabriae* are registered above this boundary (Fig. 6.6). Only in section Byala 1 *Heliolithus cantabriae* occurs in the upper portion of zone NP4, below the NP4/NP5 boundary. Therefore, this event should always be carefully traced and interpreted.

The characteristic zonal association comprises (Plate 6.4): *Neochiastozygus saepes*, *N. modestus*, *Cruciplacolithus edwardsii*, *C. tenuis*, *C. intermedius*, *Chiasmolithus danicus*, *Coccolithus subpertusus*, *Prinsius martini*, *Braarudosphaera bigelowii* and *Placozygus sigmoides*.

Distribution and correlations. The zone is observed only in the low and middle latitudes. In the high latitudes of the northern and southern hemisphere nanofloristic associations show different compositions and other zones are distinguished there. In ocean sections it corresponds to zone CP3 of Okada and Burky (1980), and in the North Sea – to the sum of zones *N. saepes*, *Ch. inconspicuus* and *N. perfectus* of van Heck and Prins (1987), to zones NTP5, NTP6, NTP7 and NTP8 of Varol (1989), as well as to CNP5, CNP6 and parts of CNP7 biozones of Agnini et al. (2014). In the Antarctic, it corresponds to parts of zones NA5 and NA6 of Wei and Pospichal (1991).

In Bulgaria the zone is proved in the section at Kladorub (Sinnyovsky, 2004b) and is 20 m thick. In the Central Fore-Balkan and Balkan, it is identified in the sections of Mishemorkov han, Drenta, Tabelite and Ichera-Gradets with thicknesses between 10 and

50 m. In the East Fore-Balkan and Balkan its thickness varies depending on the position of the section in the basin profile. In the section around the shelf margin and upper parts of the slope, it is between 35 m (Byala) and 50 m (Chudnite skali) thick. In the lower parts and the foot of the slope, the thickness of the zone reaches 100 m at Kozichino, 155 m at Emona (Sinnyovsky, 2004a) and about 200 m in the section at Ruen-Snyagovo.

6.2.3. Paleocene Series – Selandian Stage

Zone NP5 – *Fasciculithus tympaniformis* (Fig. 6.7)

Nomenclature. The zone was initially defined by Mohler and Hay (1967) (in Hay et al., 1967).

In Bulgaria it was identified by Stoykova (in Ivanov and Stoykova, 1994) in the Byala 1 and Byala 2b sections.

Definition. Interval from the FO of *Fasciculithus tympaniformis* to the FO of *Heliolithus kleinpellii*.

Stratigraphic range. Middle Paleocene, lower part of the Selandian Stage. The time equivalence of the zone is around 1.8 Ma (Westerhold et al., 2008).

Remarks. The lower boundary of the zone is fixed at the FO of *Fasciculithus tympaniformis*. In the remarks for the preceding zone – NP4 – the results of the latest complex studies of the section at Zumaia (Dinarès-Turell et al. 2007; Bernaola et al., 2008) were discussed including the proposal for fixing the

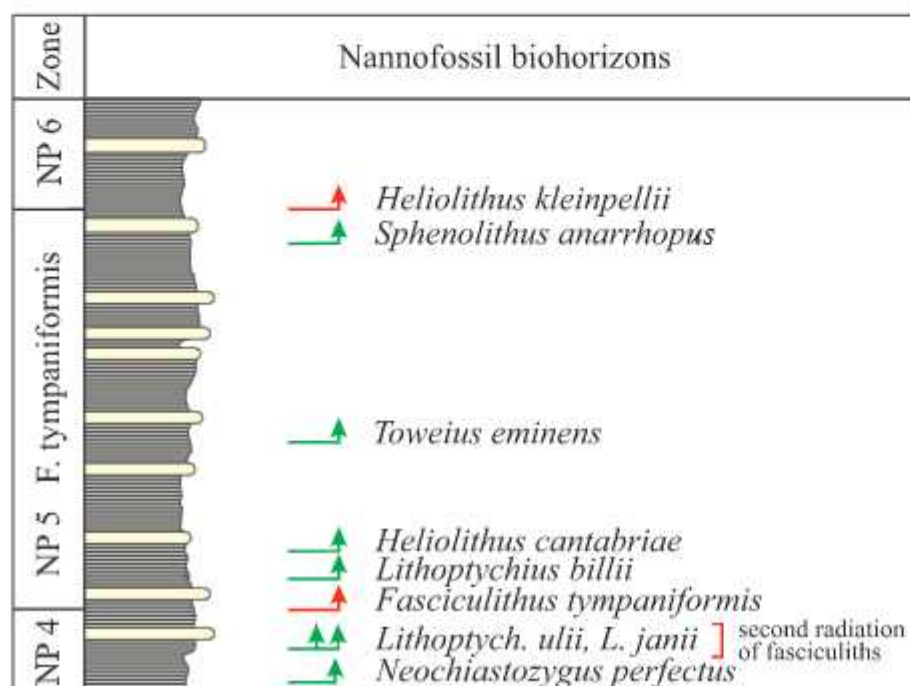


Fig. 6.7. Nannofossil biohorizons in the range of NP5 zone

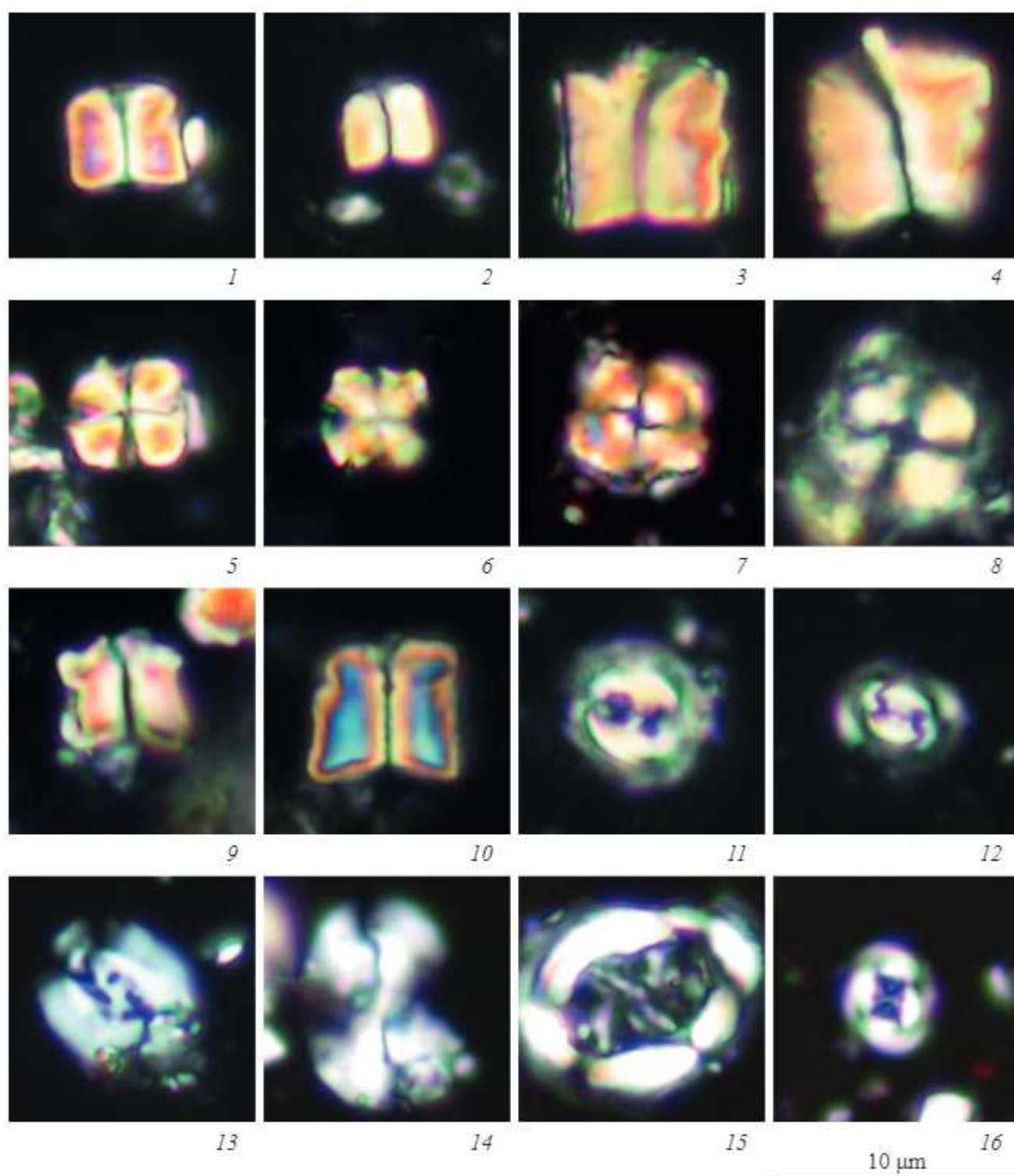


Plate 6.5. Calcareous nannofossil species from the NP5 and NP8 zones in the Byala 4 section. All photos with XPL

1-2 – *Fasciculithus tympaniformis*, zone NP5; 3-4 – *Fasciculithus* aff. *tonii*, zone NP8; 5 – *Sphenolithus primus*, zone NP5; 6-7 – *Bomolithus elegans*, zone NP5; 8 – *Heliolithus cantabriae*, zone NP5; 9 – *Tectulithus pagodiformis*, zone NP5; 10 – *Fasciculithus involutus*, zone NP8; 11 – *Toweius eminens*, zone NP5; 12 – *Toweius tovae*, zone NP5; 13 – *Ellipsolithus lajolaensis*, zone NP5; 14 – *Ellipsolithus macellus*, zone NP5; 15 – *Chiasmolithus bidens*, zone NP5; 16 – *Toweius patellus*, zone NP5.

Danian-Selandian boundary at the second radiation of the fasciculiths – *Lithoptychius ulii*, *L. jani*, *L. pileatus*. The occurrence of the species *Toweius eminens* is detected in the middle portion of the zone (Fig. 6.7).

The upper boundary of the zone is drawn at the appearance of *Heliolithus kleinpellii* – a remarkably clear event, detected in all studied sections. The FO of the species *Sphenolithus anarrhopus* is recorded around this boundary. In the sections of Central northern Bulgaria, the latter bioevent precedes the FO of *Heliolithus kleinpellii* in the upper part of NP5 zone, while in NE Bulgaria (sections around Byala) it is recorded after the FO of *Heliolithus kleinpellii*, in the lower part of NP6 zone.

The characteristic nannofossil association comprises the following species (Plate 6.5): *Fasciculithus tympaniformis*, *Lithoptychius jani*, *L. ulii*, *L. billii*, *Ellipsolithus macellus*, *E. bollii*, *Chiasmolithus bidens*, *Bomolitus elegans*, *Sphenolithus primus*, *Toweius pertusus* and *Placozygus sigmoides*.

Distribution and correlations. The zone was identified only in the low and middle latitudes. In ocean sections it corresponds to zone CP4 of Okada and Burky (1980) and in the North Sea – to zones NTp9 and NTp10 of Varol (1989). Furthermore, it corresponds to CNP7 and the lower part of CNP8 biozones of Agnini et al. (2014).

In NW Bulgaria the zone is proved in the section at Kladorub, where it is 10 m thick (Sinnyovsky, 2004b). In the sections of Central northern Bulgaria, its pres-

ence has been discovered in the course of the current study, and has a thickness of 2-3 m.

In the Central Fore-Balkan and Balkan, it is documented in the sections at Gabrovo, Drenta and Ichera-Gradets, where its thickness reaches around 10 m. It comprises a rich and diverse association in the vicinity of Stanchov han village, Elena region, however, its thickness has not been accurately determined.

It is present in all of the studied sections in the East Fore-Balkan and Balkan and its thickness ranges from several tens of metres (Esen, Podvis, Chudnite skali) to over 100 m (Ruen-Snyagovo, Kamenyak, Kozichino, Emona). In the section near Byala its thickness varies from 4 m (Byala 4) to 15 m (Goritsa).

Zone NP6 – *Heliolithus kleinpellii* (Fig. 6.8)

Nomenclature. The zone was defined for the first time by Mohler and Hay (1967) in Hay et al. (1967) as an “interval from the first occurrence of *Heliolithus kleinpellii* to the first occurrence of *Discoaster gemmeus*”. Later on, following taxonomic revision, Burky and Percival (1971) proved that the species *Discoaster gemmeus* has an Eocene range and was completely missing in the Paleocene.

Then they created a new species – *Discoaster mohleri*, based on a specimen figured by Hay and Mohler (1967) in their “zone *Discoaster gemmeus*”. Therefore, the species *Discoaster mohleri* of Burky and Percival, 1971 completely replaced *Discoaster gemmeus* in the definition of zones NP6 and NP7.

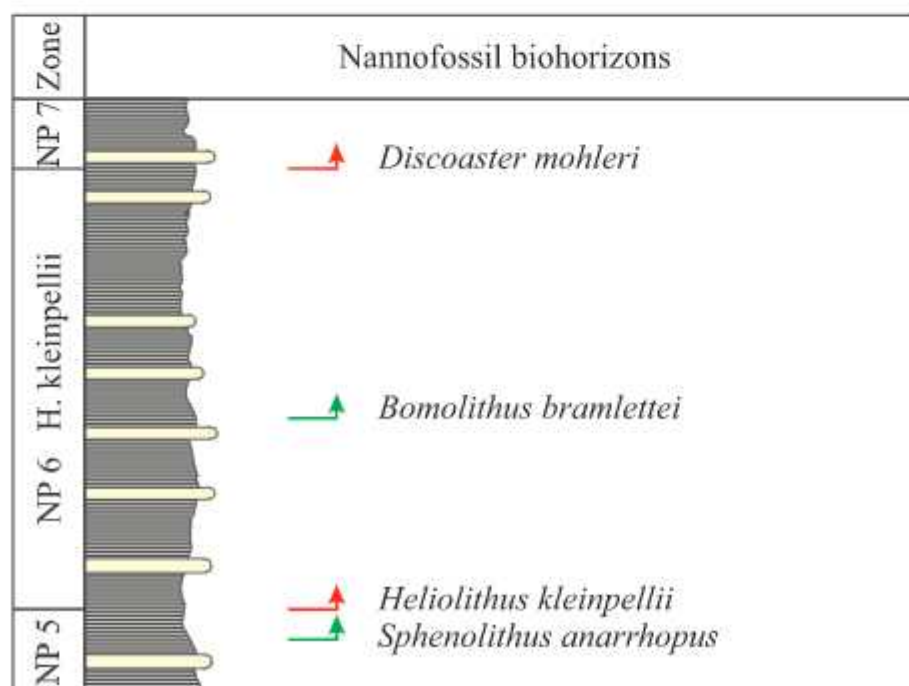


Fig. 6.8. Nannofossil biohorizons in the range of NP6 zone

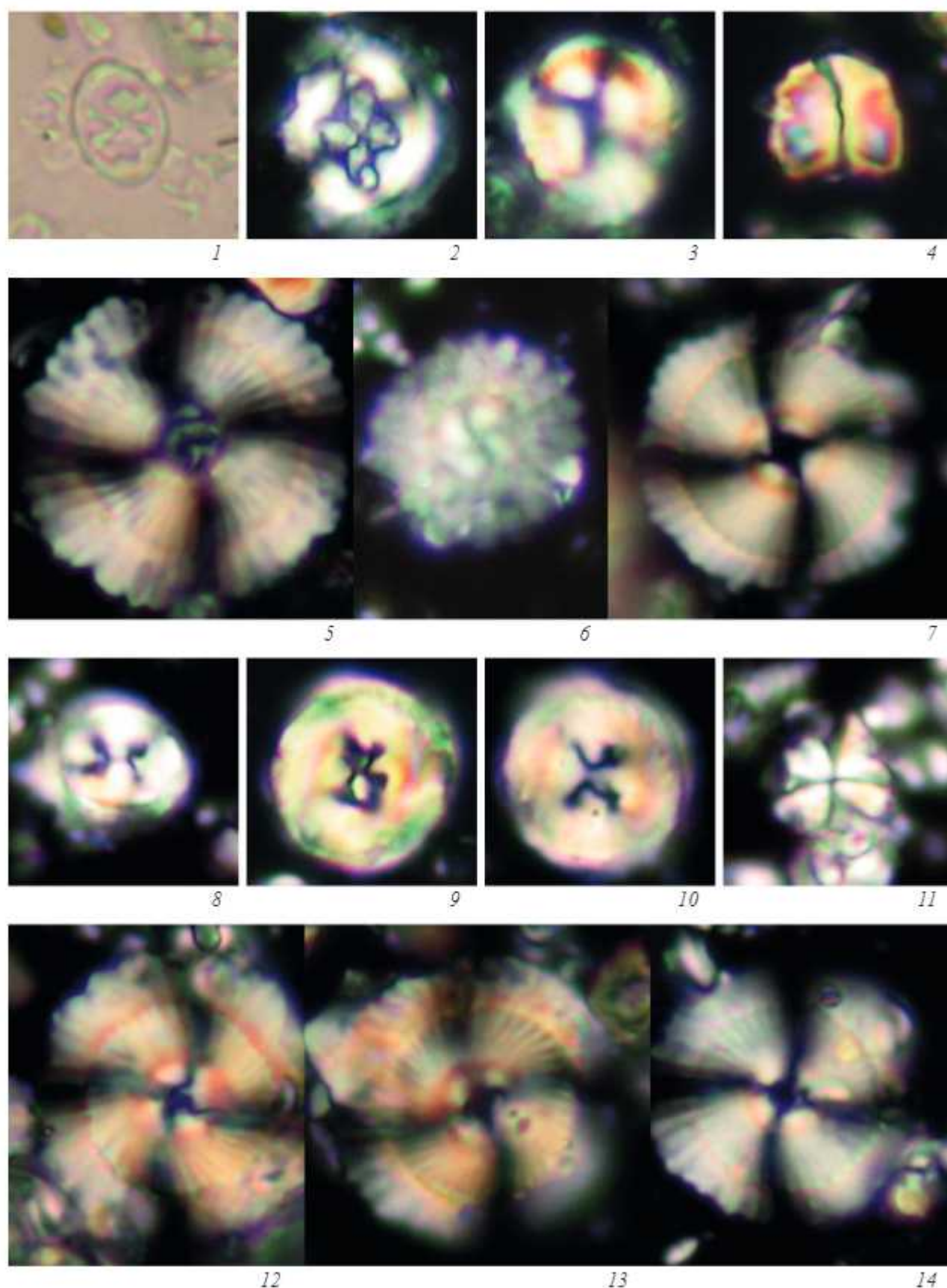


Plate 6.6. Calcareous nannofossil species from the NP6 zone in the Byala 4 section.

All photos with XPL except of 1 (PPL)

1 – *Neochiastozygus perfectus*; 2 – *Crucioplacolithus tenuis*; 3 – *Heliolithus cantabriae*; 4 – *Fasciculolithus bobii*; 5, 7, 12, 13, 14 – *Heliolithus kleinpellii*; 6 – *Heliolithus bukryi*; 8 – *Toweius eminens*; 9-10 – *T. tovae*; 11 – *Sphenolithus primus*

In Bulgaria the zone was indicated for the first time by Muzilev (in Aladjova-Hrischeva et al., 1983). More detailed characteristics have been recorded by Stoykova (1990), describing it in the sediments of the Komarevo Formation in Central northern Bulgaria.

Definition. Interval from the FO of *Heliolithus kleinpellii* to the FO of *Discoaster mohleri*.

Stratigraphic range. Middle Paleocene, upper part of Selandian Stage and lower part of the Thanetian Stage. The time equivalence of the zone is 490 Ka (Westerhold et al., 2008).

Remarks. The lower boundary of the zone is clearly traced by the FO of *Heliolithus kleinpellii*. This species, particularly with its clear taxonomic features and abundance, represents an excellent biohorizon.

The middle part of the zone is characterized by the FO of the genus *Bomolithus* with the species *Bomolithus bramlettei*. The latter has been identified only in the sections near Byala. The most probable reason for its presence only in the deeper-water sections (margin-slope location) may be ecological, because it is not detected in the shallow water sections.

The upper boundary of the zone is clearly traced by the FO of *Discoaster mohleri*.

The association of species in the zone contains (Plate 6.6): *Heliolithus kleinpellii*, *H. cantabriae*, *Chiasmolithus bidens*, *C. consuetus*, *Neochiastozygus modestus*, *N. perfectus*, *N. junctus*, *Sphenolithus primus*, *S. anarrhopus*, *Fasciculithus tympaniformis*, *F. bobii*,

F. thomasii, *Prinsius martini*, *Toweius eminens*, *T. pertusus* and *Placozygus sigmoides*.

Distribution and correlations. The zone is identified only in the low and mid latitudes. In oceanic core-drill-sections it corresponds to zone CP5 of Okada and Burky (1980) and in the North Sea – to parts of zones NTp10 and NTp11 of Varol (1989), as well as to middle and upper parts of CNP8 biozone of Agnini et al. (2014).

In NW Bulgaria it is present in the section at Kladorub with an estimated thickness of 3 m (Sinnyovsky, 2004b); in the Mezdra region, near Lyuti dol village it occurs within the sandstone formation of Sinnyovsky and Sinnyovska (1993).

In Central northern Bulgaria the zone is observed in the lower portions of the sections along the Vit River and is 15-20 m thick.

In the Central Fore-Balkan and Balkan it is documented only in the eastern parts – Ichera-Gradets section, where the thickness reaches several tens of meters.

In the East Fore-Balkan and Balkan the zone is observed in the Chudnite skali section, where its thickness is 20 m (Sinnyovsky in Vangelov & Sinnyovsky, 2000). Probably the zone is present in the section of the thick-bedded sandstone formation, but no paleontological data is available to support this so far.

In the sections around Byala its thickness varies from 4 m (Byala 4) to 8-10 m (Dolap Dere).

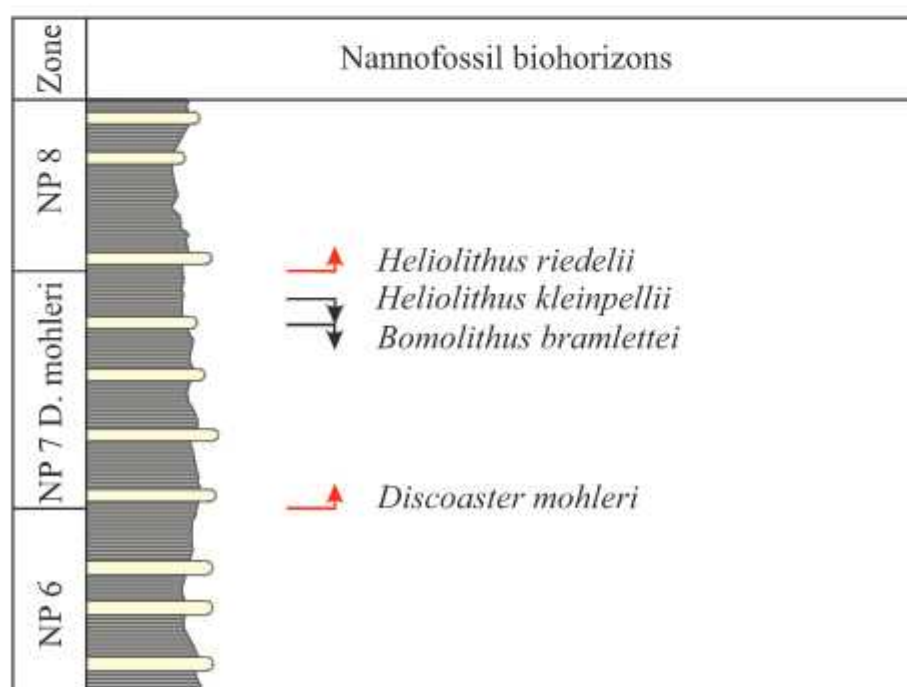


Fig. 6.9. Nannofossil biohorizons in the range of NP7 zone

The thickness of the zone in the turbidite sequences of the Emine Formation around Emona is not precisely known due to the lack of the zonal marker for the next zone NP7 *Discoaster mohleri* (Sinnyovsky, 2004a). The combined thicknesses for zones NP6 and NP7 in this region is 180 m (Sinnyovsky, 2004a).

6.2.4. Paleocene Series – Thanetian Stage

Zone NP7 – *Discoaster mohleri* (Fig. 6.9)

Nomenclature. The zone was distinguished for the first time by Hay (1964) and Mohler and Hay (1967) (in Hay et al., 1967) as “an interval from the first occurrence of *Discoaster gemmeus* to the first occurrence of *Heliolithus reidelii*”. The replacement of the index species *Discoaster gemmeus* by *Discoaster mohleri* was discussed above in the preceding zone NP6.

In Bulgaria the zone was identified for the first time by Muzilev (in Aladjova-Hrischeva et al., 1983). Detailed characteristics were given by Stoykova (1990), documenting it in sections along the Vit River in Central northern Bulgaria.

Definition. Interval from the FO of *Discoaster mohleri* to the FO of *Heliolithus reidelii*.

Stratigraphic range. Upper Paleocene, lower part of Thanetian Stage. This zone is one of the smallest in range and shortest in temporal duration within the Paleocene. The latest data indicate a duration of around 300 Ka, including 2.5 eccentricity cycles (approx. 100 Ka each) in the section at Zumaia (Dinarès-Turell et al., 2007).

Remarks. The lower boundary of the zone is clearly traced by the FO of *Discoaster mohleri*.

No significant biostratigraphic events have been detected in the zone (Fig. 6.9).

The upper boundary of the zone is fixed by the FO of the species *Heliolithus reidelii* – another clearly expressed event, registered in the studied sections. The upper part of zone NP7 contains the last appearance (extinction) of the species *Bomolitus bramlettei* and *Heliolithus kleinpellii*.

The characteristic association includes the following species (Plate 6.7): *Discoaster mohleri*, *Toweius patellus*, *T. eminens*, *T. tovae*, *Chiasmolithus bidens*, *C. consuetus*, *C. edentulus*, *Sphenolithus primus*, *Fasciculithus tympaniformis*, *Ellipsolithus macellus*, *Heliolithus kleinpellii*, *Bomolitus elegans*, *B. bramlettei* and *Placozygus sigmoides*.

Distribution and correlations. The zone is observed in the low and mid latitudes. Due to the zone's small thickness and lack of sufficient biostratigraphic data, it is often separated as one common zone NP7/NP8. In the ocean sections it corresponds to the zone of the same name – CP6 of Okada and Burky (1980), as well as to CNP9 and part of CNP10 zone of Agnini et al. (2014); and in the North Sea – to parts of zone NTp11 and NTp12 of Varol (1989).

In Bulgaria, the NP7 zone with clear lower and upper boundaries has been identified only in three regions – Vidin (the section at Kladorub), Pleven (the sections at Riben and Komarevo) and Varna (Beloslav, Trastikovo, Sindel). At Kladorub its thickness is 2 m (from +49 to +51 m), at Riben and Komarevo 2.5 m and 4 m respectively, and at Beloslav, Trastikovo and Sindel the thickness is 2 – 2.5 m.

The occurrence of the zone in the Byala 4 section is only hypothesized (estimated thickness of 1.5 m), since no outcrops of this particular interval were available (Stoykova and Ivanov, 2006a, b).

The lower boundary of the zone is not precisely fixed in the sections of the Emine Formation near Emona. Since the zonal index *Discoaster mohleri* is missing, the thickness of the zone cannot be correctly calculated. The total thickness, along with zone NP6, is 180 m (Sinnyovsky, 2004a).

Zone NP8 – *Heliolithus reidelii* (Fig. 6.10)

Nomenclature. The zone was introduced for the first time by Bramlette and Sullivan (1961) under the name “Unit 1 – provisionally referred to as the *Heliolithus reidelii* zone” with “characteristic zonal association, including *Heliolithus reidelii*, *Discoaster helianthus*, *Zygolithus junctus*”. Mohler and Hay (1967) gave a precise definition of the zone as “an interval from the first occurrence of *Heliolithus reidelii* to the first occurrence of *Discoaster multiradiatus*”.

In Bulgaria, the zone was identified for the first time by Sinnyovsky (1992) in the Paleocene section along the road cut of the highway at Devnya, Varna region, where the index species *Heliolithus reidelii* was figured from.

Definition. Interval from the FO of *Heliolithus reidelii* to the FO of *Discoaster multiradiatus*.

Stratigraphic range. Upper Paleocene, middle part of Thanetian Stage. No precise data on the time range is available, because of the missing index species in the calibrated ocean sections (Westerhold et al., 2008). Estimates indicate an approximate duration of over

300 Ka (if using the FO of *Discoaster nobilis* as a replacement of the FO of *Heliolithus riedelii*).

Remarks. The first occurrence of the index *Heliolithus riedelii* marking the base of zone NP8 represents a clearly expressed biohorizon. It is clearly recognized in the studied sections since *Heliolithus riedelii* is easily identifiable and commonly occurs throughout the entire zone. Moreover, its full vertical distribution coincides with the range of zone NP8. However, it has been recorded rarely in the lower part of the next NP9 zone, probably as a result of redeposition.

Several first occurrences of important stratigraphic species are detected in the middle portion of the zone (Fig. 6.10).

The FO of *Discoaster protomultiradiatus* Wei, 1998 is a bioevent that is clearly identified in the studied Bulgarian sections. It is possible that its high stratigraphic potential will yet be assessed worldwide.

The FOs of *Bomolitus megastypus* and *Ericsonia robusta* followed by *Fasciculithus tonii* are observed above it (Fig. 6.10). The last occurrence (the extinction) of the index species *Heliolithus riedelii* is in the uppermost part of the zone, around the NP8/NP9 boundary.

The upper boundary of the zone is fixed by the FO of *Discoaster multiradiatus* – another well-expressed biohorizon, traced in all studied sections.

The association of species commonly encountered

in the zone comprises (Plate 6.8): *Heliolithus riedelii*, *H. universus*, *Bomolitus megastypus*, *Ericsonia robusta*, *Discoaster protomultiradiatus*, *D. mohleri*, *D. splendidus*, *Fasciculithus tympaniformis*, *F. involutus*, *F. tonii*, *F. alanii*, *Zygodiscus herlyni*, *Placozygus sigmoides*, *Toweius tovae*, *T. eminens* and *T. pertusus*.

Distribution and correlations. The zone is observed in the low and mid latitudes. In the ocean sections it corresponds to zone CP7 of Okada and Burky (1980) and approximates to the upper part of CNP10 biozone of Agnini et al. (2014); in the North Sea it equates to parts of zones NTp13 to NTp15 of Varol (1989).

In NW Bulgaria the zone was discovered in the section at Kladorub by Sinnyovsky (2004b), where its estimated thickness is 5 m.

In Central northern Bulgaria the zone is identified in the Bozhuritsa Formation, in the sections along the valley of the Vit River (Bozhuritsa and Riben, as well as in the gully between Riben and Komarevo) where its thickness reaches 13–15 m.

In the Central Fore-Balkan and Balkan the zone is documented only in the eastern parts, in the Ichera-Gradets section, where the thickness is approximately 25 m.

In the East Fore-Balkan it is distinguished in the section at Chudnite skali, with a thickness between 15–17 m (Sinnyovsky in Vangelov and Sinnyovsky, 2000; Stoykova in Peybernès et al., 2004). It is quite

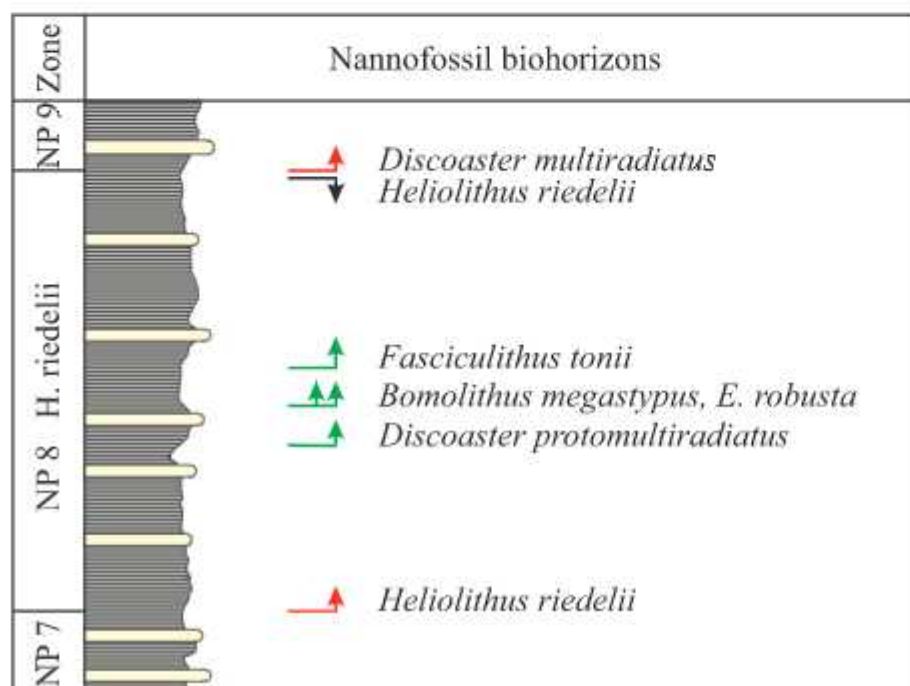


Fig. 6.10. Nannofossil biohorizons in the range of NP8 zone

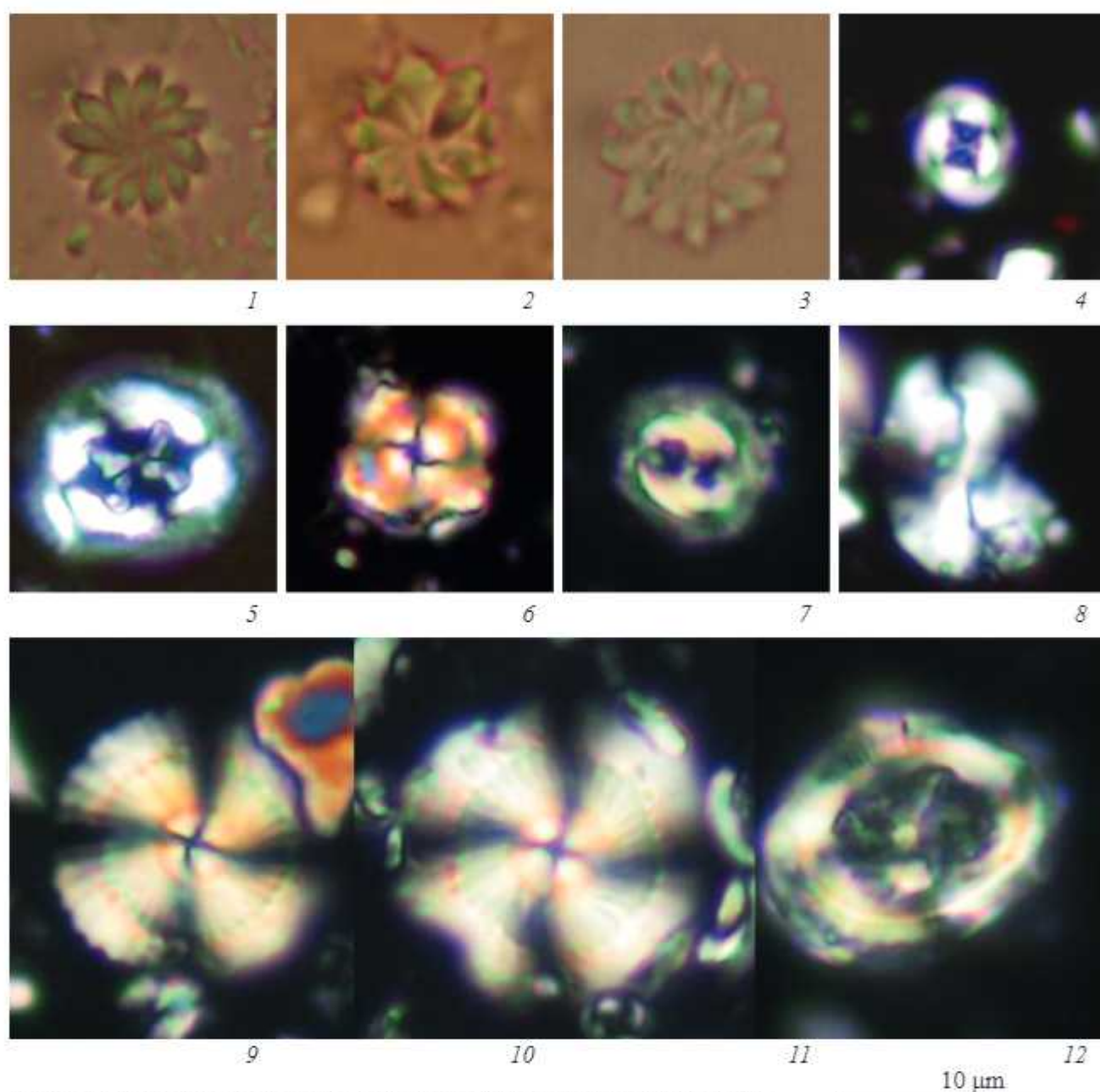


Plate 6.7. Calcareous nannofossil species from the NP7 zone in the studied sections. All photos with XPL except of 1-3 (PPL)

1-2 – *Discoaster mohleri*, Komarevo section +25 m; 3 – *Bomolithus bramlettei*, Komarevo section +30 m; 4 – *Toweius patellus*, Byala 4 section; 5 – *Chiasmolithus consuetus*; 6 – *Bomolithus elegans*, Sindel section, +2 m; 7 – *Toweius eminens*, Trastikovo section, +1.5 m; 8 – *Ellipsolithus macellus*, Byala 4 section; 9-10 – *Heliolithus kleinpellii*, Kladorub section, sample Krb 37; 11 – *Chiasmolithus edentulus*, section Beloslav-South, +0.2 m

possible NP8 zone is present in the sections of the thick-bedded sandstone formation (for instance, near Neykovo village, East Balkan), but no supporting biostratigraphic data are yet available.

In the sections near Byala the thickness of the zone is around 3 m (Stoykova & Ivanov, 2006a, b). In the Emine Formation near Emona its estimated thickness is 95 m (Sinnyovsky, 2004a).

In the eastern parts of the Moesian Platform the zone is documented in the sections at Beloslav, Sindel and Trastikovo, where its thickness varies from 2.5 m to 5 m.

In the Black Sea offshore, the zone is proved in the Yuri Shimanov and Varna-West wells, the thickness being 20 m and 6 m, respectively. As a joint zone NP8/NP9 it is documented in Galata-1 and Galata-2 wells, with a thickness between 5 – 10 m.

Zone NP9 – *Discoaster multiradiatus* (Fig. 6.11)

Nomenclature. The zone was differentiated for the first time by Bramlette and Sullivan (1961) under the name “Unit 1 – the provisional *D. multiradiatus* zone”. Mohler and Hay (1967) defined the zone as “an interval from the first occurrence of *Discoaster multiradiatus* to the first occurrence of *Marthasterites bramlettei*”. Comments on the taxonomic issues related to *Rhomboaster bramlettei* and the evolutionary lineage *Rhomboaster* – *Tribrachiatus* are presented in the next zone NP10.

The zone was indicated for the first time in Bulgaria by Sinnyovsky (in Sinnyovsky & Sultanov, 1994) in the Emine Formation section north of Irakli; the index species was also figured. Later on, Sinnyovsky recorded the zone in the sections at Emona and Kladorub (Sinnyovsky, 2004a, b). The stated criteria for setting the boundaries of zone NP9, however, are incorrect – they are valid for zone NP8.

In the sections of Central northern Bulgaria, the zone has been thoroughly documented and described by Stoykova (in Stoykova and Ivanov, 2004b).

Definition. Interval from the FO of *Discoaster multiradiatus* to the FO of the genus *Rhomboaster* (*Rhomboaster bramlettei*).

Stratigraphic range. Upper Paleocene, upper part of Thanetian Stage. The time equivalence of the zone by latest data is 1.3 Ma (Agnini et al., 2007a; Westerhold et al., 2008).

Remarks. The lower boundary of the zone represents one of the most studied globally identified biohorizons in the Paleocene (Bramlette and Sullivan, 1961; Hay and Mohler, 1967; Romein, 1979; Bralower and Mutterlose, 1995; Raffi et al., 2005; Agnini et al., 2007a; Agnini et al., 2014). The FO of *Discoaster multiradiatus* is easily identified due to clearly identifiable morphology and because it is frequently encountered in associations. Along with it, at the base of the zone, the first representatives of the rhabdoliths appear – *Blackites creber* and *B. spp.* – that regularly occur within the zone, but their acme seems to have occurred in the lower Eocene.

The middle part of the zone reveals the FOs of *Discoaster falcatus*, *D. limbatus* and *D. mediusus* (Fig. 6.11).

In the upper part of the zone, a biohorizon with successive FOs of the species *Campylosphaera eodela*, *Lophodolichus nascens*, *Transversopontis pulcher* and *Ponosphaera spp.* is clearly identifiable (Fig. 6.11). The high stratigraphic potential of the species *Campylosphaera eodela* was recognized by Okada and Burky (1980) and applied in dividing their zone

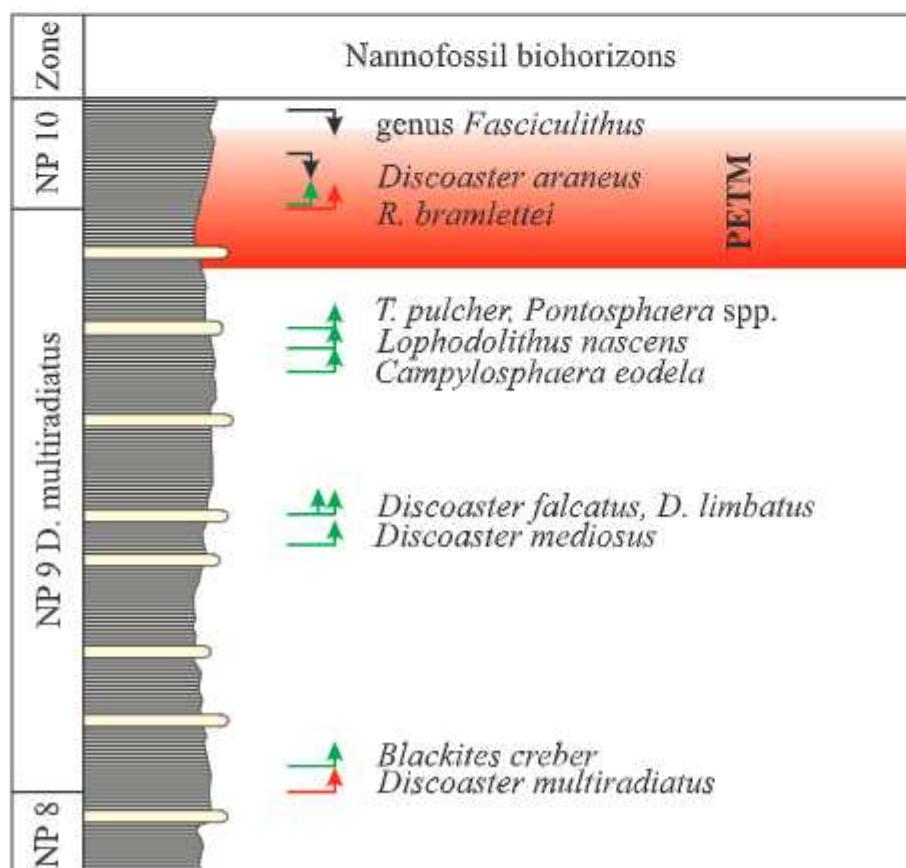


Fig. 6.11. Nannofossil biohorizons in the range of NP9 zone

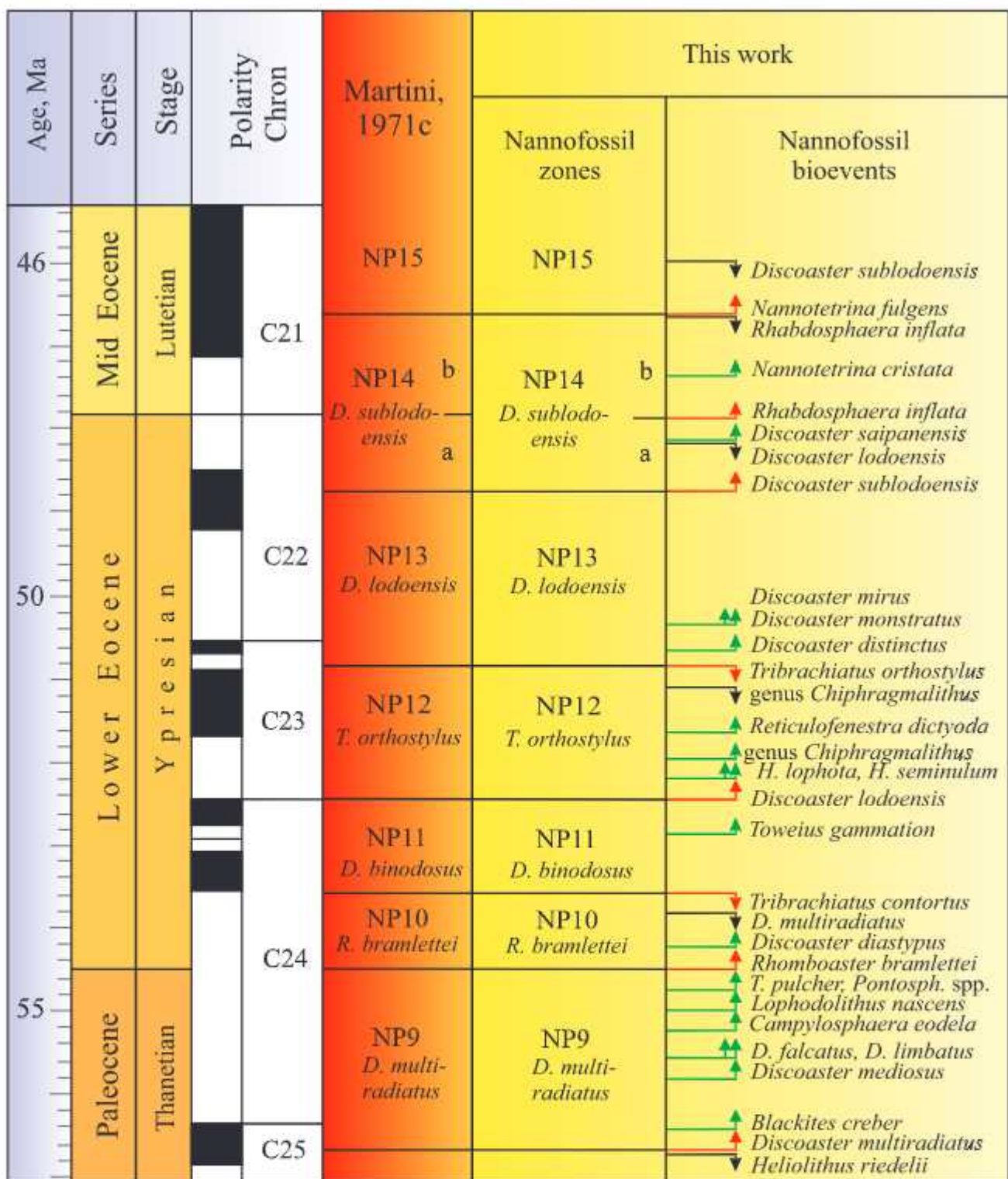
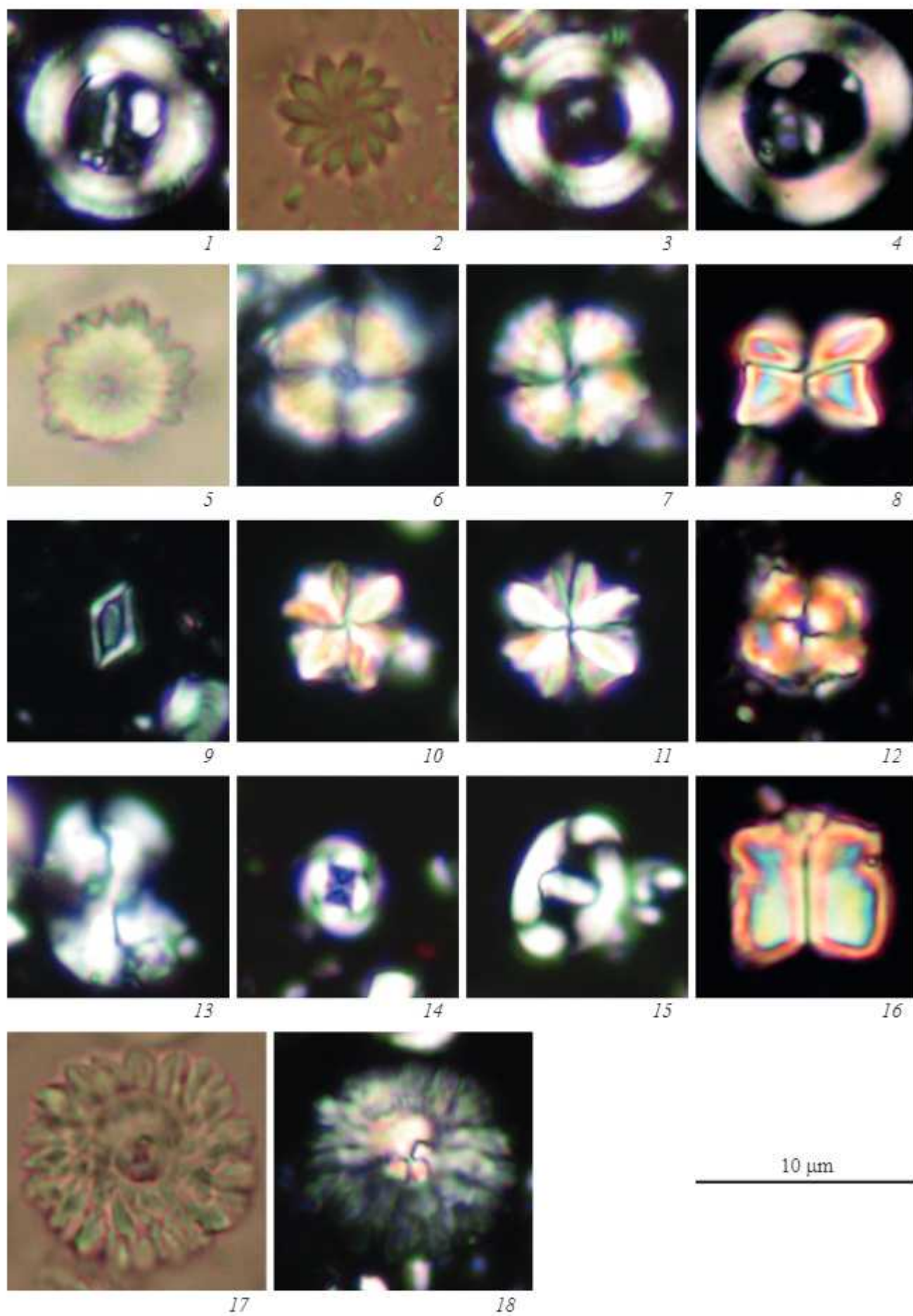


Fig. 6.12. Calcareous nannofossil biozonation of the Paleocene and lower Eocene, used in the present study (after Martini, 1971c with modifications). Some key nannofossil biohorizons of the first and last occurrence of the marker species are also shown (red, green and black arrows)

CP 8 into 2 sub-zones – CP 8a (*Ch. bidens*) and CP 8b (*Ca. eodola*). The other two species – *Lophodolichus nascens* and *Transversopontis pulcher* – have been used by Bybell and Self-Trail (1995) for detailed zonation of the boundary interval between the Paleocene and Eocene in New Jersey. In their opinion

Lophodolichus nascens occurs in the uppermost quartile of zone NP9, while *Transversopontis pulcher* is above this, in the very highest portion (Bybell & Self-Trail, 1995)

The third major radiation event among the fasciculith



group is registered in the uppermost part of the zone (the so-called *Fasciculithus richardi* group – Agnini et al., 2014). During the radiation, the following species dominate nannofossil associations: *Fasciculithus mitreus*, *F. thomasi*, *F. schaubii*, *F. tonii*, *F. involutus*, *F. bobii* and *F. siderius*. This group disappeared completely with the onset of the PETM (Agnini et al., 2014).

The upper boundary of the zone is traced by the occurrence of the first representatives of the genus *Rhomboaster* – *R. bramlettei*, *R. cuspis* and *R. calcitrata*. This boundary is marked by a global climatic event – the Paleocene-Eocene Thermal Maximum (PETM) and will be specifically discussed in Chapter 8 “Global Events”.

The association characteristic of the zone comprises the following species (Plate 6.9A, 6.9B): *Discoaster multiradiatus*, *D. salisburgensis*, *D. protomultiradiatus*, *D. mediusus*, *D. falcatus*, *D. limbatus*, *D. lenticularis*, *Fasciculithus mitreus*, *F. siderius*, *F. tonii*, *F. schaubii*, *Calcsolenia aperta*, *Toweius eminens*, *T. tovae*, *T. pertusus*, *T. serotinus*, *Zygodiscus herlyni*, *Neochiastozygus junctus*, *Bomolitus conicus* and *Ellipsolithus distichus*.

Distribution and correlations. The zone is traced in the low and middle latitudes. In the ocean sections it corresponds to zone CP8 (sub-zones CP8A and CP8B) of Okada and Burky (1980) and to CNP11 zone of Agnini et al. (2014), as well as to zones NTp16 to NTp20 of Varol (1989) in the North Sea.

In NW Bulgaria it is proved in the section at Kladorub by Sinnyovsky (2004b) with 16 m thickness (without taking into account the lower Eocene sediments of zone NP10). The thickness of zone NP9 is estimated at 7 m (Stoykova & Ivanov, 2005; Stoykova et al., 2005b).

In Central northern Bulgaria the zone is detected within the Bozhuritsa Formation in the sections along the valley of the Vit River (Bozhuritsa and Riben and in the gully between Riben and Komarevo); its thickness is between 6 and 7 m.

In the East Fore-Balkan and Balkan, the zone is documented in the sections near Byala with a thickness of around 2.5 m (Stoykova & Ivanov, 2006a, b). In the Emine Formation in the sections near Emona it has a maximum thickness of over 150 m (Sinnyovsky, 2004a).

In the Black Sea offshore the zone is present in the Yuri Shimanov and Varna-West wells, with a thickness of 10 m and 3 m, respectively. It has been penetrated in the Galata-1 and Galata-2 well in a combined NP8/NP9 zone, 5–10 m thick.

6.2.5. Lower Eocene – Ypresian Stage (Fig. 6.12)

Zone NP10 – *Rhomboaster bramlettei* (Fig. 6.13)

Nomenclature. The zone was differentiated for the first time by Hay (1964). Mohler & Hay (1967) defined the zone as “an interval from the first occurrence of *Marthasterites bramlettei* to the extinction of *Marthasterites contortus*” and Martini (1971c) used it for the definition of his standard zone NP10 *Marthasterites contortus*.

The morphological interpretation and generic affiliation of species of the evolutionary lineage *Rhomboaster* – *Tribrachiatus* has been the subject of intense discussion (Bybell & Self-Trail, 1995; Aubry, 1996; von Salis et al., 2000; Monechi et al., 2000). This taxonomic issue is of essential stratigraphic importance since the appearance of *Rhomboaster bramlettei* is the event fixing both the lower boundary of zone NP10 and the Paleocene-Eocene boundary.

The current study assumes the modified definition of zone NP10 by Bybell and Self-Trail (1995) according to which the first occurrence of representatives of the genus *Rhomboaster* (*R. bramlettei* with short rays, including *R. cuspis*) sets the lower boundary of the zone.

In Bulgaria the zone was documented for the first time by Stoykova (in Stoykova & Vangelov, 1997).

Plate 6.8. Calcareous nannofossil species from the NP8 zone in the studied sections. All photos with XPL except of 2, 5 and 17 (PPL)

1, 3–4 – *Ericsonia robusta*, Riben section, sample Rib 4 (1, 3); Bozhuritsa section, sample Boj 8 (4); 2 – *Discoaster mohleri*, Komarevo section, +25 m; 5–6 – *Heliolithus riedelii*, Riben section, sample Rib 5; 7–8 – *Heliolithus riedelii*, Kladorub section, sample Krb 39; 9 – *Calcsolenia aperta*, Riben section, sample Rib 16; 10–11 – *Fasciculithus siderius*, Riben section, sample Rib 13; 12 – *Bomolitus elegans*, Sindel section, +2 m; 13 – *Ellipsolithus macellus*, Byala 4 section; 14 – *Toweius patellus*, Byala 4 section; 15 – *Zygodiscus herlyni*, Bozhuritsa section, sample Boj 9; 16 – *Fasciculithus involutus*, Byala 4 section, BB116-4; 17–18 – *Discoaster protomultiradiatus*, Bozhuritsa section, sample Boj 12

Definition. Interval from the first occurrence of the genus *Rhomboaster* (*R. bramlettei*) to the last occurrence (extinction) of *Tribrachiatus contortus*.

Stratigraphic range. Lowermost Eocene, lowermost part of the Ypresian Stage. The chronological equivalent of the zone is 1.74 Ma (Agnini et al., 2007a).

Remarks. The lower boundary of the zone is traced by the appearance of the first representatives of the genus *Rhomboaster* – *R. bramlettei* (including *R. cuspis* and *R. calcitrata*). This bioevent is detected immediately above the clayey interval, completely devoid of carbonates and known as an interval of carbonate dissolution (Carbonate Dissolution Interval, CDI). This interval marks the onset of the global climatic event – the Paleocene-Eocene Thermal Maximum (PETM).

At the base of the zone, within the PETM interval, a particular association of species appears, named the “*Rhomboaster* spp. – *Discoaster araneus* (RD) association” (Khan & Aubry, 2004). This association has been observed in ocean sections of the low and mid latitudes, as well as in Bulgarian sections (Stoykova & Ivanov, 2005). It includes the species *Rhomboaster bramlettei*, *R. spineus*, *R. cuspis*, *Rhomboaster* spp., *Discoaster araneus* and *D. anartios*. The vertical distribution of the association is very short and coincides with the Eocene portion of the $\delta^{13}\text{C}$ negative excursion

in the PETM interval (Khan & Aubry, 2004; Tremolada & Bralower, 2004) (Fig. 6.13).

In the uppermost, Eocene portion of the PETM-interval, the LO of the genus *Fasciculithus* and particularly of *Fasciculithus tympaniformis* is registered (Fig. 6.13).

The occurrence of the typical *Discoaster diastypus* is fixed in the middle part of zone NP10. This bioevent was used by Okada and Burky (1980) to define the lower boundary of their zone CP9A.

The upper part of the zone reveals intensive speciation with the successive first appearances of species in the phylogenetic lineage *Rhomboaster* – *Tribrachiatus*. Before its extinction, *R. bramlettei* give rise to *Tribrachiatus contortus*, followed by *Tribrachiatus orthostylus* (Fig. 6.13). Also, the FO of *Sphenolithus radians* is documented in this level.

The species *Tribrachiatus digitalis* whose range was used by Aubry (1996) to differentiate subzone NP10b, is extremely rarely seen in Bulgaria. Therefore, I would refrain from using this bioevent for biostratigraphic correlation.

The upper boundary of the zone is drawn by the LO (extinction) of *Tribrachiatus contortus*. It is not always a clearly expressed biohorizon in successions, and

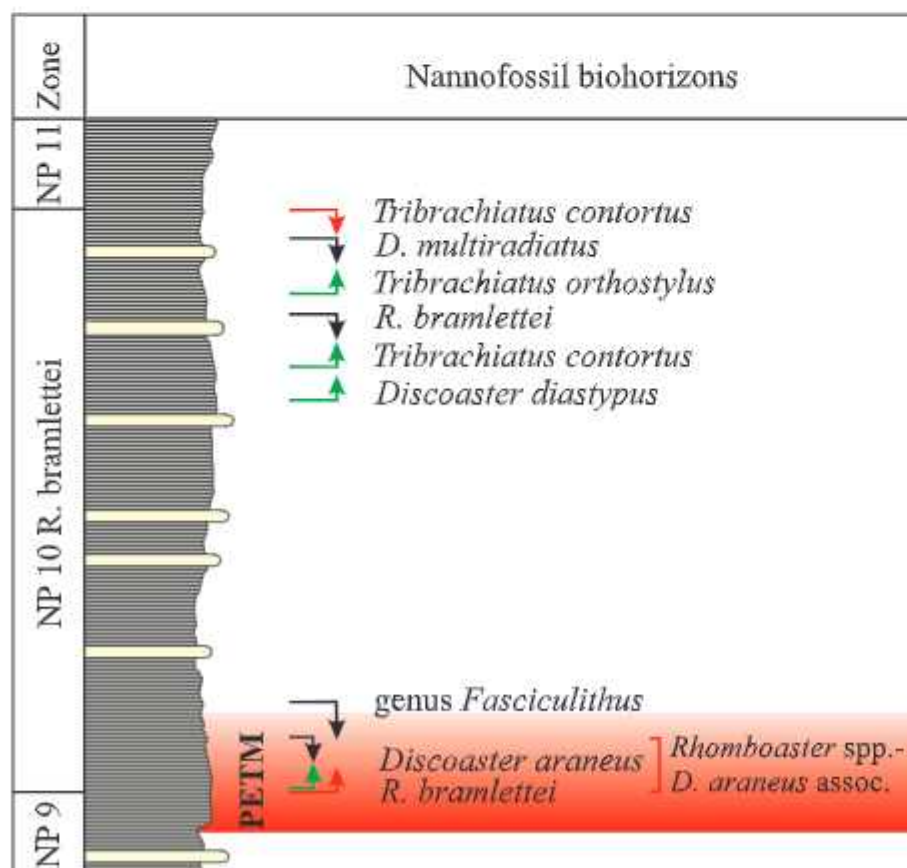


Fig. 6.13. Nannofossil biohorizons in the range of NP10 zone

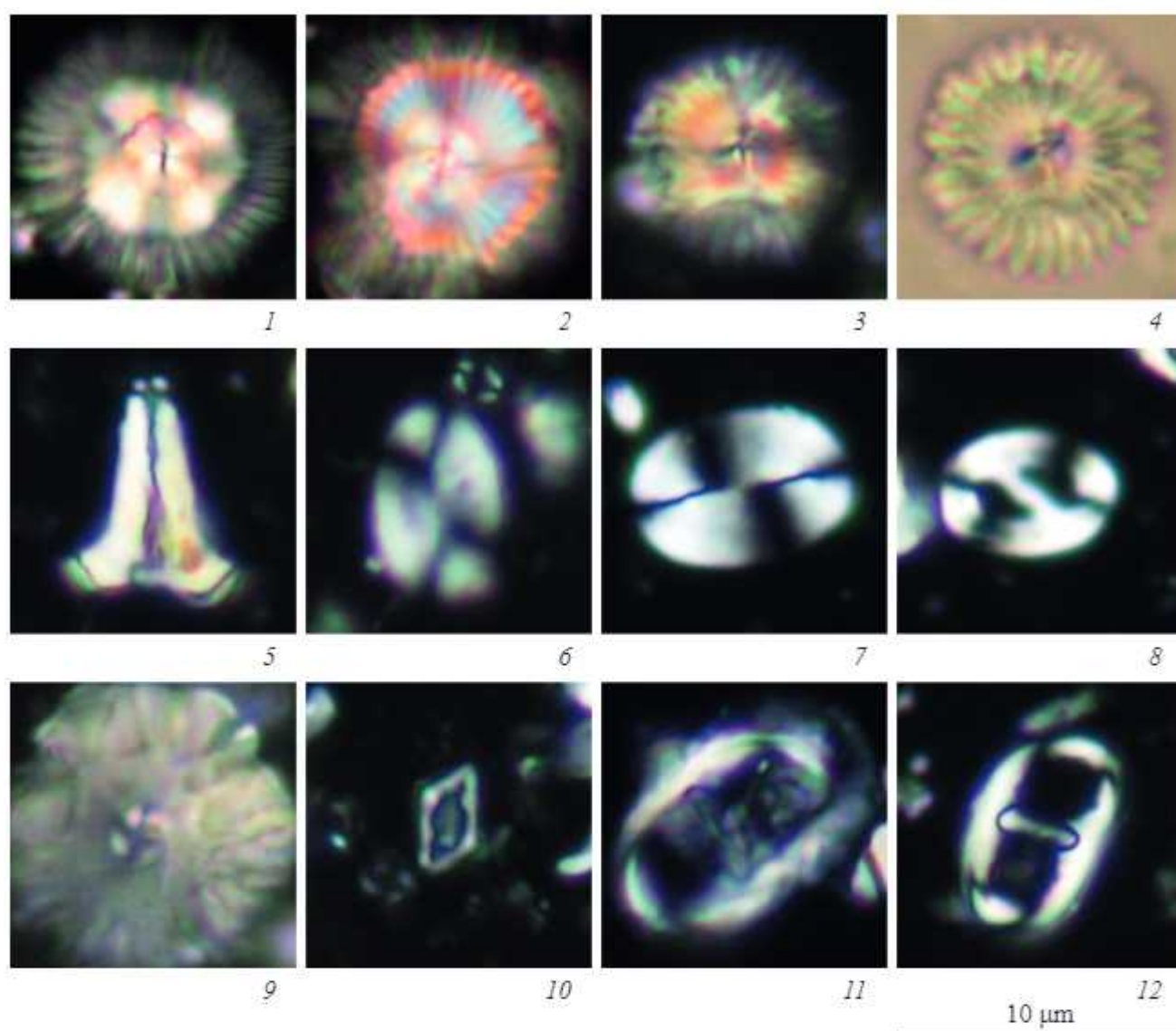


Plate 6.9A. Calcareous nannofossil species from the NP9 zone in the studied sections Byala 4 and Bozhuritsa. All photos with XPL except of 4 (PPL)

1-2 – *Bomolithus megastypus*, section Byala 4; 3-4 – *Bomolithus megastypus*, Bozhuritsa section, sample Boj14; 5 – *Zygrhablithus bijugatus*, Bozhuritsa section, sample Boj15; 6-7 – *Pontosphaera* spp., sample Boj15; 8 – *Transversopontis pulcher*, Bozhuritsa section, sample Boj14; 9 – *Discoaster protomultiradiatus*, Bozhuritsa section, sample Boj10; 10 – *Calcisolenia aperta*, Bozhuritsa section, sample Boj14; 11-12 – *Lophodolithus nascens*, Bozhuritsa section, sample Boj15.

then the tracing of the boundary is conditional. When considering the absence of *Tribrachiatus contortus*, an approximation of the boundary could be made by the use of the FO of *Tribrachiatus orthostylus* (Fig. 6.13).

The characteristic association consists of the following species (Plate 6.10 A-D): *Rhomboaster bramlettei*, *Discoaster multiradiatus*, *D. salisburgensis*, *D. limbatus*, *D. falcatus*, *D. mediusus*, *D. diastypus*, *Lophodolithus nascens*, *Toweius callosus*, *T. tovae*, *Chiasmolithus bidens*, *C. eograndis*, *C. consuetus*, *Tribrachiatus contortus*, *Pontosphaera* spp., *Transversopontis pulcher* and *Zygrhablithus bijugatus*.

Distribution and correlations. The zone is identified in the low and mid latitudes. In the ocean sections it corresponds to the uppermost part of subzone CP8b and the entire subzone CP9a of Okada and Burky (1980), as well as to CNE1, CNE2 and to lower zone CNE3 of Agnini et al. (2014).

In NW Bulgaria, Stoykova and Ivanov (2005) and Stoykova et al. (2005b, 2006) proved its presence for the first time in the section at Kladorub. In this section, only the lower part of the zone is documented, with a measured thickness of 11 m.

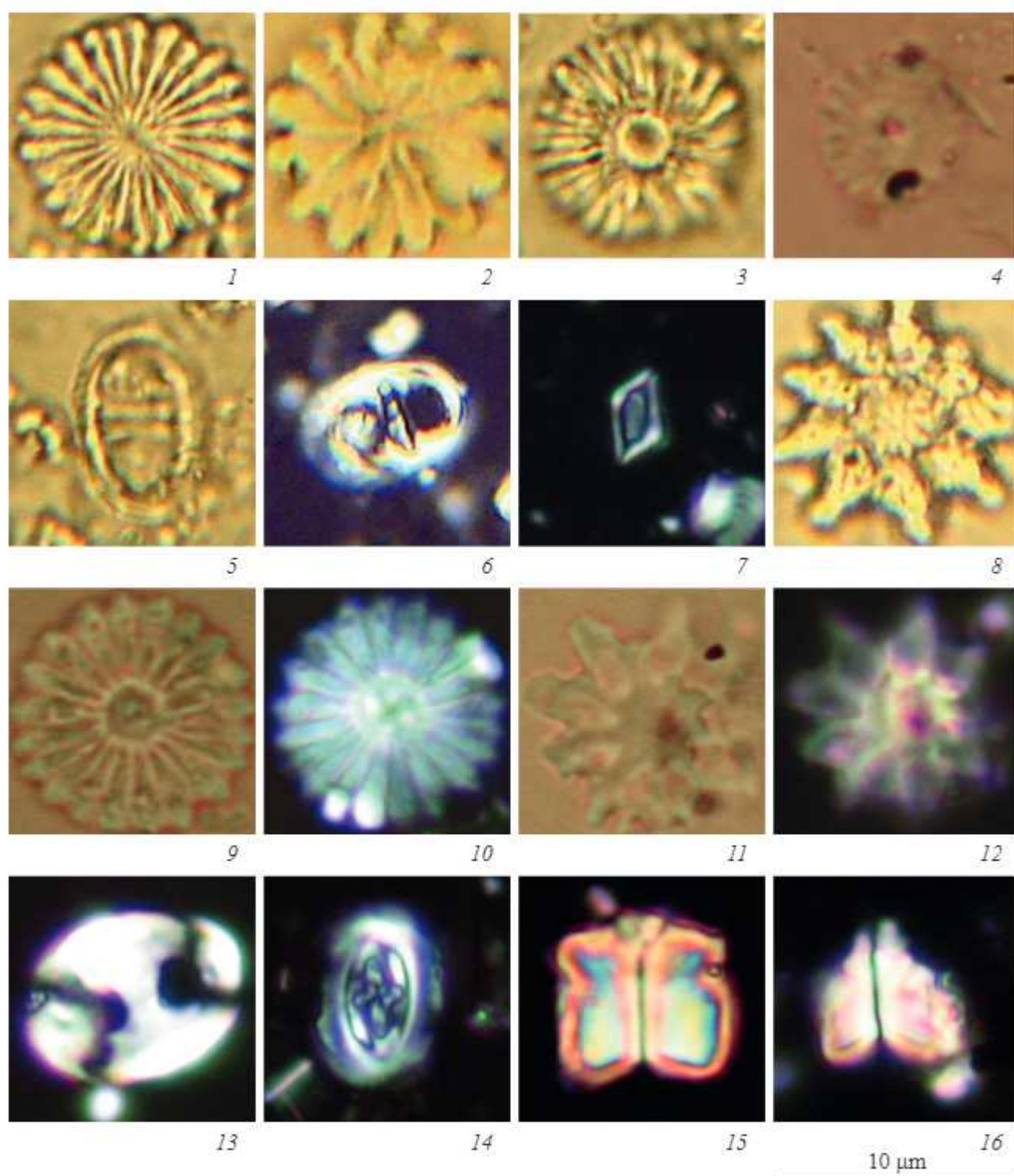


Plate 6.9B. Calcareous nannofossil species from the NP9 zone in the studied sections Byala 4 and Bozhuritsa. XPL and PPL photos

1 – *Discoaster multiradiatis*, section Bozhuritsa, sample Boj15; 2 – *Discoaster* sp. aff. *splendidus*, section Bozhuritsa, sample Boj15; 3 – *Discoaster salisburgensis*, section Bozhuritsa, sample Boj15; 4 – *Discoaster lenticularis*, section Byala 4; 5-6 – *Lophodolitus nascens*, section Bozhuritsa, sample Boj15; 7 – *Calcisolenia aperta*, section Bozhuritsa, sample Boj13; 8 – *Discoaster mediosus*, section Bozhuritsa, sample Boj15; 9-10 – *Discoaster salisburgensis*, section Byala 4, sample BSk-4; 11-12 – *Discoaster falcatus*, section Byala 4, sample BSk-4; 13 – *Transversopontis pulcher*, section Byala 4, sample BSk-4; 14 – *Campylosphaera eodela*, section Byala 4, sample BSk-4; 15 – *Fasciculithus involutus*, section Byala 4, sample BB116-4; 16 – *Fasciculithus lilianae*, section Byala 4, sample BB116-4

In Central northern Bulgaria it is detected in the section at Riben only, where its lower and middle parts are represented by a thickness of 0.6 m.

In the Central Fore-Balkan and Balkan the zone is documented in the section at Ichera-Gradets; here the thickness is 20 m. Quite likely the zone may be present at the base of the section at Veliko Tarnovo-Ledenik, where the thickness reaches 15 m.

In the East Fore-Balkan and Balkan the zone is 17 m thick in the section at Chudnite skali. It is also present in the sections near Byala – along Dolap dere, as well as in the section south of Byala (Stoykova & Ivanov, 2006b). The most complete section of the upper part of the zone is documented in the C-30 Goritsa well by Stoykova (in Stoykova & Vangelov, 1997) where its thickness reaches 12 m.

In the eastern parts of the Moesian Platform the zone is identified in the sections at Yankovo, Trastikovo, Sindel and Beloslav-South with a thickness ranging from 4 m to 20 m.

The presence of the zone in the Black Sea offshore area is evidenced in the Yuri Shimanov well and is 7 m thick.

Zone NP11 – *Discoaster binodosus* (Fig. 6.14)

Nomenclature. The zone was introduced for the first time by Mohler and Hay (1967) as “an interval from the extinction of *Marthasterites contortus* to the first occurrence of *Discoaster lodoensis*”.

In Bulgaria the zone was recorded for the first time by Muzilev (in Aladjova-Hrischeva et al., 1983) who mentioned only the name of the zone.

Definition. Interval from the LO (extinction) of *Tribra-chiatus contortus* to the FO of *Discoaster lodoensis*.

Stratigraphic range. Lower Eocene, lower part of Ypresian Stage. The time equivalent of the zone is approximately 550 Ka (Agnini et al., 2007a).

Remarks. The lower boundary of the zone is fixed by the extinction (LO) of *Tribra-chiatus contortus*. The extinction of a given taxon is a biohorizon, which may be difficult to identify due to the possibility of reworking into higher stratigraphic levels. The LO of *Tribra-chiatus contortus* cannot always be clearly pinpointed. In this case, the boundary is traced approximately by the FO of *Tribra-chiatus orthostylus* – a bioevent, which predates the LO of *T. contortus*, but *Tribra-chiatus orthostylus* occurs relatively more frequently.

The FO of species *Toweius gammatum* is observed in the middle of the zone (Fig. 6.14).

The characteristic association of the zone comprises (Plate 6.11): *Tribra-chiatus orthostylus*, *Sphenolithus radians*, *S. anarrhopus*, *Ericsonia formosa*, *Toweius gammatum*, *Discoaster barbadiensis*, *D. septem-radiatus*, *D. kuepperi*, *D. distinctus*, *D. binodosus*, *D. diastypus*, *Campylosphaera dela*, *Chiasmolithus grandis*, *C. consuetus* and *C. eograndis*.

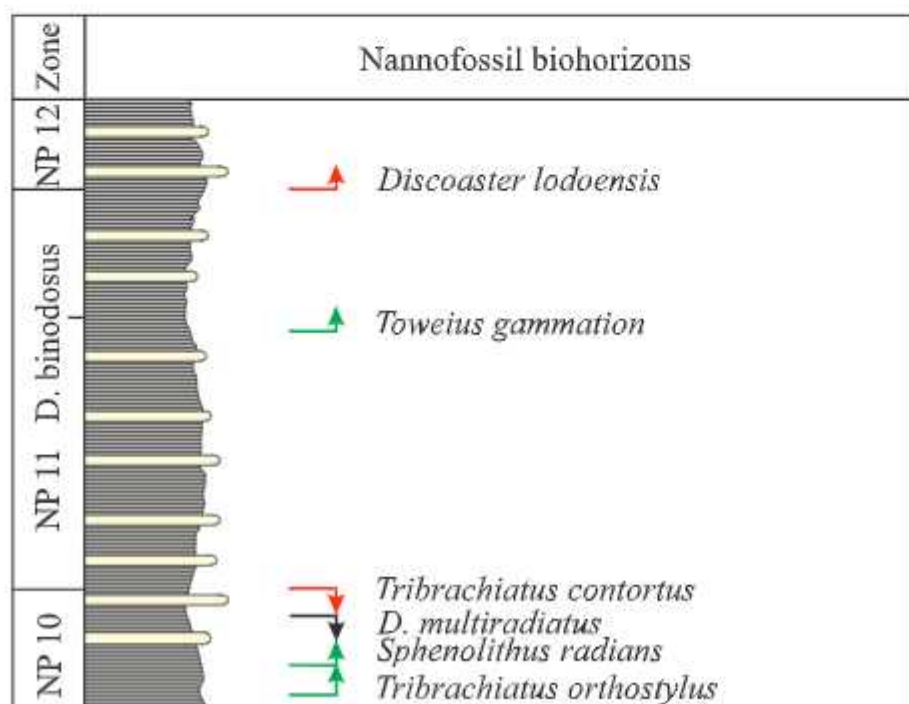


Fig. 6.14. Nannofossil biohorizons in the range of NP11 zone

The upper boundary of the zone is drawn clearly by the FO of *Discoaster lodoensis*. It is easily traced in all studied sections, as the species shows very clear morphology and occurs abundantly.

Distribution and correlations. The zone is distinguished in the low and mid latitudes. In the ocean sections it corresponds to subzone CP9b of Okada and Burky (1980), as well as to most of biozone CNE3 of Agnini et al. (2014).

In the Central Fore-Balkan and Balkan, it is documented in the region of Tarnovo, the Veliko Tarnovo-Ledenik section (20 m thick) and in the Icheri-Grads section (exceeds 25 m thickness).

In the East Fore-Balkan and Balkan it is proved in the section at Bardarevo. However, its thickness cannot be precisely estimated – around 50 m including the underlying zone NP10. In the section at Chudnite skali it is 18 m thick. Its occurrence is documented in tectonically disturbed slices in the C-30 Goritsa well, however, the precise thickness cannot be estimated.

In the eastern parts of the Moesian Platform the zone is identified in the section at Yankovo, where it is 7 m thick, and in the sections at Beloslav (South and North) where it corresponds to a barren-zone.

Zone NP12 – *Tribrachiatus orthostylus* (Fig. 6.15)

Nomenclature. The zone was introduced for the first time by Brönnimann and Strander (1960). In Bulgaria the zone was identified for the first time by Muzilev

(in Aladjova-Hrischeva et al., 1983), but more detailed characteristics were given by Stoykova (in Stoykova and Vangelov, 1997).

Definition. Interval from the FO of *Discoaster lodoensis* to the LO (extinction) of *Tribrachiatus orthostylus*.

Stratigraphic range. Lower Eocene, middle part of the Ypresian Stage.

Remarks. The lower boundary of the zone represents one of the best studied globally identified biohorizons in the lower Eocene (Brönnimann & Strander, 1960; Bramlette & Sullivan, 1961; Hay & Mohler, 1967; Bralower & Mutterlose, 1995; Raffi et al., 2005; Agnini et al., 2007a; Agnini et al., 2014). This level has been dated as 52.52 Ma (Agnini et al., 2007a). The first occurrence of *Discoaster lodoensis* is easily detected in the sections, due to its clear morphology and common occurrence in associations.

Moreover, the FO of another very characteristic species – *Discoaster kuepperi* – is concomitant with the FO of *D. lodoensis* or slightly predates it, in the upper portion of the preceding NP11 zone (Fig. 6.15).

In the lower part of the zone, the appearance of the genus *Helicosphaera* with the species *H. lophota* and *H. seminulum* is recorded (Fig. 6.15).

The representatives of genus *Chiphragmalithus* – *C. calathus*, *C. acanthodes*, and *C. barbatus* occur only within this zone.

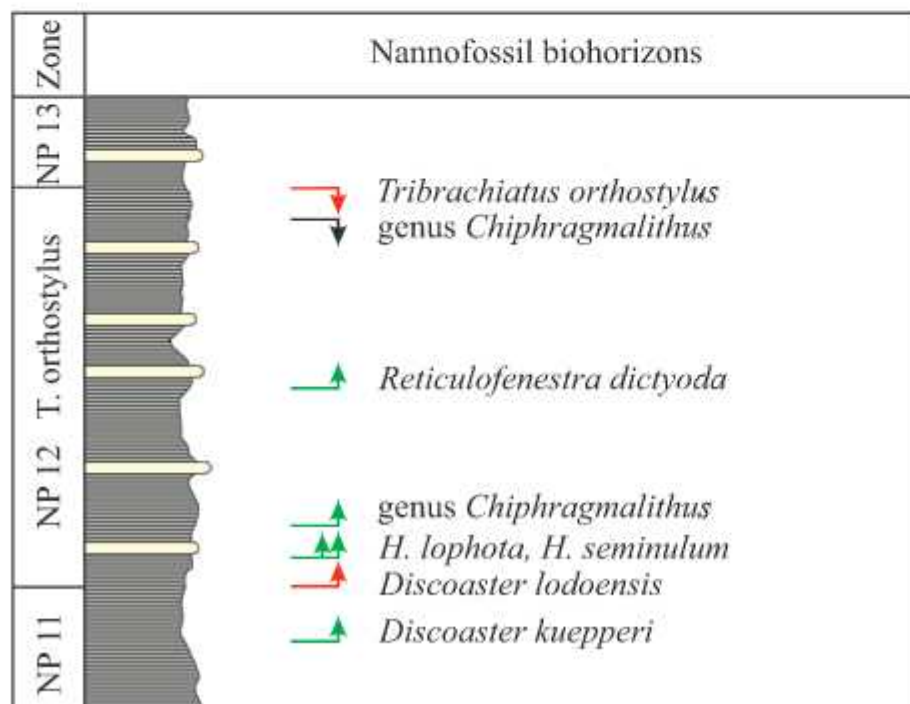


Fig. 6.15. Nannofossil biohorizons in the range of NP12 zone

The FO of another typical and commonly occurring species – *Reticulofenestra dictyoda* – is noted around the middle part of the zone.

Various species of the genus *Discoaster* are documented consistently in the zone – *D. istanbulensis*, *D. distinctus*, *D. gemmifer*, *D. germanicus*, *D. septemradiatus* and *D. nonaradiatus*. Their ranges, however, are not adequately explored globally to determine which of these render high stratigraphic value and utility as reliable markers. It seems they could be used in subdivision and correlation once sufficient data is gathered.

The uppermost part of the zone shows the LO (extinction) of the genus *Chiphragmalithus*.

The upper boundary is traced by the LO of *Tribra-chiatus orthostylus*. In discussing the preceding zone, I already commented on the reliability of bioevents related to extinction of nannofossil species. These events are not always clearly evident in the sequences due to potential reworking, as a consequence of which the tracing of a boundary may be conditional. These considerations apply fully when tracing the upper boundary of zone NP12, too. The LO of *T. orthostylus* is not an abrupt event, or the species is missing in the associations. In the majority of cases, joint NP12-13 zone is recognized in the sections at Sveti Atanas, Obzor-Meshelika, Kipilovo and Zhaltesh-Yaseni, etc.

The characteristic association of the zone consists of the following species, among others (Plates 6.12A, 6.12B): *Discoaster lodoensis*, *D. kuepperi*, *D.*

distinctus, *D. barbadiensis*, *D. germanicus*, *D. septemradiatus*, *D. nonaradiatus*, *Tribra-chiatus orthostylus*, *Chiphragmalithus calathus*, *C. acanthodes*, *Toweius gammaton*, *T. callosus*, *Helicosphaera lophota*, *H. seminulum*, *Sphenolithus radians*, *S. conspicuus*, *Chiasmolithus eograndis*, *Zygrhablithus bijugatus*, *Reticulofenestra dictyoda*, *Lophodolichus nascens* and *Neococcolithus dubius*.

Distribution and correlations. The zone is distinguished in the low and mid latitudes. In the ocean sections it corresponds to CP10 zone and lower part of CP11 zone of Okada and Burky (1980), as well as to CNE4 zone of Agnini et al. (2014).

Stoykova and Ivanov (2005) detected it for the first time in the section at Kladorub, Kula Zone. It is documented in the coarse-clastic sediments of the Staropatisa Formation, with a thickness exceeding 200 m. It is also recorded in the section at Rakovitsa village.

In the region of Lukovit, the zone is documented in all studied sections, and its thickness varies between 150 m and 200 m.

In Central northern Bulgaria it is identified in all studied sections, with an average thickness of around 5 m.

Within the Central Fore-Balkan and Balkan, the NP 12 zone is documented in sections in the region of Tarnovo, Gabrovo and Tryavna (Veliko Tarnovo, Vrabtsite, Gabrovo, Yaseni-Zhaltesh, Belitsa and Mishemorkovhan) and Sliven (Kipilovo), showing significant thickness of 50-70 m.

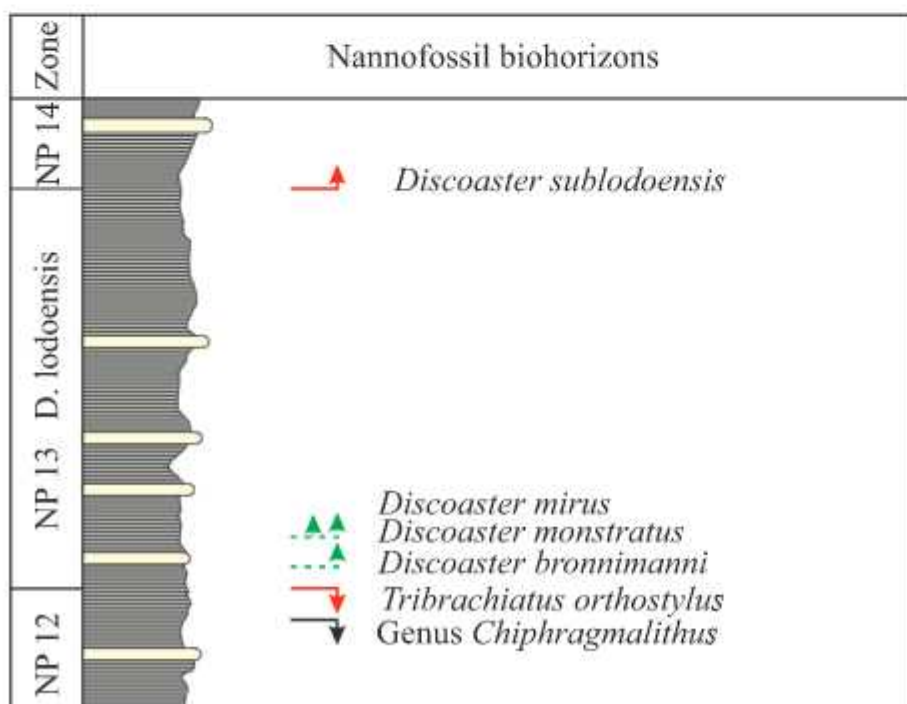


Fig. 6.16. Nannofossil biohorizons in the range of NP13 zone

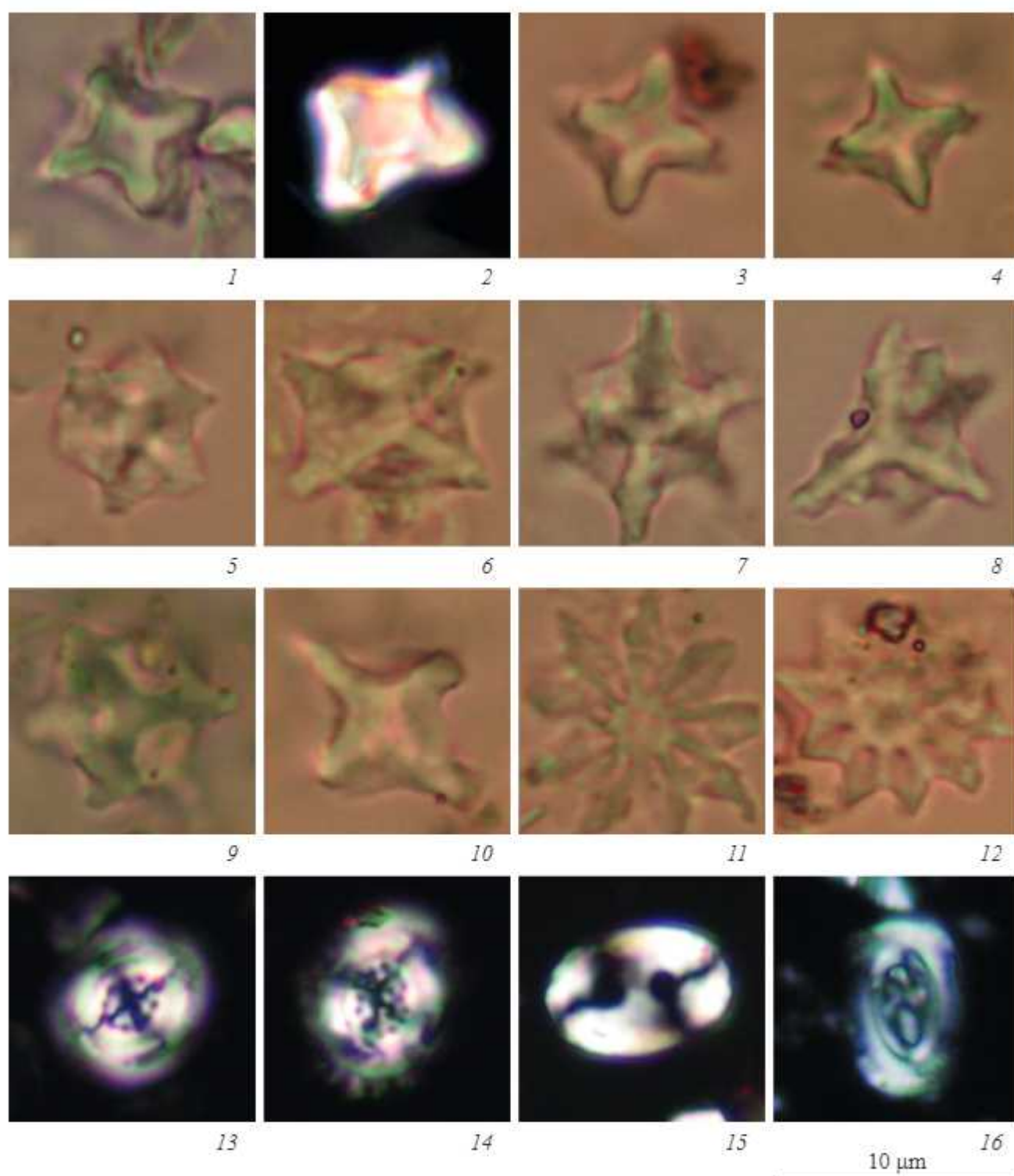


Plate 6.10A. Calcareous nannofossil species from the NP10 zone in the Dolap Dere, SE of Goritsa (1-10) and Byala 4 (11-16) sections. All photos with PPL except of 2, 13-16 (XPL)

1-4 – *Rhomboaster bramlettei*, section Dolap Dere, SE of Goritsa; 5-7 – *Rhomboaster bramlettei*, Ibid; 8 – *Rhomboaster spineus*, Ibid; 9-10 – *Rhomboaster bramlettei*, Ibid.; 11-12 – *Discoaster limbatus*, section Byala 4; 13-14 – *Toweius serotinus*, Ibid.; 15 – *Transversopontis pulcher*, Ibid.; 16 – *Campylosphaera eodela*, Ibid.

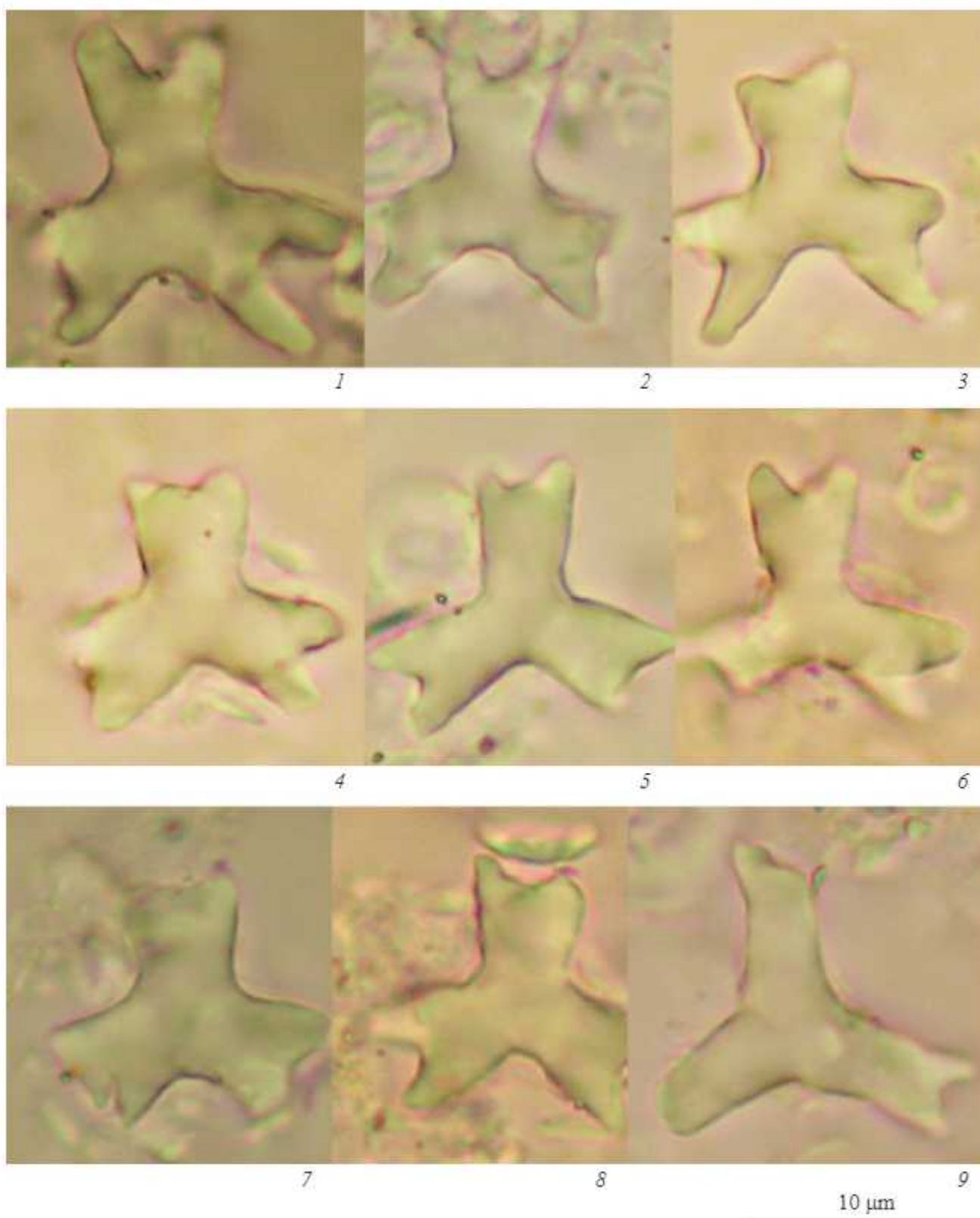


Plate 6.10B. Calcareous nannofossil species from the NP10 zone in the well section C-30 Goritsa. All photos with PPL

1-3 – *Tribrachiatus digitalis*, depth 126.50 m; 4-8 – *Tribrachiatus contortus*, depth 126.50 m; 9 – *Tribrachiatus contortus*, a transitional specimen to *Tribrachiatus orthostylus*, depth 130.00 m.

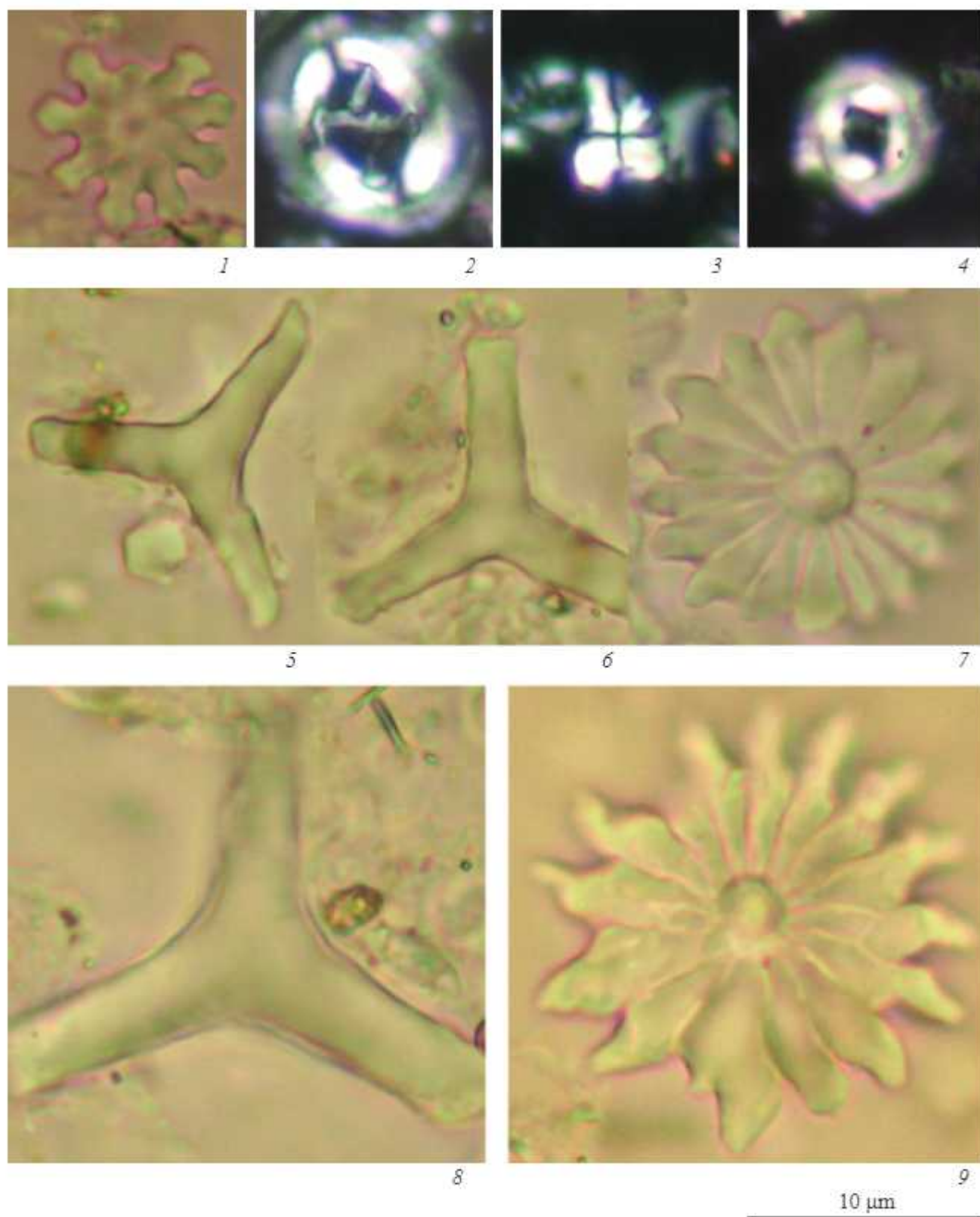


Plate 6.10C. Calcareous nannofossil species from the NP10 zone in the well section C-30 Goritsa. All photos with PPL except of 2, 3 and 4

1 – *Discoaster septemradiatus*, depth 126.50 m; 2 – *Chiasmolithus edentulus*, Ibid.; 3 – *Sphenolithus anarrhopus*, Ibid.; 4 – *Toweius callosus*, Ibid.; 5-6, 8 – *Tribrachiatus orthostylus*, depth 111.20 m; 7 – *Discoaster diastypus*, depth 126.50 m; 9 – *Discoaster pacificus*, Ibid.

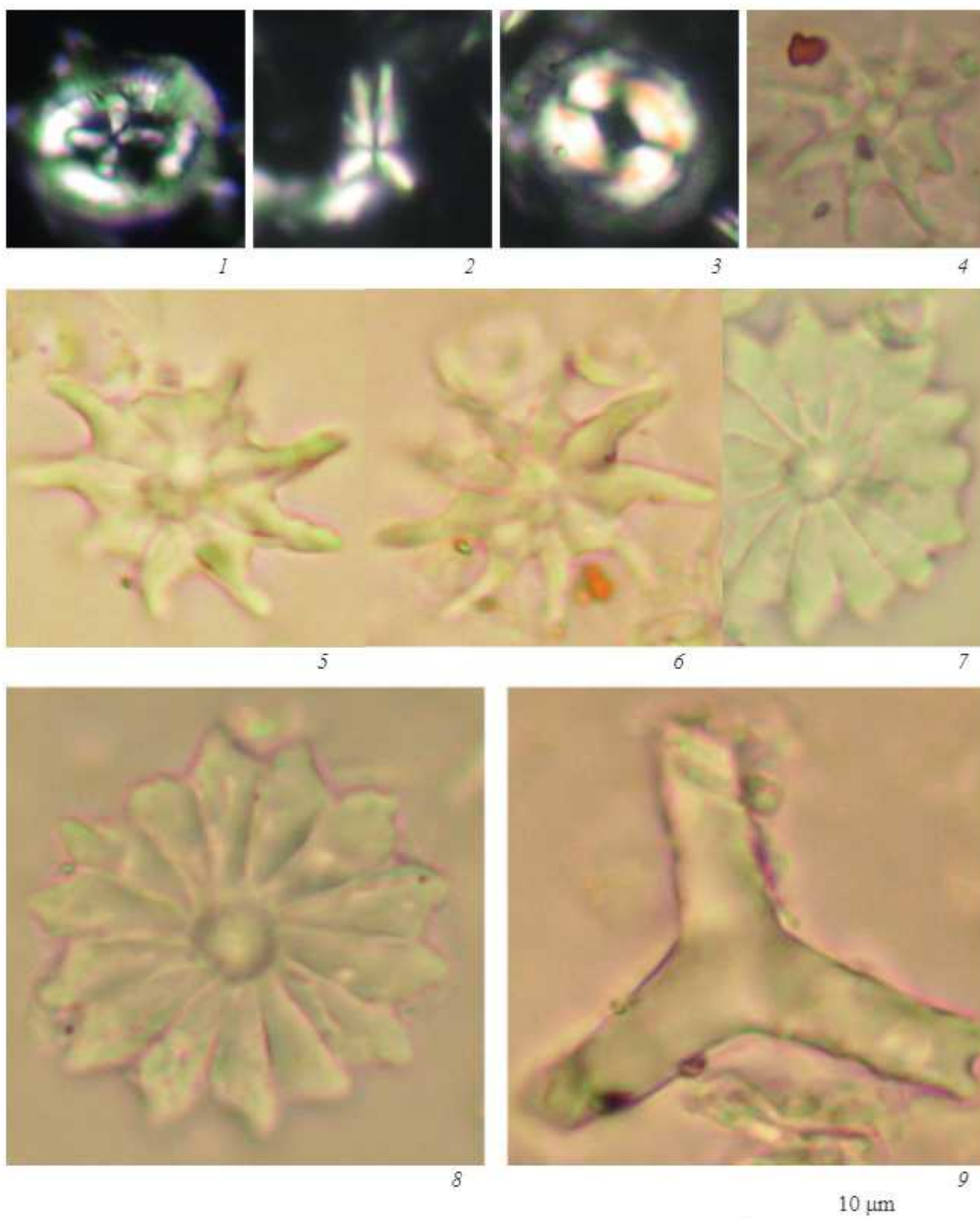


Plate 6.10D. Calcareous nannofossil species from the NP10 zone in the well section C-30 Goritsa. All photos with PPL except of 1-3

1 – *Chiasmolithus consuetus*, depth 126.50 m; 2 – *Sphenolithus editus*, Ibid.; 3 – *Coccolithus eopelagicus*, depth 130.00 m; 4-6 – *Discoaster araneus*, depth 126.50 m; 7-8 – *Discoaster diastypus*, depth 126.50 m; 9 – *Tribrachiatus orthostylus*, depth 111.20 m.

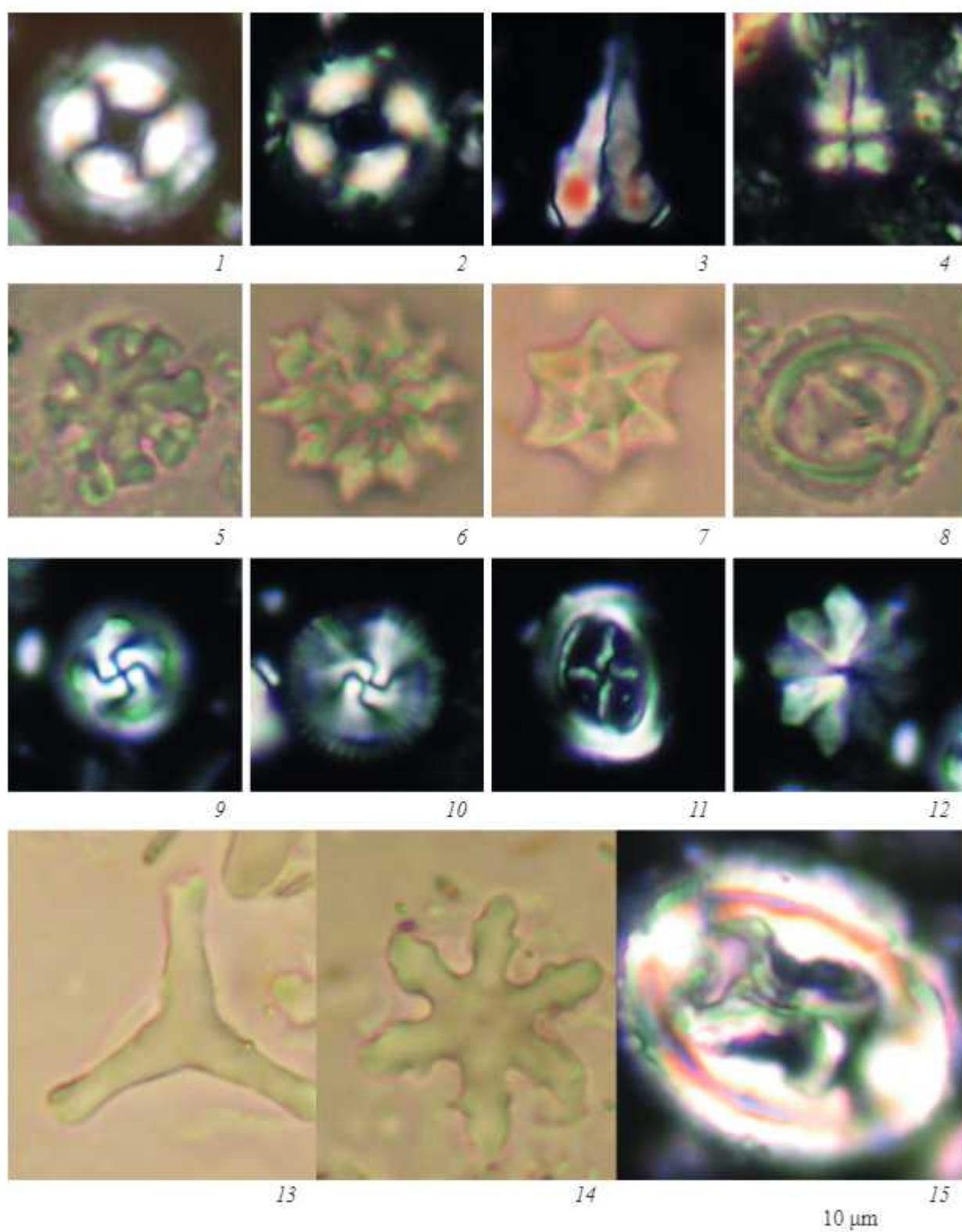


Plate 6.11. Calcareous nannofossil species from the NP11 zone in the studied sections. XPL and PPL photos

1, 2 – *Ericsonia formosa*, Chudnite skali section (1); Beloslav-North section, +17m (2); 3 – *Zygrhablithus bijugatus*, Yankovo section, +8 m; 4 – *Sphenolithus radians*, Chudnite skali section; 5 – *Discoaster nonaradiatus*, Ibid.; 6, 12 – *Discoaster barbadiensis*, Yankovo section, +8 m; 7 – *Discoaster kuepperi*, C-30 Goritsa, depth 130 m, 8 – *Chiasmolithus eograndis*, Riben section, sample Rib 22; 9-10 – *Toweius gammatum*, Beloslav-North section, +17 m (9); Yankovo section, +4.50 m (10); 11 – *Campylosphaera dela*, Yankovo section, +6 m; 13 – *Tribrachiatus orthostylus*, C-30 Goritsa, depth 130 m; 14 – *Discoaster binodosus*, Ibid.; 15 – *Chiasmolithus bidens*, Ibid.

In the East Fore-Balkan and Balkan, it is proved in the section at Chudnite skali where the thickness reaches 7 m. The greatest thickness of the zone is measured in the sections around Obzor – 150-200 m.

In the eastern parts of the Moesian Platform, the zone is detected in the sections at Yankovo and Beloslav, with a thickness of about 10 m.

In the offshore Black Sea, the zone is proved in the wells Samotino-More (the greatest thickness penetrated – 250-300 m), Galata-1 (7 m) and Galata-2 (7 m).

Zone NP13 – *Discoaster lodoensis* (Fig. 6.16)

Nomenclature. The zone was introduced by Brönnimann and Strander (1960). In Bulgaria, the zone was recorded for the first time by Muzilev (in Aladjova-Hrischeva et al., 1983), but its detailed characteristics were elaborated upon by Stoykova (in Stoykova & Ivanov, 2004b).

Definition. Interval from the LO (extinction) of *Tribrachiatus orthostylus* to the FO of *Discoaster sublodoensis*.

Stratigraphic range. Lower Eocene, middle and upper parts of Ypresian Stage.

Remarks. The lower boundary of the zone has been discussed in the preceding zone NP12. Usually, a joint zone NP12-13 is recognized in the sections, where the LO of *Tribrachiatus orthostylus* is ambiguous or difficult to trace precisely.

The lower part of the zone reveals the FO of a group of species of the genus *Discoaster* with particular morphology: *Discoaster broennimannii*, *D. monstratus* and *D. mirus*.

Their ranges are likely restricted only within this zone, but due to lack of sufficient data they could not be used for stratigraphic purposes (Fig. 6.16).

The upper boundary of the zone is traced by the FO of *Discoaster sublodoensis* – a clearly expressed biohorizon, observed in all studied sections.

The following species occur typically in the zone (Plate 6.13): *Discoaster lodoensis*, *D. barbadiensis*, *D. broennimannii*, *D. turkyensis*, *D. mirus*, *D. binodosus*, *D. septemradiatus*, *D. germanicus*, *Lophodolichus nascens*, *Chiasmolithus grandis*, *C. eograndis*, *Sphenolithus radians*, *Toweius gammation*, *Ericsonia formosa*, *Helicosphaera lophota*, *Neococcolithes dubius* and *Reticulofenestra dictyoda*.

Distribution and correlations. The zone is identified in the low and mid latitudes. It corresponds to zone CP11 of Okada and Burky (1980) and to CNE5 zone of Agnini et al. (2014).

In the West Fore-Balkan, the zone is evidenced in all studied sections in the Lukovit region, with thickness varying from 150 m to 200 m.

In Central northern Bulgaria it is observed in the Riben and Bozhuritsa sections, where the measured thickness is 4 m. It is also present in the sections north of Gradina village and near Tarnene village (not described here) in the marls of the Avren Formation.

Within the Central Fore-Balkan and Balkan, the zone is documented in sections of the Tarnovo, Gabrovo, Tryavna and Sliven regions, as one combined zone NP12-13 of considerable thickness (70-100 m).

In the East Fore-Balkan and Balkan, the zone is proved in the section at Chudnite skali and is 10 m thick. In the sections near Obzor (Sveti Atanas and Meshelika), the zone shows its greatest thickness – 200-300 m.

In the eastern parts of the Moesian Platform the zone is observed in the Beloslav-South section with a thickness of around 10 m.

In the Black Sea area, it is proved in the wells Samotino-More (thickness around 300 m), Galata-1 (10 m), Galata-2 (7 m) and Yuri Shimanov (10 m).

Zone NP14 – *Discoaster sublodoensis* (Fig. 6.17)

Nomenclature. The zone was introduced by Hay (1964) as “an interval from the first occurrence of *Discoaster sublodoensis* to the first occurrence of *Chiphragmalithus quadratus* (= *Nannotetrina quadrata*)”. Burky (1973) divided the zone into 2 sub-zones, using the FO of *Rhabdosphaera inflata*.

Okada and Burky (1980) used the LO of *Rhabdosphaera inflata* as a biohorizon for defining the upper boundary of their zone CP12 along with the appearance of *Nannotetrina quadrata*.

Since *Nannotetrina quadrata* (Bramlette & Sullivan, 1961) Burky, 1973 is a subjective synonym of *Nannotetrina fulgens* (Strander in Martini & Strander, 1960) Achuthan & Strander, 1969, the definition of the zone uses the valid name *Nannotetrina fulgens*.

In Bulgaria the zone was identified for the first time by Stoykova (1990) in sections of the Avren Formation in Central northern Bulgaria.

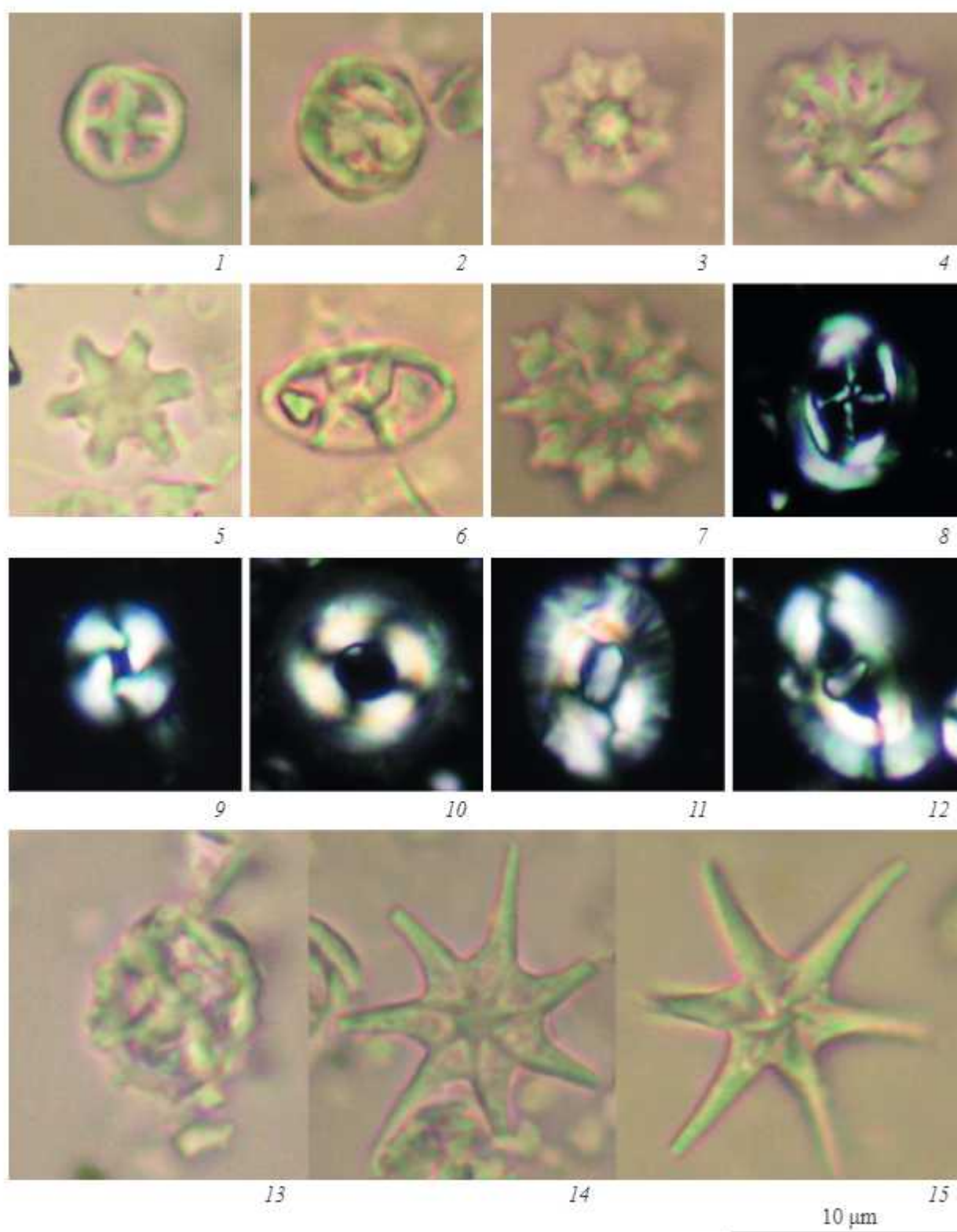


Plate 6.12A. Calcareous nannofossil species from the NP12 zone in the studied sections Riben and Bozhuritsa. XPL and PPL photos

1-2 – *Chiphagmalithus barbatus*, sample Boj16; 3-4 – *Discoaster kuepperi*, sample Boj17; 5 – *Discoaster* spp. sample Boj17; 6 – *Neococcolithes dubius*, sample Rib21; 7 – *Discoaster barbadiensis*, sample Rib21; 8 – *Campylosphaera dela*, sample Rib20; 9 – *Reticulofenestra dictyoda*, sample Rib21; 10 – *Ericsonia formosa*, sample Boj16; 11 – *Helicosphaera lophota*, sample Boj16; 12 – *Helicosphaera seminulum*, sample Boj17; 13 – *Chiphragmalithus calathus*, sample Boj16; 14-15 – *Discoaster lodoensis*, sample Boj17.

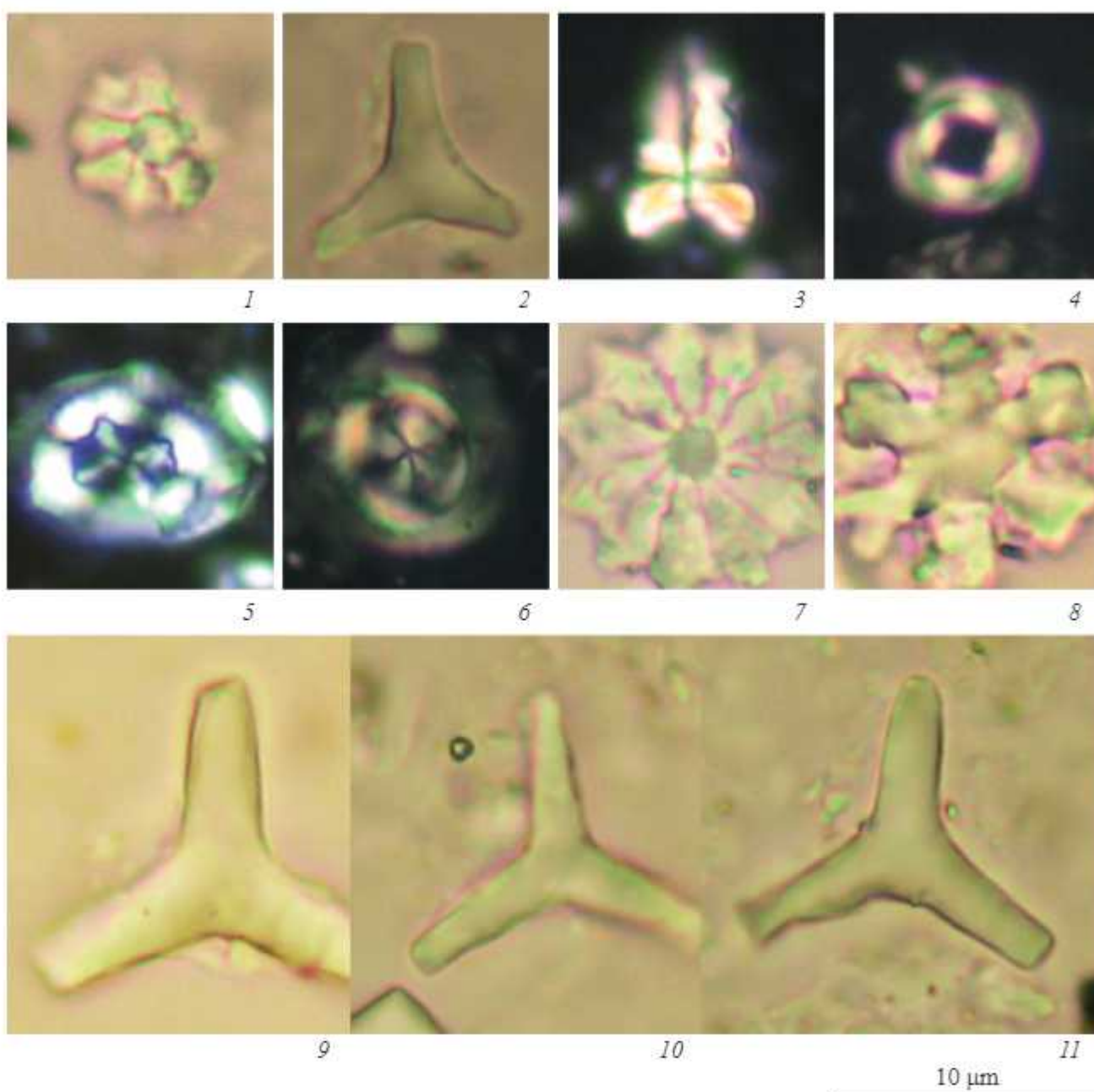


Plate 6.12B. Calcareous nannofossil species from the NP12 zone in the studied sections Riben and Bozhuritsa. All photos with PPL except of 3-6

1 – *Discoaster kuepperi*, sample Boj16; 2 – *Tribrachiatus orthostylus*, sample Boj16; 3 – *Sphenolithus radians*, sample Boj17; 4 – *Toweius callosus*, sample Rib 18; 5 – *Chiasmolithus consuetus*, sample Boj17; 6 – Gen. et sp.?, sample Boj16; 7 – *Discoaster barbadiensis*, sample Rib 20; 8 – *Discoaster deflandrei*, Rib 20; 9-11 – *Tribrachiatus orthostylus*, sample Boj17.

Definition. Interval from the FO of *Discoaster sublodoensis* to the FO of *Nannotetrina fulgens*. It is divided into two subzones:

- Subzone NP14a. Interval from the FO of *Discoaster sublodoensis* to the FO of *Rhabdosphaera inflata*;
- Subzone NP14b. Interval from the FO of *Rhabdosphaera inflata* to the FO of *Nannotetrina fulgens*.

Stratigraphic range. Lower Eocene, the uppermost part of the Ypresian Stage (subzone NP14a) and middle Eocene, the lowermost part of the Lutetian Stage (subzone NP14b).

Remarks. The subzones 14a and 14b are very clearly differentiated in the studied sections and the boundary between them coincides with the lower-middle Eocene boundary (Ypresian – Lutetian).

Subzone NP14a

The lower boundary of subzone 14a is traced by the appearance of the species *Discoaster sublodoensis*. This biohorizon is explicitly evident and easily recognized in the sections. The index species, 5-rayed *Discoaster sublodoensis* is commonly observed in the associations, although not in abundant quantities. Along with it the subzone reveals the presence of *Discoaster lodoensis* as well, i.e. the ranges of these two important stratigraphic markers overlap only in this subzone. The LO (extinction) of *Discoaster lodoensis* is detected in the uppermost portion of the zone, although it is commonly reworked in the upper zone NP15.

The FO of *Discoaster saipanensis*, a typical and commonly occurring species in the middle and upper Eocene, is documented after the extinction of *Discoaster lodoensis*, in the uppermost part of subzone NP14a.

The upper boundary of subzone NP14a, coinciding with the lower/middle Eocene boundary, is one of the most clearly expressed biohorizons as it is traced by the FO of *Rhabdosphaera inflata*.

The species *Rhabdosphaera inflata* bears clear taxonomic features and is easily identified. Moreover, shortly after its FO, it reaches a high abundance and dominates the nannofossil associations.

The subzonal association comprises the following species (Plate 6.14A): *Discoaster sublodoensis*, *D. lodoensis*, *D. barbadiensis*, *D. germanicus*, *D. distinctus*, *D. nonaradiatus*, *Reticulofenestra dictyoda*, *Toweius gammation*, *Helicosphaera lophota*, *Rhabdosphaera tenuis*, *Chiasmolithus grandis*, *C. solitus*, *Ericsonia formosa*, *Zygrhablithus bijugatus* and *Neococcolithes dubius*.

Distribution and correlations. The subzone is documented in the low and mid latitudes. In the ocean sections it corresponds to zone CP12a of Okada and Burky (1980), as well as to CNE6 and part of CNE7 zones of Agnini et al. (2014).

In the West Fore-Balkan it is proved in the region of Lukovit, occupying the uppermost portions of the Rumyantsevo and Golyama Brestnitsa-Daben sections, with a thickness of around 20 m.

In Central northern Bulgaria the subzone is detected in the sections at Yasen, Bivolare and Bozhuritsa, with a thickness of 18-20 m. It is also present in the sections north of Gradina village and near Tamene village (not described here), in the marls of the Avren Formation. In Central Fore-Balkan and Balkan the subzone is not clearly divided, although it seems to be present in the sections of the Lukovit Formation within the range of the composite zone NP12-14.

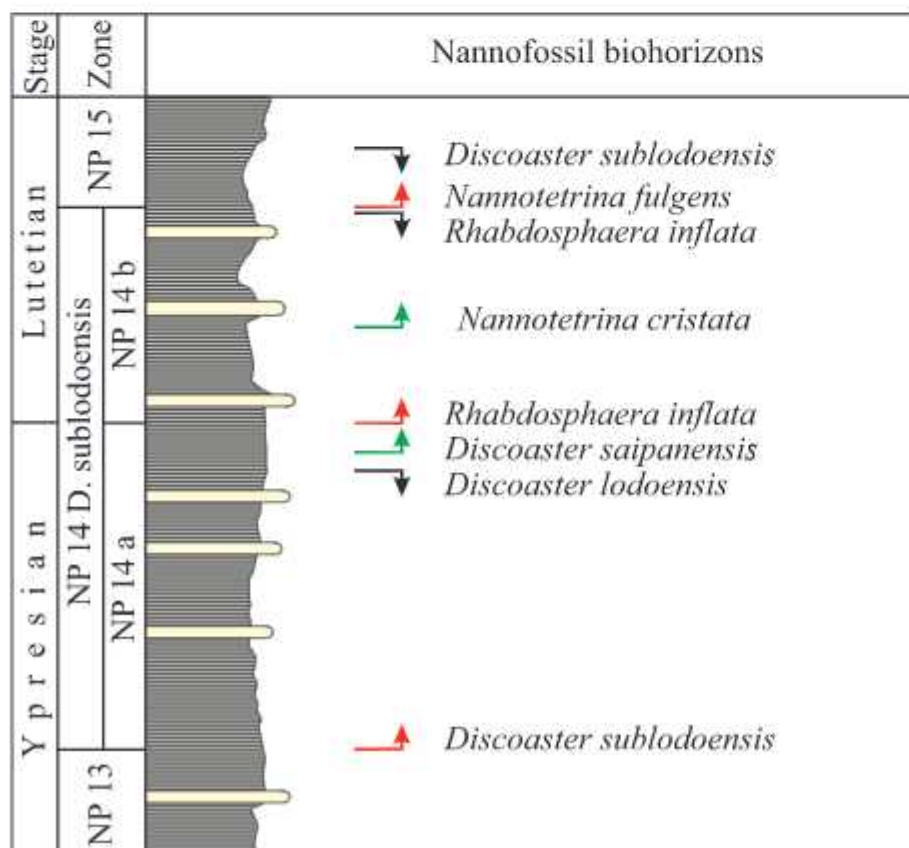


Fig. 6.17. Nannofossil biohorizons in the range of NP14 zone

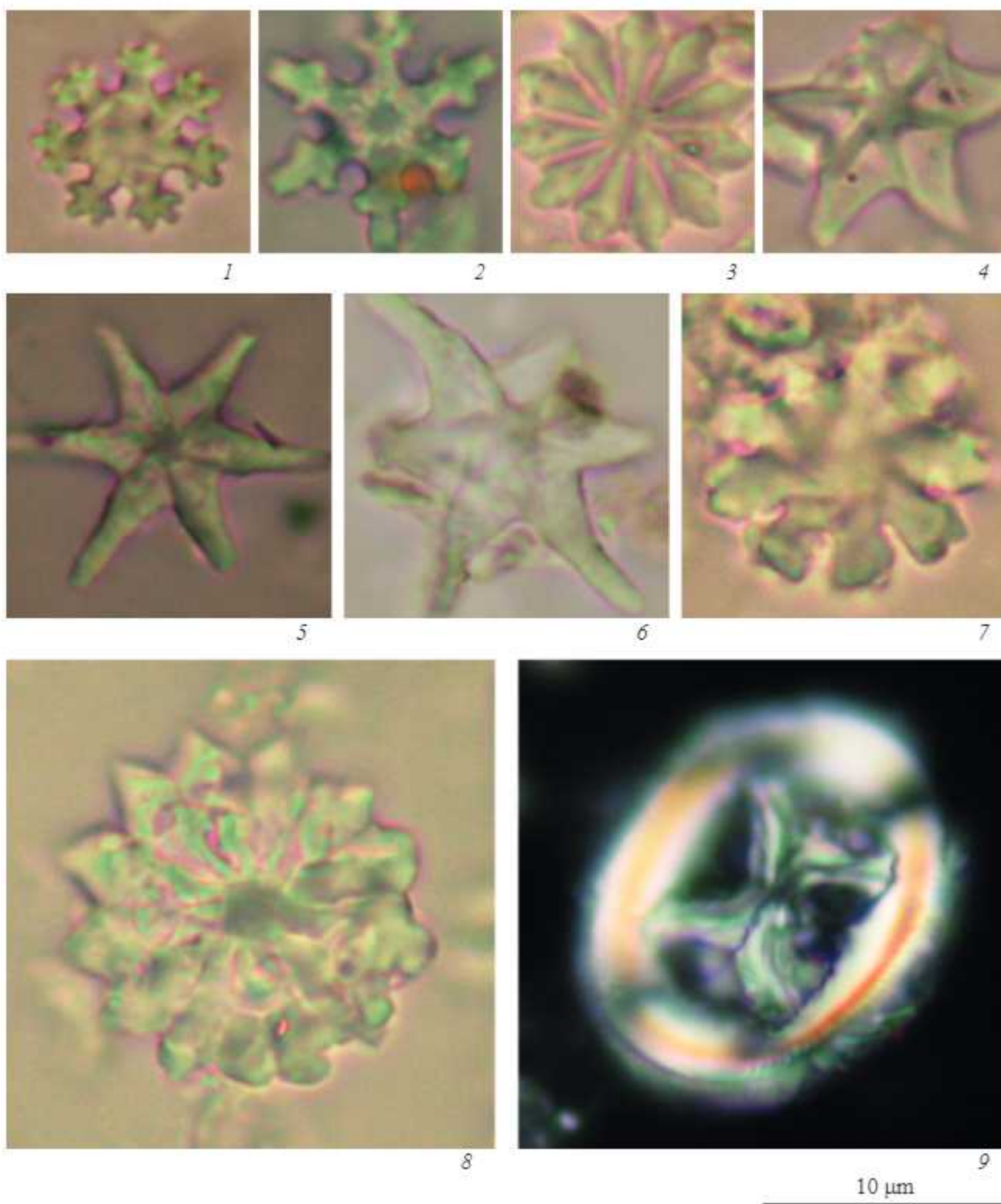


Plate 6.13. Calcareous nannofossil species from the NP13 zone in the studied section Bozhuritsa. All photos with PPL except of 9

1 – *Discoaster bronnimannii*, sample Boj18; 2 – *Discoaster binodosus*, sample Boj20; 3 – *Discoaster barbadiensis*, sample Boj19; 4-6 – *Discoaster lodoensis*, Ibid.; 7 – *Discoaster monstratus*, sample Boj20; 8 – *Discoaster barbadiensis*, sample Boj19; 9 – *Chiasmolithus grandis*, sample Boj20

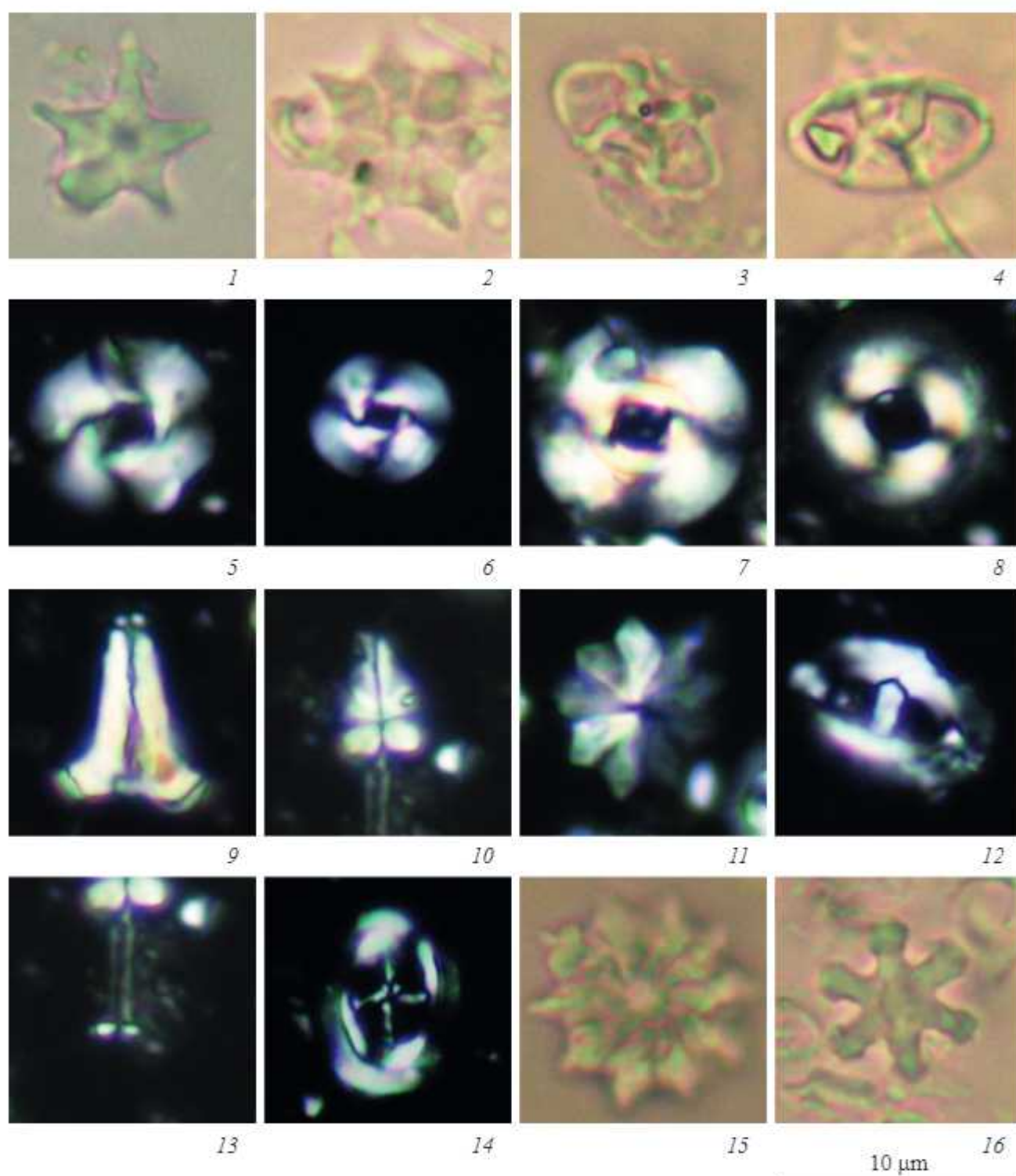


Plate 6.14A. Calcareous nannofossil species from the NP14a subzone in the studied sections Yasen and Bivolare. XPL and PPL photos

1 – *Discoaster subloboensis*, sample Yas +5 m; 2 – *Discoaster saipanensis*, sample Yas +15 m; 3-4 – *Neococcolithes dubius*, sample Biv +10 m; 5-6 – *Reticulofenestra dictyoda*, sample Biv +15 m; 7 – *Reticulofenestra wadeae*, sample Biv +18 m; 8 – *Ericsonia formosa*, sample Biv +5 m; 9 – *Zygrhablithus bijugatus*; 10 – *Sphenolithus radians*, sample Biv +15 m; 11 – *Discoaster barbadiensis*, sample Yas +10 m; 12 – *Lophodolichus nascens*, sample Biv +10 m; 13 – *Blackites truncatus*, Ibid.; 14 – *Campylosphaera dela*, Ibid.; 15 – *Discoaster barbadiensis*, sample Yas +5 m; 16 – *Discoaster germanicus*, sample Yas +10 m.

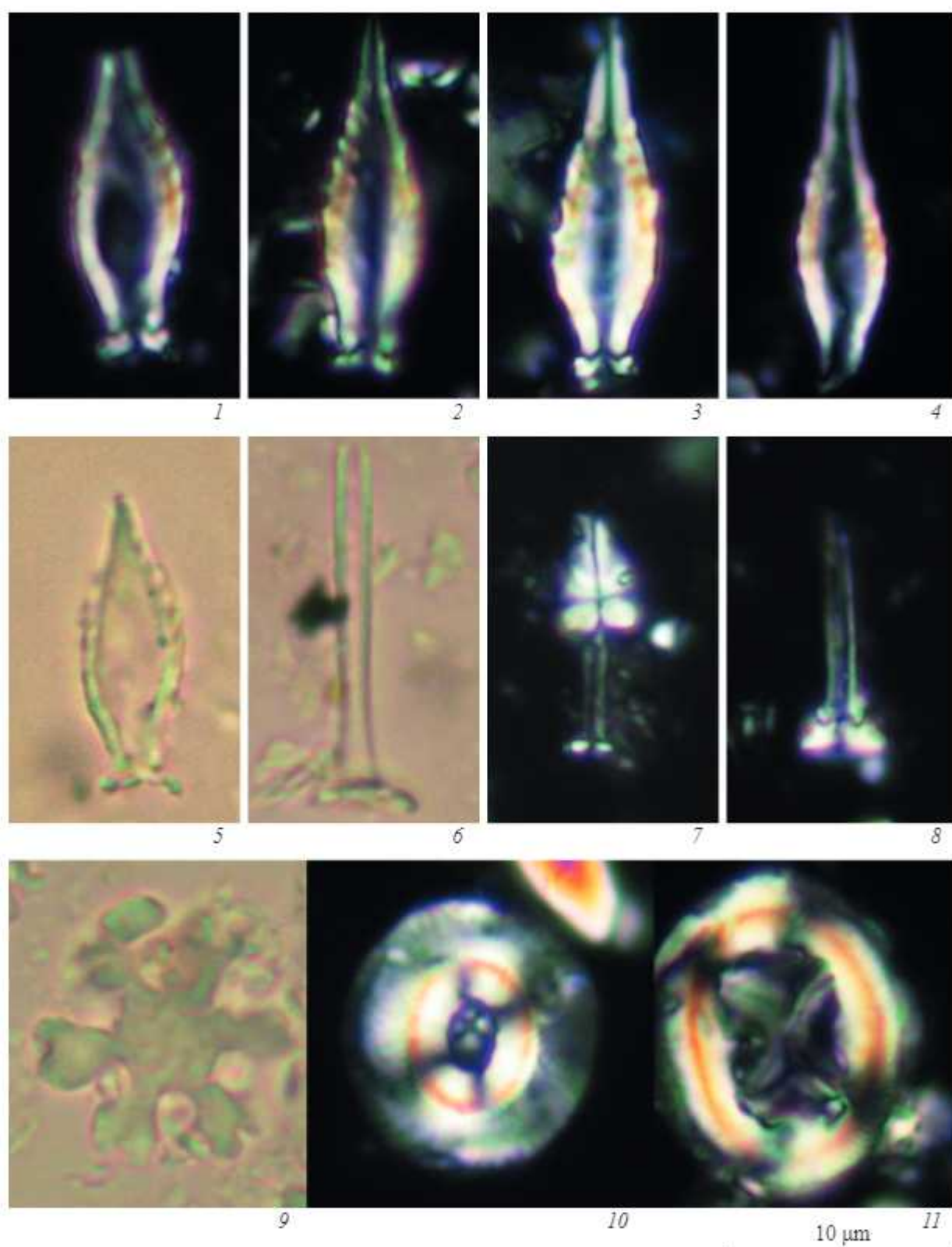


Plate 6.14B. Calcareous nannofossil species from the NP14b subzone in the studied sections Yassen and Bivolare. All photos with XPL except of 5, 6 and 9

1-5 – *Rhabdosphaera inflata*, samples Yas +17 m and Biv +20 m; 6 – *Rhabdosphaera perlonga*, sample Yas +20 m; 7 – *Blackites truncatus* (below) and *Sphenolithus radians*, sample Yas +17 m; 8 – *Blackites creber*, sample Yas +15 m; 9 – *Discoaster deflandrei*, sample Yas +30 m; 10 – *Coccolithus eopelagicus*, sample Yas +25 m; 11 – *Chiasmolithus grandis*, sample Yas +20 m.

In the East Fore-Balkan and Balkan it is evidenced in the section at Chudnite skali, corresponding with the last 2 m of the Avren Formation, immediately below the conglomerates (Obzor Formation, the so called "exotic conglomerate"). The subzone is identified in the uppermost levels of the section south of Obzor (Meshelika) where its thickness reaches 40–50 m.

In the Black Sea offshore area, the subzone is proved in the wells of Samotino-More (around 300 m within the composite zone NP12–14), Galata-1 (2 m), Galata-2 (3 m) and Yuri Shimanov (8 m).

Subzone NP14b

The biostratigraphic boundary between subzones NP14a and NP14b is considered as a boundary between the lower and middle Eocene and also the Ypresian and Lutetian Stages, respectively. The lower boundary of subzone 14b has already been discussed in the text on the preceding subzone. It is traced by the FO and abundant increase in numbers of *Rhabdosphaera inflata* (Fig. 6.17). In fact, the range of the subzone covers the complete vertical distribution of the species *Rhabdosphaera inflata*, i.e. it represents a taxon range zone. However, the commonly accepted criteria for the lower and upper boundary of the subzone describe it as an interval zone – from the FO of *Rhabdosphaera inflata* to the FO of *Nannotetrina fulgens*.

Representatives of the genus *Nannotetrina* occur for the first time near the middle of this subzone (Fig. 6.17). *Nannotetrina cristata* is the first species to appear, occupying the base of the evolutionary lineage *N. cristata* – *N. fulgens* – *N. pappii* (Romein, 1979) with subsequent representatives appearing higher in zone NP15.

The upper boundary of the subzone is clearly fixed by the FO of *Nannotetrina fulgens* – a bioevent, occurring concomitantly with the extinction of *Rhabdosphaera inflata* (Fig. 6.17).

In the base of the next NP15 zone, the LO (extinction) of *Discoaster sublodoensis* is registered.

The association of the subzone consists of the following species (Plate 14B): *Rhabdosphaera inflata*, *R. tenuis*, *Discoaster sublodoensis*, *D. saipanensis*, *D. deflandrei*, *D. barbadiensis*, *D. germanicus*, *Reticulofenestra dictyoda*, *Helicosphaera semimulum*, *H. lophota*, *Chiasmolithus solitus*, *C. grandis*, *Neococcolithes dubius*, *N. minutus*, *Transversopontis pulcher* and *Ericsonia formosa*.

Distribution and correlations. The subzone is observed in the low and mid latitudes. In the ocean sections it corresponds to zone CP12b of Okada and Burky (1980), as well as to part of CNE7 and CNE8 zones of Agnini et al. (2014).

The subzone is proved to exist in the region of Lukovit, occupying the highest portions of the Golyama Breznitsa-Daben section where its thickness is over 20 m.

In Central northern Bulgaria it is identified in the sections at Yassen and Bivolare, with a thickness of 15 m. The subzone is also present in the sections north of Gradina village and near Tarnene village (not described here), in the marls of the Avren Formation.

In the Black Sea area, the subzone is proved in the wells Galata-1 (1 m), Galata-2 (1 m) and Yuri Shimanov (12 m).

Chapter 7

Chronostratigraphy

7.1. Development of the concept concerning chronostratigraphic subdivision in the Paleocene and lower Eocene

The Paleogene System was introduced by Naumann in 1866. The names for the three Series were proposed by: Lyell, 1833 – for the Eocene, Beyrich, 1854 – for the Oligocene and finally by Schimper, 1874 – for the Paleocene. The volume of these Series is filled by seven Stages, as proposed by the International Subcommission on Paleogene Stratigraphy and formally approved by the International Geological Congress, held in Washington in 1989 (Jenkins & Luterbacher, 1992). These include Danian, Selandian and Thanetian Stages for the Paleocene Series; Ypresian, Lutetian, Bartonian and Priabonian for the Eocene Series and Rupelian and Chattian Stages for the Oligocene Series (Jenkins & Luterbacher, 1992).

At the present moment (2021) the International Subcommission on Paleogene Stratigraphy has officially ratified and approved eight Global Stratotype Sections and Points (GSSP). These are:

- GSSPs for Danian Stage;
- GSSPs for Selandian Stage;
- GSSPs for Thanetian Stage;
- GSSPs for Ypresian Stage;
- GSSPs for Lutetian Stage;
- GSSPs for Priabonian Stage;
- GSSPs for Rupelian Stage;
- GSSPs for Chattian Stage.

Many terms were introduced as stage names for the different parts of the Paleocene and Eocene Series during the nineteenth century. The stratotypes of the majority of Stages are of limited exposure, with lateral and vertical change of facies, representing marine, coastal and continental deposits. Therefore, correlation between these, as well as global application and use of the stage names has proved impossible. A brief review of some important stage terms, broadly used in current geological practice along with justification of their validity and use, or rejection in modern stratigraphic practice, is compiled and discussed below.

7.1.1. Paleocene Series

Danian Stage

The Danian Stage is the oldest chronostratigraphic unit in the Paleocene Series, encompassing all rocks formed during the Danian Age (65.5 Ma to 61.7 Ma – Luterbacher et al., 2004).

The Danian Stage was proposed by the geologist Pierre Jean Edouard Desor in 1847, to describe the limestones exposed at Stevns Klint and Fakse, Denmark. Initially the Stage had been assigned to the Cretaceous System due to the significant similarities between the invertebrate fauna in these limestones with the Cretaceous fauna. It was only later that the Stage was reasonably granted its position at the base of the Paleocene Series. In the type area at Stevns Klint, the Danian Stage includes the sediments occurring between the Maastrichtian chalky limestones and the basal conglomerate (clastic sediments) of the Selandian.

The base of the Cenozoic Era, Paleogene System, Paleocene Series and Danian Stage is defined at the reddish layer at the base of the 50 cm thick, dark boundary clay, west of El Kef, Tunisia, where it coincides with the Iridium Anomaly fallout from a major asteroid impact. The GSSP is located about 7 km west of the town of El Kef, at latitude 36°09'13.2"N, longitude 8°38'54.8"E. The GSSP is defined at the base of the boundary clay. It is overlain by a rusty red layer containing a peak of Ni-rich spinel, which is more highly concentrated than in the iridium anomaly. This millimetre-thick layer, containing the evidence of the meteorite impact and other significant geochemical changes, coincides with a sudden catastrophic mass extinction event – dinosaurs, ammonites, foraminifers, etc. (Molina et al., 2006b; <https://www.paleogene.org/danian-stratotype/>).

The modern analyses of the microfossils in the stratotype area show that the Danian Stage includes the nanofossil zones from NP1 to the upper part of NP4 (Perch-Nielsen, 1979; Varol, 1989) and the planktonic foraminifera zones from P0 to P2 (Figs. 7.1, 7.2).

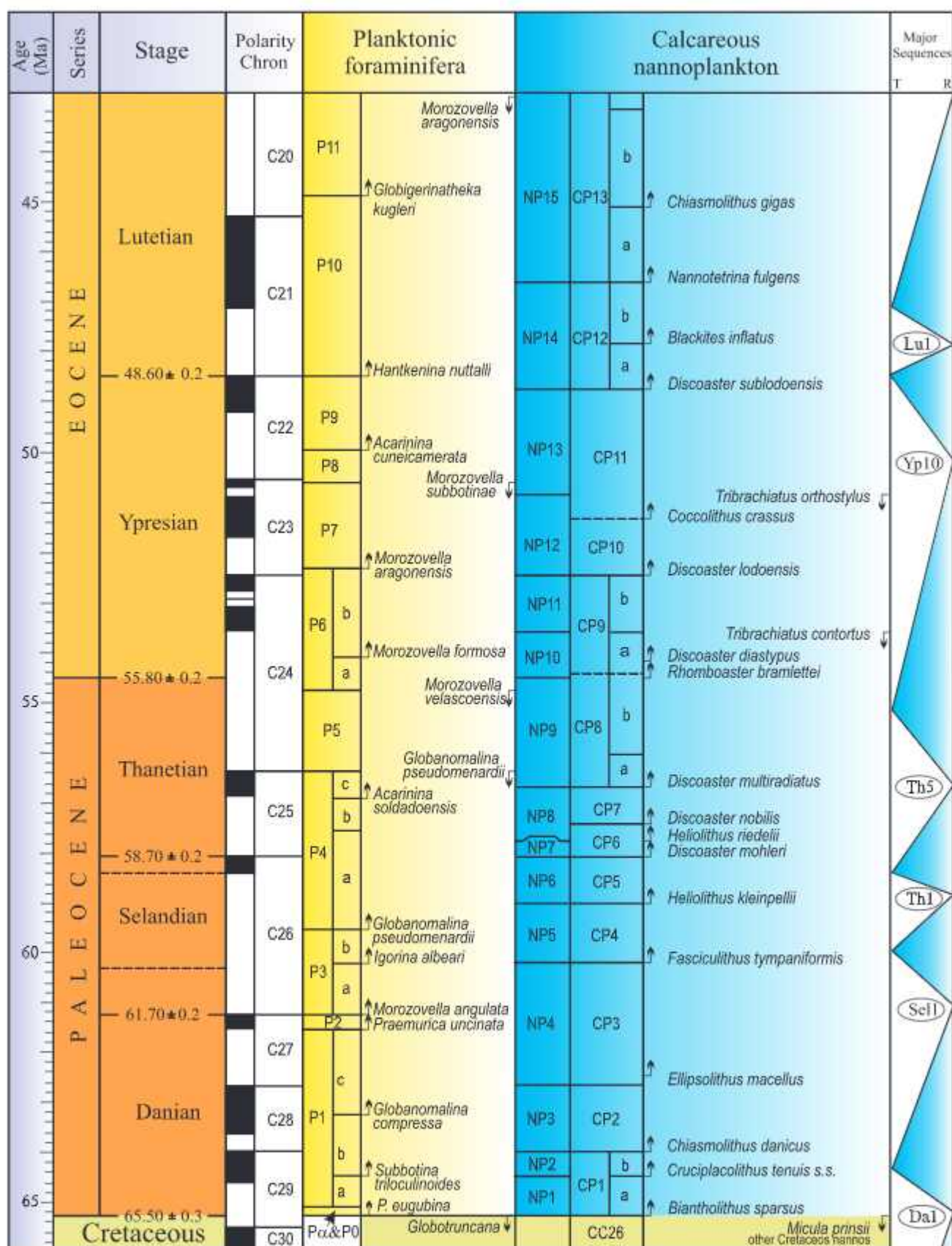


Fig. 7.1. Chronostratigraphic scale for the Paleocene and Eocene Series, plotted against biozonations by planktonic foraminifera and calcareous nannoplankton and sequence stratigraphy scheme (after Luterbacher et al., 2004)

Monsian Stage

The Monsian Stage was proposed by Dewalque (1868) to denote the limestones ("Calcaire de Mons") outcropping in the outskirts of the city of Mons, Belgium. These limestones contain exceptionally rich mollusk associations of clearly Cenozoic affinity. In fact, it is the fossil content that justified the proposal of this new stage term, since at that time the Danian Stage (Desor, 1847) was considered as belonging to the Upper Cretaceous.

Much later, the detailed micropaleontological studies in the stratotype area proved that the sediments are clearly Cenozoic in age, but they represent a lateral-temporal analogue of the middle and upper parts of the Danian Stage (Fig. 7.2). Therefore, the Monsian Stage is not a valid name and its use is not recommended.

Selandian Stage

The Selandian Stage includes all rocks formed during the Selandian Age – from 61.7 to 58.7 Ma (Luterbacher et al., 2004; Fig. 7.1, 7.2).

The Selandian Stage was introduced by Rosenkrantz (1924) to nominate the clastic sequence that unconformably overlies the Danian limestones and occurs under the clays with volcanic ash (Mo-clay) in Denmark. The sequence is composed of conglomerates, sandstones, marls and clays. The section at Vestre Gasvaerk, exposed in the vicinity of Copenhagen, is assumed to be the type section. The section covers the uppermost part of nannofossil zone NP4, the entire NP5 zone and the lower part of zone NP6 (Perch-Nielsen & Hansen, 1981).

The base of the Selandian Stage is defined in the sea-cliff along the main beach of the coastal town Zumaia, Basque Country, northern Spain (latitude 43°17'57.1"N, longitude 02°15'39.6"W). The GSSP is at the base of the Itzurun Formation, about 49 m above the Cretaceous/Paleogene boundary. The best event for global marine correlation is the second radiation of the fasciculith group of calcareous nannofossils, occurring from slightly below to 1.1 m above the GSSP.

The marker species for the base of nannofossil zone NP5 (*Fasciculithus tympaniformis*) occurs 1.1 m above the GSSP. The GSSP level is interpreted to be coincident with a widespread rapid sea-level fall, and to be 30 precession cycles (~630 kyr) above the top of magnetic polarity Chron 27n (Schmitz et al., 2011; <https://www.paleogene.org/selandian-stratotype/>).

Thanetian Stage

The Thanetian Stage is the uppermost Stage in the Paleocene Series. The rocks of this Stage are formed in the time interval from 58.7 to 55.8 Ma (Luterbacher et al., 2004; Fig. 7.1 and 7.2).

The term "Thanet sands" was originally used as a lithostratigraphic unit by Prestwich in 1850. Later, Renevier (1874) introduced the Thanetian Stage by bringing together the Thanet Sands, Woolwich Bottom Bed and Oldhaven Beds in Kent, England. According to modern studies of the nannoplankton content in the type area, the "Thanet Sands" include zones NP6/7 and NP8 (Fig. 7.2). The remaining two lithobodies – Woolwich Bottom Bed and Oldhaven Beds are referred to zone NP9.

The base of the Thanetian Stage is defined in the sea-cliff along the main beach of the coastal town Zumaia, Basque Country, northern Spain (latitude 43°17'58.4"N, longitude 02°15'39.1"W). The GSSP is about 78 m above the Cretaceous/Paleogene boundary. The GSSP is defined at a level 2.8 m or eight precession cycles above the base of the core of the distinct clay-rich interval associated with the Mid-Paleocene Biotic Event, and it corresponds to the base of magnetochron C26n (Schmitz et al., 2011; <https://www.paleogene.org/thanetian-stratotype/>).

7.1.2. Lower Eocene Subseries

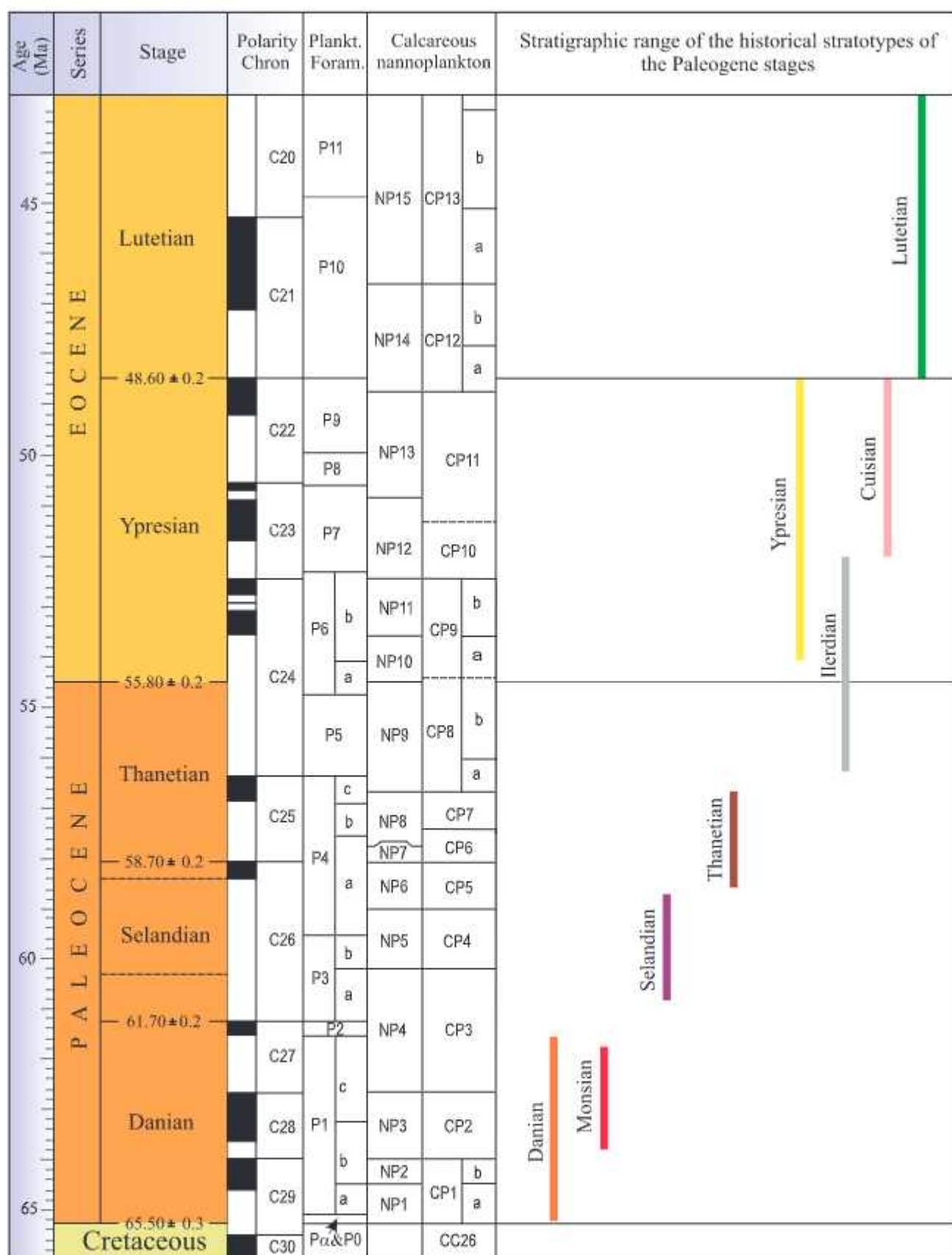
Ypresian Stage

The Ypresian Stage is the lowest chronostratigraphic unit in the Eocene Series. It includes all rocks formed during the Ypresian Age (55.8 to 48.6 Ma – Fig. 7.1).

The lower boundary of the Stage is set at the base of the negative carbon isotope excursion of $\delta^{13}\text{C}$, marking the onset of a sharp climatic event – the Paleocene-Eocene Thermal Maximum.

The base of the Eocene Series and Ypresian Stage is defined in the DBH Subsection of the Dababiya Section near Luxor, Egypt, at the base of a lithostratigraphic unit, where the initiation of the so-called Carbon Isotope Excursion (CIE) is recorded (latitude 25°30'00"N, longitude 32°31'52"E, Dupuis et al., 2003; Aubry et al., 2007; <https://www.paleogene.org/ypresian-stratotype/>).

From the nannofossil viewpoint, the lower boundary of the Ypresian is coincident with the base of zone NP10.



The upper boundary of the Stage is defined by the appearance of the planktonic foraminifera genus *Hantkenina* and more precisely the *Hantkenina nuttalli* species. Based on calcareous nannoplankton it is positioned in the middle of zone NP14, at the boundary of subzones NP14a and NP14b. A clear criterion for its identification is the FO of the species *Rhabdosphaera inflata*.

The full stratigraphic range of the Ypresian Stage, according to its definition, encompasses the nannofossil zones NP10, NP11, NP12, NP13 and NP14a (Fig. 7.1).

Ilerdian and Cuisian Stages

Hottinger and Schaub (1960) differentiated two regional stages in the Tethyan area – the *Ilerdian* and *Cuisian*, corresponding to the lower and upper parts of the Ypresian. These stages reflect important phases of the evolution of the large foraminifera, but unfortunately may not be traced globally and therefore ICS does not recommend their use (Fig. 7.2).

7.2. Chronostratigraphic units

7.2.1. Adopted chronostratigraphic scheme

The present work uses the official chronostratigraphic division, as approved by the International Geological Congress in Washington (Jenkins & Luterbacher, 1992). According to this division, the Paleogene System is separated into three Series: Paleocene, Eocene and Oligocene. The data on the absolute age of the Stages, as well as correlation of their boundaries with the commonly accepted biostratigraphic schemes based on planktonic foraminifera and calcareous nannoplankton are shown in Fig. 7.1 and 7.2.

The Paleocene Series is divided into Danian, Selandian and Thanetian Stages. The Danian Stage comprises the zones NP1, NP2, NP3 and greater portion of NP4 zone. The Selandian includes the uppermost parts of zone NP4, the entire zone NP5 and the lower part of zone NP6. The Thanetian Stage covers the upper part of zone NP6 and zones NP7, NP8 and NP9.

The lower Eocene is considered to include only one Stage – the Ypresian. It covers the successive range of nannofossil zones from NP10 at the base through NP14a in the uppermost portions of the Stage.

The boundary between the lower and middle Eocene coincides with the boundary between the Ypresian and Lutetian Stages and, respectively, with the boundary between nannofossil zones NP14a and NP14b.

The adopted chronostratigraphic scheme, applied in this work, does not differ from the global one, and is illustrated on Fig. 7.2.

7.2.2. Paleocene Series

Currently there is no formally adopted subdivision of the Series into Subseries. It encompasses three Stages: Danian, Selandian and Thanetian. The lower and upper boundaries of the Series are marked by global events – the impact event at the Cretaceous-Paleocene boundary (also referred to as K/T and K/Pg) and the climatic event (global warming) at the Paleocene-Eocene boundary (Paleocene-Eocene Thermal Maximum; PETM).

The lower boundary of the Paleocene Series is also the lower boundary of the Paleogene System. Following the work of Alvarez et al. (1980) and the launch of the impact hypothesis, this boundary became one of the most explored and analysed geological intervals, identified in tens of sections all over the world. The boundary is set on the iridium peak that marks the impact event in the complete sections, and the related mass extinction of marine and terrestrial organisms.

The upper boundary of the Paleocene Series is fixed at the sharp negative excursion of $\delta^{13}\text{C}$ that marks the onset of the Paleocene-Eocene Thermal Maximum.

More data on the boundaries within the Series are provided below, in the description of the Stages.

Danian Stage

Boundaries. The lower boundary of the Danian Stage has an approved global reference section, GSSP – the one at El Kef, Tunisia. It was ratified by ISC in 1991 and since then its condition has substantially worsened (Fig. 7.3). The detailed description of the stratotype section of the lower boundary of the Danian Stage is published by Molina et al. (2006b) in the journal *Episodes* (Fig. 7.3).

From the nannofossil point of view, this boundary coincides with the mass extinction of many Cretaceous species, but with the domination of the “survivor” species *Thoracosphaera operculata* and *Braarudosphaera bigelowii* and the appearance of the new species *Cyclagelosphaera alta*, *Biantholithus sparsus* and *Neobiscutum romeinii*.

The upper boundary of the Danian Stage with the Selandian is fixed at the base of the Izturun Fm along with the lithological replacement of limestones by marls (Fig. 7.4, 7.5, 7.6). It coincides with the “second



Fig. 7.3. Global stratotype section (GSSP) of the Cretaceous/Paleogene boundary, which is the lower boundary of the Danian Stage (after Molina et al., 2006b), El Kef, Tunisia

radiation" of the fasciculiths (Dinarès-Turell et al., 2007; Bernaola et al., 2008) and also with another important nannofossil event – the appearance of *Neochiastozygus perfectus* and *Chiasmolithus edentulus* (Bernaola et al., 2008).

Range. It includes nannofossil zones from NP1 to the upper part of NP4, as well as the planktonic foraminifera zones P0, P_a, P1a, P1b, P1c and P2. It encompasses the following magnetic chrons: upper part of chron C29r, chrons C29n, C28r, C28n, C27r, C27n and lower part of chron C26r (Dinarès-Turell et al., 2003).

Three third-order sequence stratigraphic units are included in the Danian Stage – from Da-1 to Da-3 and the upper part of the Maastrichtian sequence Ma-5 (Haq et al., 1988; Hardenbol et al., 1998).

The duration of the Danian Stage is estimated at 3.8 Ma [according to the Geological Time Scale 2004 (GTS2004) – Luterbacher et al., 2004], 4.05 Ma (after Dinarès-Turell et al., 2007) or 4.2 Ma (after Westerhold et al., 2008).

Regional characteristics. The Danian Stage is evidenced in Kula Zone in the sections near Kladorub, (Sinnyovsky et al., 2002; Sinnyovsky, 2004b) and near Rakovitsa village (Stoykova & Ivanov, unpublished data). Its presence has been proved by typical nannofossil associations. The Stage is fully developed in these sections, including zones from NP1 to NP4. It relates to the clayey siltstones and marlstones of the Kladorub Fm. The thickness of the Stage in these sections is 35 m.

There is no paleontological evidence confirming the presence of the Danian in the Lom Depression. Tsaneva and Vaptsarova (1961) described "Danian?" in well R-6 Dalgodeltsi represented by a thick complex of grey clayey limestones. These belong to the limestone-marl formation (Filipov et al., 1995b). Tsaneva (1964) supposes that "lower Paleocene-Danian" is present only in C-7 near Lom, but again without any paleontological evidence. The thickness of the sediments that supposedly might be referred to the Danian Stage in the Lom Depression is between 50 and 85 m.

In the West Fore-Balkan and Balkan, the Danian Stage is exposed in the Mezdra region where only the lower and middle parts are documented by nannofossils (zones NP1 and NP2 – Sinnyovsky, 1993a; Sinnyovsky, 1999; zone NP1-NP3 – Stoykova et al., 2000; Stoykova & Ivanov, 2004a; zone P1b – Peybernes et al., 2004). The Stage is represented by carbonate successions, associated with the Mezdra Fm and the limestone formation (Sinnyovsky & Sinnyovska, 1993). Its thickness ranges from 35 m to 50 m.

Indications about the occurrence of the lower parts of the Danian in Central Balkan are known in the region of Botev peak, west of Rai hut and near Tuja hut. In the conglomerate formation, located in the autochthon of the Central Balkan granite thrust, poor nannofossil associations of zones NP1 and NP2 have been recorded (Stoykova in Zagorchev et al., 2001). The Danian occurs in the Elena-Tvarditsa part of Stara Planina Mountain, along the Republica Pass near Mishemorkov han, where its full development is observed. Here its sediments are assigned to the limestone-marl

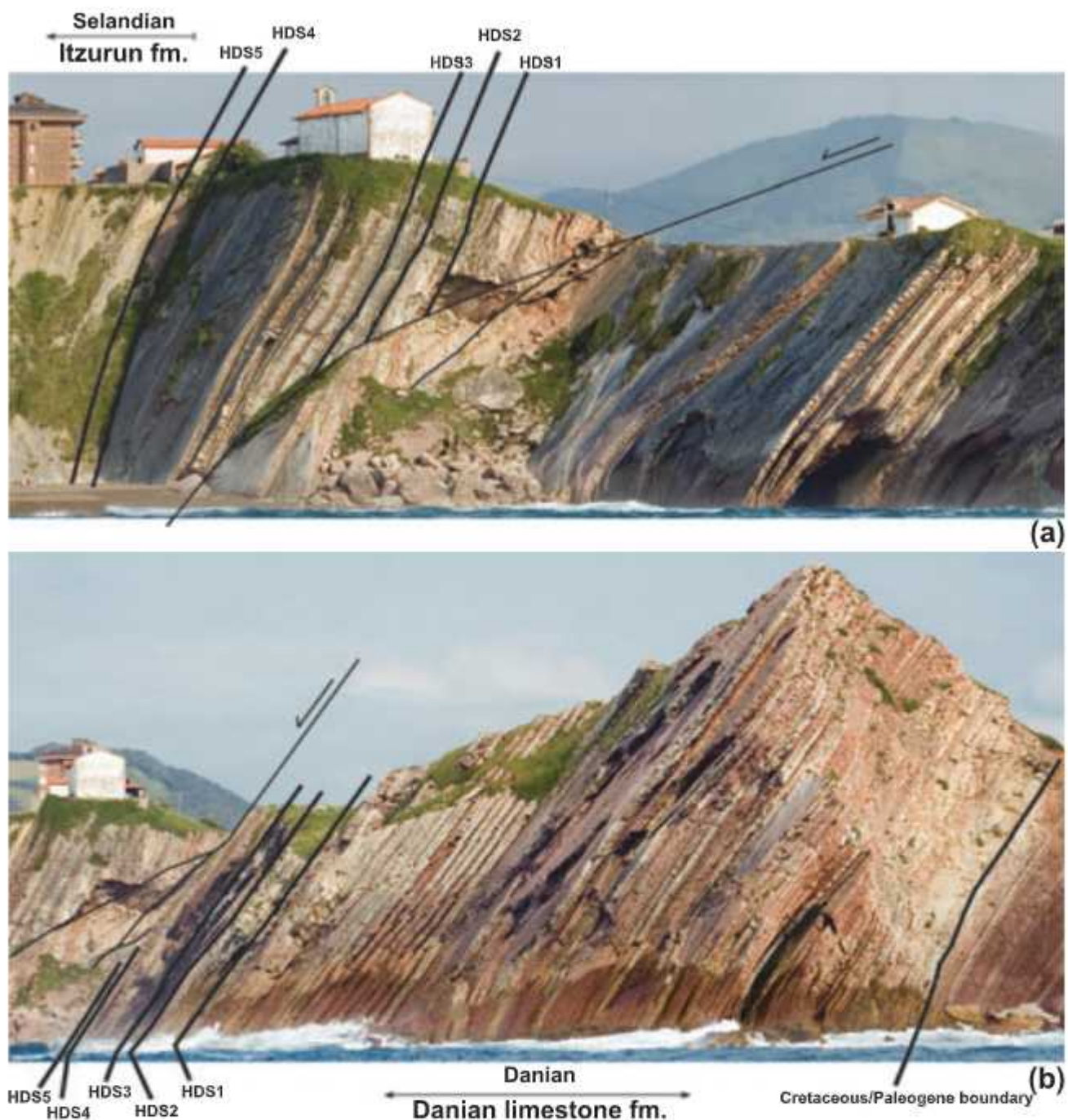


Fig. 7.5. (a) – Danian succession and Danian – Selandian boundary in the Zumaia section; (b) – The Cretaceous/Paleogene boundary in the Zumaia section, Basque Country, Spain and the Danian sedimentary succession (after Arenillas et al., 2008)

Selandian Stage

Boundaries. The lower boundary of the Selandian was discussed above. In the proposed global stratotype section (GSSP) at Zumaia, it is fixed along the lithological boundary between two formations – the limestones of the Aitzgorri Fm and the marls of the Itzurun Fm. The transition between the two formations is gradual without any signs of a break in sedimentation (Dinarès-Turell et al., 2003, 2007; Fig. 7.4; 7.5b; 7.6).

From the nannofossil point of view, this boundary occurs 1.1 m below the level of FO of *Fasciculithus tympaniformis*, i.e., at 1.1 m below the lower boundary of zone NP5. It coincides with an important globally recorded nannofossil event – the “second radiation of the fasciculiths” with the appearance of *Lithoptychius ulii*, *L. billii*, *L. jani*, *Fasciculithus involutus* and *F. pileatus* (Bernaola et al., 2008).

Studies of the planktonic foraminifera distribution

around the Aitzgorri – Itzurun Fm boundary reveal 5 essential bioevents, that might be used for correlation and fixing of the Danian-Selandian boundary. The closest of these (HDS4) is the lower boundary of zone *Igorina pusilla* (Fig. 7.7 – Arenillas et al., 2008).

The upper boundary of the Selandian is set at the base of magnetochron C26n, i.e. at the C26r/C26n boundary (Dinarès-Turell et al., 2007).

Range. It encompasses the uppermost portion of zone NP4, the entire zone NP5 and the main portion of the of zone NP6. The uppermost part of planktonic foraminiferal zone P3a, the whole zone P3b and the lower portion of zone P4 belong to it. The Selandian Stage falls entirely within magnetochron C26r (Dinarès-Turell et al., 2007).

Two third-order sequence stratigraphic units are noted in the Selandian – Se-1 and Se-2 (Haq et al., 1988; Hardenbol et al., 1998).

The duration of the Selandian Age is calculated at 3 Ma [according to the Geological Time Scale 2004 (GTS2004) – Luterbacher et al., 2004], 2.18 Ma (after Dinarès-Turell et al., 2007) or 2.4 Ma (after Westerhold et al., 2008).

Regional characteristics. In the Kula Zone the Selandian is identified in the section near Kladorub village (Sinnyovsky, 2004b); it is fully developed and documented by characteristic nannofossil associations of zones NP5 and NP6. It is composed of clayey siltstones and marls of the Kladorub Fm and the thickness in the section at Kladorub is 14 m.

The Stage is probably present in the section near Rakovitsa village as well, but no paleontological proof is available.

The data from the wells in the Lom Depression (G. Gnoynitsa, Dalgodeltsi, Medkovets, Drenovets and Lom) published by Tsaneva and Vaptsarova (1961) and Tsaneva (1964), do not cite any foraminifera typical for the Selandian. Nevertheless, its occurrence in this area is supposed as quite possible. Tsaneva (1964) mentions “Upper Paleocene that lies immediately over the Danian limestones”. It is represented by grey sandstones and silty marls (probably Kladorub Fm?).

In the West Fore-Balkan the distribution of the Selandian is quite limited. It crops out only in the outskirts of Lyuti dol village, in the core of the Lyuti dol Syncline (west of Tishovska mahala and near Dilkovtsi). Its presence is proved by Sinnyovsky and Sinnyovska (1993) and Sinnyovsky (2001b), who documented the NP6 zone *Helicolithus kleinpellii*. It is

represented by sandstones and siltstones with a thickness of up to 10 m.

In the central part of the the Moesian Platform, Selandian rocks are proved for the first time in the course of this study. The Stage is identified in the sections south and north of Plevna (Petarnitsa, Kailaka, Komarevo, Kreta and Somovit), occupying the base of the Paleogene profile in these areas. It is represented by carbonate sediments – detritic and clastic limestones that are only between 1-3 m. The regional trend suggests thickness increase from south to the north with the greatest thickness measured at Somovit – 3.5 m. Since the lower and upper boundaries are erosional, it is likely that the Stage is not fully developed, although parts of nannofossil zones NP5 and NP6 have been recorded.

In the Central Fore-Balkan, the Selandian Stage has limited outcrops in the region of the towns of Gabrovo and Elena (the sections at Gabrovo, Iztochnik and Drenta). It is built of detritic and sandy limestones and sandstones, referred to the Iztochnik Fm and an unnamed body of clastic limestones. Only the lower portions of the Stage – zones NP4 (upper part) and NP5 are evidenced by nannofossils. The thickness varies from several metres to 10 m.

In the East Balkan, the Selandian is fully developed, built up by clastic sediments – rhythmic turbidites (Emine Fm), thick-bedded sandstones, coarse-grained sandstones and gravels (Kozichino Fm). It crops out in vast areas and is documented in the sections at Ichera-Gradets, Esen, Podvis, Prilep, Ruen-Snyagovo, Kamenyak, Kozichino and Emona. Here the greatest thickness of the Stage is recorded – from 60-70 m to 300 m. In the section at Emona it is 305 m thick (Sinnyovsky, 2004a).



Fig. 7.6. Danian – Selandian boundary in the Zumaia section, drawn at the lithological boundary between the Aitzgorri Fm and the Itzurun Fm (after Dinarès-Turell et al., 2007)

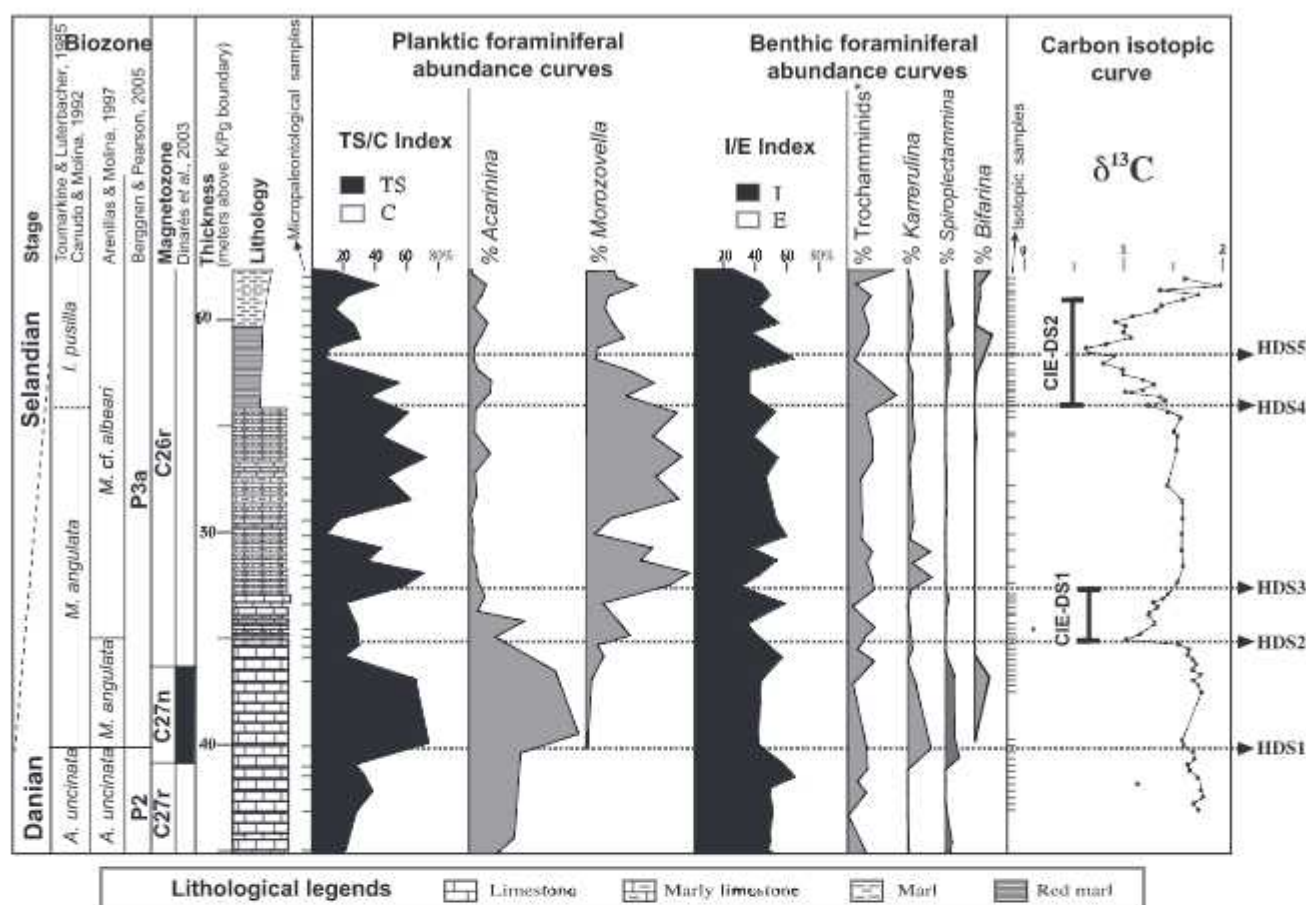


Fig. 7.7. Position of important planktonic foraminifera bioevents around the Danian – Selandian boundary in the Zumaia section (after Arenillas et al., 2008)

In the section near Byala and Goritsa the stage is represented by limestone-marly sequences (Byala Fm). It is evidenced by rich nannofossil associations of the zones NP5 and NP6. The thickness is 10-15 m.

In the East Fore-Balkan the Selandian is proved in the section at Chudnite skali, where is it composed of clastic and biodetrital limestones of the "Kailaka" Fm. The thickness is around 50 m.

The Stage is not detected in either the eastern parts of the Moesian Platform or the wells drilled in the Black Sea shelf. Its absence in these areas, like the Danian Stage, suggests initial lack of sedimentation and/or later subsequent disappearance resulting from erosion or underwater wash-out during the Selandian Age.

The complete sections and the maximum thickness of the Selandian Stage are noted within the Kula Unit and in the East Balkan Zone. Reduced thicknesses are documented in Central northern Bulgaria (the sections along the Vit River valley). An incomplete development of the Stage is also identified in the East Fore-Balkan, in the section at Chudnite skali.

Thanetian Stage

Boundaries. The lower boundary of the Thanetian Stage in the GSSP at Zumaia is fixed at the base of magnetochron C26n (at C26r/C26n boundary). It is located some 2.8 m above the clayey interval, marking the Mid-Paleocene Biotic Event (MPBE – Dinarès-Turell et al., 2007; Bernaola et al., 2008). The GSSP is located along the main beach of the coastal town Zumaia, Basque Country, northern Spain at latitude 43°17'58.4"N, longitude 02°15'39.1"W. The GSSP for the Thanetian is about 78 m above the Cretaceous/Paleogene boundary.

The integrated paleomagnetic and nannofossil studies of the stratotype section at Zumaia set the Selandian-Thanetian boundary 6.5 m above the level of FO of *Heliolithus kleinpellii* (index of zone NP6) and 3.5 m below the level of first appearance of *Discoaster mohleri* (index of zone NP7), i.e., in the upper part of zone NP6.

From the viewpoint of planktonic foraminifera zones, the lower boundary of the Thanetian falls in the middle of zone P4a.

The upper boundary of the Stage is also the upper boundary of the Paleocene Series. It is marked by one of the most pronounced climatic events in the history of the Earth, the Paleocene-Eocene Thermal Maximum. The latter is observed in the sections through a typical clayey interval and sharp negative excursion of $\delta^{13}\text{C}$. More data on this boundary and the PETM are available in Chapter 8, devoted to global events.

Range. It covers the upper part of zone NP6 and the entire NP7, NP8 and NP9 nannofossil zones. The upper part of zone P4a, the whole subzones P4b and P4c as well as zone P5 of the planktonic foraminifera zones are referred to it. The Thanetian includes the following magnetochrons: C26n, C25r, C25n, C24r (Dinarès-Turell et al., 2007).

Five third-order sequence stratigraphy units are differentiated in the Thanetian: Th-1 to Th-5 (Hardenbol et al., 1998).

The duration of the Thanetian Age is estimated at 2.9 Ma [according to the Geological Time Scale 2004 (GTS2004) – Luterbacher et al., 2004], 3.3 Ma (after Dinarès-Turell et al., 2007) or 3.4 Ma (after Agnini et al., 2007a; Westerhold et al., 2008).

Regional characteristics. The Stage is fully developed in Kula Unit and in the Lom Depression. In the section at Kladorub, it is characterized by rich and diverse nannofossil associations, indicating the presence of zones NP6 to NP9 (Sinnyovsky, 2004b; Stoykova & Ivanov, 2005). The sediments of the Stage consist of clayey siltstones and marls, with a thickness of 15 m.

The Thanetian Stage (referred to by Tsaneva, 1964 as “upper Paleocene”) is proved by rich finds of planktonic and benthic foraminifera in the wells drilled in the Lom Depression (Tsaneva & Vaptsarova, 1961; Tsaneva, 1964). It is represented by grey to grey-greenish silty marls and siltstones (Kladorub Fm?). The thickness ranges from 10 m (R-4 G. Gnoynitsa) to 100 m (R-2 Medkovets).

No Thanetian sediments have been encountered by the wells drilled in the Vidin Uplift (Tsaneva, 1964).

Moreover, the Thanetian Stage has not been identified in the West Fore-Balkan and Balkan.

In the central part of the Moesian Platform, the Stage is detected in all studied sections along the Vit River valley, being represented by carbonate and terrigenous-carbonate sediments – clastic limestones, sandy limestones with glauconite, clayey limestones (Komarevo Fm) and marls with chert nodules (Bozhuritsa Fm). The uppermost parts are composed of mixed

hypo-rocks – siltstones to sandy marls. The complete stratigraphic range of the Thanetian is evidenced by nannofossils – from zone NP6 to NP9 (Stoykova & Ivanov, 2004b).

Indications regarding the presence of parts of the Thanetian, zone NP7 and NP8? in the Central Fore-Balkan, are detected only in the Elena region, in the section at Drenta (Stoykova in Nikolov et al., 1998). It is built of detritic limestones with interbeds of glauconitic sandstones and siltstones, referred to the Komarevo Fm. Its thickness is 10-15 m.

In the eastern parts of the Central Balkan (Sliven region) the Stage is fully developed. The complete succession of zones (from NP6 to NP9) is proved in the Ichera-Gradets section, where the Stage is composed of sediments of the thick-bedded sandstone formation. The thickness is in the range of 75-80 m.

In the East Balkan Unit, the Thanetian is developed to its full volume. It is built up of clastic sediments – rhythmic turbidites of the Emine Fm and the thick-bedded sandstone formation, coarse-grained sandstones (Sveti Atanas Fm) and conglomerates (Bardarevo Member). It crops out in vast areas and is evidenced by nannofossils in the sections at Emona, Bardarevo and Mona Petra. The greatest thickness of the Stage is recorded here – from 150 to 300 m (Sinnyovsky, 2004a).

In the sections near Byala and Goritsa, the Stage is represented by marly and clayey sediments, referred to the upper part of the Byala Formation. It is evidenced by rich nannofossil associations, proving the full range of zones NP6 to NP9 (Stoykova & Ivanov, 2006a, b). The thickness is 6-7 m.

In the East Fore-Balkan, the Stage is proved in the section at Chudnite skali, where the lower and upper boundaries are erosional and its thickness is reduced. Only the presence of nannofossil zone NP8 and foraminiferal zone P4c is proved (Peybernès et al., 2004). The Stage here is composed of clastic and bioterritic limestones – calcarenites, referred to the Komarevo Formation. The thickness is around 30 m.

The Stage is identified in sections throughout the eastern parts of the Moesian Platform, as well as in the wells drilled in the Black Sea shelf. In this area, it exhibits reduced stratigraphic range and lesser thickness, being represented by clastic limestones and calcarenites (Komarevo Fm), and the upper parts – by sandy marls and siltstones with glauconite (Bozhuritsa Fm).

In the eastern parts of the Moesian Platform only zones

NP7-8 have been proved (sections at Beloslav, Sindel and Trastikovo). The thickness of the Thanetian sediments in the platform sections is between 4 and 5 m.

In the Black Sea, besides zones NP7 and NP8 documented in all wells, the uppermost parts of the Thanetian (zone NP9) are also proved in the Yuri Shimanov and Varna-West wells. The thickness of the Stage in the marine sections is greater than in the eastern part of the Moesian Platform – around 30 m.

7.2.3. Lower Eocene Subseries

This includes one stage – the Ypresian. The lower boundary of the Subseries is marked by a global event – the Paleocene-Eocene Thermal Maximum (PETM) expressed as a sharp negative excursion of $\delta^{13}\text{C}$, and the upper boundary is set at the FO of calcareous nannofossil *Rhabdosphaera inflata* (Molina et al., 2011; <https://www.paleogene.org/lutetian-boundary-stratotype/>).

Ypresian Stage

Boundaries. The lower boundary of the Ypresian Stage is set at the base of the negative excursion of $\delta^{13}\text{C}$ that marks the onset of the Paleocene-Eocene Thermal Maximum. In the global stratotype section at Dababaya, near Luxor, Egypt, it has clear chemostratigraphic (carbon isotopes) and biostratigraphic expression. This is due to the essential changes in marine microorganisms – calcareous nannoplankton, benthic and planktonic foraminifera – have undergone as a result of the abrupt warming. A formal detailed description and discussion of the GSSP section at Dababiya (Fig. 7.8) was published in *Episodes*

(Aubry et al., 2007).

The upper boundary of the Ypresian Stage is drawn at the FO of the calcareous nannofossil *Rhabdosphaera inflata* (NP14a/NP14b boundary). The GSSP for the base of the Lutetian Stage (early/middle Eocene boundary) is defined at 167.85 metres in the Gorronatxe sea-cliff section (NW of Bilbao city, Basque Country, northern Spain; 43°22'46.47"N, 3°00'51.61"W). This dark marly level coincides with the lowest occurrence of the calcareous nannofossil *Rhabdosphaera inflata* (CP12a/b boundary) in the middle of magnetochron C21r (Molina et al., 2011; <https://www.paleogene.org/lutetian-boundary-stratotype/>).

From the calcareous nannoplankton viewpoint, the Thanetian-Ypresian boundary coincides with the lower boundary of zone NP10, at the FO of *Rhombaster bramlettei*. The Ypresian-Lutetian boundary is set at the base of subzone NP14b, at the FO of *Rhabdosphaera inflata*.

Range. It incorporates the full range of zones NP10, NP11, NP12, NP13 and NP14a (Fig. 6.12, Fig. 7.1), as well as the uppermost part of zone P5 and zones P6, P7, P8 and P9 of the planktonic foraminifera. The Ypresian encompasses the following magnetic chrons: C24r, C24n, C23r, C23n, C22r, C22n (Dinarès-Turell in Bernaola et al., 2006a; Dinarès-Turell in Payros et al., 2007).

Ten third-order sequence stratigraphic units are differentiated in the Ypresian – Yp-1 to Yp-10 (Haq et al., 1988; Hardenbol et al., 1998). The duration of the Ypresian Age is estimated at 7.2 Ma [according to the Geological Time Scale 2004 (GTS2004) – Luterbacher et al., 2004].



Fig. 7.8. Global stratotype section (GSSP) of the Paleocene – Eocene boundary in Dababaya near Luxor, Egypt (after Aubry et al., 2007). White letters delineate lithostratigraphic boundaries of the local formations

Regional characteristics. The complete volume of the Ypresian is likely developed only in the central part of the Lom Depression, where it lies through a gradual transition over Paleocene sediments – in the wells near Bazovets, Dalgodeltsi, Medkovets, Drenovets and Byalo pole villages (Tsaneva, 1964). In the periphery of the Depression (to the east and west), the Stage overlies with wash-out older rocks and its sections are incomplete. It is represented by grey, dark-grey to greenish marls (Tsaneva, 1964; 1971; Kladorub Fm?, Avren Fm?) The thickness of the Ypresian in the central part of the Lom Depression ranges from 100 m (R-7 Bazovets) – 150 m (R-6 Dalgodeltsi) to over 320 m (C-2 Byalo pole) (Tsaneva, 1964).

In the Kula Zone the lowermost portion of the Ypresian (zone NP10, thickness 10 m) is in the Kladorub Fm, in the section along Tsiganski dol near Kladorub village. The same section shows, following a break in sedimentation, the upper part of the Stage in the Staropatitsa Fm – zones NP12-14a (Stoykova & Ivanov, 2005). The total thickness exceeds 250 m.

No Ypresian sediments have been penetrated by wells in the Vidin Uplift except for the well near Gramada, drilled on its southern flank. In this well the Stage is evidenced by foraminifera and is represented by 5 m of sandy marls (Avren Fm?, Tsaneva, 1964).

In the West Fore-Balkan and Balkan the Ypresian has a limited distribution in the Vratsa and Mezdra regions, where its upper parts are documented. The Stage is represented by poorly cemented polymictic sandstones and siltstones, referred to the Pavolche Fm. Here it is proved by characteristic nummulitid associations (“Cuisian” – Aladjova-Hrischeva et al., 1991); its thickness varies from 10 m to 70 m.

In the Central Fore-Balkan the Ypresian is widespread in the Lukovit and Gabrovo regions, where its upper parts are developed only. It is built of various clastic sediments – sandstones, siltstones, clays and marls. These represent several Formations: Petrevene, Lukovit, Ugarchin, Boynovtsi and Staropatitsa. The thickness of the Stage here varies from 150 m to 320 m.

In the central part of the Moesian Platform the Stage is identified in all sections along the valley of the Vit River. Its lowest part is evidenced by nannofossils only in the section at Riben (basal part of zone NP10). The Ypresian here is represented by sandy marls and siltstones, rich in glauconite (“Beloslav” Fm – Stoykova & Ivanov, 2004b).

In the sections at Gradina, Tarnene, Kailaka, Grivitsa, Yasen, Bivolare and Bozhuritsa, the upper parts of the

Ypresian (zones NP12-14a) usually occur transgressively over the Thanetian sediments, starting with the “*Ostrea* marker horizon”. The upper parts of the Stage are built of Avren Fm marls and clays; thickness is 15-20 m.

In the region of Veliko Turnovo the Ypresian is of limited distribution within the Balvan Syncline, where its lower and middle portions are developed (NP10-12). It is represented by terrigenous sediments – fine-grained sandstones, siltstones and clays. Limestone interbeds rarely occur. The Stage in this region is associated with the Shemshevo and Avren Formations and the thickness is 50-60 m.

In the Central Balkan the Ypresian Stage is widely distributed. It is proved in the sections at Gabrovo, Vrabtsite, Yaseni-Zhultesh, Belitsa, Mishemorkovhan in the Republika Pass, Kipilovo and near Gradets. It is composed of irregular alternations of marls, siltstones, sandstones and seldom – gravels and conglomerates, reaching a thickness of several hundred meters. The Stage here is represented by the Lukovit, Staropatitsa and Gebesh Formations and the thick-bedded sandstone formation.

In the East Balkan and the Fore-Balkan, the Ypresian is widespread and at its maximum development. It consists of clastic sediments – sandstones, sands, siltstones, marls and clays with interbeds of conglomerates and gravels, developed at some levels (Dvoynitsa Group – Sveti Atanas Fm, Gebesh Fm). The thickness of the Ypresian sediments in the East Balkan may not be precisely known, but considering the sections near Obzor and Byala, it appears to be in the range of 350-600 m.

The lower parts of the Stage in the region north of Byala and near Goritsa are represented by marly-clayey successions where zones NP10 and NP11 are documented (section C-30 Goritsa). They are referred to the variegated clayey-marly formation and the thickness is in the range of several tens of meters.

In the East Fore-Balkan, the Stage has a complete suite of zones in the section at Chudnite skali, where it consists of various sediments – quartz sands and sandstones (Beloslav-Dikilitash Fm) and calcareous clays and marls (Avren Fm). The thickness is 55 m.

In the eastern parts of the Moesian Platform, the complete zonal sequence of the Ypresian is evidenced (zone NP10 to NP14a). It is composed of sandstones, calcareous sandstones and sands (Beloslav and Dikilitash Fms), silty marls and clays (Krivnya Member) and bioclastic limestones (Aladan Fm). The thickness of the Stage in the platform sections is 70-75 m.

The middle and upper parts of the Ypresian (zones NP12 to NP14a) are evidenced by nannofossils in the well sections in the Black Sea offshore, where it lies through unconformity over Paleocene or Upper Cretaceous sediments. The lower parts of the Stage are documented only in the Yuri Shimanov well (zone NP10), represented by poorly cemented sandstones, sands and marls (Beloslav Fm). In the remained of the offshore sections the Ypresian is represented by the Avren Fm marls. The thickness is between 10 and 40 m.

The greatest thickness of the Ypresian is detected in the Samotino-More well, where very thick terrigenous sediments were penetrated – sandstones, siltstones, clays and thin-bedded rhythmic turbidites, corresponding to the Dvoynitsa Group formations outcropping onshore. The total thickness of the Ypresian rocks in this well is 425 m.

In conclusion, the complete section of the Ypresian and its maximum thickness are detected in the East Balkan zone and the southern portions of the Black Sea offshore.

Chapter 8

Global events and their impact on the nannofloras

During the last four decades a series of scientific discoveries have been made that shed light on different global events in the geological history of the Earth. Enormous scientific interest was attracted by the impact hypothesis as the cause of mass extinction at the Cretaceous/Tertiary (K/T) boundary, resulting from a collision of an asteroid with the Earth (Alvarez et al., 1980). A comparable level of interest has focused on the most dramatic warming in the geological past – the Paleocene-Eocene Thermal Maximum (PETM), after it had been discovered by Kenneth and Stott (1991). During the last two decades, another climatic event proved to be of global expression – the short-term warming in the middle of the Paleocene Epoch, the so-called mid-Paleocene biotic event (MPBE – Bralower et al., 2003; Zachos et al., 2004; Petrizzo, 2005).

8.1. Cretaceous/Tertiary boundary (K/T) event

8.1.1. Introduction

The Cretaceous/Tertiary boundary focused the interest of numerous scientists in the beginning of the

1980s, after the publication of the remarkable article by Luis and Walter Alvarez and a team of researchers (Alvarez et al., 1980). Here they recorded an anomalously high Iridium concentration along with other rare earth elements, in the boundary layer between the Cretaceous and Paleogene in the sections near Gubbio, Italy and Stevns Klint, Denmark. The exceptionally high Ir anomaly (Ir above 40 ppb), as well as the elevated concentrations of Cr, Co, Ni, Rb, Zr, Sb, Cs and Ba, are explained by the impact hypothesis, according to which the Earth collided with a gigantic space body – an asteroid, resulting in dramatic change in climate and biota on our planet (Fig. 8.1). The size of the asteroid is estimated at 10–15 km in diameter and the location of impact is considered to be the northern part of the Yucatan Peninsula, Mexico. As a result of the collision, a gigantic crater has been formed – Chixculub, approximately 160 – 240 km in diameter, with its greater portion now lying below sea level (Shulte et al., 2010).

As a consequence of the impact, huge energy was released (several hundreds of millions megatonnes of TNT, amounting to tens of thousands of atomic bombs). A substantial portion of that energy was



Fig. 8.1. Illustration of the impact of the Earth with a giant meteorite at the end of the Cretaceous Period (K/T boundary) (Source: Internet)

transformed into products around the collision site (for instance, shocked quartz, tektites, iron spherules, etc.). The high volumes of fine dust, ash and spherules ejected into the upper levels of the stratosphere, had a global effect. They spread over the entire planet and were deposited within the next few hundreds of years, forming a discrete clay layer. It is assumed that for a certain period of time this thick dust-cloud wrapping would have blocked sunlight, leading to a subsequent decrease in global temperatures and a temporary ceasing of photosynthesis. Other scenarios have been considered including vast fires, acid rains, tsunami and mass extinction of the organisms of different biotopes – marine and terrestrial.

What followed was an avalanche of publications – as the researchers split into two groups: those who supported the impact hypothesis (with several versions) and those who explained the source of the high Ir concentrations from powerful volcanic eruptions. The majority of facts acquired in the course of studies on the Cretaceous/Paleogene boundary do support the impact hypothesis (Smit & ten Kate, 1982; Alvarez et al., 1984; Smit & Romein, 1985; Wolfe, 1991; Alvarez et al., 1992). Consequently, the great interest in impacts as a process in geological history led to the discovery of other impact events at other chronostratigraphic boundaries (e.g., Silurian-Devonian, Permian-Triassic, Cenomanian-Turonian, etc.) and suggested the idea of cyclic recurrence of these events in Earth history (Raup & Sepkoski, 1986).

8.1.2. Global expression of the event

Lithological expression. The K/T boundary event is marked by a boundary clay layer of variable thickness, usually 1-5 cm thick. The layer is traced in both marine and continental sediments. More than one hundred marine and over 20 continental localities with well-preserved lithological markers of the event are known so far. The carbonate content in the rocks sharply decreases while the silicates increase (mainly clay minerals). Figure 8.2. shows the K/T boundary clay layer in the complete sequence of the section near Zumaia, Spain.

Geochemical and mineralogical expression. The most remarkable geochemical expression of the event is the Iridium anomaly. The anomalously high Ir and other element concentrations (RRE: Cr, Sc, Co, Ni, Rb, Zr, Sb, Cs, Ba) exceed 5-10 times their normal background concentrations. The boundary interval shows Ni-enriched spinels with Ir and Cr that are considered to be of extraterrestrial origin.

Stable isotopes – an indicator of climatic changes.

Abrupt negative excursion of $\delta^{13}\text{C}$ has been documented at the K/T boundary varying from 1 to 4‰ in different localities. The change in the $\delta^{18}\text{O}$ isotope ratios indicate a sharp drop in temperature after the event. It is assumed that after the collision, huge tsunamis formed that flooded vast land areas and decimated life in their path. A huge amount of fine particles, released in the upper parts of the stratosphere, blocked sunlight for a short period of time. As a result, photosynthesis temporarily ceased and temperatures sharply dropped by 5 to 10 degrees C (the so-called “nuclear winter”). The effects are most noticeable in low latitude localities, while in the high northern and southern latitudes the magnitude is far smaller.

Magnetostratigraphy. Magnetostratigraphic analyses show that the K/T boundary and the event marker fall within the reverse magnetic polarity chron 29r.

Biotic expression. It is well known that the dinosaurs and a major part of the cephalopods – ammonites and belemnites, as well as inoceramid bivalves, became completely extinct. Profound and almost complete replacement of extinct Cretaceous forms by new species and genera occurred within the marine microplankton – planktonic foraminifera and calcareous nannoplankton. As to the nannofossils, mass extinction of the Cretaceous nannoplankton species is identified at the K/T boundary – as well as explosive development and dominance of the “disaster” species *Thoracosphaera operculata*, *T. saxea* and *Braarudosphaera bigelowii*.

The mass extinction at the K/T boundary has been extensively studied by scientists from around the world for the past 40 years. Despite these many years of efforts, the specifics of the nature, rates and main causes of this biological catastrophe still remain unclear. This is partly due to the fact, that many of the studied K/T boundary sections are somewhat geographically restricted, located in the lower northern latitudes (Tethys area) – Spain, France, Tunisia, Italy, Austria, Texas and Mexico. Several K/T boundary sections in the Atlantic and Pacific Ocean, as well as in the Caribbean, have been studied (MacLeod & Keller, 1991; Keller et al., 1993a, b) but these were either too condensed, incomplete or eroded at the boundary interval. Moreover, in vast ocean areas the boundary sediments are either missing as a result of subduction (Indian Ocean, the northern and eastern parts of the Pacific Ocean) or have never been studied. Thus, our current knowledge on the mass extinction at the K/T boundary in the marine ecosystem is based mainly on analysis of sections located within the Tethys area. Thus observed biotic effects are incorrectly generalized and globally applied. This conclusion became evident following the publication of results of analy-

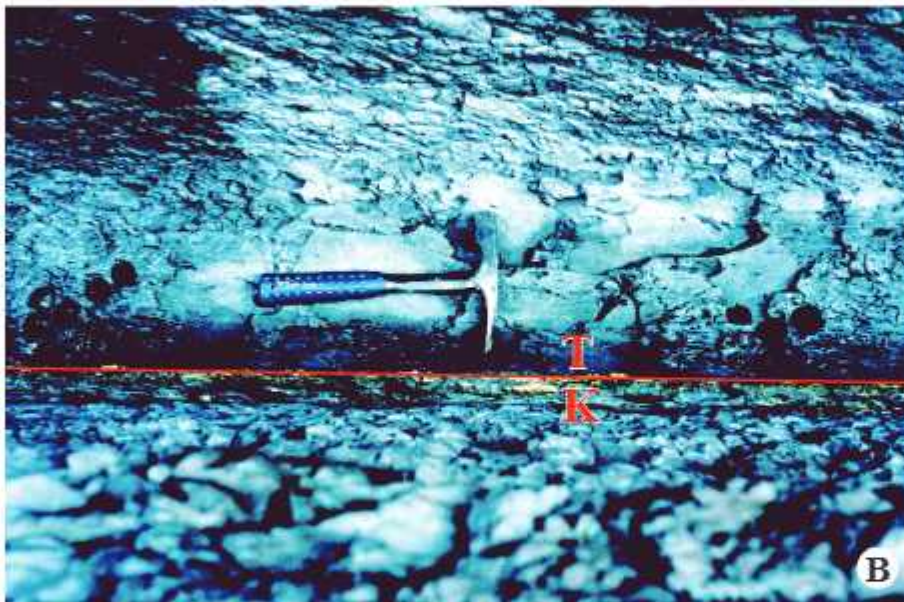


Fig. 8.2. Photos of the Zumaya section, Basque Country, Spain. A – Position of the Cretaceous-Tertiary (K/T) boundary; B – Detail of the boundary clay bed, marking the impact event; C – Lower Danian sedimentary succession above the K/T boundary. Pictures taken by the author during the field-trip of the fifth International Nannoplankton Association Meeting, 1993

ses of sections located in other parts of the world: the northern and southern high latitudes; and subequatorial Ecuador, where the environment was dominated by strong, upwelling, cold marine Antarctic water currents, flowing from high latitudes (Keller et al., 1997).

To illustrate these latitudinal differences among the planktonic foraminifera (which along with the calcareous nannoplankton are one of the most affected microfossil groups at the K/T boundary), around 2/3 of the species disappeared at or before the K/T boundary in the Tethys area (Keller & Perch Nielsen, 1995; Keller, 1996). Although the extinction was not sudden, the species that disappeared at the K/T boundary included all the tropic-subtropic, large and complex ornamented species. The smaller, poorly ornamental species of simple morphology and the cosmopolitan taxa survived the event and disappeared some 100 and 300 Ka later, in the Danian Age. The studies of fairly complete sections in the high latitudes, both south (ODP Site 738, Keller, 1993, 1996; Keller & MacLeod, 1996) and north (Denmark, Kazakhstan; Keller et al., 1993b) indicate that the selective extinction model is not global and does not apply to the northern latitudes. Actually, there is no clearly demonstrated extinction at the K/T boundary in the high latitudes which is due primarily to the fact that the tropic-subtropic species are not present in these areas except for occasional migration during warming of the climate. The fauna and flora in these areas is quite similar due to the cosmopolitan species of the low latitudes (Keller, 1996). This understanding of different extinction models in the low and high latitudes appeared to be rather simplified as well which was proved by the results of studies from Ecuador (Keller et al., 1997).

Other fossil groups do not undergo mass extinction at the K/T boundary in the high southern latitudes, too. For instance, the *radiolarians* known from localities in New Zealand, demonstrate faunistic change but no significant extinction. Similarly, the *spores*, *pollen* and the *fossil flora* in New Zealand and Seymour Island, Antarctica, Chile and Brazil do not show substantial changes but more probably reflect climatic fluctuations and changes in sea level (Bowman et al., 2014).

The association of *marine invertebrates* (mollusks – ammonites, inoceramids; echinoids) around the K/T boundary documented from sections on Seymour Island, Antarctica, Chile and Brazil also demonstrate a gradual, long-term faunistic change but not a mass extinction at the K/T boundary (Stinnesbeck, 1996).

Similar observations have been made on the behaviour of macro-invertebrates – ammonites, inoceramids and echinoids (sea urchins) in the Bulgarian sec-

tions across the K/T boundary (Ivanov & Stoykova, 1994, 1995). The ammonites show step-by-step change from the beginning of the late Maastrichtian with gradual reduction of the number of genera and species. Of 18 species, belonging to 12 genera and 7 families at the beginning of the late Maastrichtian, this number gradually decreases to some 10 species belonging to 8 genera, 6 species belonging to 6 genera to finally reach 3 species belonging to 3 genera at the very end of the late Maastrichtian and then to become extinct at about 40 cm below the K/T boundary in the sections near Byala (Ivanov in Ivanov & Stoykova, 1995). The inoceramids disappeared completely in the Bulgarian localities in the middle of the late Maastrichtian without surviving to the “event” at the K/T boundary, i.e. without any relation to it (Ivanov & Stoykova, 1995). The trends in the change of the echinoids through the K/T boundary are quite similar: gradual reduction in taxonomic diversity and abundance during late Maastrichtian, change at species level at the K/T boundary and then gradual renewal of the taxonomic composition during the Danian (Ilieva, 1998, 2000).

All these data indicate that the global mass extinction hypothesis at the K/T boundary as a result of simply a bolide impact might not be accepted as the only plausible explanation.

It is also widely perceived that the destructive effect of the big impact on the environment had global dimensions. The latest data from stable isotope analyses also refute this initial concept. In the Tethyan localities, the $\delta^{13}\text{C}$ values in surface waters decreased by 2-3‰ at the K/T boundary, thus registering considerable reduction in primary productivity (Barrera & Keller, 1990). It had been assumed until recently that this reduction in productivity was global and probably provoked by the temporary suspension of photosynthesis as a result of the thick clouds, covering the Earth after the impact. In the high latitudes, however, the $\delta^{13}\text{C}$ values decrease very slightly (0.5‰ in Nye Klov, Denmark and Koshak, Kazakhstan – Keller et al., 1993b) or even increase (ODP Site 738, 750 – Barrera & Keller, 1990). This shows no substantial changes in the primary productivity in these locations at the K/T boundary. A significant drop of the $\delta^{13}\text{C}$ values is traced, however, in the Danian sediments, around 300 Ka after the K/T event (Barrera & Keller, 1994). Later on, during the Danian Age, around 500 Ka after the K/T event, primary productivity returned to its end-Maastrichtian values in both the northern and southern high latitudes. These significant differences in the manifestation of the event at the K/T boundary from different geographical latitudes accounts for different impacts on the biota and the environment.

Recently, Gibbs et al. (2020) published an intriguing study and suggested a new model for survival and recovery of marine microplankton after the impact at the K/T boundary. The authors assume that algal plankton turned to hunting to survive and recover from end-Cretaceous impact darkness. They found, that “most of the incoming, post-extinction acme taxa (*Praeprinsius*, *Futyania*, and early *Prinsius*) have distinct openings in their fossilized coccospheres. These openings indicate the presence of flagella in life that would have allowed for motility.... Motility can therefore be considered a prerequisite for phagotrophy” (Gibbs et al. 2020, p. 3). Furthermore, Gibbs et al. (2020) found, that “the Cretaceous nannoplankton taxa that survived the mass extinction event either have morphologies indicative of phagotrophy (i.e., flagellar openings) or typically have inhabited shelf or coastal regions where today mixotrophic haptophytes are predominantly found. This potential capacity for mixotrophy in the survivors suggests that nannoplankton endured the mass extinction event using phagotrophy, likely feeding on bacteria and/or organic matter washed in from rivers and tsunamis during the post-impact blackout that may have persisted from weeks to 2 years” (Gibbs et al. 2020, p. 4). Therefore, their conclusion is that widespread phagotrophy (prey ingestion) was fundamental to plankton surviving the impact and also for the subsequent reestablishment of

primary production. Ecological selectivity points to extreme post-impact light inhibition as the principal kill mechanism, with the marine food chain temporarily reset to a bacteria-dominated state. Subsequently, in a sunlit ocean inhabited by only rare survivor grazers but abundant small prey, it was mixotrophic nutrition (autotrophy and heterotrophy) and increasing cell sizes that enabled the eventual reestablishment of marine food webs some 2 million years later (Gibbs et al., 2020).

8.1.3. Documenting the event from Bulgarian localities

Before 1991, the Cretaceous-Paleogene boundary in Bulgaria had been mentioned only in regional geological and regional stratigraphic studies (Kanchev, 1960-1970; Nachev, 1970-1992; Karagyuleva & Kostadinov, 1977). To trace the boundary, lithological considerations without sufficient biostratigraphic support had been used. Particularly unclear are the criteria used to recognize it within the rhythmic complexes, which appear to be very provisional. Biostratigraphic criteria have been applied in specialized articles on paleontology and stratigraphy (Trifonova, 1959, 1960; Juranov, 1983, 1989), but the position of the K/T boundary was not precisely specified and fixed in any section.

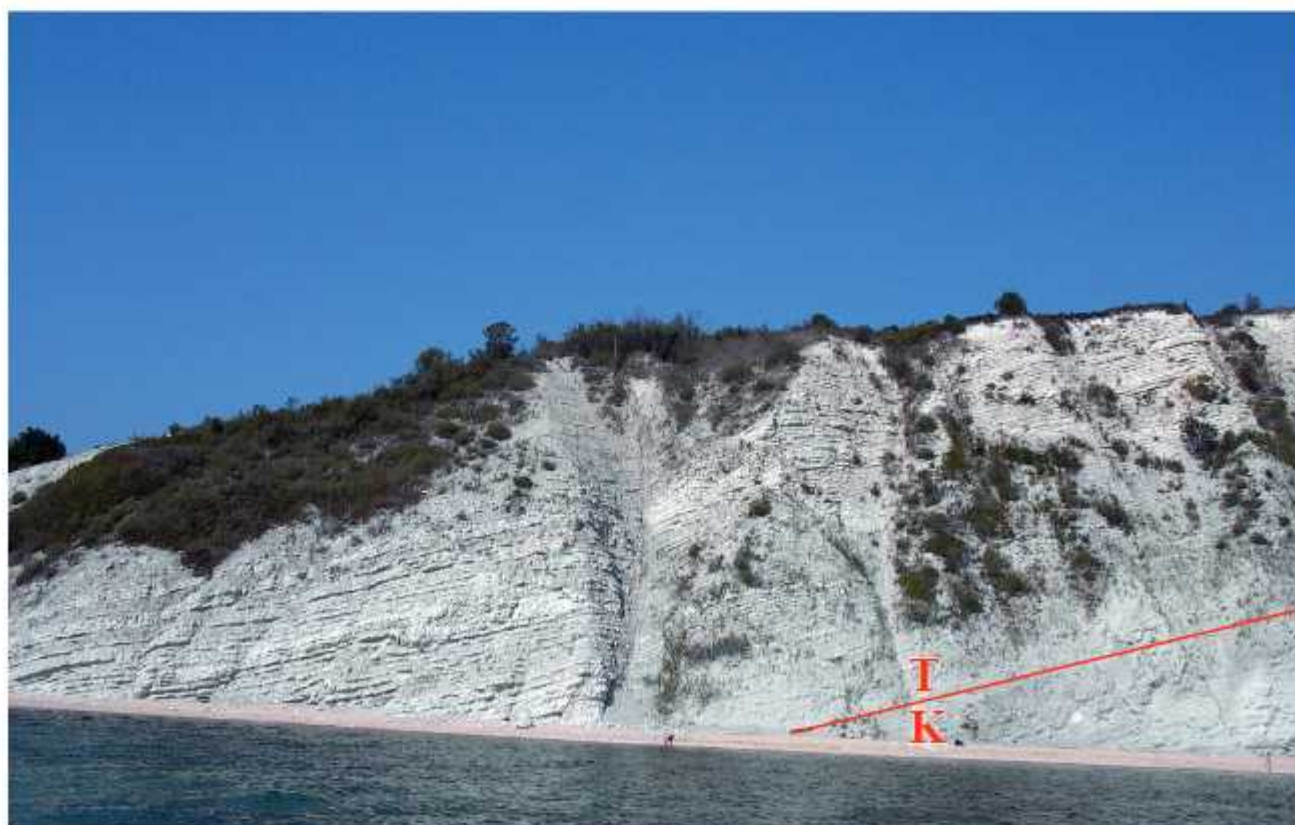


Fig. 8.3. The first continuous section across the K/T boundary in Bulgaria. Described from Byala, Varna District, discovered in June 1991 (Stoykova & Ivanov, 1992)

From the event viewpoint, the studies of the K/T boundary were initiated by the author (K. Stoykova) in 1990 and have been intensively carried out under the Bulgarian-Austrian joint project entitled "Mesozoic boundaries in Bulgaria (Permian-Triassic and Cretaceous-Tertiary Boundary)", 1991-1993.

The first continuous section across the K/T boundary in Bulgaria with the clay layer present was discovered near Byala, Byala 2b section in June 1991 (Stoykova & Ivanov, 1992, Fig. 8.3). Later on, in September 1991, an iridium anomaly of 6 ppb was detected in samples from the same section (Preisinger et al., 1993a; 1993b).

After the Bulgarian-Austrian project was completed, studies on the K/T boundary continued. The biostratigraphy of the Maastrichtian-Paleocene interval based on calcareous nannoplankton and ammonites has been extensively studied (Ivanov, 1993b; Ivanov & Stoykova, 1994; Stoykova et al., 2000; Stoykova & Ivanov, 2004a, c). The first paleontological study on the taxonomic composition of the ammonite fauna in the Upper Maastrichtian was published (Ivanov, 1993b). Another aspect of the studies focussed on the role of the impact event in the changes in faunistic and floristic assemblages at the K/T boundary (Ivanov & Stoykova, 1995; Stoykova, 1996a, b). New, uninterrupted sections through the K/T boundary within different basin settings have been discovered:

- in deep water environment: turbidites of the Emine Fm near Emona (Sinnyovsky and Stoykova, 1995); Marash, Sliven region (Stoykova et al., 2000);

Kozichino, Burgas region (Sinnyovsky, 2003);

- in carbonate shelf sequences near the village of Moravitsa, Mezdra region – Sinnyovsky (1999); along Razkrachenitsa and Kozya Rivers, East Fore-Balkan – Vangelov and Sinnyovsky (2000);
- in hemipelagic sediments, siltstones and marls of the Kladorub Fm near Kladorub village, Vidin region (Sinnyovsky et al., 2002).

Expression of the event at the K/T boundary in the complete sections around Byala town

Mineralogical and geochemical analyses of the boundary interval (from -7 m to +5 m below and above the K/T boundary, respectively) revealed mineral composition, fluctuations in the carbonate content, $\delta^{13}\text{C}$, $\delta^{18}\text{O}$ and the content of RREs such as Ir, Pt, Pd, Ru, Rh and others. The results of these analyses were obtained through cooperation with foreign colleagues (Adate et al., 2002) and are shown in Fig. 8.4 and 8.5.

The extinction of the fauna and flora at the K/T boundary and their recovery afterwards are examined as one whole process. The features and trends of this process are interpreted and described as a model. The Kauffman & Erwin (1995) model has been used as a basis in the interpretation.

Several stages are indicated throughout the change in the assemblages: background conditions, mass extinction, survival and recovery (Stoykova, 1996b; Stoykova & Ivanov, 2002a) – Fig. 8.6.

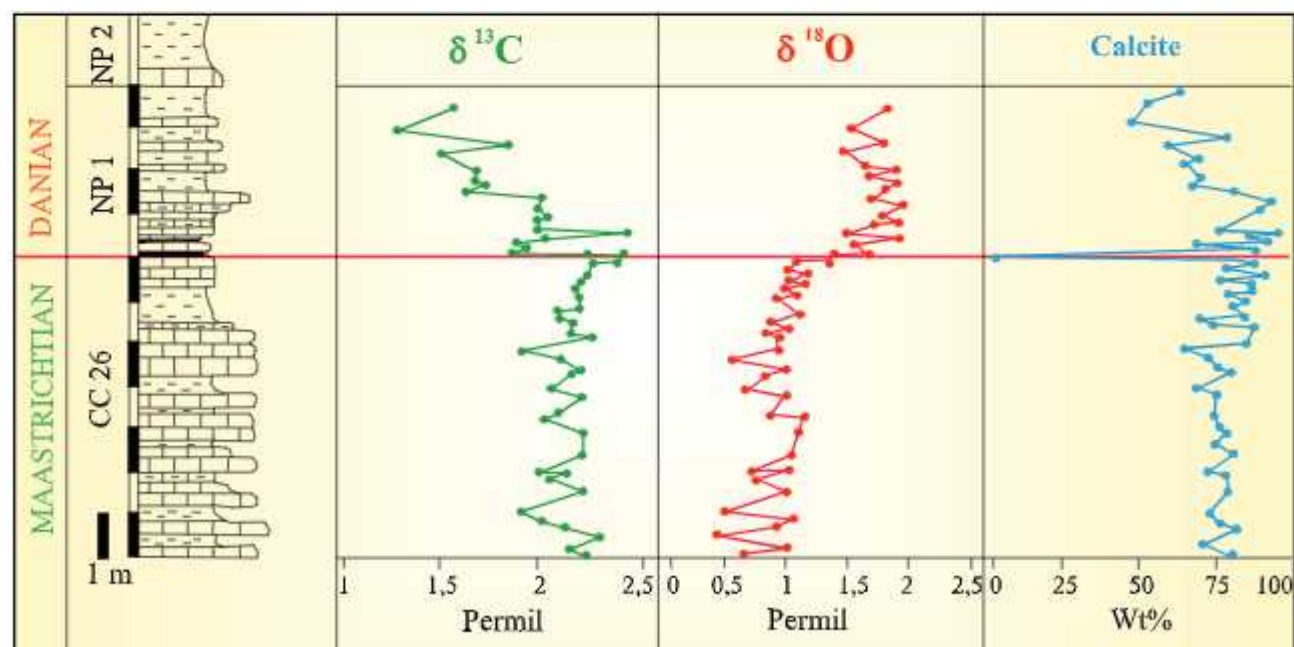


Fig. 8.4. Changes in the isotope content ($\delta^{13}\text{C}$ and $\delta^{18}\text{O}$) and carbonate content across the K/T boundary in the Byala 2b section (after Adate et al., 2002)

At the beginning of the late Maastrichtian, the calcareous nannoplankton are abundant and diverse, showing great species richness (over 70 species). The marine invertebrates are represented by ammonites, inoceramids, echinoids, rarely belemnites and brachiopods (Ivanov & Stoykova, 1994). The ammonites are represented by commonly occurring 23 species. At some levels inoceramids dominate, represented by several species, some of which reach up to 25 cm in length. The echinoids are also diverse; 13 species have been documented. The background communities are abundant and highly diversified.

At the beginning of the late Maastrichtian, the inoceramids disappeared. The species diversity of the ammonites gradually decreases during the late Maastrichtian – and just below the K/T boundary only 4 species have been detected. All these events and evolutionary trends preceded the impact event (Ivanov & Stoykova, 1995).

The boundary clay layer corresponds to the stage of mass extinction. Rare fragments of the surviving nannoplankton species are seen while macrofossil remains are totally absent. The Cretaceous/Paleogene boundary marks the complete extinction of the ammonites and belemnites, as well as of all Maastrichtian echinoid species.

In the first few meters above the clay layer, the composition of the nannofossil assemblages is drastically reduced. However, calcareous dinoflagellates seem to flourish explosively – *Thoracosphaera operculata*, *T.*

saxea and nannoplankton species *B. bigelowii*, considered a “disaster” species. As a whole, the nannofossil associations are dominated by the surviving species. Also, 2-3 newly emerging species are identified here.

This interval corresponds to the survival stage and encompasses the nannofossil zone NP1. From the quantitative point of view, the pre-adapted survivors and disaster species prevail. The newly evolving species represent a relatively small portion of the assemblages (Fig. 8.6).

In the next interval that corresponds to the zones NP2 and NP3, the species diversity and abundance of the organism groups present (nannoplankton and echinoids) recover to the levels of the beginning of the late Maastrichtian. The recovery stage is characterized by high speciation rates, leading to rapid diversification (Fig. 8.6).

In conclusion, the following characteristic biological events are registered within the K/T boundary interval:

- mass extinction of the specialized forms;
- explosion in the populations of disaster species;
- relatively fast occupation of the vacated ecological niches and recovery of the marine communities. The pre-adapted “survivors” as well as the newly evolving species play a substantial role in this process (Fig. 8.6).

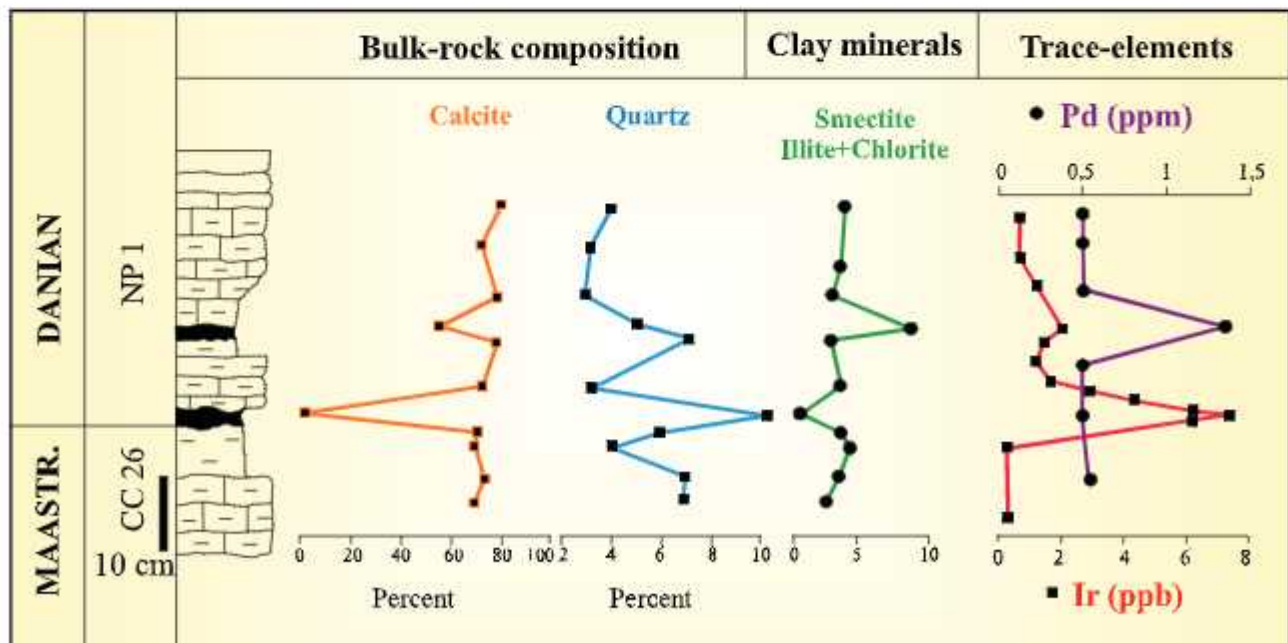


Fig. 8.5. Bulk rock composition, clay minerals and trace elements around the K/T boundary in the Byala 2b section (after Adatte et al., 2002)

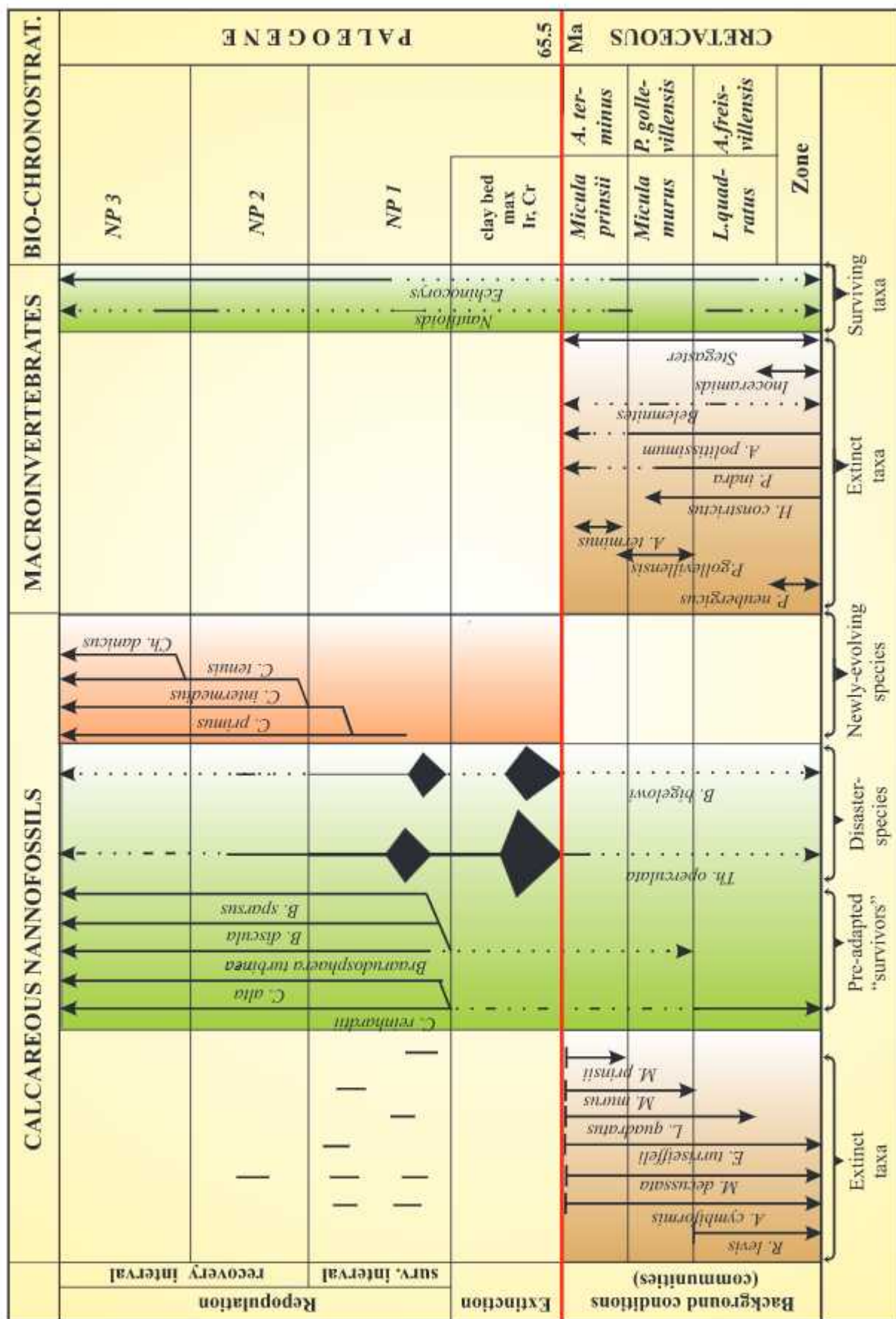


Fig. 8.6. Model of the response of the calcareous nannoplankton and macroinvertebrates across the K/T boundary (after Stoykova & Ivanov, 2002a)

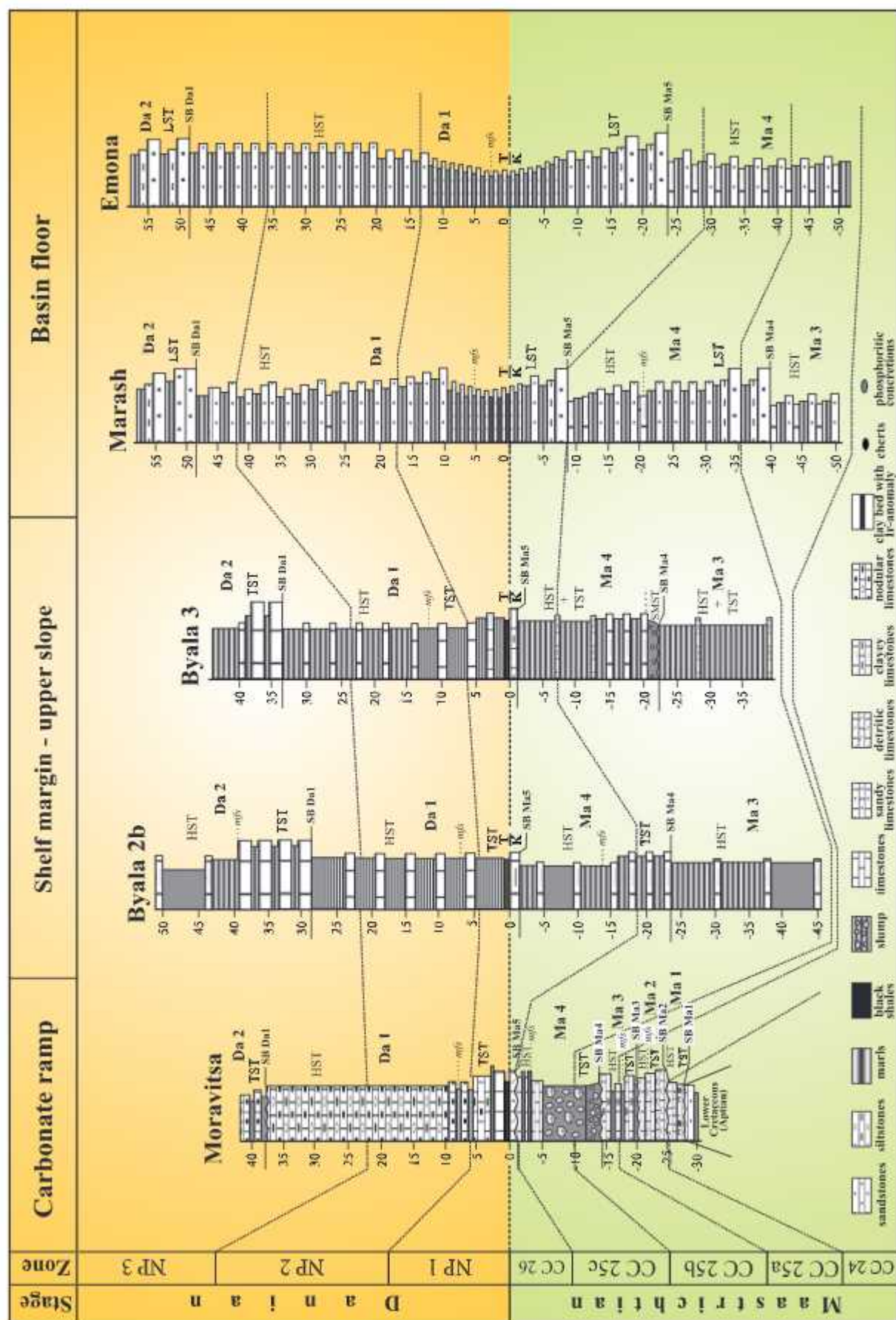


Fig. 8.7. K/T boundary sections in different basin environments – shelf/ramp, shelf margin/slope and deep water/basin (after Stoykova & Ivanov, 2002a; 2004a)

The study of geological sections across the K/T boundary in Bulgaria and the analysis of the acquired data suggests that they record different biotic responses to the event. Of key importance is the location of the section in the basin profile and its recognition as representing a specific basinal zone (Fig. 8.7).

The sections that contain a continuous record across the K/T boundary in Bulgaria allowed for analysis of the differences recorded for the event between various basin zones (Ivanov & Stoykova in Stoykova et al., 2000; Stoykova & Ivanov, 2002a; 2004a). The sections are grouped in three types:

- sediments deposited in *deep water* environments – turbidite sequences of flysch type. The Emona and Marash sections are included here.
- deposition on the *basin margin and slope* – hemipelagic sediments; represented by the sections near Byala (Byala 1, Byala 2b, Byala 2c, Byala 3) and Goritsa;
- deposition in the *shelf* area – sequences dominated by calcareous sediments formed on a carbonate ramp. These include the sections of the West Fore-Balkan around Mezdra – south of Moravitsa, near Mezdra and Lyuti dol, and in the East Fore-Balkan – at Chudnite skali.

In the deepwater parts of the basin, the sedimentary successions comprise typical rhythmic sediments – turbidites. The Upper Maastrichtian and the lower Danian are relatively thick. The sections are continuous across the K/T boundary. These sediments are formed in basinal submarine fans with alternating proximal and distal turbidites. The cyclic sequences are represented by typical flysch rhythms of different type and completeness. In some places (for instance, near Marash), the rhythmic sedimentation is interrupted by event sediments formed by large flows (mega-slumps). In the middle part of the Maastrichtian Stage, rhythms of relatively thin clastic basal sediments with dominant pelitic and carbonate portions of the rhythms prevail. These are probably distal turbidites. In the uppermost parts of the Upper Maastrichtian, the change in the sedimentation regime is marked by a packet of proximal turbidites with relatively thick clastic elements at the base of the rhythms. The K/T boundary falls at the base or within a packet of thin-rhythmic silty-pelitic rhythmic sediments, that also represent distal turbidites. Some 15–20 m above the boundary, the sedimentation regime shifts again – thick (up to 1–1.5 m) sandstone beds,

probably formed in the proximal portion of the fan, interrupt the rhythmicity.

The event marker of the K/T boundary in these sections is not clearly expressed. The specific character of the sedimentation in this environment obviously prevents preservation of any clear lithological benchmark. The boundary is placed only by biostratigraphic criteria.

The event nature of the K/T boundary in these sections is proved solely by the considerable change in the marine plankton. No benthic and nektonic fauna has been found so far. The calcareous nannofossil data reveal an essential increase in the thickness of the biostratigraphic zones (by 3 times) in both the Upper Maastrichtian and the lowermost Paleocene. A complete nannofloristic succession with both a high diversity of species and an abrupt change in the boundary interval have been identified. In the first meters of the Paleocene, an important peculiarity is the considerable occurrence of reworked (or surviving) Cretaceous species. The nannofossil associations in the boundary interval have a typical Tethyan appearance. However, *Ceratolithoides kamptneri*, considered a typical Tethyan species, has been detected in the turbidite successions only. Moreover, in these sections the species *Micula prinsii* occurs relatively more frequently. The representatives of the genus *Braarudosphaera* are not found in this type of section at all, since they are considered an ecological indicator of shallow water-depths in the shelf zone.

The second group of sections – Byala 2b, Byala 3 and Goritsa are formed around the shelf margin and in the upper part of the basin slope. The sedimentary succession in the boundary interval is represented by alternating clayey limestones and marls. From the sedimentological point of view these are defined as wackestones and mudstones, composed mainly of calcite and clay with up to 15% allochems of biotritus. These rocks hardly contain terrigenous admixtures, being formed in calm, low-energy environments. The authigenous minerals are represented by pyrite, glauconite and quartz. The succession is composed of alternations of clayey limestones and marls. Careful observation shows that these are periodites of variable carbonate and pelitic content. They reflect the orbital cycles, known also as Milankovitch cycles. Regardless of the common clayey-carbonate background of the sedimentation, the Upper Maastrichtian and Paleocene rocks differ visually. The elementary cycles in the Upper Maastrichtian are relatively thicker, with lower carbonate content in the doublets. In the Paleocene, the limestones as an element in the periodites disclose higher carbonate content. It is well known that the K/T boundary in these sections is marked by a

boundary event marker – dark grey to black clay layer (Fig. 8.8).

This type of section is very suitable for observing paleobiological changes at the K/T boundary interval. Parallel studies on the macro- and microfauna and a complete sedimentary record and abundance of fossil finds provide a high degree of confidence and reliability in the results. Actually, this paleoenvironment is where the model of Kauffman & Erwin (1995) on mass extinction, survival and recovery of the ecosystems after catastrophic events, has been tested. Furthermore, the behaviour and the response of the various organisms and ecological groups to the K/T boundary event have been studied here (Stoykova, 1996a, b; Stoykova & Ivanov, 2002a).

The most significant and abrupt change is seen in the marine plankton – nannoplankton and planktonic foraminifera. A major part of the Cretaceous forms became extinct. Single species, predominantly in shelf and coastal habitats, survived the event and became explosively abundant shortly after. Cretaceous forms predominated or are still present in a rather thick interval, 5–7 m above the boundary (in NP1 and the base of NP2 zones). Unfortunately, the lack of analysis of $\delta^{13}\text{C}$ signals makes it impossible to determine whether these are reworked or surviving (Perch-Nielsen et al., 1982).

The change in the marine macro-invertebrates reveals different features. The sections near Byala confirm the fact that the inoceramids disappeared at the beginning of the late Maastrichtian. The results from studies on echinoid evolution are analogous with other European

sections. Their species diversity decreases gradually in the late Maastrichtian. Substantial change in the echinoid fauna occurred at the K/T boundary, but it took place at the species level. Diversity in the ammonite fauna gradually decreased as of the beginning of the late Maastrichtian. Only four species of ammonites almost reached the K/T boundary. It is not a mere coincidence that the echinoids and ammonites demonstrate comparatively high species diversity in the interval from -45 m to -15 m below the boundary, with subsequent sharp decrease. Also curious is the coincidence with some other sections in Europe – for instance, at Zumaia, where the decrease occurs at -13 m below the boundary. It seems that the extinction of the ammonites and the change in echinoid fauna have been dramatically influenced by eustatic changes in sea level, therefore the stepwise model of extinction is rather applicable to them (Fig. 8.6; Ivanov & Stoykova, 1995; Stoykova & Ivanov, 2002a).

The third type of sections is characterized by sedimentary sequences, dominated by the carbonate spectrum and deposited in the shelf area over the carbonate ramp with poorly expressed shelf margin. From the sedimentological viewpoint, the rocks are represented by wackestones and packstones, described as clayey, micritic and bioclastic limestones, alternating with thin-bedded marls.

In the stratigraphic sequences it is easy to trace the transgressive-regressive cycles, marked by marine flooding surfaces – sedimentation gaps and unconformities. In the relatively deeper sections, clear Milankovitch cyclicity is differentiated (Sinnyovsky, 1999). The K/T boundary in these sections coincides



Fig. 8.8. Clay bed, marking the K/T boundary at the Byala 3 section, containing an elevated Ir level (6 ppb) and other rare elements

with such a surface – probably a maximum flooding surface (mfs). This fact, as well as the higher dynamics in the shelf environments, determine also the incompleteness of the K/T boundary interval in the majority of sections. A boundary event marker – the Iridium anomaly, has been detected only in the section south of Moravitsa (Sinnyovsky, 1999). This marker is not so clearly expressed as in the hemipelagic sections.

The K/T boundary coincides with the boundary between the Asparuhovo and "Mezdra" Fms in the East Fore-Balkan and occurs inside the Mezdra Fm in the West Fore-Balkan. Biostratigraphically it is marked by the change in the nannoplankton associations. No explosion of disaster species is recorded here. Some typically Maastrichtian and Paleocene species are missing as well, probably due to ecological reasons. The so called reworked (or surviving) Cretaceous species are rather rarely seen at the base of the Paleocene. It is difficult to assess whether this is a feature of the shelf associations or a consequence of the incomplete geological record of the sections.

Macro-invertebrates commonly occur in these sections. The inoceramids here also disappear at the base of the Upper Maastrichtian. The benthic echinoid fauna exhibits substantially different species composition (in the Maastrichtian as well as in the Paleocene), due to ecological reasons. But even in this pattern, the echinoid fauna changes across the boundary at the species level. Ammonites are found to the middle part of the Upper Maastrichtian. The presence of an unidentifiable ammonite 1 m below the K/T boundary, is noted by Sinnyovsky (1999). In general, regardless of the sediments and sedimentological features and limited material, the trends in the behaviour of the different macro-invertebrate groups across the boundary are similar to those in the sections near Byala.

The Bulgarian sections around the K/T boundary are compared with those known from the Tethyan area and beyond. Their paleogeographic location was likely intermediate, between the low and high latitudes (Stoykova et al., 2000; Stoykova & Ivanov, 2004a). The data from the analyses of the Bulgarian sections are essential in complementing global knowledge on the event and the consequences it had on the life and environment of the planet.

8.2. Middle Paleocene biotic event (MPBE)

8.2.1. Introduction

The intensive studies of the deep-water sections under the ODP programme in Shatsky Rise (Central Pacific Ocean) and Walvis Ridge (Southern Atlantic Ocean)

confirmed the expression of a global event in the middle of the Paleocene Epoch. It is called the "Middle Paleocene Biotic Event" or the "Early Late Paleocene Event" (MPBE or ELPE – Bralower et al., 2002; Bralower et al., 2003; Zachos et al., 2004; Petrizzo, 2005; Lourens et al., 2005). The event is marked by a clearly visible clay layer, reflecting a sharp drop in carbonate content and an increase in clay minerals in these sediments.

The observations on the changes in the marine microplankton – calcareous nannoplankton and planktonic foraminifera, suggest a short-term climatic event – global warming, that greatly contributed to enhanced rates of evolution in these groups.

The key hypothesis explaining the sudden warming at the Paleocene-Eocene boundary is the influx of large volumes of greenhouse gases (mainly CO₂ and CH₄) into the sea water and the atmosphere, as a result of decomposition of methane hydrates on the ocean bottom (Dickens et al., 1995; 1997). The same suggestion is also hypothesized to explain short-term transient warming in the middle of the Paleocene Epoch.

Moreover, it is considered that all identified short-term warming events (hyperthermal events) in the Paleocene and early Eocene were forced by astronomical factors. As a result of the analysis of orbital cycles in the Paleocene and Eocene sequences, a hypothesis has been advanced that the hyperthermal events correspond to maximums in short-term eccentricity cycles (Lourens et al., 2005).

8.2.2. Globally identified trends in the manifestation of the event

Until 2007, the MPBE was documented only in the oceanic sections at Shatsky Rise and Walvis Ridge (Bralower et al., 2003; Zachos et al., 2004; Petrizzo, 2005). The first land-based locality was described by Bernaola et al. (2007) at the Zumaia section, W Pyrenees (Fig. 8.9). According to Bernaola et al. (2007), the MPBE is positioned within the nannofossil zone NP6, at 4.5 m above the first occurrence of *Heliolithus kleinpellii* and 2 m below the C26r-C26n boundary. The nannoplankton response to this short-lived warming event suggests a shift from cooler mesotrophic to warmer oligotrophic conditions, as evidenced by relative abundance of selected calcareous nannofossil taxa (Bernaola et al., 2007).

The main characteristics of the event are as follows:

Lithological expression. The event is marked by a clearly visible clayey interval, where the carbonate

content is below 30%. In Shatsky Rise the clay layer is red in color and 5-30 cm thick, rich in crystals of philipsite and phosphate microgranules. In the section at Zumaia it is grey in color and 30 cm thick (Fig. 8.9 C – 3), underlain by a 52 cm thick marly bed, where carbonate content gradually decreases. The mineral composition of the clay layer includes smectite (46-60%), illite (35-51%) and small amounts of chlorite (2-10%) (Bernaola et al., 2007).

Geochemical expression. Negative excursion of $\delta^{13}\text{C}$ by 1‰ is proved in the section near Zumaia, indicating the pH drop in the deep parts of the ocean. As

a result, the lysocline level increases (becomes shallower) as does the calcite compensation depth (CCD), and the clayey interval is deposited.

Magnetostratigraphy. Magnetostratigraphic investigations indicate that the event occurs in the uppermost part of chron 26r, immediately below the boundary with chron 26n. Quite typical are the high values of magnetic susceptibility of rocks detected in the interval of the lowest carbonate content (the clay layer). In the section at Zumaia the magnetic susceptibility values are measured at $6.58 \times 10^{-6} \text{ m}^3/\text{kg}$ (Dinarès-Turell et al., 2007; Bernaola et al., 2007).

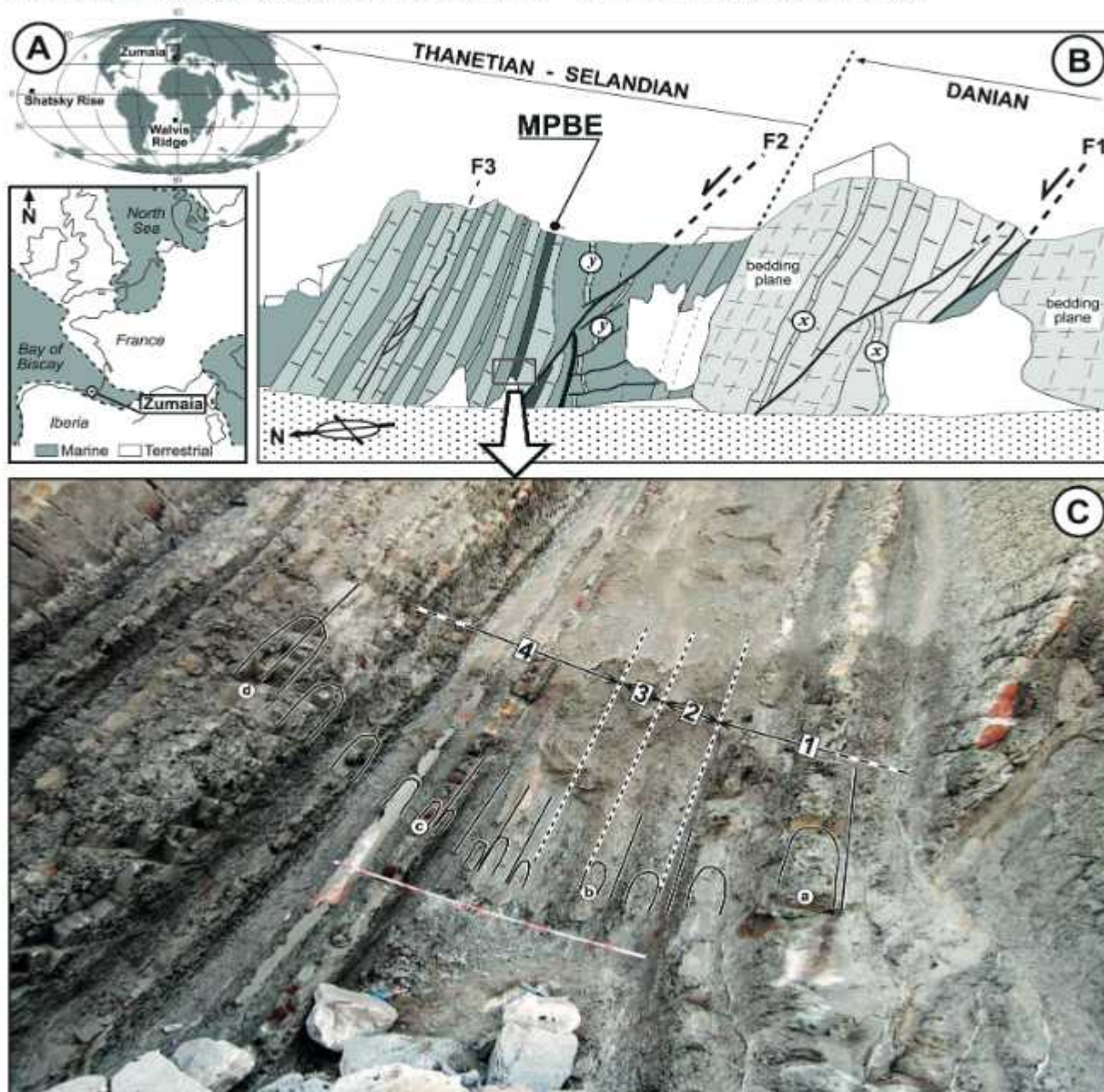


Fig. 8.9. Localities with proven Mid Paleocene Biotic Event (MPBE): A – ocean sections in Shatsky Rise and Walvis Ridge and location of the Zumaia section, W Pyrenees, Spain; B – schematic sketch of the mid-Paleocene outcrop in the Zumaia section showing the location of the MPBE; C – detailed view of the MPBE-interval, Zumaia section, showing the main lithological beds (a, b, c, d – reference beds, 3 – 30 cm clay layer, marking the core of the event, after Bernaola et al., 2007)

Biostratigraphy. Based on nannofossil data, MPBE falls within NP6 nannofossil zone – above the FO of *Heliolithus kleinpellii* and below the FO of *Discoaster mohleri* (Dinarès-Turell et al., 2007; Bernaola et al., 2007). The event occurs within the planktonic foraminiferal zone P4.

Biotic expression. In ocean sections MPBE is marked by a sharp drop in species diversity and strong dissolution of the planktonic foraminifera shells, their associations being poor, dominated by the genus *Igorina* (mainly *I. tadjikistanensis* – Röhl et al., 2007). Calcareous nannoplankton records an abrupt increase in the abundance of the representatives of genus *Ericsonia*, considered typical of the low latitudes and warm waters.

The quantitative analyses of the nannoplankton associations in Zumaia show a substantial change occurring during the event. The cold-water mesotrophic associations (*Toweius pertusus*, *Prinsius* and *Fasciculithus*) have been replaced by warm-water oligotrophic associations (*Ericsonia*, *Coccolithus pelagicus*, *Heliolithus* and *Toweius tovae*). This shift clearly corresponds to the peak of the negative excursion of $\delta^{13}\text{C}$ (Bernaola et al., 2007).

The quantitative analyses of the planktonic foraminifera in the same section reveal a sharp drop in species diversity from 16-19 species before the event down to some 5-6 species in the clayey interval, marking the core of the event. The plankton/benthos ratio (P/B)

rapidly decreases from 87% through 50% to below 10% in the clay layer. The wall thickness of the shell of the planktonic foraminifera is also sharply reduced as a result of the carbonate dissolution. Drastic change in the benthic foraminifera associations is also observed (Bernaola et al., 2007).

Duration. The duration of MPBE is calculated using biostratigraphic, magnetostratigraphic and cyclostratigraphic methods in the Zumaia section, assuming average duration of the precession cycles of ~21 Ka (Bernaola et al., 2007). It is calculated that the event has been relatively short lived – lasted for ~52-53 Ka. Its most intense expression, the essential part that corresponds to the clay layer, lasted around 10-11 Ka. The total thickness of the MPBE interval is 4.6 m. The clay layer, marking the core of the event is 30 cm thick, and represents half of a precession cycle, i.e. ~10-11 Ka (Bernaola et al., 2007).

8.2.3. Documenting the event from Bulgarian localities

Only biostratigraphic methods have been applied so far in identifying the event in Bulgarian localities.

Using nannofossils as a key tool, the event is traced through its lithological expression – a thin clayey-marl layer within NP6 zone in the sections at Petaritsa and Kreta in Central northern Bulgaria (Fig. 5.29 and 5.47-48).

Fig. 8.10. Supposed lithological expression of the mid-Paleocene biotic event in the Kladorub section (Fig. 5.3) – two layers of red clayey marls in the upper part of NP6 zone, contrasting with the grey background color of the sediments



It is also localized in the uninterrupted Paleocene successions near Kladorub and Byala. The presence of a particular clay-rich interval at Kladorub (NW Bulgaria) and Byala (NE Bulgaria) has been recorded, characterized by significant changes in the composition of calcareous nannofossil assemblages. In the Kladorub section, two distinct reddish clay layers (7–10 cm thick) occur that probably represent the lithological manifestation of the MPBE (Fig. 8.10). It is situated within the upper part of NP6 zone, above the first occurrence of *Bomolithus bramlettei*, and likely represents the sedimentary response of the MPBE. The calcareous nannofossil assemblage in the reddish layers is characterized by the remarkable abundance of *Heliolithus kleinpellii*, *Coccolithus pelagicus* and *Toweius eminens*. In the Byala section (Byala 4), the clay interval is greyish with reddish interbeds (Fig. 8.11). The assemblage is dominated by *Heliolithus kleinpellii*, *H. cantabriae*, *Bomolithus elegans*, *Coccolithus pelagicus*, *Toweius tovae* and *Ericsonia subpertusa* (Stoykova & Ivanov, 2006a, b). Further isotope ($\delta^{13}\text{C}$) and paleomagnetic studies are needed in the mid-Paleocene sequences of both sections, in order to prove undoubtedly the presence of the MPBE.

Therefore, the biotic response of the event is clearly recorded by nannofossil associations in the Bulgarian sections: a replacement “cold-water”, mesotrophic to eutrophic species (*Prinsius martini* and *Prinsius bisulcus*) by warmer, more oligotrophic taxa (*Fasciculithus*, *Heliolithus*, *Sphenolithus* and *Toweius*), suggesting a shift from relatively cooler mesotrophic to warmer oligotrophic conditions during the event.

8.3. Paleocene/Eocene boundary event – PETM

8.3.1. Introduction

At the boundary between the Paleocene and Eocene Epochs, some 55.5–56 Ma ago, the Earth was subject to one of the most abrupt warming events in its entire history, leading to substantial perturbations in the global carbon cycle – the Paleocene-Eocene Thermal Maximum (PETM). The leading hypothesis, explaining this extreme climatic event, relates to the dissociation of 1.4 to 3 Gt of methane hydrates, deposited in huge quantities at the ocean bottom (Dickens et al., 1995; Dickens, 2011). According to the “gas hydrate dissociation” hypothesis, some Earth system threshold was crossed, so that deep ocean temperatures rose rapidly. This warmth (heat) propagated into sediment on continental slopes, which shoaled the base of the Gas hydrate stability zone (GHSZ) and converted large amounts of gas hydrate to free gas (Dickens et al., 1995).

The following triggering mechanisms have been suggested to be responsible for the event:

- crossing of the temperature threshold gradually warming the Earth (the temperature rises);
- a bolide impact (Cramer & Kent, 2005);
- emission of huge volumes of greenhouse gases following:



Fig. 8.11. Greyish clay interval with reddish interbeds in Byala 4 section, representing the MPBE

- contact metamorphism – intrusion of magmatic rocks in carbon-rich sediments, and
- vast combustion of peat bogs (Higgins & Schrag, 2006);
- explosive volcanism followed by emission of large volumes of greenhouse gases;
- reorganization of the main ocean currents and intensive erosion on the continental slopes;
- astronomical reasons (orbital cyclicity): hyperthermal events in the Paleocene and Eocene Epochs correspond to the maximums of the 405 Ka and 100 Ka eccentricity cycles (Lourens et al., 2005).

The duration of the PETM is calculated at 175-200 Ka (Röhl et al., 2000; 2007), but its most intensive manifestation occurred at the onset, when for some 10 000 to 30 000 years the average annual temperature increased by 4-5°C in the tropical areas, by some 6-8°C in the high latitudes and by 4-5°C in the deep

parts of the ocean (Kenneth & Stott, 1991; Röhl et al., 2000; Zachos et al., 2004).

Drastic warming was accompanied by a change in the sedimentation regime with enhanced terrigenous input, resulting from onshore weathering and erosion and significant deposition of clastic sediments in the basins.

8.3.2. Globally identified trends in the manifestation of the event

The PETM was originally discovered in deep-water sections at ODP Site 690 (Kenneth & Stott, 1991). However, soon afterwards it was recognized in both additional deep-water and also land sections.

Lithological expression. The event is marked by a characteristic clayey interval. As a result of the global warming, the volume of carbonate deposited in the vast marine basins dropped dramatically and a characteristic clayey interval was deposited (Carbonate

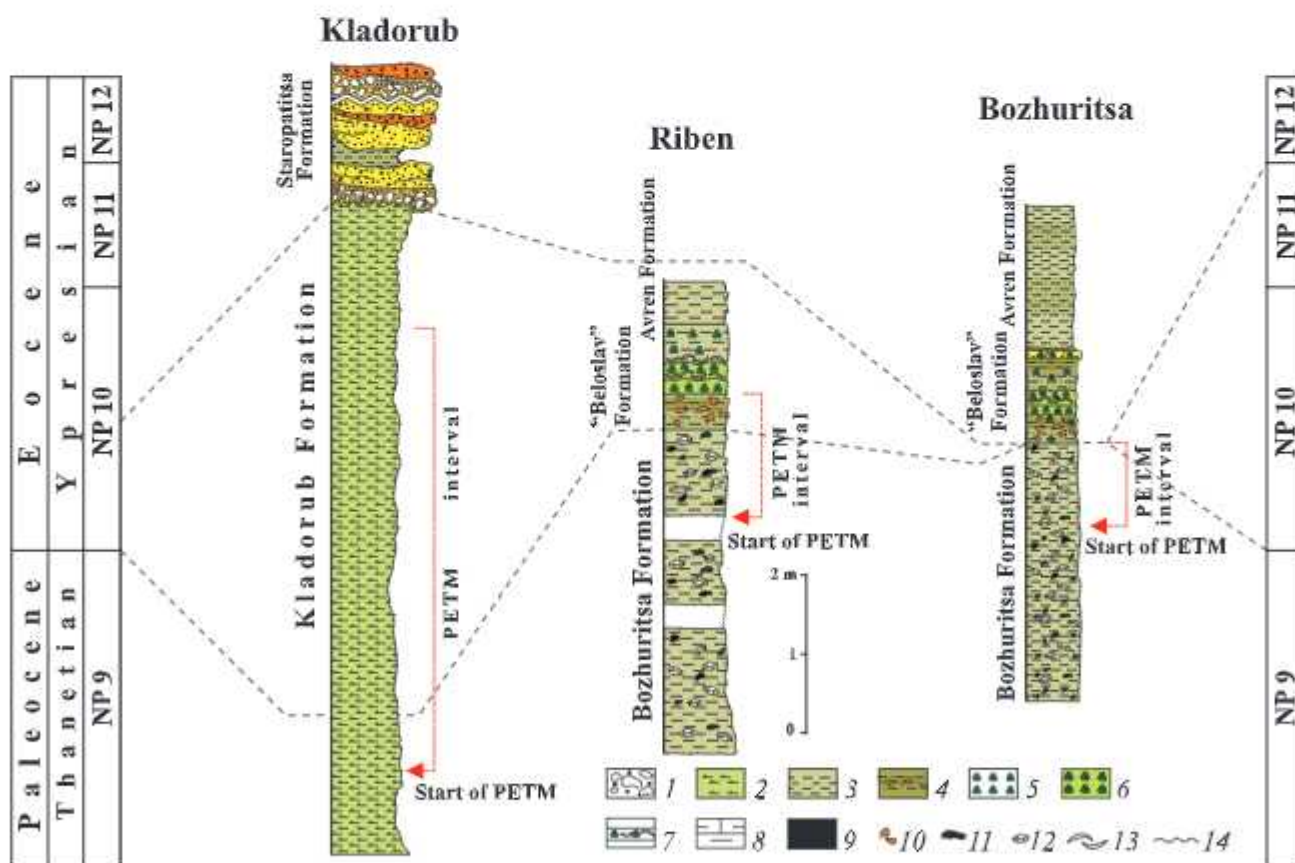


Fig. 8.12. Correlation of the sections with proven expression of the PETM in Bulgaria – Kladorub, Riben and Bozhuritsa 1 – conglomerates; 2 – marls; 3 – claystones; 4 – interval enriched in Fe-hydroxides; 5 – glauconitic marls; 6 – glauconite; 7 – condensed level with *Ostraea* shells; 8 – clayey limestones; 9 – dark grey to black claystones; 10 – Fe-concretions; 11 – flint; 12 – carbonate concretions; 13 – *Ostraea* shells; 14 – wash-out surface (after Stoykova & Ivanov, 2005). All sections drawn to the same vertical scale

Dissolution Interval, CDI) from several centimeters to several meters thick (Monechi et al., 2000).

Geochemical expression. The onset of the PETM is marked by a sharp negative excursion, from 4.00‰ to 2.5‰, in the carbon isotope composition in the marine and continental carbonate sediments, as well as in the organic matter, known as the Carbon Isotope Excursion (CIE – Zachos et al., 1993; Bralower et al., 1995). The CIE is considered to reflect the injection and subsequent removal of huge amounts of $\delta^{13}\text{C}$ -depleted carbon into the ocean-atmosphere system

(Dickens et al., 1995). An even higher amplitude of the $\delta^{13}\text{C}$ excursion, from 5‰ to 6‰, is registered in carbonates from paleosols and in the tooth enamel and bones of contemporary terrestrial vertebrate organisms (Bowen et al., 2002).

The negative CIE of $\delta^{13}\text{C}$ in both marine as well as in continental environments, labels it as a universal, globally identifiable geochemical marker, allowing precise correlation between marine and terrestrial sections at the Paleocene-Eocene boundary (Kenneth & Stott, 1991).

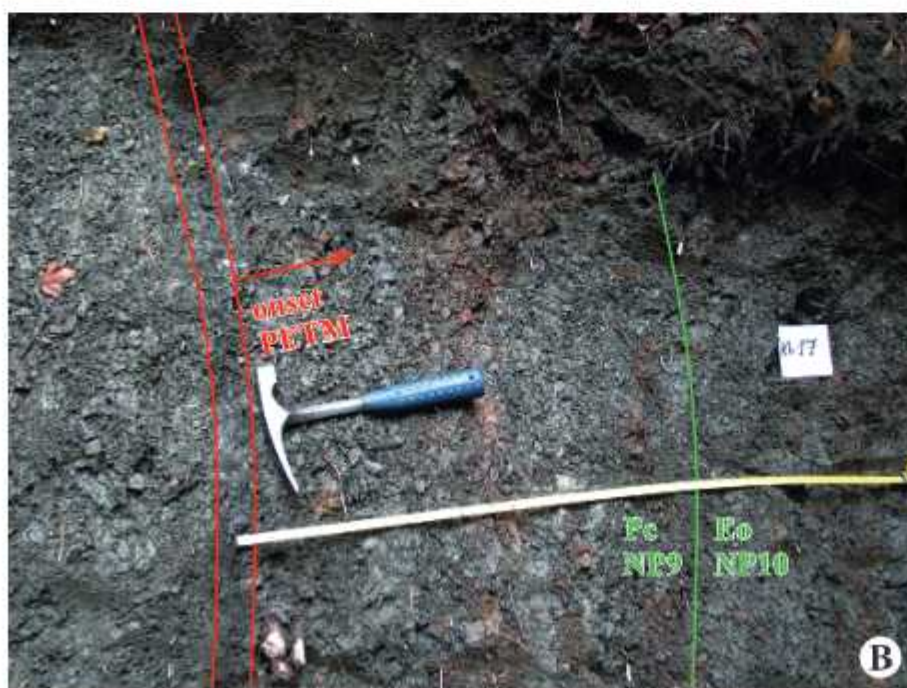


Fig. 8.13. Clayey interval, representing the PETM in the sections near Riben (A) and Kladorub (B). The onset of the climatic event, as well as the position of the Paleocene-Eocene boundary are marked. Yellow tape measure = 1 m

Magnetostratigraphy. Magnetostratigraphic studies indicate that the event falls within the range of Chron 24r.

Biostratigraphy. It was initially supposed (in the 1990s) that the event had occurred during the late Paleocene, and as such was termed the Late Paleocene Thermal Maximum (LPTM) (Zachos et al., 1993). Numerous studies performed later on, in onshore and offshore sections proved, however, that the onset of the event occurred at the very end of the Paleocene

(the uppermost part of NP9 zone), and ended in the early Eocene (the base of NP10 zone). Therefore, the name was changed to the Paleocene-Eocene Thermal Maximum (PETM). The event falls within P5 planktonic foraminiferal zone.

Biotic expression. The impact of the abrupt global warming reflects on the entire biosphere. It affected marine planktonic and benthic communities and terrestrial ecosystems. Deep oceanic benthic foraminifera

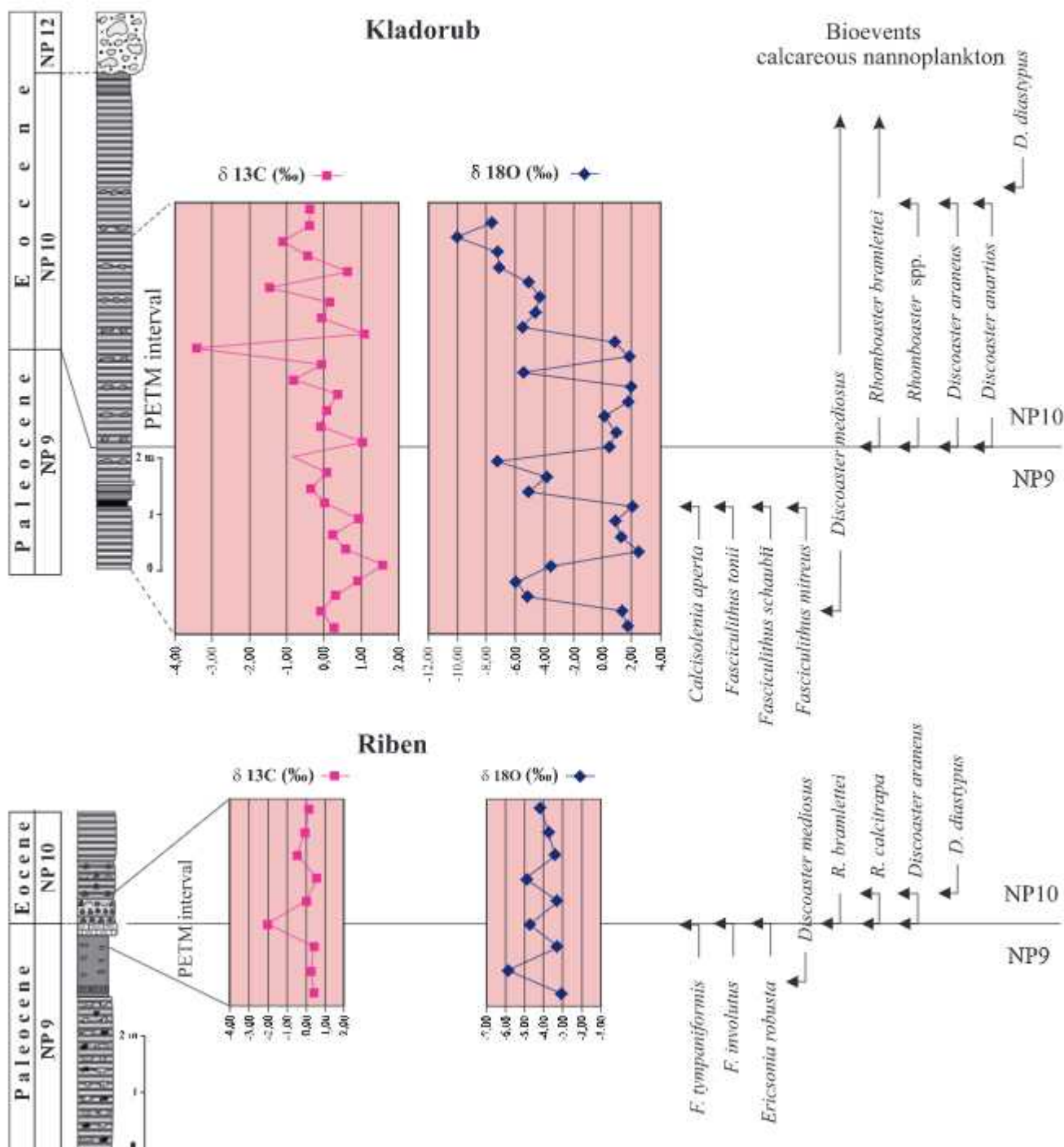


Fig. 8.14. Variations of $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ content in bulk rock samples from the PETM-interval in the Kladorub and Riben sections. The ranges of some key nannofossil species are also shown (after Stoykova et al., 2005b)

fera were one of the most affected groups by the warming; they became extinct – the so-called Benthic Foraminifera Extinction Event (BFEE) related to the PETM is detected in sections.

The calcareous nannoplankton has also experienced major changes in abundance of certain taxa. Substantial evolutionary changes took place – a large group of species of the genus *Fasciculithus* declined in abundance and richness, and the genus *Rhomboaster* emerged, giving rise to the *Rhomboaster* – *Tribra-chiatus* phylogenetic lineage during the early Eocene.

8.3.3. Documenting the event from Bulgarian localities

The first biostratigraphic data identifying the PETM in Bulgaria was published by Stoykova and Ivanov (2005). Three sections in northern Bulgaria – near the villages of Kladorub (NW Bulgaria), Riben and Bozhuritsa, and one section in the Yuri Shimanov well drilled in the Bulgarian Black Sea shelf, were investigated. Utilizing nannofossil biostratigraphy showed the relative completeness of the sections across the Paleocene-Eocene boundary. Biostratigraphic analysis of the distribution of calcareous nannofossils in the boundary interval and documented bioevents and substantial changes in the nannoflora served as key evidence in identifying the PETM in Bulgaria for the first time (Stoykova & Ivanov, 2005 – Fig. 8.12).

The onset of the event in all of the studied sections is marked by a decrease in the carbonate content of the sediments and deposition of a clayey interval. Figure 8.13 shows the onset of the PETM and the position of the Paleocene-Eocene boundary in the sections near Riben and Kladorub.

Analysis of isotope content of $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$. Following biostratigraphic confirmation of the PETM, bulk rock samples of these sections have been analysed for isotopes, mainly of $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ in the laboratory in Naples, Italy by my colleague Mario Sprovieri. The results of the analyses are shown in Fig. 8.14. They unambiguously prove the essential changes (excursions) in the carbon and oxygen isotope content in the boundary interval between the Paleocene and Eocene and do confirm the geochemical expression of the PETM in the sections (Sprovieri in Stoykova et al., 2005b).

Impact of the PETM on the calcareous nannoflora in the Bulgarian sections. In the present study, three land sections (Kladorub, Riben and Bozhuritsa) and one offshore site (Yuri Shimanov well in the Bulgarian Black Sea shelf) have been investigated in order to document the composition of the nannofossil as-

semblages during the PETM and to provide insight into the biotic response of nannoplankton communities to the extreme global warming. High-resolution sampling, approximately every 20 cm, has been performed through the entire PETM interval. Calcareous nannofossil associations before, during and after the PETM were examined to infer biotic responses to abrupt warming. The sedimentology of the studied successions suggests that deposition likely took place in a middle to outer shelf setting.

The pre-PETM nannofossil associations are rich and diversified, comprising abundant *Discoaster protomultiradiatus*, *D. multiradiatus*, *Fasciculithus mitreus*, *F. siderius*, *F. fenestrellatus*, *F. tonii*, *F. thomasi*, *F. bobii*, *F. involutus*, *Chiasmolithus bidens*, *Toweius eminens*, *T. tovae*, *Neochiastozygus junctus* and *Ellipsolithus distichus*.

The onset of the climatic event is lithologically marked by a drop in carbonate content and deposition within a Carbonate Dissolution Interval (CDI). The thickness of the dissolution zone, where calcareous nannofossils are completely absent, varies between 0.6 – 2.5 m in different sections. At the top of the dissolution zone, fragments of dissolution-resistant species such as *Discoaster multiradiatus*, and *Fasciculithus* spp. are present. The association is very poor, with poor preservation and bears the signs of dissolution. All sections reveal the drastic decrease to complete extinction of *Fasciculithus* species, following the onset of the PETM.

The Paleocene-Eocene boundary is drawn at the first occurrence of representatives of *Rhomboaster* (*Rhomboaster* spp., *R. bramlettei*, *R. cuspidis*). In all the sections studied it is located above the onset of the climatic event.

Above, in the Eocene portion of the PETM, a specific warm-water nannofossil association has been identified. Khan and Aubry (2004) defined it as a specific “*Rhomboaster* spp. – *Discoaster araneus* (RD) association”, whereas Self-Trail et al. (2012) called it “Carbon Isotope Excursion (CIE)-taxa”, restricted entirely to the PETM interval. In Bulgaria, the “excursion” taxa assemblage includes *Toweius serotinus*, *Coccolithus bowni*, *Rhomboaster* spp., *Discoaster araneus* and *D. sp. aff. anartios*. The last two species have a very sporadic occurrence and are never abundant in the overall nannofossil association, as noted by Self-Trail et al. (2012). The vertical distribution of the CIE-association entirely coincides and reflects the negative $\delta^{13}\text{C}$ excursion. However, in Bulgarian localities the RD association occurs slightly higher than the CIE-onset, as previously pointed out by Angori et al. (2007) and Self-Trail et al. (2012).

By the time that carbon isotope values are beginning to recover, the *Rhomboaster*-lineage quickly flourished, rapidly increasing in abundance up section with successive, almost simultaneous occurrence of *Rhomboaster bramlettei*, *R. cuspid* and *R. calcitrata*. *Toweius* and *Discoaster* representatives also recover in the upper portion of the PETM – *T. callosus*, *T. occultatus*, *T. pertusus*, *D. multiradiatus*, *D. falcatus* and *D. limbatus*. Other Lazarus taxa include *Zygrhablithus bijugatus*, *Chiasmolithus bidens* and *C. consuetus*. Bulgarian data indicate that the first occurrence of *Discoaster diastypus* is rather later in the early Eocene, beyond the climatic event interval. Some of the key bioevents in the calcareous nannoplankton (first and last occurrence), as well as stratigraphically important nannofossil species are shown on Fig. 8.14.

Reviewing the variable evolution of the Earth's climate during the last 66 Ma, the Paleogene period is justifiably considered as a transitional one between "the warm Cretaceous world" and the "cold Oligocene world" (Zachos et al., 2004). The evolution of climate in the Paleogene is of particular importance to both organismal evolution and to environmental changes. In addition to the above discussed mid-

Paleocene biotic event (MPBE) and the Paleocene-Eocene Thermal Maximum (PETM), two short-lived transient hyperthermal events have been outlined in the early Eocene:

- ELMO – Early Eocene Layer of Mysterious Origin identified by Lourens et al. (2005), 53.7 Ma;
- "X-event" – the last Early Eocene thermal maximum identified by Röhl et al. (2005), 52.6 Ma.

The data presented herein on global events in the Paleocene and early Eocene show that the Earth and its inhabiting organisms have survived substantial catastrophic events – asteroid impacts at the K/T boundary, several abrupt warming events – in the mid-Paleocene, at the Paleocene/Eocene boundary and in the early Eocene. However, their consequences have always been overcome after a relatively short period of time (recovery stage) due to the precise functioning of the complex, perfectly organized and self-regulating systems that construct the different spheres on the planet – lithosphere, hydrosphere, atmosphere and biosphere. After any dramatic event, life on Earth managed to find pathways to survival, recovery and new proliferation.

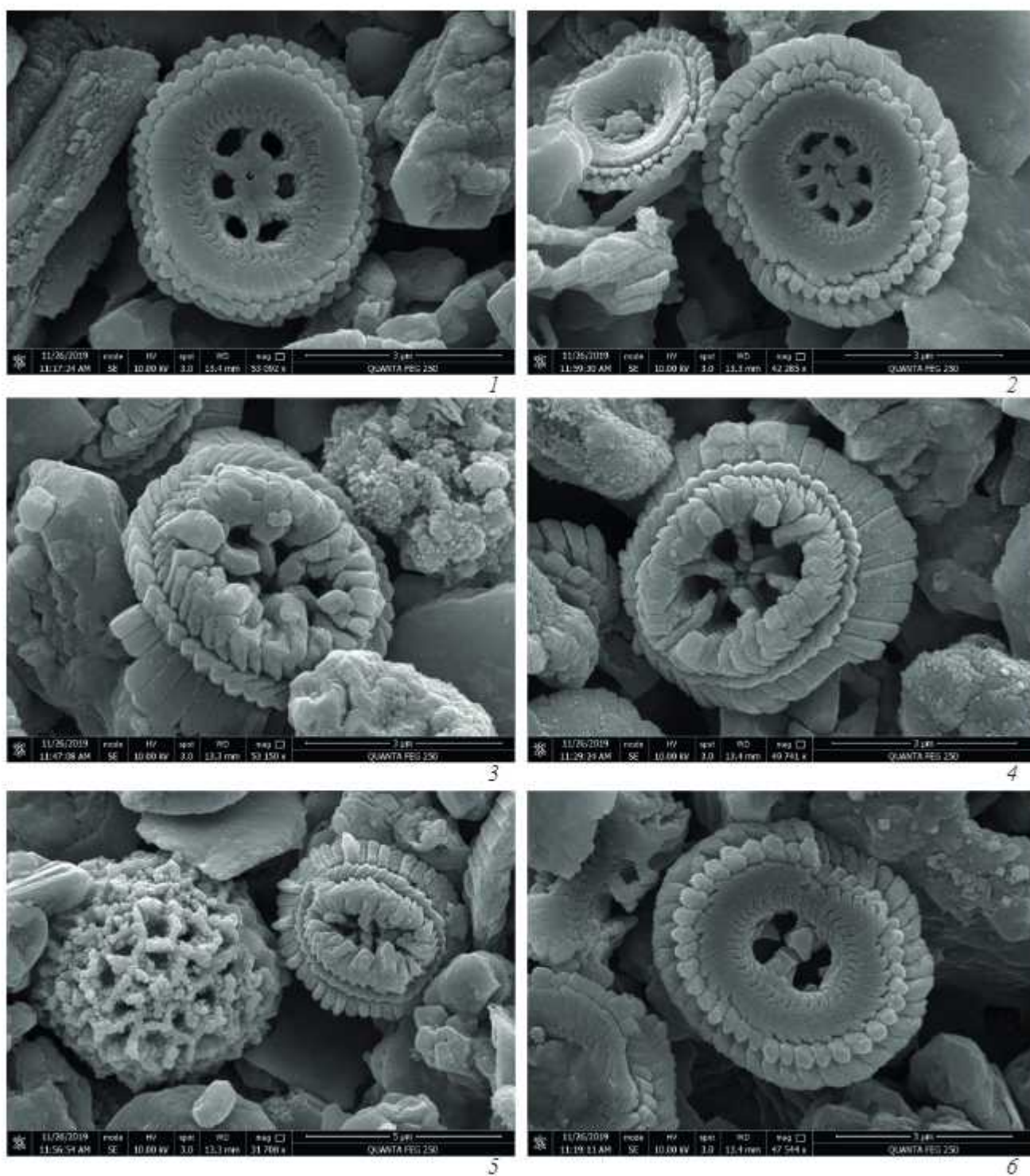


Plate 8.1.

SEM photographs of calcareous nannofossils from the PETM interval in Riben section, Central northern Bulgaria. All species from sample Ri -0.6 m, uppermost Paleocene, Thanetian Stage, NP9 zone.

1-2 – *Towetus tovae*, proximal view; 3-4 – *Towetus tovae*, distal view; 5 – *Towetus tovae*, distal view and *Thoracosphaera* spp.; 6 – *Towetus emineus*, proximal view

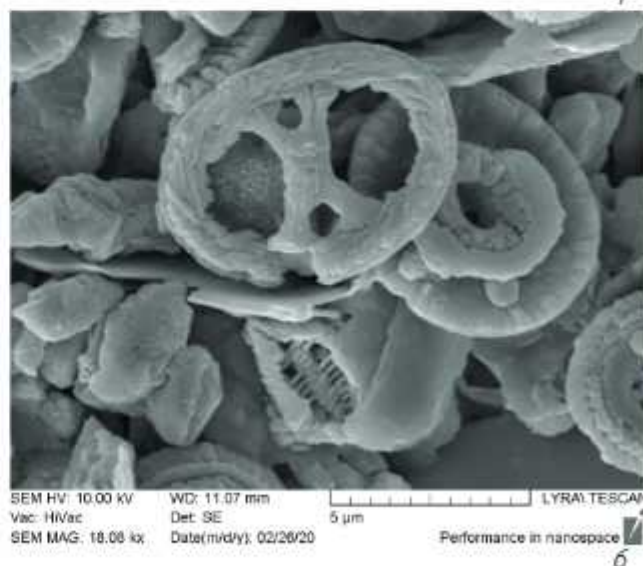
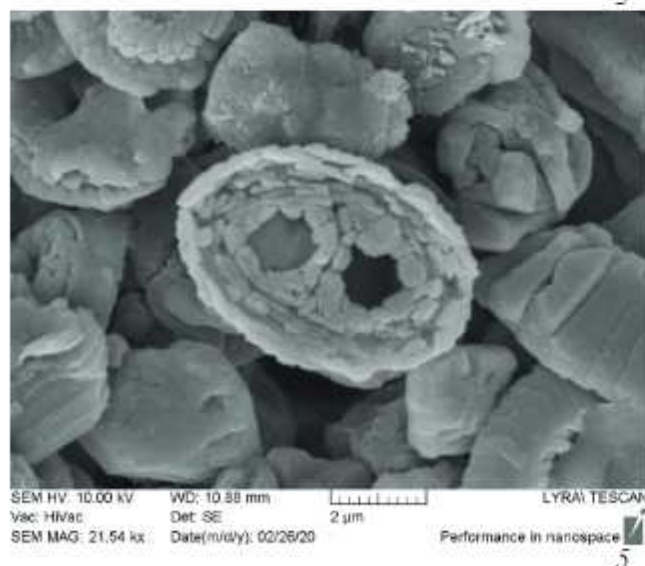
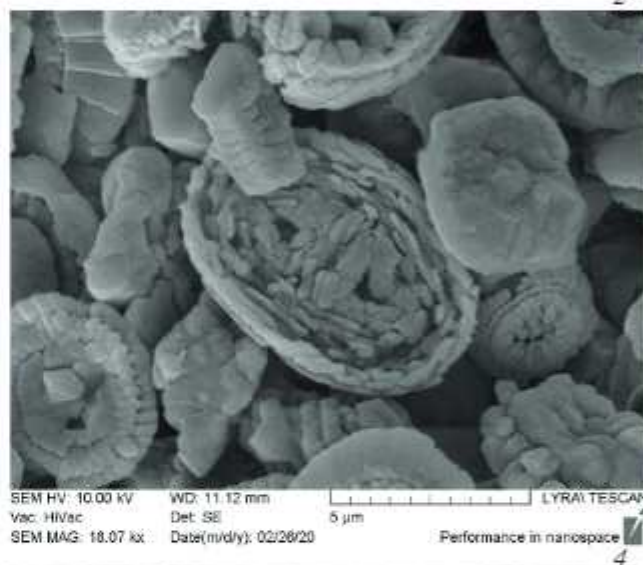
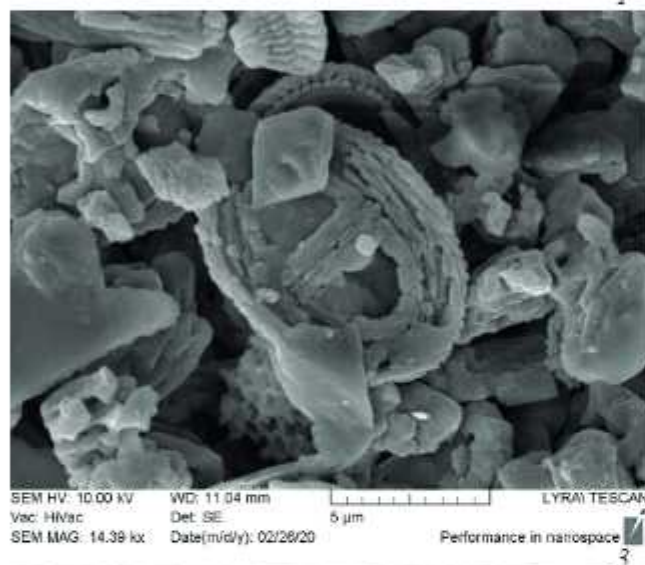
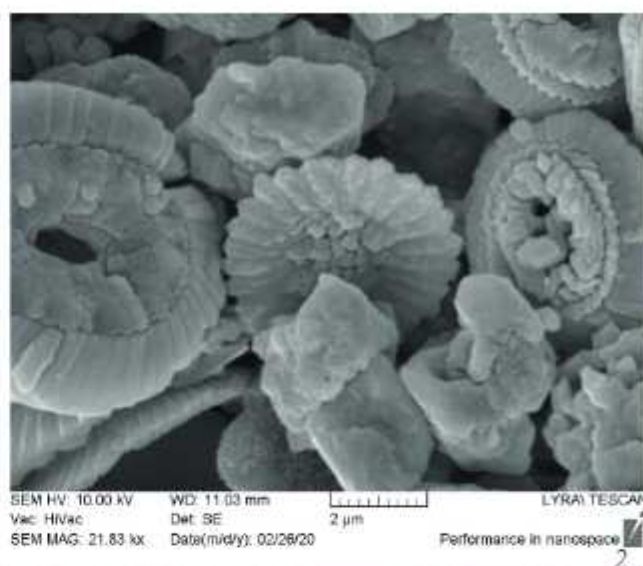
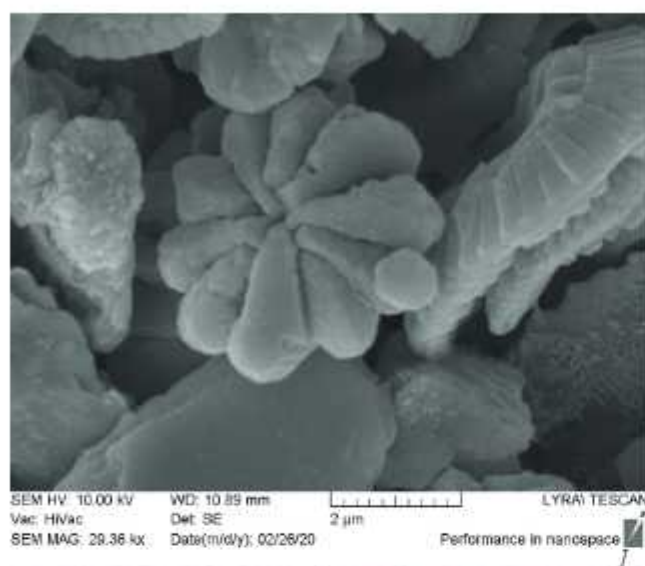


Plate 8.2.

SEM photographs of calcareous nannofossils from the PETM interval in Riben section, Central northern Bulgaria. All species from sample Ri -0.6 m, uppermost Paleocene, Thanetian Stage, NP9 zone.

1 – *Discoaster mohleri*; 2 – *Coccolithus pelagicus*, *Bomolitus* spp. and *Towellus tovae* distal view; 3-4 – *Zygodiscus herlynii*; 5 – *Transversopontis pulcher*; 6 – *Neochiastozygus junctus*

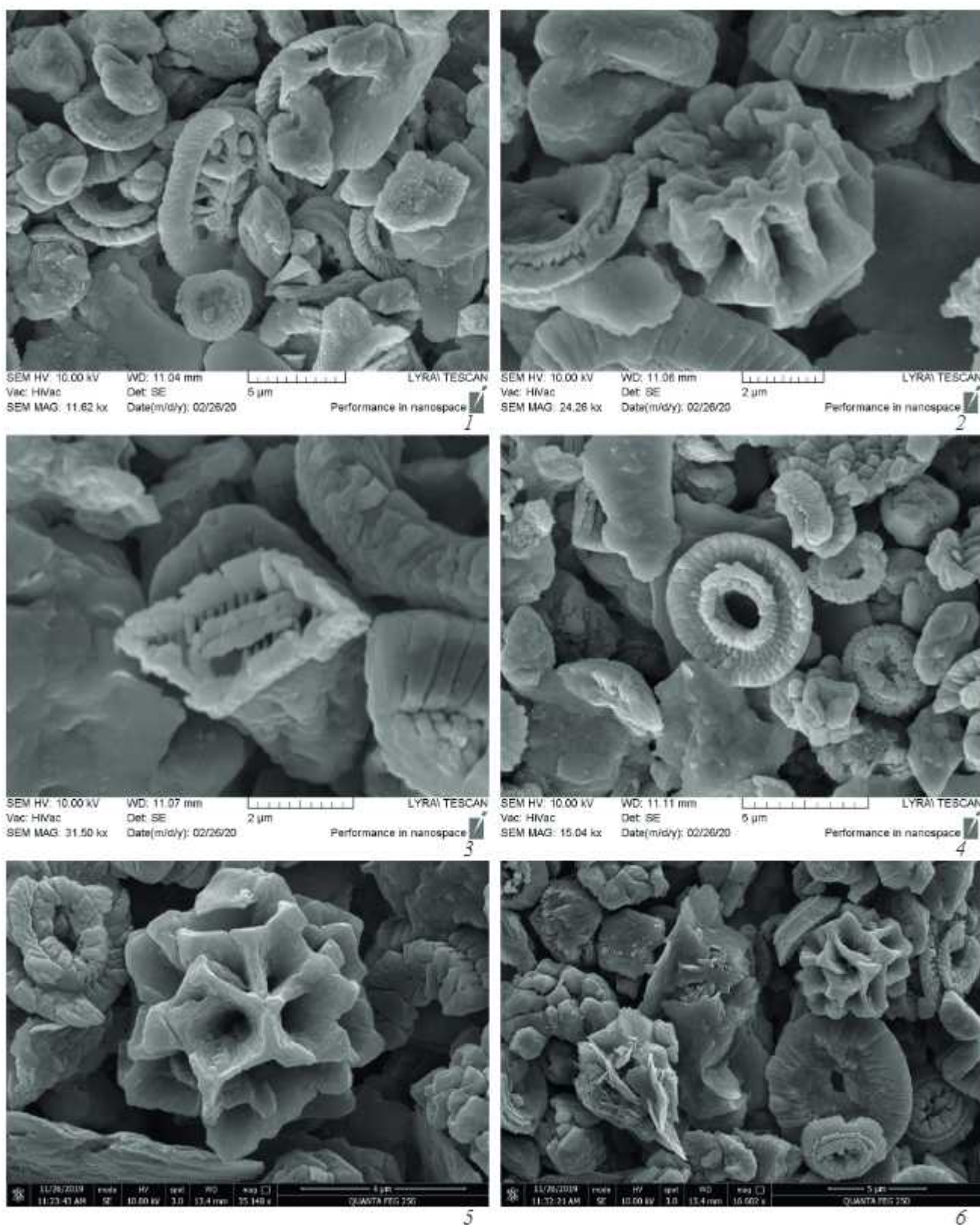


Plate 8.3.

SEM photographs of calcareous nannofossils from the PETM interval in Riben section, Central northern Bulgaria. All species from sample Ri -0.6 m, uppermost Paleocene, Thanetian Stage, NP9 zone.

1 – *Ellipsolithus distichus*; 2 – *Fasciculithus involutus*; 3 – *Calcsolenia aperta*; 4 – *Coccolithus foraminis*; 5 – *Sphenolithus primus*; 6 – *Coccolithus pelagicus*, *Toweius eminent* and *Sphenolithus primus*



Plate 8.4.

SEM photographs of calcareous nannofossils from the PETM interval in Riben section, Central northern Bulgaria. All species from sample Ri -0.6 m, uppermost Paleocene, Thanetian Stage, NP9 zone.

1 – *Coccolithus pelagicus*, 2 – *Coccolithus* spp., 3 – *Toweius callosus*; 4 – *Coccolithus bowni* – two sandwiched inbetween specimens; 5 – general view of the sample with *Toweius callosus*, *Coccolithus foraminis*, *Coccolithus bowni*, *Discoaster mohleri*, *Toweius pertusus*, *Toweius tovae*, *Toweius callosus*; 6 – general view of the sample with *Discoaster mohleri*, *Coccolithus pelagicus*, *Toweius pertusus*, *Toweius callosus*

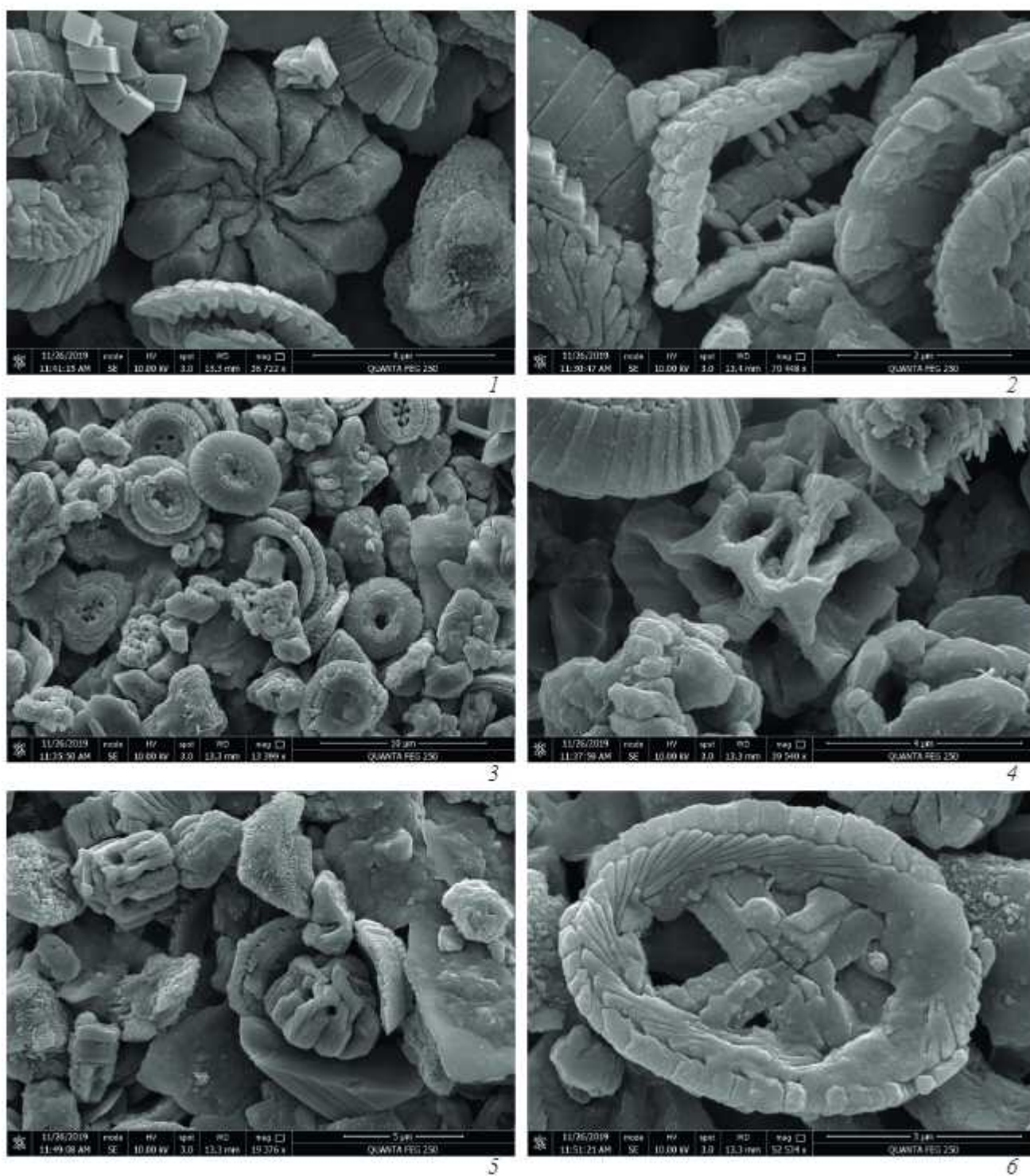


Plate 8.5.

SEM photographs of calcareous nannofossils from the PETM interval in Riben section, Central northern Bulgaria. All species from sample Ri -0.6 m, uppermost Paleocene, Thanetian Stage, NP9 zone.

1 – *Discoaster mohleri*; 2 – *Calcisolenia aperta*; 3 – general view with *Ericsonia robusta* in the centrum; 4 – *Fasciculithus thomasi*; 5 – *Fasciculithus involutus*; 6 – *Neochiastozygus distentus*

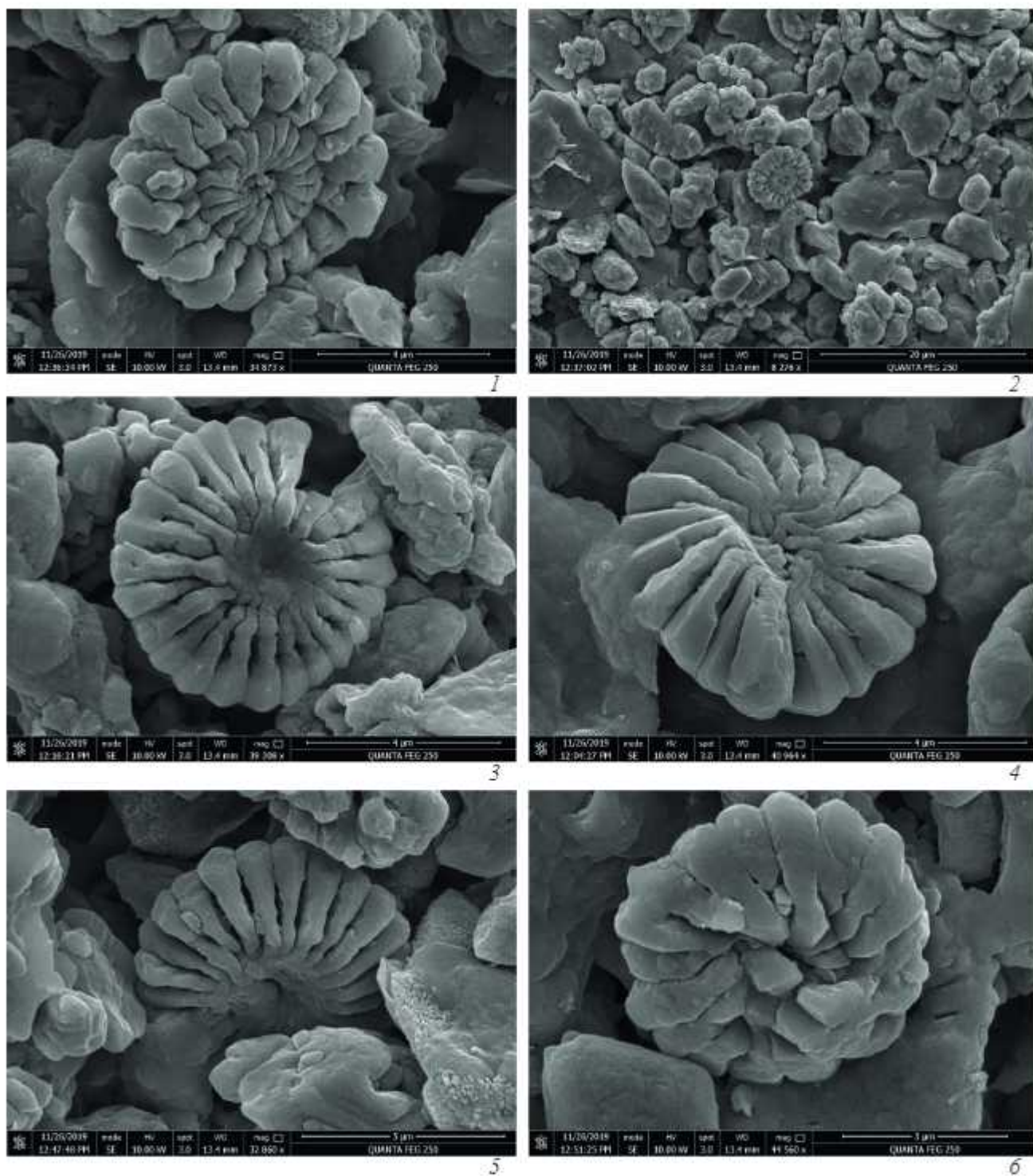


Plate 8.6.

SEM photographs of calcareous nannofossils from the PETM interval in Riben section, Central northern Bulgaria. All species from sample Ri +0.1 m, lowermost Eocene, Ypresian Stage, NP10 zone.

1-2 – *Bomolithus supremus*; 3-5 – *Discoaster lenticularis*; 6 – *Discoaster mohleri*

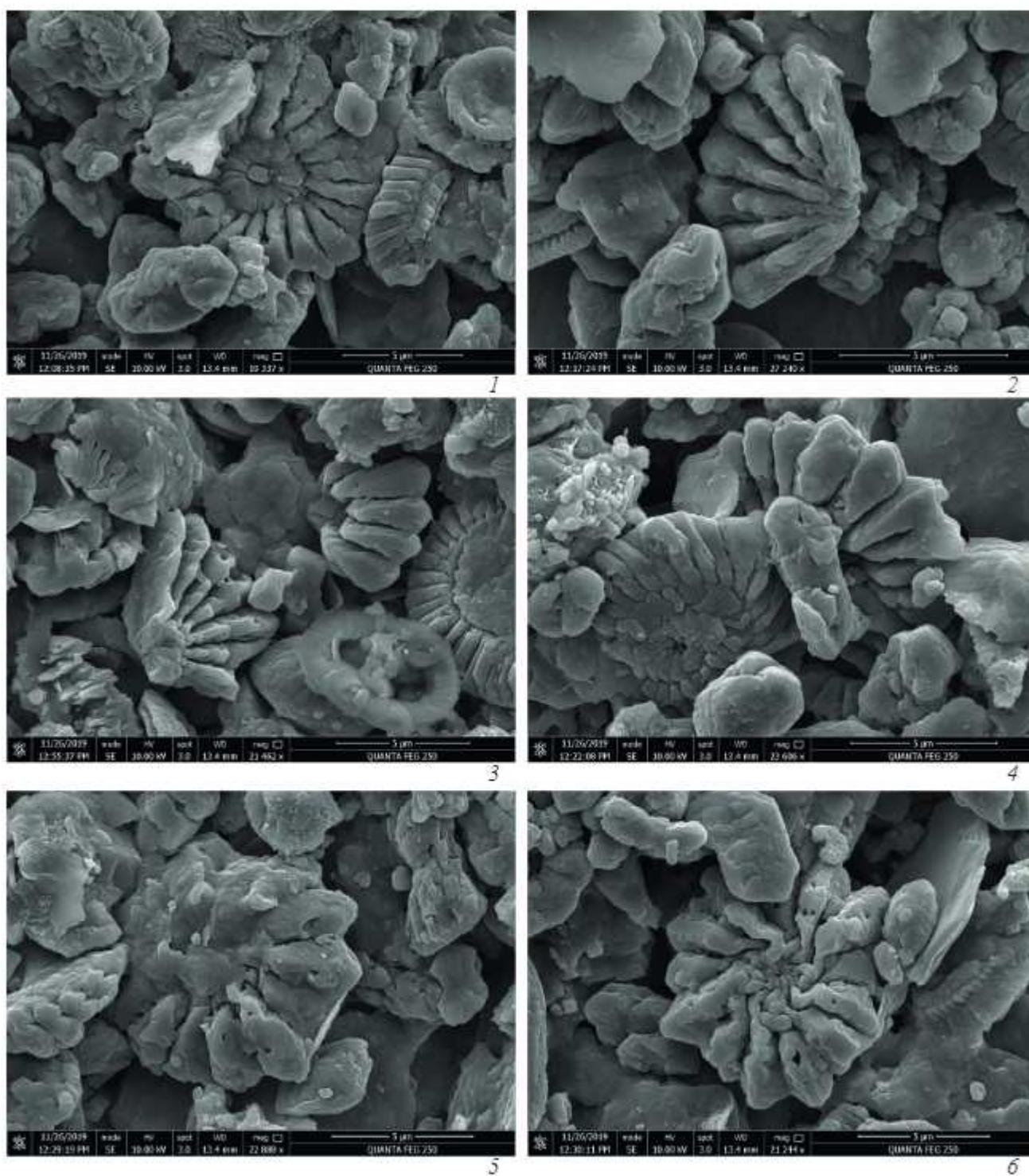


Plate 8.7.

SEM photographs of calcareous nannofossils from the PETM interval in Riben section, Central northern Bulgaria. All species from sample Ri +0.1 m, lowermost Eocene, Ypresian Stage, NP10 zone.

1-3 – *Discoaster multiradiatus*; 4 – *Discoaster multiradiatus* and *Coccolithus pelagicus*; 5-6 – *Discoaster mohleri*

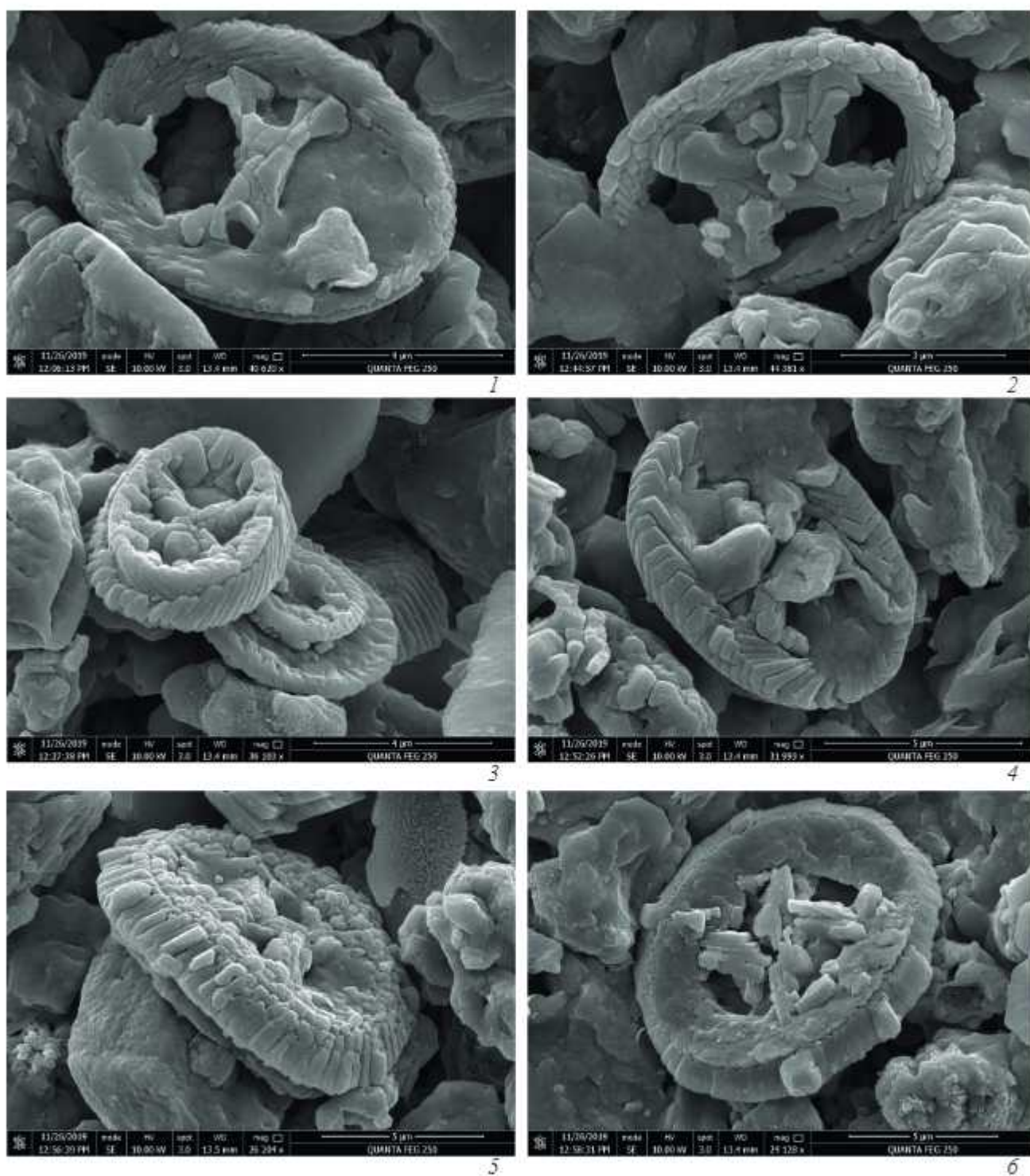


Plate 8.8.

SEM photographs of calcareous nannofossils from the PETM interval in Riben section, Central northern Bulgaria. All species from sample Ri +0.1 m, lowermost Eocene, Ypresian Stage, NP10 zone.

1 – *Neochiastocyclus junctus*; 2 – *Neochiastocyclus modestus*; 3 – *Neochiastocyclus concinnus*; 4 – *Neochiastocyclus cf. perfectus* (reworked); 5-6 – *Chiasmolithus bidens*

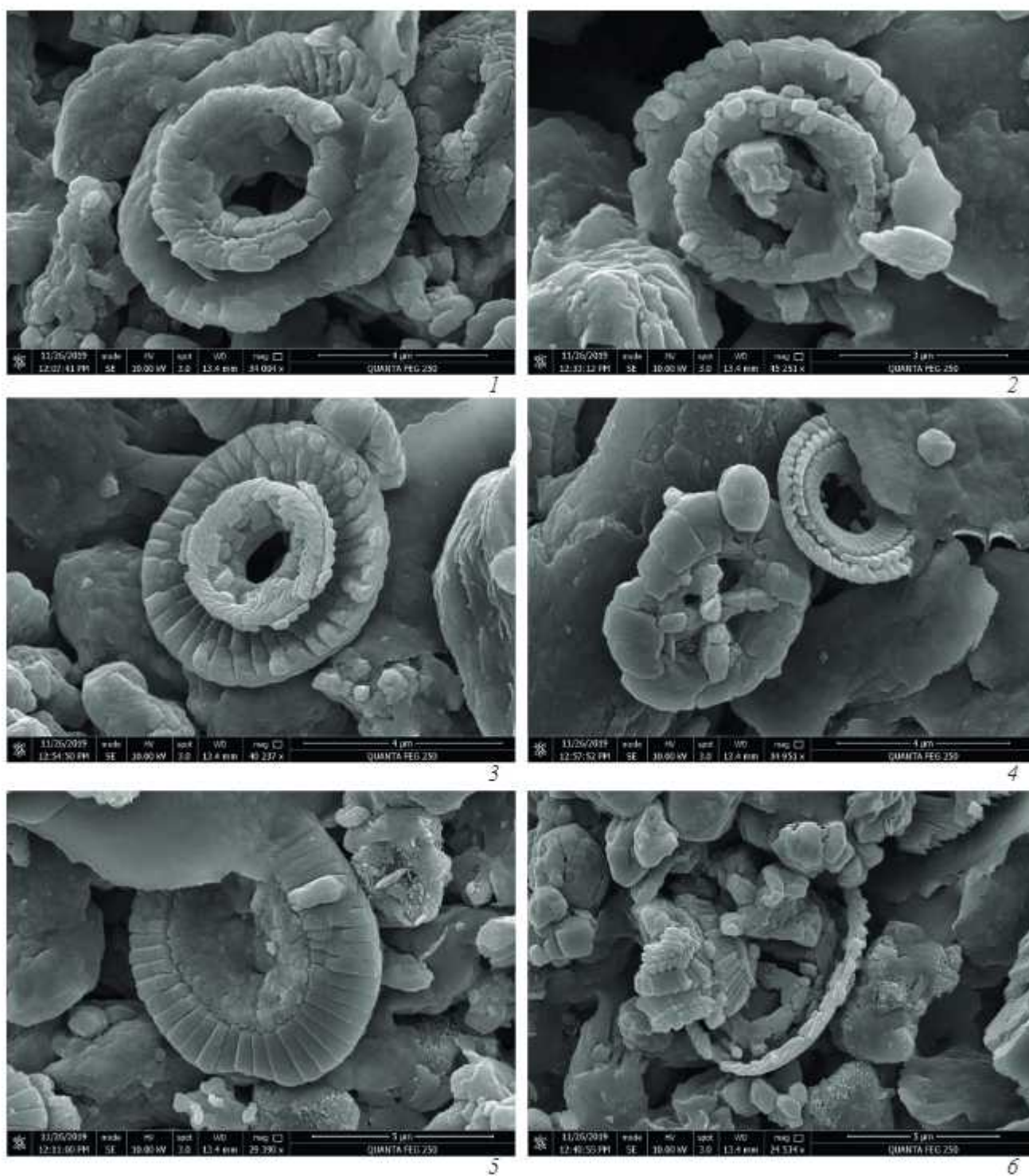


Plate 8.9.

SEM photographs of calcareous nannofossils from the PETM interval in Riben section, Central northern Bulgaria. All species from sample Ri +0.1 m, lowermost Eocene, Ypresian Stage, NP10 zone.

1-3 – *Coccolithus foraminis*; 4 – *Prediscosphaera cretacea* (reworked); and *Toweius rotundus*; 5 – *Coccolithus pelagicus*; 6 – *Transversoponthis pulcher*

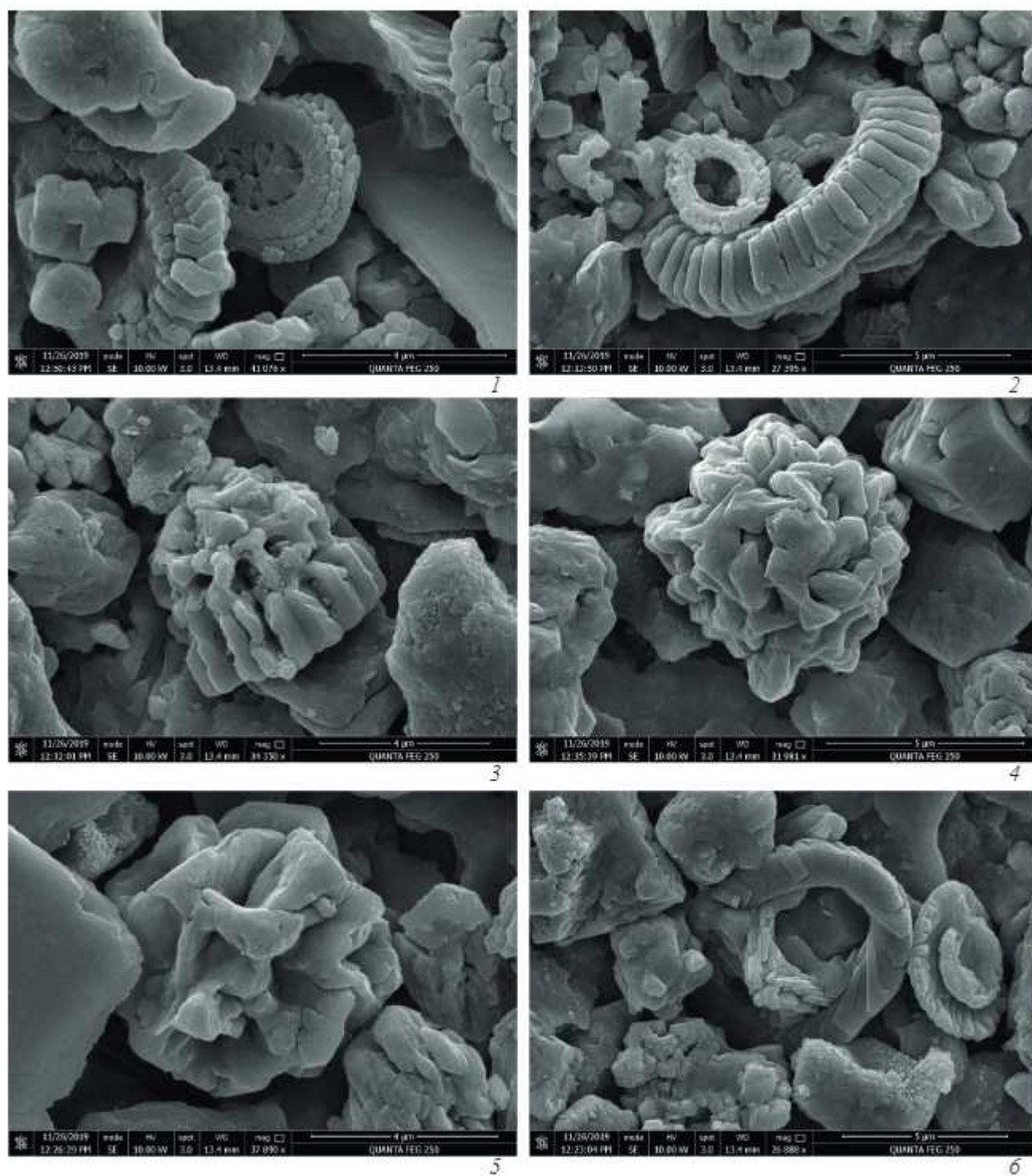


Plate 8.10.

SEM photographs of calcareous nannofossils from the PETM interval in Riben section, Central northern Bulgaria. All species from sample Ri +0.1 m, lowermost Eocene, Ypresian Stage, NP10 zone.

1 – *Toweius pertusus*; 2 – *Chiasmolithus* sp. aff. *solitus* and *Coccolithus bownii*; 3-4 – *Fasciculolithus involutus* – side view (3) and top view (4); 5 – *Sphenolithus primus*; 6 – *Placozygus sigmoides*

Chapter 9

Main results and unresolved problems

9.1. Main results

The present study provides essential new data on the stratigraphy of the Paleocene and lower Eocene in northern Bulgaria acquired as a result of investigation of calcareous nannofossils. Important global events established in the Paleocene and early Eocene Epochs are precisely studied and documented in Bulgarian sections.

The geological material forming the basis of this study includes about 4000 samples from 55 sections and numerous outcrops, located in northern Bulgaria and the adjacent Black Sea shelf area. Modern methods were used in processing and interpreting the samples, mainly paleontological and stratigraphical, as well as other supplementary methods, allowing documentation of global events.

The calcareous nannofossils have been analysed using appropriate modern devices – Zeiss *Jenapol-d* polarized light microscope, Zeiss polarized light microscope *Axioskop 40 Pol* with an attached *ProRes® Capture Pro* digital camera and scanning electronic microscope, enabling high resolution images and accurate, reliable observations.

A starting point of this study was the summary of all available regional geological and stratigraphic data on the Paleocene and lower Eocene Series from previous studies. The study included a review of the historical development of the knowledge and application of different fossil groups for stratigraphic purposes.

The main results that were achieved concern the following major fields:

Regional stratigraphy and lithostratigraphy:

- Detailed description, subdivision and correlation performed on 55 key sections, located throughout northern Bulgaria between the Timok River and the Black Sea. Complex correlation has been carried out using lithostratigraphic, biostratigraphic and event stratigraphic methods.
- Complete descriptions and characteristics of 31

lithological units in the Paleocene Series and the lower Eocene Subseries, including 1 Group, 23 Formations, 2 Members and 6 informal formations. Several new official lithostratigraphic units are proposed: the Sveti Atanas Formation and the Bardarevo Member; the Gebesh Formation and the Meshelika Member. The Dvoynitsa Formation is promoted to group rank, comprising the mentioned Formations and Members.

- New concepts about the spatial-temporal relationships of the lithobodies in each of the studied regions are elaborated, supported by nannofossil evidences.
- The main data on the lithostratigraphy and regional patterns in the distribution and presence of the stages in each of the studied areas have been synthesised.
- Sediments of Selandian Age have been identified for the first time in Central northern Bulgaria (Komarevo, Kreta, Somovit, Petamitsa sections).
- A number of unresolved issues in the lithostratigraphic scheme of the Paleocene and lower Eocene have been outlined and options for resolving these have been proposed.

In the field of biostratigraphy:

- A complete zonation for the Paleocene and lower Eocene in Bulgaria by nannofossils has been developed, based on the standard scheme of Martini (1971c). 14 biozones have been characterized in detail – 9 biozones in the Paleocene (from NP1 to NP9) and 5 biozones in the lower Eocene (from NP10 to NP14).
- Within each biozone, events of appearance and/or extinction of species with high correlation value have been outlined. A total of 38 bioevents in the Paleocene and 17 bioevents in the lower Eocene have been identified and traced. These bioevents, selected in the current study, appear to be among the most prominent global biohorizons (Agnini et al., 2007a, 2014). Their identification in the sections

provides high resolution and reliability in biostratigraphic subdivision as well as in the correlation of the Bulgarian successions with sections from different parts of the world.

- The vertical range of a number of important nanofossil species has been specified. The biostratigraphic interpretations herein rely on 206 species from 65 genera of calcareous nanofossils.
- Considerable improvement has been achieved in the level of resolution, accuracy and reliability in dating the sedimentary sequences in the Paleocene-lower Eocene interval, compared to that previously available. High rates of evolution of the calcareous nannoplankton combined with magnetostratigraphic analyses and deciphering the orbital cyclicity in suitable sections (Byala section) allowed a resolution to ~ 100 Ka in the Paleocene and lower Eocene.
- The distinguished biostratigraphic units (biozones) have been correlated to the existing zonal subdivisions worldwide.

In the field of chronostratigraphy:

- The chronostratigraphic scheme for the Paleocene and lower Eocene in Bulgaria has been updated and adjusted to modern world standards. *Selandian Stage* has been introduced and used for the first time in Bulgaria to describe the middle portion of the Paleocene Series.
- The information on the definition, completeness and thicknesses of the stage divisions in the studied stratigraphic interval and geological sections has been synthesised. The globally accepted criteria for setting their boundaries have been clearly outlined. Each stage unit has an approved global reference section (global boundary stratotype section and point, GSSP). The globally approved criteria have been applied to the studied Bulgarian sections.
- The stages included in the Paleocene and lower Eocene Series have been thoroughly characterized. Moreover, the regional trends in their distribution in northern Bulgaria have been outlined.

In the field of event stratigraphy:

The expression of the following global events has been proved in Bulgarian sections:

- The impact event at the Cretaceous-Tertiary (K/T) boundary (Stoykova & Ivanov, 1992);

- The Middle Paleocene biotic event (MPBE);
- The Paleocene-Eocene thermal maximum (PETM) (Stoykova & Ivanov, 2005).

These events have been initially identified and discovered in Bulgaria using nanofossil biostratigraphy. Subsequently, along with detailed nanofossil analyses, these have been studied and characterized by a complex of methods – mineralogical, geochemical, isotopic, magnetostratigraphic, etc. The specific nature of the manifestation of the K/T boundary event in various depositional environments (deep water, shelf margin and shelf areas of the marine basin) has been identified.

Each of the studied events has been documented by its features with special focus on the impact on the marine communities. The responses of the marine nannoplankton and the macro-invertebrates to the K/T Boundary event are studied in detail. A model for survival and recovery of communities after natural disasters is proposed.

9.2. Unresolved problems

The majority of the unresolved problems relates to the lithostratigraphic scheme of the Paleocene and lower Eocene units. Another portion of the unresolved problems involves various aspects of the global events – detailed biostratigraphic studies aimed at precise fixing of the event markers in the sections and the application of complex methods for their thorough assessment.

Lithostratigraphic issues

- Synonymy is supposed concerning the units introduced by Aladjova-Hrischeva et al. (1991) in the West and Central Fore-Balkan and Balkan (Lukovit, Ugarchin, Petrevene, Boynovtsi and Pavolche Formations) and the ones defined in the East Fore-Balkan and Balkan by Kanchev (1995a, b, c, d) and Juranov and Pimpirev (1989) – the Dvoynitsa Formation and the thick-bedded sandstone formation.
- The problem should be solved by means of tracing the lithological bodies in the field and strict biostratigraphic control on their chronostratigraphic range.
- The clarification of this issue would determine the valid names and would reduce the number of lithostratigraphic units used.

Event stratigraphy problems

- It is necessary to apply paleomagnetic and isotope geochemistry studies combined with quantitative analyses of the nannofossils in sections where the Middle Paleocene biotic event (MPBE) has been biostratigraphically proved. Considering the fact that by now the only onshore section of proved MPBE is the one at Zumaia, its identification in Bulgarian localities would attract much scientific interest, similar to that for the K/T boundary at Byala.
- Manifestation of two globally identified hyperthermal events – “ELMO”-event and “X”-event, should be looked for in the lower parts of the Ypresian Stage.

The new stratigraphic data and interpretations presented in this work may be used in both regional geo-

logical and specific studies.

The elaborated complete biozonation scheme in the Paleocene and lower Eocene is valuable for high biostratigraphic resolution. It has been repeatedly used in practice – in the course of petroleum exploration in the Black Sea shelf and onshore, and also for geological mapping in various parts of the country.

At the same time, the unique cyclical successions in the Byala section have already been used by Westerhold et al. (2008) as one of the standards for astronomical calibration of the Paleocene Epoch.

Stratigraphic synthesis is a mandatory tool in basin and geodynamic reconstructions. It would be a required element in any further research on the Paleogene evolution and geological development of the Bulgarian lands.

Taxonomical index of calcareous nannofossil taxa

- Ahmuellerella** Reinhardt, 1964
A. octoradiata (Gorka, 1957) Reinhardt, 1966
- Arkhangelskiella** Vekshina, 1959
A. confusa Burnett, 1998
A. cymbiformis Vekshina, 1959
A. maastrichtiana Burnett, 1998b
A. specillata Vekshina, 1959
- Biantholithus** Bramlette & Martini, 1964
B. sparsus Bramlette & Martini, 1964
- Blackites** Hay and Towe, 1962
B. creber (Deflandre in Deflandre & Fert, 1954) Sherwood, 1974
B. gladius (Locker, 1972) Varol, 1989
B. spinosus (Deflandre and Pert, 1954) Hay and Towe, 1962
B. tenuis Bramlette and Sullivan, 1961
B. truncatus (Bramlette & Sullivan, 1961) Varol, 1989
- Bomolithus** Roth, 1973
B. bramlettei (Bukry & Percival, 1971) Young and Bown, 2014
B. conicus (Perch-Nielsen, 1971) Perch-Nielsen, 1984
B. elegans Roth, 1973
B. megastypus (Bramlette & Sullivan, 1961) Bown, 2010
B. supremus Bown & Dunkley Jones, 2006
- Braarudosphaera** Deflandre, 1947a
B. africana Stradner, 1961
B. bigelowii (Gran and Braarud, 1935) Deflandre, 1947
B. turbinea Stradner, 1963
- Broinsonia** Bukry, 1969
B. parca parca (Stradner, 1963) Bukry, 1969
B. parca constricta Hattner et al., 1980
- Calcisolenia** Gran, 1912
C. aperta (Hay & Mohler, 1967) Bown, 2005
- Calculites** Prins & Sissingh, 1977
C. obscurus (Deflandre, 1959) Prins & Sissingh, 1977
- Campylosphaera** Kamptner, 1963
C. dela (Bramlette and Sullivan, 1961) Hay & Mohler, 1967
C. eodela Bukry & Percival, 1971
- Chiasmolithus** Hay, Mohler & Wade, 1966
C. bidens (Bramlette and Sullivan, 1961) Hay & Mohler, 1967
C. consuetus (Bramlette and Sullivan, 1961) Hay & Mohler, 1967
C. danicus (Brotzen, 1959) Hay & Mohler, 1967
C. edentulus van Heck & Prins, 1987
C. eograndis Perch-Nielsen, 1971
C. expansus (Bramlette and Sullivan, 1961) Gartner, 1970
C. gigas (Bramlette and Sullivan, 1961) Radomski, 1968
C. grandis (Bramlette and Riedel, 1964) Radomski, 1968
C. solitus (Bramlette and Sullivan, 1961) Locker, 1968
- Chiastozygus** Gartner, 1968
C. litterarius (Górka, 1957) Manivit, 1971
- Chiphragmalithus** Bramlette and Sullivan, 1961
C. acanthodes Bramlette and Sullivan, 1961
C. armatus Perch-Nielsen, 1971
C. barbatus Perch-Nielsen, 1967
C. calathus Bramlette and Sullivan, 1961
- Coccolithus** Schwarz, 1894
C. bownii Jiang and Wise, 2007
C. cavus Hay and Mohler, 1967
C. eopelagicus (Bramlette and Riedel, 1954) Hay, Mohler & Wade, 1966
C. foraminis Bown, 2005
C. pelagicus (Wallich, 1877) Schiller, 1930
- Corannulus** Stradner, 1962
C. germanicus Stradner, 1962

- Coronocyclus** Hay, Mohler & Wade, 1966
C. nitescens (Kamptner, 1963) Bramlette & Wilcoxon, 1967
- Cribrosphaerella** Deflandre in Pivetaeu, 1952
C. daniæ Perch-Nielsen, 1973
C. ehrenbergii (Arkhangelsky, 1912) Deflandre in Pivetaeu, 1952
- Cruciplacolithus** Hay and Mohler in Hay et al., 1967
C. asymmetricus van Heck and Prins, 1987
C. edwardsii Romein, 1979
C. intermedius van Heck and Prins, 1987
C. latipons Romein, 1979
C. primus Perch-Nielsen, 1977
C. subrotundus Perch-Nielsen, 1969
C. tenuis (Stradner, 1961) Hay and Mohler in Hay et al., 1967
- Cyclagelosphaera** Noël, 1965
C. alta Perch-Nielsen, 1979
C. margerelii Noël, 1965
C. reinhardtii (Perch-Nielsen, 1968) Romein, 1977
- Discoaster** Tan Sin Hok, 1927
D. araneus Bukry, 1971
D. anartios Bybell & Self-Trail, 1995
D. barbadiensis Tan Sin Hok, 1927
D. binodosus Martini, 1958
D. bronnimanni Stradner, 1961
D. deflandrei Bramlette and Riedel, 1954
D. distinctus Martini, 1958
D. falcatus Bramlette and Sullivan, 1961
D. kuepperi Stradner, 1959
D. lenticularis Bramlette and Sullivan, 1961
D. limbatus Bramlette and Sullivan, 1961
D. lodoensis Bramlette and Riedel, 1954
D. mahmudii Perch-Nielsen, 1981
D. medius Bramlette and Sullivan, 1961
D. mohleri Bukry & Percival, 1971
D. monstratus Martini, 1961
D. multiradiatus Bramlette and Riedel, 1954
D. pacificus Haq, 1969
D. protomultiradiatus Wei, 1998
D. saipanensis Bramlette and Riedel, 1954
D. salisburgensis Stradner, 1961
D. septemradiatus (Klumpp, 1953) Martini, 1958
D. splendidus Martini, 1960
D. sublodoensis Bramlette and Sullivan, 1961
D. tani Bramlette & Riedel, 1954
D. turkyensis Sadek & Ozer, 1981
- Eiffellithus** Reinhardt, 1965
E. eximius (Stover, 1966) Perch-Nielsen, 1968
E. gorkae Reinhardt, 1965
E. parallelus Perch-Nielsen, 1973
E. turiseiffelii (Deflandre in Deflandre & Fert, 1954) Reinhardt, 1965
- Ellipsolithus** Sullivan, 1964
E. distichus (Bramlette and Sullivan, 1961) Sullivan, 1964
E. macellus (Bramlette and Sullivan, 1961) Sullivan, 1964
- Ericsonia** Black, 1964
E. formosa (Kamptner, 1963) Haq, 1971
E. robusta (Bramlette and Sullivan, 1961) Edwards & Perch-Nielsen, 1975
E. subpertusa Hay & Mohler, 1967
- Fasciculithus** Bramlette and Sullivan, 1961
F. alanii Perch-Nielsen, 1971
F. bobii Perch-Nielsen, 1971
F. bitectus Romein, 1979
F. fenestrellatus Bown, 2005
F. involutus Bramlette and Sullivan, 1961
F. mitreus Gartner, 1971
F. richardii Perch-Nielsen, 1971
F. schaubii Hay & Mohler, 1967
F. siderius Bybell & Self-Trail, 1995
F. thomasi Perch-Nielsen, 1971
F. tonii Perch-Nielsen, 1971
F. tympaniformis Hay and Mohler in Hay et al., 1967
- Futyania** Varol, 1989
F. petalosa (Ellis and Lohmann, 1973) Varol, 1989
- Gomphiolithus** Aubry in Aubry et al., 2011
G. magnicordis (Romein, 1979) Aubry in Aubry et al., 2011
- Goniolithus** Deflandre, 1957
G. fluckigeri Deflandre, 1957
- Helicosphaera** Kamptner, 1954
H. lophota (Bramlette and Sullivan, 1961) Locker, 1973
H. seminulum Bramlette and Sullivan, 1961
- Heliolithus** Bramlette and Sullivan, 1961
H. bukryi Wei, 1988
H. cantabriae Perch-Nielsen, 1971
H. kleinpellii Sullivan, 1964
H. riedelii Bramlette and Sullivan, 1961
H. universus Wind & Wise, 1976

- Hornibrookina** Edwards, 1973
H. arca Bybell & Self-Trail, 1995
- Kamptnerius** Deflandre 1959
K. magnificus Deflandre 1959
- Lanternitus** Stradner, 1962
L. duocavus Locker, 1967
- Lithoptychius** Aubry in Aubry et al., 2011
L. billii (Perch-Nielsen, 1971) Aubry in Aubry et al., 2011
L. jani (Perch-Nielsen, 1971) Aubry in Aubry et al., 2011
L. pileatus (Bukry, 1973) Aubry in Aubry et al., 2011
L. ulii Perch-Nielsen, 1971) Aubry in Aubry et al., 2011
- Lithraphidites** Deflandre, 1963
L. carniolensis Deflandre, 1963
L. praequadratus Roth, 1978
L. quadratus Bramlette and Martini, 1964
- Lophodolithus** Deflandre in Deflandre and Fert, 1954
L. nascens Bramlette and Sullivan, 1961
- Lucianorhabdus** Deflandre, 1959
L. arcuatus Forchheimer, 1972
L. cayeuxii Deflandre, 1959
L. maleformis Reinhardt, 1966
- Manivitella** Thierstein, 1971
M. pemmatoidea (Deflandre in Manivit, 1965) Thierstein, 1971
- Markalius** Bramlette and Martini, 1964
M. apertus Perch-Nielsen, 1979
M. inversus (Deflandre in Deflandre and Fert, 1954) Bramlette and Martini, 1964
- Microrhabdulus** Deflandre, 1959
M. decoratus Deflandre, 1959
- Micula** Vekshina, 1959
M. concava (Stradner in Martini and Stradner, 1960) Verbeek, 1976
M. murus (Martini, 1961) Bukry, 1973
M. praemurus (Bukry, 1973) Stradner & Steinmetz, 1984
M. prinsii Perch-Nielsen, 1979
M. staurophora (Gardet, 1955) Stradner, 1963
M. swastica Stradner and Steinmetz, 1984
- Nannotetrina** Achuthan and Stradner, 1969
N. alata (Martini in Martini & Stradner, 1960) Haq and Lohmann, 1976
N. cristata (Martini, 1958) Perch-Nielsen, 1971
N. fulgens (Stradner in Martini & Stradner, 1960) Achutan & Stradner, 1969
- Neobiscutum** Varol, 1989b
N. parvulum (Romein, 1979) Varol, 1989
N. romeinii (Perch-Nielsen, 1981) Varol, 1989
- Neochiastozygus** Perch-Nielsen, 1971
N. concinnus (Martini, 1961) Perch-Nielsen, 1971
N. eosaeus Perch-Nielsen, 1981
N. imbricatus Haq and Lohmann, 1976
N. junctus (Bramlette & Sullivan, 1961) Perch-Nielsen, 1971
N. modestus Perch-Nielsen, 1971
N. perfectus Perch-Nielsen, 1971
N. primitivus Perch-Nielsen, 1981
N. saepes Perch-Nielsen, 1971
- Neococcolithes** Sujkowski, 1931
N. dubius (Deflandre in Deflandre and Fert, 1954) Black, 1967
N. proteus (Bramlette & Sullivan, 1961) Black, 1967
- Neocrepidolithus** Romein, 1979
N. neocrassus (Perch-Nielsen, 1968) Romein, 1979
- Nephrolithus** Górka, 1957
N. frequens Górka, 1957
- Octolithus** Romein, 1979
O. multiplus (Perch-Nielsen, 1973) Romein, 1979
- Placozygus** Hoffman, 1970
P. sigmoides (Bramlette and Sullivan, 1961) Romein, 1979
- Pontosphaera** Lohmann, 1902
P. plana (Bramlette & Sullivan, 1961) Haq, 1971
- Prediscosphaera** Vekshina, 1959
P. cretacea (Arkhangelsky, 1912) Gartner, 1968
P. grandis Perch-Nielsen, 1979
P. majungae Perch-Nielsen, 1973
P. pontica (Bukry, 1969) Perch-Nielsen, 1984
P. stoveri (Perch-Nielsen, 1968) Shafik and Stradner, 1971

- Prinsius** Hay and Mohler, 1967
P. bisulcus (Stradner, 1963) Hay and Mohler, 1967
P. dimorphosus (Perch-Nielsen, 1969) Perch-Nielsen, 1977
P. martinii (Perch-Nielsen, 1969) Haq, 1971
P. tenuiculus (Okada & Thierstein, 1979) Perch-Nielsen, 1984
- Reinhardtites** Perch-Nielsen, 1968
R. anthophorus (Deflandre, 1959) Perch-Nielsen, 1968
R. levis Prins & Sissingh in Sissingh, 1977
- Retecapsa** Black, 1971
R. crenulata (Bramlette and Martini, 1964) Grün in Grün and Allemann, 1975
- Reticulofenestra** Hay, Mohler & Wade, 1966
R. dyctioda (Deflandre in Deflandre & Fert, 1954) Stradner in Stradner & Edwards, 1968
- Rhabdosphaera** Haeckel, 1894
R. perlonga (Deflandre in Grasse, 1952) Bramlette and Sullivan, 1961
R. inflata Bramlette & Sullivan, 1961
- Rhomboaster** Bramlette and Sullivan, 1961
R. bramlettei (Brönnimann & Stradner, 1961) Bybell & Self-Trail, 1995
R. cuspidis Bramlette and Sullivan, 1961
R. calcitrata Gartner, 1971
- Sphenolithus** Deflandre in Grasse, 1952
S. anarrhopus Bukry & Bramlette, 1969
S. conspicuus Martini, 1976
S. editus Perch-Nielsen in Perch-Nielsen et al., 1978
S. furcatholithoides Locker, 1967
S. moriformis (Brönnimann & Stradner, 1960) Bramlette & Wilcoxon, 1967
S. obtusus Bukry, 1971
S. primus Perch-Nielsen, 1971
S. radians Deflandre in Grasse, 1952
- Tectulithus** Miniatti, Cappelli & Monechi, 2021
T. pagodiformis Miniatti, Cappelli & Monechi, 2021
- Thoracosphaera** Kamptner, 1927
T. operculata Bramlette and Martini, 1964
T. saxea Stradner, 1961
- Toweius** Hay and Mohler, 1967
T. callosus Perch-Nielsen, 1971
T. eminens (Bramlette and Sullivan, 1961) Perch-Nielsen, 1971
T. gammation (Bramlette and Sullivan, 1961) Romein, 1979
T. occultatus (Locker, 1967) Perch-Nielsen, 1971
T. pertusus (Sullivan, 1965) Romein, 1979
T. patellus Bown, 2016
T. rotundus Perch-Nielsen in Perch-Nielsen et al., 1978
T. selandianus Perch-Nielsen, 1979
T. serotinus Bybell & Self-Trail, 1995
T. tovae Perch-Nielsen, 1971
- Transversopontis** Hay et al., 1966
T. pulcher (Deflandre in Deflandre & Fert, 1954) Perch-Nielsen, 1967
T. pulcheroides (Sullivan, 1964) Baldi-Beke, 1971
- Tribrachiatus** Shamrai, 1963
T. contortus (Stradner, 1958) Bukry, 1972
T. digitalis Aubry, 1996
T. orthostylus Shamrai, 1963
- Watznaueria** Reinhardt, 1964
W. barnesiae (Black, 1959) Perch-Nielsen, 1968
- Zygodiscus** Hay & Mohler, 1967
Z. adamas Bramlette & Sullivan, 1961
Z. herlyni Sullivan, 1964
- Zygrhablithus** Deflandre, 1959
Z. bijugatus (Deflandre in Deflandre and Fert, 1954) Deflandre, 1959

References

- Adatte, T., G. Keller, S. Burns, K. Stoykova, M. Ivanov, D. Vangelov, U. Kramar, D. Stüben. 2002. Paleoenvironment across the Cretaceous-Tertiary transition in eastern Bulgaria. – In: Adatte, T., C. Koeberl, and K. G. MacLeod, (Eds.). *Catastrophic Events and Mass Extinctions: Impact and Beyond*. Boulder, Colorado, *Geol. Soc. of America, Spec. Paper 356*, 231-251.
- Agnini, C., G. Muttoni, D. Kent, D. Rio. 2006. Eocene biostratigraphy from Possagno, Italy: the calcareous nannofossil response to climate variability. – *Earth Planet. Sci. Letters* 241, 815-830.
- Agnini, C., E. Fornaciari, I. Raffi, R. Catanzariti, H. Pälike, J. Backmann, D. Rio. 2014. Biozonation and biochronology of Paleogene calcareous nannofossils from low and middle latitudes. – *Newsletters on Stratigraphy* 47, 2, 131-181.
- Agnini, C., E. Fornaciari, I. Raffi, D. Rio, U. Röhl, T. Westerhold. 2007a. High-resolution nannofossil biochronology of middle Paleocene to early Eocene at ODP Site 1262: Implications for calcareous nannoplankton evolution. – *Mar. Micropal.* 64, 3-4, 215-248.
- Agnini, C., E. Fornaciari, D. Rio, F. Tateo, J. Backman, L. Giusberti. 2007b. Responses of calcareous nannofossil assemblages, mineralogy and geochemistry to the environmental perturbations across the Paleocene/Eocene boundary in the Venetian Pre-Alps. – *Mar. Micropal.* 63, 1-2, 19-38.
- Aladjova-Hrischeva, K. 1973. On the age of the Eocene sediments near the village of Kladorub, Belogradchik area. – *Ann. Univ. Sofia, Fac. of Geol. and Geogr.* 65, 1, 37-40. (in Bulgarian)
- Aladjova-Hrischeva, K. 1976. On the age of the Palaeogene sediments near the village of Devene, Vratsa District (NW Bulgaria). – *Palaeontol., Stratigr., Lithol.* 4, 63-67. (in Bulgarian)
- Aladjova-Hrischeva, K. 1979. New data on the stratigraphy of the Eocene in the Lukovit Syncline. – *Ann. Univ. Sofia, Fac. of Geol. and Geogr.* 70, 1, 93-117. (in Bulgarian)
- Aladjova-Hrischeva, K. 1980. *Nummulitids from the Central North and Northwest Bulgaria and their stratigraphic significance*. PhD Thesis Summary, S., 30 pp. (in Bulgarian)
- Aladjova-Hrischeva, K. 1984a. Stratigraphy of the Eocene sediments near the village of Beloslav, Varna District. – *Rev. Bulg. Geol. Soc.* 45, 1, 33-44. (in Bulgarian)
- Aladjova-Hrischeva, K. 1984b. Nummulitids and Operculinids from the village of Beloslav, Varna District. – *Rev. Bulg. Geol. Soc.* 45, 2, 161-174. (in Bulgarian)
- Aladjova-Hrischeva, K. 1984c. Biostratigraphic justification of the stage boundaries in the lower Paleogene of North Bulgaria. Discussion. – *Geologica Balc.* 14, 6, 71-78. (in Bulgarian)
- Aladjova-Hrischeva, K. 1985. Nummulites and Assilines from the village of Obzor, Burgas District. – *Ann. Univ. Sofia, Fac. of Geol. and Geogr.* 75, 1, 43-76. (in Bulgarian)
- Aladjova-Hrischeva, K. 1988a. Stratigraphy of the lower Eocene sediments of Balvan Syncline (Veliko Tarnovo area). – *Rev. Bulg. Geol. Soc.*, 49, 3, 57-64.
- Aladjova-Hrischeva, K. 1988b. Nummulites and Assilines from the Aladan Limestone Formation (lower Eocene) in the NE Bulgaria plateaus. – *Palaeontol., Stratigr., Lithol.* 25, 37-48. (in Bulgarian)
- Aladjova-Hrischeva, K. 1990. Stratigraphy of the lower Eocene sediments in part of the NE Bulgaria plateaus. – *Rev. Bulg. Geol. Soc.* 51, 1, 21-31. (in Bulgarian)
- Aladjova-Hrischeva, K. 1991. Stratigraphic subdivision and correlation of the Palaeogene deposits in NE Bulgaria. – *Geologica Balc.* 21, 2, 12-38. (in Russian)
- Aladjova-Hrischeva, K., H. Hrishev. 1976. Burial conditions and preservation of nummulitid fauna (on the example of Palaeogene deposits in North Bulgaria). – *Geologica Balc.* 6, 1, 21-30. (in Russian)
- Aladjova-Hrischeva, K., N. G. Muzilev, S. G. Juranov. 1983. New data on the stratigraphy of the Palaeogene in NE Bulgaria. – *C. R. de l'Acad. Bulg. Sci.* 36, 7, 937-940. (in Russian)
- Aladjova-Hrischeva, K., L. Nedyalkova, T. Tzankov. 1991. Lithostratigraphy and deformations of Palaeogene sediments in the West and Central Fore-Balkan and Balkan Mountains. – *Geologica Balc.* 21, 6, 49-90. (in Russian)
- Aladjova-Hrischeva, K., B. F. Zernetskiy, E. Y. Kraeva. 1986. *Correlation of the Palaeogene deposits of the Black Sea coastal and shelf zones of Bulgaria and Ukraine*. Preprint 86-21, Acad. Sci. Ukraine, Kiyuv, 54 pp. (in Russian)
- Alvarez, L. W., W. Alvarez, E. Asaro, H. V. Michel. 1980. Extraterrestrial cause for the Cretaceous-Tertiary extinction. – *Science* 208, 1095-1108.
- Alvarez, W. E. G. Kauffman, F. Surlyk, L. W. Alvarez, F. Asaro, H. V. Michel. 1984. Impact Theory of Mass Extinctions and the Invertebrate Fossil Record. – *Science* 223, 4641, 1135-1141, DOI: 10.1126/science.223.4641.1135
- Alvarez, W., J. Smit, W. Lowrie, F. Asaro, S. V. Margolis, P. Claeys, M. Kastner, A. R. Hildebrand. 1992. Proximal impact deposits at the Cretaceous-Tertiary boundary in

- the Gulf of Mexico: A restudy of DSDP Leg 77 Sites 536 and 540. – *Geology* 20, 8, 697-700.
- Angori, E., G. Bernaola, S. Monechi. 2007. Calcareous nannofossil assemblages and their response to the Paleocene-Eocene Thermal Maximum event at different latitudes: ODP Site 690 and Tethyan sections. – In: Monechi, S., R. Cocconi, M.R. Rampino. (Eds.), Large ecosystem perturbations: causes and consequences. *Geological Society of America Special Paper* 424, 69-85.
- Applegate, J. L., S. W. Wise. 1987. Eocene calcareous nannofossils, Deep Sea Drilling Project Site 605, Upper continental Rise off New Jersey, U. S. A. – In: van Hinte, J. E., S. W. Wise, et al. *Init. Repts. DSDP* 92, 685-698.
- Arenillas, I., E. Molina, S. Ortiz, B. Schmitz. 2008. Foraminiferal and $\delta^{13}\text{C}$ isotopic event-stratigraphy across the Danian-Selandian transition at Zumaya (northern Spain): chronostratigraphic implications. – *Terra Nova* 20, 1, 38-44.
- Armentrout, J. M. 1996. High resolution sequence biostratigraphy: examples from the Gulf of Mexico Pliocene-Pleistocene. – In: Howell, J. A. & Aitken, J. F. (Eds.) High Resolution Sequence Stratigraphy: Innovations and Applications. *Geol. Soc. Spec. Publ.* 104, 65-86.
- Atanasov, A. 1961a. Senonian in the coastal zone of North Bulgaria. – *Rev. Bulg. Geol. Soc.* 22, 2, 175-186. (in Bulgarian)
- Atanasov, A. 1961b. Geology of the seaside part of the Fore-Balkan and Kamchiya Valley. – *Work Geol. Bulg. Ser. Strat. Tect.* 2, 99-157. (in Bulgarian)
- Atanasov, G., E. Belmustakov, S. Trashliev, A. Goranov. 1964. Stratigraphy and lithology of the Palaeogene in the vicinity of Zlatna Livada village, Chirpan area. – *Ann. Univ. Sofia, Fac. of Geol. and Geogr.* 58, 1, 75-98. (in Bulgarian)
- Aubry, M.-P. 1982. Calcareous nannofossil biostratigraphy, Leg 64. – *Init. Repts. DSDP* 44, 2, 955-972.
- Aubry, M.-P. 1996. Towards an upper Paleocene-lower Eocene high-resolution stratigraphy based on calcareous nannofossil stratigraphy. – *Israel J. Earth Sci.* 44, 239-253.
- Aubry, M.-P. 2000. Where should the global stratotype section and point (GSSP) for Paleocene/Eocene boundary be located? – *Bull. Soc. Geol. France* 171, 4, 461-476.
- Aubry, M.-P., C. Requirand, J. Cook. 2000. The *Rhombaster* – *Tribrachiatulus* lineage: a remarkable succession of events from 55.5 to 53.2 Ma. – *GFF* 122, 15-18.
- Aubry, M.-P., K. Ouda, C. Dupuis, W. A. Berggren, J. A. Van Couvering, and the members of the Working Group on the Paleocene/Eocene Boundary. 2007. The Global Standard Stratotype-section and Point (GSSP) for the base of the Eocene Series in Dababiya section (Egypt). – *Episodes* 30, 4, 271-286.
- Bakalova, D., L. Dodekova, H. Chamberski. 1982. List of the names of the sedimentary and volcano-sedimentary lithostratigraphic units, introduced in Bulgaria. – *Rev. Bulg. Geol. Soc.* 43, 1, 102-112. (in Bulgarian)
- Barrera, E., G. Keller. 1990. Stable isotope evidence for gradual environmental changes and species survivorship across the Cretaceous/Tertiary boundary. – *Paleoceanography* 5, 6, 867-890.
- Barrera, E., G. Keller. 1994. Productivity across the Cretaceous/Tertiary boundary in high latitudes. – *GSA Bulletin* 106, 10, 1254-1266.
- Barron, E., C. Harrison, J. Sloan II, W. Hay. 1981. Paleogeography, 180 million years ago to the present. – *Eclogae Geol. Helv.* 74, 2, 443-470.
- Belmustakov, E. 1956. Lutetian in the Kamchia part of East Balkan. – *Bull. of the Geological Institute* 4, 3-35. (in Bulgarian)
- Belmustakov, E. 1958. Priabonian in the Luda Kamchia Valley. – *Bull. of the Geological Institute* 6, 15-102. (in Bulgarian)
- Belmustakov, E. 1959. *The Fossils of Bulgaria. Volume VI Paleogene, Large Foraminifera*. S., Bulgarian Academy of Sciences, 80 p., 20 pl. (in Bulgarian)
- Belmustakov, E. 1960. Palaeocene deposits in Momino Plateau, Varna area. – *Rev. Bulg. Geol. Soc.* 21, 1, 106-109. (in Bulgarian)
- Belmustakov, E. 1961. Thanetian fauna from Momino and Varna plateaus. – *Bull. of the Geological Institute* 3, 5-47. (in Bulgarian)
- Belmustakov, E. 1962. Stratigraphy of the lower Palaeogene in NE Bulgarian plateaus. – *Bull. of the Geological Institute* 10, 89-111. (in Bulgarian)
- Belmustakov, E. 1963. Stratigraphy of the upper Palaeocene in the River Vit valley (Northern Bulgaria). – *Bull. of the Geological Institute* 12, 113-123. (in Bulgarian)
- Belmustakov, E. 1966. Unknown Thanetian species in Plevna and Gabrovo areas (Northern Bulgaria). – *Ann. Univ. Sofia, Fac. Geol. Geogr.* 59, 1, 43-68. (in Bulgarian)
- Belmustakov, E. 1968. Palaeogene. – In: Tzankov, V., H. Spasov (Eds.) *Stratigraphy of Bulgaria*. S., Nauka i izkustvo, 309-355. (in Bulgarian)
- Belmustakov, E. 1969. Large Foraminifera from the Lutetian of the Lukovit Syncline (Northern Bulgaria). – *Ann. Soc. Geol. Pologne* 39, 1-3, 265-276.
- Belmustakov, E. 1980. Regarding the lower Eocene-middle Eocene boundary. – *Palaeontol., Stratigr., Lithol.* 13, 71-76. (in Bulgarian)
- Belmustakov, E. 1984. About definition of the boundaries of some Palaeogene stages in Northern Bulgaria. – *Geologica Balc.* 14, 5, 79-80. (in Russian)
- Belmustakov, E., N. Jolkichev. 1965. Stratigraphy of the Maastrichtian and Thanetian in Gabrovo Syncline (Northern Bulgaria). – *Work on Geol. Bulg.* 6, 177-194. (in Bulgarian)
- Belmustakov, E., P. Tsaneva. 1965. Unified scheme for the Paleogene in Bulgaria. – In: Tzankov, V. (Ed.) *Unified and regional scheme for stratigraphy of P. R. Bulgaria*. S., 55-60. (in Bulgarian)
- Beregov, R. 1937. Tertiary in NW Bulgaria. – *Rev. Bulg. Geol. Soc.* 9, 3, 185-260. (in Bulgarian)
- Beregov, R. 1946. Tertiary in Bulgaria. – In: Cohen, E. (Ed.) *Fundamentals of the geology of Bulgaria*. – *Ann. Dir. Geol. Min. Res. A* 4, 169-196. (in Bulgarian)
- Bernaola, G., M. Martin-Rubio, J. I. Baceta. 2008. New high resolution calcareous nannofossil analysis across

- the Danian – Selandian transition at the Zumaia section: comparisons with South Tethys and Danish sections. – *Geologica Acta* 7, 1-2, 79-92.
- Bernaola, G., X. Orue-Etxebarria, A. Payros, J. Dinarès-Turell, J. Tosquella, E. Appellaniz, F. Caballero. 2006a. Biomagnetostratigraphic analysis of the Gorronatxe section (Basque Country, W Pyrenees): its significance for the definition of the Ypresian/Lutetian boundary stratotype. – *N. Jb. Geol. Palaont. Abh.* 241, 1, 67-109.
- Bernaola, G., J. Baceta, A. Payros, X. Orue-Etxebarria, E. Appellaniz. 2006b. The Paleocene and lower Eocene of the Zumaya section (Basque Basin). *Climate and Biota of the Early Paleogene 2006. Post Conf. Field Trip Guidebook*. Bilbao, 82 p., ISBN 84-689-8940-1.
- Bernaola, G., J. I. Baceta, X. Orue-Etxebarria, L. Alegret, M. Martín-Rubio, J. Arostegui, J. Dinarès-Turell. 2007. Evidence of an abrupt environmental disruption during the mid-Paleocene biotic event (Zumaya section, western Pyrenees). – *GSA Bulletin* 119, 7-8, 785-795.
- Beyrich, E. 1854. Über die Stellung der Hessischen Tertiärbildungen. – *Berichte der Königlichen Preussischen Akademie der Wissenschaften zu Berlin*, 640-660.
- Bombita, C. 1957. Ypresianul de la Varna. – *Bull. Sci. Acad. RP Romania, geol. si geogr.* 2, 3-4, 625-632.
- Bonchev, G. 1926. The rocks in the northern parts of the Balkan between Black sea, Kotel-Derwent Pass and the rivers Vrana and Golyama Kamchia. – *Proceedings BAS* 34, nat.-math., 16, 1-99. (in Bulgarian)
- Bonchev, G. 1927. Eocene in Provadia area, to the North of Kamchia. – *Rev. Bulg. Geol. Soc.* 1, 1, 61-72. (in Bulgarian)
- Bonchev, G. 1929. The rocks in Varna region. – *Proceedings BAS* 40, 20, 143-203. (in Bulgarian)
- Bonchev, E. 1955. *Geology of Bulgaria. Part I*. S., Nauka i izkustvo, 264 pp. (in Bulgarian)
- Bonchev, E. 1960. *Geology of Bulgaria. Part II*. S., Nauka i izkustvo, 163 pp. (in Bulgarian)
- Bonchev, E., B. Kamenov. 1934. Senonian between the rivers Iskar and Ogosta. – *Rev. Bulg. Geol. Soc.* 6, 1, 69-104. (in Bulgarian)
- Bonchev, E., E. Belmustakov, M. Yordanov, J. Karagyuleva. 1957. The main lines in the geological structure of the Fore-Balkan between the Yantra Valley and the Black Sea. – *Bull. of the Geological Institute* 5, 3-78. (in Bulgarian)
- Bonchev, E., M. Yordanov, G. Mandov, P. Pironkov, S. Stoianov. 1975. A new look at the geological structure of the Balkan coal basin. – *Geotect., Tectonophys., Geodynam.* 2, 27-52. (in Bulgarian)
- Bonchev, S. 1934. The origin (genesis) of the "upright stones" (Dikilitash) or "stick ups" in Varna District. – *Geologica Balc.* 1, 1, 5-15.
- Boshev, S., B. Strashimirov, S. Zafirov. 1972. *Geology of Bulgaria with palaeontology and historical geology*. S., Technika, 419 pp. (in Bulgarian)
- Boshev, S., B. Strashimirov, S. Zafirov, M. Stoianova, M. Moev. 1958. Geology of part of Nikopol and Svishtov area. – *Ann. Univ. of Mining and Geology* 4, 2, 1-23. (in Bulgarian)
- Boshev, S., B. Strashimirov, S. Zafirov, R. Hristov, M. Moev. 1967. Geology of the coastal part of the Eastern Stara planina. – *Ann. Univ. of Mining and Geology* 12, 7-62. (in Bulgarian)
- Botev, B. 1953. Notes on the geology of the easternmost part of the East Stara Planina Mt. – *Bull. of the Geological Institute* 2, 3-26. (in Bulgarian)
- Boué, A. 1840. *Esquisse géologique de la Turquie d'Europe*. Paris, 190 pp.
- Bowen, G. J., W. C. Clyde, P. L. Koch, S. Ting, J. Alroy, T. Tsubamoto, Y. Wang, Y. Wang. 2002. Mammalian dispersal at the Paleocene/Eocene boundary. – *Science* 295, 5562, 2062-2065. <https://doi.org/10.1126/science.1068700>
- Bowman, V., J. F. Francis, R. A. Askin, J. B. Riding, G. T. Swindless. 2014. Latest Cretaceous–earliest Paleogene vegetation and climate change at the high southern latitudes: palynological evidence from Seymour Island, Antarctic Peninsula. – *Palaeogeogr., Palaeoclimatol., Palaeoecol.* 408, 26-47.
- Bown, P. R. (Ed.). 1998. *Calcareous Nannofossil Biostratigraphy*. British Micropalaeontological Society Publications Series, Chapman and Hall/Kluwer Academic Publishers, London, 315 pp.
- Bown, P. 2001. Calcareous nannofossils of the Gault, Upper Green Sand and Glauconitic Marl (Middle Albian–Lower Cenomanian) from the BGS Selborne boreholes, Hampshire. – *Proc. Geol. Assoc.*, 112, 223-236.
- Bown, P. R. 2005. Paleogene calcareous nannofossils from the Kilwa and Lindi areas of coastal Tanzania (Tanzania Drilling Project 2003-4). – *J. Nannopl. Res.* 27, 1, 21-95.
- Bown, P. R., J. R. Young. 1998. Techniques. In: Bown, P. R. (Ed.), *Calcareous Nannofossil Biostratigraphy*. British Micropalaeontological Society Publications Series, Chapman and Hall/Kluwer Academic Publishers, London, 16-28.
- Bralower, T., J. Mutterlose. 1995. Calcareous nannofossils biostratigraphy of Site 865, Allison guyot, Central Pacific Ocean: a tropical Paleogene reference section. – *Proc. ODP, Sci. Res.* 143, 31-56.
- Bralower, T. J., J. C. Zachos, E. Thomas, M. Parrow, C. K. Paull, D. C. Kelly, I. Premoli-Silva, W. V. Silter, K. C. Lohmann. 1995. Late Paleocene to Eocene paleoceanography of the equatorial Pacific Ocean: stable isotopes recorded at ODP Site 865 Allison Guyot. – *Paleoceanography* 10, 841-865.
- Bralower, T., I. Premoli-Silva, M. Malone et al. 2002. *Proc. ODP, Init. Repts. Leg 198* [online] www.odp.tamu.edu/publications/198_IR/198ir.htm
- Bralower, T., U. Röhl, M. Petrizzo, J. Zachos, I. Premoli-Silva, D. Thomas. 2003. Constraining the control on carbonate accumulation in deep-sea sequences: a global dissolution event in the early Late Paleocene. – *Geol. Soc. America* 35, 6, p. 205.
- Bramlette, M., W. Riedel. 1954. Stratigraphic value of Discoasters and some other microfossils related to recent coccolithophores. – *J. Paleont.* 28, 385-403.
- Bramlette, M., F. Sullivan. 1961. Coccolithophorids and related Nannoplankton of the early Tertiary in California. – *Micropaleontol.* 7, 2, 129-188.

- Bramlette, M., J. Wilcoxon. 1967. Middle Tertiary calcareous nannoplankton of the Cipero section, Trinidad, W. I. – *Tulane Stud. Geol. Paleontol.* 5, 3, 93-131.
- Brönnimann, P., H. Stradner. 1960. Die Foraminiferen- und Discoasteriden zonen von Kuba und ihre interkontinentalen Korrelation. – *Erdoel-Zeitschr.* 76, 10, 364-369.
- Bukry, D. 1973. Low-latitude coccolith biostratigraphic zonation. – *Init. Repts. DSDP 15*, 685-703.
- Bukry, D. 1990. Remarks on calcareous and siliceous nannoplankton biostratigraphy for some Cretaceous and Tertiary core samples from southern New Jersey. – *U.S. Geol. Survey Open-File Report 90-278*, 1-23.
- Bukry, D. 1993. Cretaceous coccolith Correlation for Point Loma Formation outfall test well, San Diego, California. – *U.S. Geol. Survey Open-File Report 93-567*, 1-14.
- Bukry, D., S. F. Percival. 1971. New Tertiary calcareous nannofossils. – *Tulane Stud. in Geol. and Paleontol.* 8, 123-146.
- Bukry, D., E. Brabb, J. Vedder. 1977. Correlation of Tertiary Nannoplankton assemblages from the Coast and Peninsular Ranges of California. – *Geol. Bull. Spec. Publ.* 7, 3, 1461-1483.
- Burnett, J. 1998. Upper Cretaceous. – In: Bown, P. R. (Ed.). *Calcareous Nannofossil Biostratigraphy*. British Micropalaeontological Society Publications Series, Chapman and Hall/Kluwer Academic Publishers, London, 315 pp.
- Burnett, J. 2002. Calcareous nannofossil biogeography illustrates palaeoclimate change in the Late Cretaceous Indian Ocean. – *Cretaceous Res.* 23, 537-634.
- Burnett, J., J. Kennedy, P. Ward. 1992. Maastrichtian nannofossil biostratigraphy in the Biscay region (southwestern France, northern Spain). – *Newsl. Strat.* 26, 145-155.
- Bybel, L., J. Self-Trail. 1995. Evolutionary, biostratigraphic and taxonomic study of calcareous nannofossils from a continuous Paleocene/Eocene boundary section in New Jersey. – *US Geol. Surv., Prof. Paper 1554*, 1-36.
- Bystricka, H. 1973. Palaeozane nannoplankton-zonen in dem Slowakischen teil der Westkarpaten. – *Geol. Zborn.-Geol. Carp.* 24, 2, 375-383.
- Bystricka, H. 1976. Calcareous nannoplankton of the Martasterites tribrachiatus zone from the Lower Eocene sediments of Slovakia. – *Geol. Zborn.-Geol. Carp.* 27, 2, 273-297.
- Cheshitev, G. (Ed.). 1994. *Explanatory note to the geological map of Bulgaria in scale 1:100000. Map sheets Varna and Zlatni piasatsi*. S., 75 pp. (in Bulgarian)
- Cohen, E. 1938. General profiles through East Stara Planina Mt. regarding petroleum geology. – *Rev. Bulg. Geol. Soc.* 10, 1, 1-34. (in Bulgarian)
- Cohen, E. 1946. Mesozoic in Bulgaria. – In: Cohen, E. (Ed.) *Fundamentals of the geology of Bulgaria*. – *Ann. Dir. Geol. Mining Res. A 4*, 105-168. (in Bulgarian)
- Covington, M. 1985. New morphologic information on Cretaceous nannofossils from the Niobrara Formation (Upper Cretaceous) of Kansas. – *Geology* 13, 683-686.
- Cramer, B. S., D. V. Kent. 2005. Bolide summer: The Paleocene/Eocene thermal maximum as a response to an extraterrestrial trigger. – *Palaeogeogr., Palaeoclimatol., Palaeoecol.* 224, 1-3, 144-166.
- Dabovski, C., B. Kamenov, D. Sinnyovsky, E. Vasilev, E. Dimitrova. 2009. Upper Cretaceous geology. – In: *Geology of Bulgaria. Vol. II. Mesozoic Geology* (Eds I. Zagorchev, C. Dabovski, T. Nikolov), S., "Prof. M. Drinov" Acad. Press, 303-589. (in Bulgarian with English summary)
- Dabovski, C., I. Boyanov, Kh. Khrishev, T. Nikolov, I. Sapunov, Y. Yanov, I. Zagorchev. 2002. Structure and Alpine evolution of Bulgaria. – *Geologica Balc.* 32, 2-4, 9-15.
- Dachev, D. 1967. New data on the Thanetian in Plevna region. – *Ann. Univ. Sofia, Fac. of Geol. Geogr.* 60, 1, 107-124. (in Bulgarian)
- Dachev, D. 1975. Stratigraphy of the Palaeocene deposits in Plevna region. – *Rev. Bulg. Geol. Soc.* 36, 1, 37-47. (in Bulgarian)
- Davitashvili, Sh. L., K. Zaharieva-Kovacheva. 1975. *Origin of the stone forests*. Tbilisi, Metsniereba, 195 pp. (in Russian)
- De Boever, E., D. Birgel, V. Thiel, P. Muchez, J. Peckmann, L. Dimitrov, R. Swennen. 2009. The formation of giant tubular concretions triggered by anaerobic oxidation of methane as revealed by archaeal molecular fossils (Lower Eocene, Varna, Bulgaria). – *Palaeogeogr., Palaeoclimatol., Palaeoecol.* 280, 23-36.
- Desor, P. J. É. 1847. Sur le terrain Danien, nouvel étage de la craie. – *Bulletin de la Société Géologique de France* 4, 179-181.
- Dewalque, G. 1868. *Prodrome d'une description géologique de la Belgique*. Librairie Polytechnique De Deque, Brussels & Liège, 1-442.
- Dickens, G. 2011. Down the Rabbit Hole: toward appropriate discussion of methane release from gas hydrate systems during the Paleocene-Eocene thermal maximum and other past hyperthermal events. – *Climate of the Past* 7, 831-846.
- Dickens, G. R., M. M. Castillo, J. C. G. Walker. 1997. A blast of gas in the latest Paleocene: Simulating first-order effects of massive dissociation of oceanic methane hydrate. – *Geology* 25, 3, 259-262.
- Dickens, G., J. R. O'Neil, D. K. Rea, R. M. Owen. 1995. Dissociation of oceanic methane hydrate as a cause of the carbon isotope excursion at the end of the Paleocene. – *Paleoceanography* 10, 6, 965-971.
- Dimitrova, E. 1994a. Foraminiferal associations of the Maastrichtian in the Srednogorie and Eastern Stara Planina. – *Rev. Bulg. Geol. Soc.* 55, 2, 91-96. (in Bulgarian)
- Dimitrova, E. 1994b. Foraminiferal associations of the Campanian in the Srednogorie and Eastern Stara Planina. – *Rev. Bulg. Geol. Soc.* 55, 3, 65-68. (in Bulgarian)
- Dinarès-Turell, J., K. Stoykova, M. Ivanov. 2006. Paleocene integrated cyclo-, magneto- and calcareous nannofossils Stratigraphy in the Bjala section (Black Sea coast, Bulgaria). – In: *Climate and Biota of the Early Paleogene 2006*. Abstract book, p. 33.
- Dinarès-Turell, J., V. Pujalte, K. Stoykova, J. Elorza. 2013a.

- Detailed correlation and astronomical forcing across the Upper Maastrichtian succession from the Basque-Cantabrian Basin. – *Special issue on cyclostratigraphy on the Boletín Geológico y Minero* 124, 2, 253-282.
- Dinarès-Turell, J., J. Elorza, V. Pujalte, K. Stoykova. 2013b. An integrated stratigraphy and orbital tuning of the Maastrichtian (Late Cretaceous) from the Basque Basin (W Pyrenees) and re-appraisal of the Campanian/Maastrichtian boundary. – *Cretaceous Symposium*, Ankara.
- Dinarès-Turell, J., V. Pujalte, K. Stoykova, J. Elorza. 2014. Extending back the Paleogene astronomical time scale: an integrated analysis of the Upper Maastrichtian strata in the Basque basin. – In: Rocha, R. et al. (Eds.), *STRATI 2013, Springer Geology*, Springer International Publishing Switzerland 2014, 185-189.
- Dinarès-Turell, J., J. Baceta, G. Bernaola, X. Orue-Etxebarria, V. Pujalte. 2007. Closing the Mid-Paleocene gap: toward a complete astronomically tuned Paleocene Epoch and prospective Selandian and Thanetian GSSPs at Zumaya (Basque Basin, W Pyrenees). – *Earth Plan. Sci. Letters* 262, 450-467.
- Dinarès-Turell, J., K. Stoykova, J. I. Baceta, M. Ivanov, V. Pujalte. 2010. High-resolution intra and interbasinal correlation of the Danian-Selandian transition (Early Paleocene): the Bjala section (Bulgaria) and the Selandian GSSP at Zumaia (Spain). – *Palaeogeogr., Palaeoclimatol., Palaeoecol.* 297, 2, 511-533.
- Dinarès-Turell, J., V. Pujalte, K. Stoykova, J. I. Baceta, M. Ivanov. 2012. The Paleocene "Top Chron C27n" transient greenhouse episode: evidences from marine pelagic Atlantic and peri-Tethyan sections. – *Terra Nova* 24, 6, 477-486.
- Dinarès-Turell, J., J. Baceta, V. Pujalte, X. Orue-Etxebarria, G. Bernaola, S. Lorito. 2003. Untangling the Paleocene climatic rhythm: an astronomically calibrated Early Paleocene magnetostratigraphy and biostratigraphy at Zumaya (Basque basin, northern Spain). – *Earth Plan. Sci. Letters* 216, 483-500.
- Dupuis, C., M.-P. Aubry, E. Steurbaut, W. Berggren, K. Ouda, R. Speijer, C. Herman-Clausen. 2003. The Dababiya Quarry Section: lithostratigraphy, clay mineralogy, geochemistry and paleontology. – *Micropaleontol.* 49, 41-59.
- Emery, D., K. J. Myers. 1996. *Sequence Stratigraphy*. Blackwell Science Ltd., Oxford, 297 pp.
- Filipov, L. 1992. Upper Cretaceous Series – Paleogene System. – In: Cheshitev, G., L. Filipov (Eds.), *Explanatory note to the geological map of Bulgaria in scale 1:100 000. Map sheets Bregovo and Bayleshti*. S., Geology and Geophysics Ltd., 12-13. (in Bulgarian)
- Filipov, L., G. Cheshitev, (Eds.). 1995a. *Explanatory note to the geological map of Bulgaria in scale 1:100 000. Map sheets Zaechar and Bor*. S., ET "Avers", 43 pp. (in Bulgarian)
- Filipov, L., G. Cheshitev, (Eds.). 1995b. *Explanatory note to the geological map of Bulgaria in scale 1:100 000. Map sheet Vidin*. S., ET "Avers", 60 pp. (in Bulgarian)
- Filipov, L., A. Decheva, E. Kojumdzhieva, N. Popov. 1995c. *Explanatory note to the geological map of Bulgaria in scale 1:100 000. Map sheets Nikopol and Pleven*. S., Geology and Geophysics Ltd, 61 pp. (in Bulgarian)
- Fiorentino, A. 1993. Nannofossil stratigraphy of the Maastrichtian Ponte Chiusita section, Umbro-Marchean Apennines, Central Italy. – *Paleopelagos* 3, 279-287.
- Gardin, S. 2002. Late Maastrichtian to early Danian calcareous nannofossils at Elles (Northwest Tunisia). A tale of one million years across the K-T boundary. – *Paleogeogr., Paleoclimatol., Paleoecol.* 178, 3-4, 211-231.
- Garofalo, Y., H. Luterbacher, K. Perch-Nielsen, I. Premoli-Silva, W. Riedel, A. Sanfilippo. 1975. Zonations a l'aide de microfossiles pelagiques du Paleocene superieur et de l'Eocene inferieur. – *Bull. Soc. Geol. France* 7, 17/2, 125-147.
- Gartner, S. 1970. Phylogenetic Lineages in the Lower Tertiary Coccolith Genus *Chiasmolithus*. – *Proc. of the North Amer. Paleontol. Conv.*, 930-957.
- Gellert, J. 1929. Die Neogenbucht von Varna und ihre Umrandung. – *Abh. d. Sachs. Akad., matli.-phis. Kl.*, 5 L, 2, 90 S.
- Georgiev, G., C. Dabovski, G. Stanisheva-Vassileva. 2001. East Srednogorie-Balkan rift zone. – In: Ziegler, P. A., W. Cavazza, A. F. Robertson, S. Crasquin-Soleau (Eds.), *Peri-Tethyan rift/wrench basins and passive margins*. – *Mem. Mus. Nat. Hist. Natur.* 186, 259-293.
- Gibbs, S. J., P. R. Bown, B. A. Ward, S. A. Alvarez, H. Kim, O. A. Archontikis, B. Sauterey, A. J. Poulton, J. Wilson, A. Ridgwell. 2020. Algal plankton turn to hunting to survive and recover from end-Cretaceous impact darkness. – *Sci. Adv.* 6, eabc9123, 1-11.
- Gocev, P. 1929. Neue Beitrage zur Kenntniss des Altterziars in Bulgarien. – *Zbl. Mineral., Geol. u. Paläont. Abt. B* 11, 543-548.
- Gocev, P. 1926. Eocene in NE Bulgaria. – *Work Bulg. Natur. Soc.* 12, 97-105. (in Bulgarian)
- Gocev, P. 1929. The age and the fauna of the old Tertiary marls near the village of Murgis (Burgas District). – *Ann. Univ. Sofia, Fac. of Phys. Math.* 25, 3, 71-110. (in Bulgarian)
- Gocev, P. 1932. Geological observations along the Black Sea coast between the mouth of the Kamchia River and Cape Emine. – *Rev. Bulg. Geol. Soc.* 4, 3, 200-213. (in Bulgarian)
- Gocev, P. 1933. Palaeontological and stratigraphic studies on the Eocene in Varna region. – *Rev. Bulg. Geol. Soc.* 5, 1, 1-32. (in Bulgarian)
- Gocev, P. 1934. Geological notes about the vicinities of Varna Lakes. – *Rev. Bulg. Geol. Soc.* 6, 1, 31-60. (in Bulgarian)
- Gocev, P. 1935. An attempt for correlation of the Paleogene in the Balkan countries. – *Rev. Bulg. Geol. Soc.* 7, 1, 24-49. (in Bulgarian)
- Gocev, P. 1937. Eocene subdivision in NE Bulgaria. – *Rev. Bulg. Geol. Soc.* 9, 1, 46-58. (in Bulgarian)
- Gradstein, F. M., J. G. Ogg, A. G. Smith (Eds.). 2004. *A Geologic Time Scale 2004*. Cambridge University Press, Cambridge, 589 pp.
- Gradstein, F. M., J. G. Ogg, A. G. Smith, W. Bleeker, L. Lourens. 2004. A new Geological Time Scale, with

- special reference to Precambrian and Neogene. – *Epi-sodes* 27, 2, 83-100.
- Granchovski, G. 2019. Calcareous nannofossils from the upper Campanian – Maastrichtian (Upper Cretaceous) in the Kladorub Formation (Kula tectonic unit, NW Bulgaria). – *Geologica Balc.* 48, 1, 73-101.
- Haq, B. U. 1973. Evolutionary trends in the Cenozoic coccolithophore genus *Helicopontosphaera*. – *Micropaleontol.* 19, 1, 32-52.
- Haq, B. U. 1981. Paleogene paleoceanography: Early Cenozoic oceans revisited. – *Oceanologica Acta*, 71-82.
- Haq, B. U. 1984. Paleoceanography: A Synoptic Overview of 200 Million Years of Ocean History. – In: Haq, B. U., J. D. Milliman (eds). *Marine geology and oceanography of Arabian Sea and Coastal Pakistan*. Van Nostrand Reinhold Company, New York, 201-231.
- Haq, B. U., J. Hardenbol, P. R. Vail. 1988. Mesozoic and Cenozoic Chronostratigraphy and cycles of sea-level change. – In: C. K. Wilgus, B. S. Hastings, C. G. St. C. Kendall, C. A. Ross, J. C. Van Wagoner (Eds.) *Sea-level Changes – An Integrated Approach*, *SEPM Spec. Publ.* 42, 71-108.
- Haq, B. U., I. Silva, G. Lohmann. 1977. Calcareous Plankton Paleobiogeographic Evidence for Major Climatic Fluctuations in the Early Cenozoic Atlantic Ocean. – *J. Geophys. Research* 82, 27, 3861-3876.
- Harbury, N., M. Cohen. 1997. Sedimentary history of Late Jurassic – Paleogene of Northeast Bulgaria and the Bulgarian Black Sea. – In: Robinson, A. G., (Ed.) *Regional and petroleum geology of the Black Sea and surrounding region*. *AAPG Mem.* 68, 129-168.
- Hardenbol, J., J. Thierry, B. Farley, T. Jacquin, P.-C. Graciansky, P. R. Vail. 1998. Mesozoic and Cenozoic Sequence Chronostratigraphic Framework of European Basins. – In: Graciansky, P.-C., J. Hardenbol and P. R. Vail, (Eds.) *Mesozoic and Cenozoic Sequence Stratigraphy of European Basins*. *SEPM Spec. Publ.*, 60.
- Hay, W. 1964. Utilisation stratigraphique des Discoasterides pour la zonation du Paleocene et de l'Eocene inferieur. – *Mem. Bur. Rech. Geol. Min.* 28, 885-889.
- Hay, W. 1971a. Preliminary dating by fossil calcareous nannoplankton Deep Sea Drilling Project: Leg 6. – *Init. Rep. DSDP*, 6, 1005-1012.
- Hay, W. 1971b. Preliminary dating by fossil calcareous nannoplankton Deep Sea Drilling Project: Leg 8. – *Init. Rep. DSDP*, 8, 809-818.
- Hay, W., H. Mohler. 1967. Calcareous nannoplankton from Early Tertiary rocks at Pont Labau, France, and Paleocene-Early Eocene correlations – *J. Paleontol.* 41, 6, 1505-1541.
- Hay, W., H. Mohler, P. Roth, R. Schmidt, J. Boudreaux. 1967. Calcareous nannoplankton zonation of the Cenozoic of the Gulf coast and Caribbean-Antillean area, and transoceanic correlation. – *Gulf Coast Assoc. Geol. Soc. Trans.* 17, 428-480.
- Heck, S. E. van, B. Prins. 1987. A refined nannoplankton zonation for the Danian of the Central North Sea. – *Abh. Geol. Bundesanst.* 39, 285-303.
- Higgins, J., D. Schrag. 2006. Beyond methane: toward a theory for the Paleocene-Eocene Thermal Maximum. – *Earth Planet. Sci. Letters* 245, 3-4, 523-537.
- Hottinger, L., H. Schaub. 1960. Zur Stufeneinteilung des Paleozäns und Eozäns. Einführung der Stufen Herdiden und Biarritzien. – *Eclogae Geologicae Helvetiae*, 53, 1, 453-479. Traduction en Espagnol, 1961: *Notas y Comunicaciones Instituto Geológico y Minero de España (Madrid)*, 61, 199-234.
- Hramov, A. N. 1957. About paleomagnetism as a base for new method for correlation and subdivision of the sedimentary rocks. – *Proc. Acad. Sci. USSR* 112, 5, 849-852. (in Russian)
- Hrischev, H. (Ed.). 1992. *Explanatory note to the geological map of Bulgaria in scale 1:100000. Map sheet Sevelievo*. S., 55 pp. (in Bulgarian)
- Hrischev, H. (Ed.). 1993. *Explanatory note to the geological map of Bulgaria in scale 1:100000. Map sheet Veliko Tarnovo*. S., ET "Bolid", 64 pp. (in Bulgarian)
- Ilieva, T. 1998. Change of the echinoid fauna across the Cretaceous-Tertiary boundary sections in the area of the town of Byala, Varna District. – *Rev. Bulg. Geol. Soc.* 59, 3, 133-138. (in Bulgarian)
- Ilieva, T. 2000. Echinoids from Cretaceous/Tertiary boundary sequence at Byala, Varna area, Bulgaria. – *Geologica Balc.* 30, 1-2, 49-57.
- Ivanov, M. 1993a. In: Tenchov, Y. (Ed.). *Dictionary of the Bulgarian formal lithostratigraphic units (1882-1992)*. S., BAS, 397 pp. (in Bulgarian)
- Ivanov, M. 1993b. Uppermost Maastrichtian ammonites from the uninterrupted Upper Cretaceous-Paleogene section at Bjala (East Bulgaria). – *Geologica Balc.* 23, 4, p. 54.
- Ivanov, M., K. Stoykova. 1994. Cretaceous/Tertiary boundary in the area of Bjala, eastern Bulgaria – biostratigraphic results. – *Geologica Balc.* 24, 6, 3-22.
- Ivanov, M., K. Stoykova. 1995. Cretaceous/Tertiary boundary and "mass extinction" problem as could be seen in the sections around Bjala (Bulgaria). – *C. R. de l'Acad. Bulg. Sci.* 48, 2, 77-79.
- Jafar, S., E. Martini. 1975. On the validity of the calcareous nannoplankton genus *Helicosphaera*. – *Senckenberg. Lethaea* 56, 4-5, 381-397.
- Jenkins, D. G., H. P. Luterbacher. 1992. Paleogene stages and their boundaries: introductory remarks. – *N. Jahrb. Geol. Palaontol. Abh.* 186, 1-5.
- Jolkichev, N. 1982. Upper Cretaceous Stratigraphy in the Area of Stara Planina Granite Nappe (Central Stara Planina). – *Rev. Bulg. Geol. Soc.* 43, 1, 25-40. (in Bulgarian)
- Jolkichev, N. A. 1986. Lithostratigraphic units associated with the Upper Cretaceous series in the western and central Fore-Balkan. – *Rev. Bulg. Geol. Soc.* 47, 3, 49-61. (in Bulgarian)
- Jolkichev, N. A. 1987. Lithostratigraphic units associated with the Upper Cretaceous series in the central parts of the Moesian Plate. – *Rev. Bulg. Geol. Soc.* 48, 2, 25-37. (in Bulgarian)
- Jolkichev, N. A. 1988. Lithostratigraphic units associated with the Upper Cretaceous series in the eastern parts of the Moesian Plate. – *Rev. Bulg. Geol. Soc.* 49, 1, 11-25. (in Bulgarian)

- Jolkichev, N. A. 1989. *Stratigraphy of the epicontinental type Upper Cretaceous in Bulgaria*. S., University Publ. House "St. Kl. Ohridski", 184 pp. (in Bulgarian)
- Jolkichev, N. A. 1993. In: Tenchov, Y. (Ed.). *Dictionary of the Bulgarian formal lithostratigraphic units (1882-1992)*. S., BAS, 397 pp. (in Bulgarian)
- Jolkicev, N. 2006. The Cretaceous/Paleogene (K/Pg) boundary in the Mezdra and Lyutidol syncline, Vratza District (West Fore-Balkan, Bulgaria). – *Ann. Geol. Penn. Balkanique* 67, 41-49.
- Juranov, S. 1983. Planktonic foraminiferal zonation of the Paleocene and Lower Eocene in part of East Balkan Mountain. – *Geologica Balc.* 13, 2, 59-73.
- Juranov, S. 1984. Lithostratigraphy of the sediments in Senonian-middle Eocene interval around Byala and Goritsa villages, Varna District. – *Ann. Univ. of Mining and Geology* 30, 2, 13-23. (in Bulgarian)
- Juranov, S. 1989. Data on the geological structure of Byala area – East Stara Planina. – *Ann. Univ. of Mining and Geology* 32, 1, 7-18. (in Bulgarian)
- Juranov, S. 1991. Stratigraphy of the Upper Cretaceous and Palaeogene in the marine well section near Samotino village. – *Rev. Bulg. Geol. Soc.* 52, 3, 19-29. (in Bulgarian)
- Juranov, S. 1993. In: Tenchov, Y. (Ed.). *Dictionary of the Bulgarian formal lithostratigraphic units (1882-1992)*. S., BAS, 397 pp. (in Bulgarian)
- Juranov, S. 1994. Paleocene planktonic foraminifera from the type area of the Emine flysch Formation (Eastern Stara Planina). – *Palaeontol., Stratigr., Lithol.* 30, 3-21. (in Bulgarian)
- Juranov, S., S. Darachchieva. 1986. Early-middle Eocene planktonic foraminifera from Dobrudzha (NE Bulgaria). – *Palaeontol., Stratigr., Lithol.* 22, 31-35. (in Bulgarian)
- Juranov, S., C. Pimpirev. 1989. Lithostratigraphy of the Upper Cretaceous and Palaeogene in the coastal part of the Eastern Stara Planina. – *Rev. Bulg. Geol. Soc.* 50, 2, 1-18. (in Bulgarian)
- Kanchev, I. (Ed.). 1995a. *Explanatory note to the geological map of Bulgaria in scale 1:100 000. Map sheet Dolen Chiflik*. S., ET "Avers", 113 pp. (in Bulgarian)
- Kanchev, I. (Ed.). 1995b. *Explanatory note to the geological map of Bulgaria in scale 1:100 000. Map sheet Sungurlare*. S., ET "Avers", 73 pp. (in Bulgarian)
- Kanchev, I. (Ed.). 1995c. *Explanatory note to the geological map of Bulgaria in scale 1:100 000. Map sheet Aytoz*. S., ET "Avers", 111 pp. (in Bulgarian)
- Kanchev, I. (Ed.). 1995d. *Explanatory note to the geological map of Bulgaria in scale 1:100 000. Map sheet Sliven*. S., ET "Avers", 155 pp. (in Bulgarian)
- Kanchev, I., T. Nikolov (Eds.). 1995. *Explanatory note to the geological map of Bulgaria in scale 1:100 000. Map sheet Tvarditsa*. S., ET "Avers", 139 pp. (in Bulgarian)
- Karagyuleva, J. 1960. Ypresian in the Lukovit Syncline. – *Rev. Bulg. Geol. Soc.* 21, 1, 78-80. (in Bulgarian)
- Karagyuleva, J. 1961. Some new mollusks from the Palaeogene of Bulgaria. – *Work Geol. Bulg. Ser. Palaeontol.* 3. (in Bulgarian)
- Karagyuleva, J. 1964. *Les Fossiles de Bulgarie, Via, Palaeogene Mollusca*. S., Academie des Sciences de Bulgarie, 270 p., 57 pl.
- Karagyuleva, J., V. Kostadinov. 1977. Geological structure of the eastern part of the Luda Kamchia area. – *Geotect., Tectonophys., Geodynam.* 7, 42-75. (in Bulgarian)
- Kauffman, E. G., D. Erwin. 1995. Surviving mass extinction. – *Geotimes*, March 1995, 14-17.
- Keller, G. 1993. The Cretaceous-Tertiary boundary transition in the Antarctic Ocean and its global implications. – *Marine Micropal.* 21, 1-3, 1-45.
- Keller, G. 1996. The K/T mass extinction in planktic foraminifera biotic constraints for catastrophe theories. – In: Keller, G., N. MacLeod (Eds.) *Cretaceous-Tertiary mass extinction: Biotic and environmental changes*. New York, Norton & Co., 63-100.
- Keller, G., K. Perch-Nielsen. 1995. Cretaceous-Tertiary (K/T) mass extinction: effect of global change on calcareous microplankton. – In: S. Stanley and J. P. Kennett (Eds.). *Effects of Past Global Change on Life*, National Academy of Science, 72-93.
- Keller, G., N. MacLeod, J. B. Lyons, C. B. Officer. 1993a. Is there evidence for Cretaceous-Tertiary boundary-age deep-water deposits in the Caribbean and Gulf of Mexico. – *Geology* 21, 9, 776-780.
- Keller, G., E. Barrera, B. Schmitz, E. Mattison. 1993b. Gradual mass extinction, species survivorship, and long-term environmental changes across the Cretaceous-Tertiary boundary in high latitudes. – *Geol. Soc. of America Bull.* 105, 8, 979-997.
- Keller, G., T. Adatte, C. Hollis, M. Ordonez, I. Zambrano, N. Jimenes, W. Stinnesbeck, A. Aleman, W. Hale-Erich. 1997. The Cretaceous/Tertiary boundary event in Ecuador: reduced biotic effects due to eastern boundary current setting. – *Mar. Micropal.* 31, 97-133.
- Kenneth, J. P., L. D. Stott. 1991. Abrupt deep-sea warming, palaeoceanographic changes and benthic extinction at the end of the Palaeocene. – *Nature* 353, 225-229.
- Khan, A., M.-P. Aubry. 2004. Provincialism associated with the Paleocene/Eocene thermal maximum: temporal constraint. – *Mar. Micropal.* 52, 117-131.
- Khrovsky, J., J. Adamova, H. Maslowska. 1992. Paleoenvironmental dance and Pouzdryan Units (Western Carpathians, Czechoslovakia): The Long-Term trend and orbitally forced changes in calcareous nannofossil assemblages. – In: Hamrsmid, B., J. Young (Eds.). *Nannoplankton Research, Proc. 4th INA Conf., 1991, Knihovnicka ZPN, 14b*, 2, 105-187.
- Kockel, C. 1927. Zur Stratigraphie und Tektonik Bulgariens. Mit einem Beitrag von F. Kossmat. Das Grenzgebiet zwischen ostlichen und zentralen Balkan. – *Geol. Rundsch.* 18, 5, 349-355.
- Konstantinova, V. 1958. Stratigraphic studies of the Tertiary in Tarnovo area. – *Ann. Univ. Sofia, Fac. Geol. Geogr.* 51, 2 – geol., 1-19. (in Bulgarian)
- Kostov, R., R. Tzankarska. 1997. Mineralogical content of boundary clay layers at and above the K-T boundary at Byala on the Black sea coast of Bulgaria. – *C. R. de l'Acad. Bulg. Sci.* 50, 9-10, 55-58.

- Kostov, R. I., R. Tsankarska. 2000. Mineralogy of the clay layer at the Cretaceous/Tertiary boundary in Mezdra area. – *Geology and Mineral Resources*, 4-6. (in Bulgarian)
- Lamolda, M., X. Orue-Etxebarria, F. Proto-Desima. 1983. The Cretaceous-Tertiary boundary in Sopelana (Biscay, Basque Country). – *Zitteliana* 10, 663-670.
- Lang, T. H., S. W. Wise. 1987. Neogene and Paleogene-Maestrichtian calcareous nannofossil stratigraphy, deep sea Drilling Project Sites 604 and 605, Open continental rise off New Jersey: sedimentation rates, hiatuses, and correlations with seismic stratigraphy. – In: Hinte, J. E., S. W. Wise, et al. – *Init. Repts. DSDP* 92, 661-683.
- Lees, J. A. 2002. Calcareous nannofossils biostratigraphy illustrates palaeoclimate change in the Late Cretaceous Indian Ocean. – *Cretaceous Res.* 23, 537-634.
- Leu, M., S. Gartner, I. Gostea. 1983. The Paleocene-Eocene in the South-West of the Moesian Platform (Romania). – *Ann. de l'Inst. de Geol. et de geoph.* 59, 213-219.
- Lourens, L., A. Sluijs, D. Kroon, J. Zachos, E. Thomas, U. Röhl, J. Bowles, I. Raffi. 2005. Astronomical pacing of late Palaeocene to early Eocene global warming events. – *Nature* 435, 1083-1087. <https://doi.org/10.1038/nature03814>
- Luterbacher, H. P., J. R. Ali, H. Brinkhuis, F. M. Gradstein, J. J. Hooker, S. Monechi, J. G. Ogg, J. Powell, U. Röhl, A. Sanfilippo, B. Schmitz. 2004. The Paleogene Period. – In: Gradstein, F., J. Ogg, A. Smith (Eds.). *A Geologic Time Scale 2004*. Cambridge University Press, Cambridge, 589 pp.
- Lyell, C. 1833. *Principles of geology, being an attempt to explain the former changes of the Earth's surface, by reference to causes now in operation*. London, John Murray, vol. 3.
- MacLeod, N., G. Keller. 1991. Hiatus distributions and mass extinctions at the Cretaceous/Tertiary boundary. – *Geology* 19, 5, 497-501.
- Mandev, P. 1955. On the Palaeogene in Stalin area. – *Ann. Univ. Sofia, Fac. Biol. Geol. Geogr.* 49, 2, 73-154. (in Bulgarian)
- Mandev, P. 1970. On the formation of "Pobitite kamani" in Varna area. – *Geography* 20, 9, 18-21. (in Bulgarian)
- Manivit, H. 1984. Paleocene and Upper Cretaceous calcareous nannofossils from Deep Sea Drilling Project Leg 74. – *Init. Rep. DSDP* 74, 475-499.
- Manivit, H., H. Feinberg. 1984. Correlation of magnetostratigraphy and nannofossil biostratigraphy in Upper Cretaceous and lower Paleocene sediments of the Walvis Ridge Area. – *Init. Rep. DSDP* 74, 469-474.
- Marroni, M., S. Monechi, N. Perilli, G. Principi, B. Treves. 1992. Late Cretaceous flysch deposits of the Northern Apennines, Italy: age of inception of orogenesis-controlled sedimentation. – *Cretaceous Res.* 13, 487-504.
- Martini, E. 1958. Discoasteriden und verwandte Formen im NW-deutschen Eozan (Coccolithophorida). – *Senckenberg. Leth.* 39, 5-6, 353-388.
- Martini, E. 1959. Der stratigraphische Wert von Nannofossilien im nordwestdeutschen Tertiär. – *Sond., Erdöl und Kohle* 3, 137-140.
- Martini, E. 1961. Der stratigraphische Wert der Lithostromationidae. – *Erdöl-Zeitschrift* 3, 100-103.
- Martini, E. 1969. Calcareous nannoplankton from the Kallio well. – *Mem. Expl. Cartes Geol. Min. Belgique* 11, 39-41.
- Martini, E. 1970a. *Imperiaster* n. g. aus dem europäischen Unter-Eozan (Nannoplankton, incertae sedis). – *Senckenberg. Lethaea* 51, 383-386.
- Martini, E. 1970b. Standard Palaeogene calcareous nannoplankton zonation. – *Nature* 226, 560-561.
- Martini, E. 1971c. Standard Tertiary and Quaternary calcareous nannoplankton zonation. – In: Farinacci, A. (ed.). *Proc. II Plankt. Conference Roma*, 1970, 2, Tecnoscienza, 739-785.
- Martini, E., 1981. Nannoplankton in der Ober-Kreide, im Altertär und im tieferen Jungtertiär von Süddeutschland und dem angrenzenden Österreich. – *Geol. Bavarica* 82, 345-356.
- Martini, E., S. Ritzkowski. 1970. Stratigraphische Stellung der obereozanen Sande von Mandrikovka (Ukraine) und Parallelisierungs-Möglichkeiten mit Hilfe des fossilen Nannoplanktons. – *Newsl. Stratigr.* 1, 49-60.
- Martini, E., H. Stradner. 1960. *Nannotetraster*, eine stratigraphisch bedeutsame neue Discoasteridengattung. – *Sond. Erdöl-Zeitschrift* 76, 8, 3-7.
- Martini, E., T. Worsley. 1971. Tertiary calcareous nannoplankton from the Western Equatorial Pacific. – In: *Init. Rept. DSDP* 7, 2, 1471-1507.
- Mehrnagha, A. 1996. Cretaceous and Tertiary calcareous nannofossil biostratigraphy of North and Northeast Libya. – In: Salem, M. J., A. J. Mouzoughi, O. S. Hammuda (eds). *The Geology of Sirt Basin*. Elsevier, 1, 475-512.
- Milanova, V., G. Cheshitev (Eds.). 1992. *Explanatory note to the geological map of Bulgaria in scale 1:100 000. Map sheet Provadia*. S., BAS, 54 pp. (in Bulgarian)
- Minoletti, F., M. Rafelis, M. Renard, S. Gardin. 2004. Remaniement des nannofossiles calcaires Maastrichtiens dans les sediments du Danien basal de Bidart (France): arguments isotopiques (Carbone et Oxygene). – *Rev. Micropal.* 47, 145-152.
- Mohler, H. P., W. W. Hay. 1967. Zonation of the Paleocene-Lower Eocene interval. – In: Hay, W., H. Mohler, P. Roth, R. Schmidt, J. Boudreaux. Calcareous nannoplankton zonation of the Cenozoic of the Gulf coast and Caribbean-Antillean area, and transoceanic correlation. – *Gulf Coast Assoc., Geol. Soc. Trans.* 17, 428-480.
- Molina, E., V. Cosovic, C. Gonzalvo, K. von Salis. 2000. Integrated biostratigraphy across the Ypresian/Lutetian boundary at Agost, Spain. – *Rev. Micropaleontol.* 43, 3, 1-19.
- Molina, E., C. Gonzalvo, M. Mancheno, S. Ortiz, B. Schmits, E. Thomas, K. von Salis. 2006a. Integrated stratigraphy across the Ypresian-Lutetian transition in the Fortuna section (Betic Cordillera, Spain). – *Newsl. Stratigr.* 42, 1, 1-19.
- Molina, E., L. Alegret, I. Arenillas, J. A. Arz, N. Gallala, J. Hardenbol, K. von Salis, E. Steurbaut, N. Vandenbeuge, D. Zaghbib-Turki. 2006b. The Global Boundary

- Stratotype Section and Point for the base of the Danian Stage (Paleocene, Paleogene, „Tertiary“, Cenozoic) at El Kef, Tunisia: original definition and revision. – *Episodes* 29, 4, 263-273.
- Molina, E., L. Alegret, E. Apellaniz, G. Bernaola, F. Caballero, J. Dinarès-Turell, J. Hardenbol, C. Heilmann-Clausen, J. C. Larrasoña, H. Luterbacher, S. Monechi, S. Ortiz, X. Orue-Etxebarria, A. Payros, V. Pujalte, F. J. Rodríguez-Tovar, F. Tori, J. Tosquella, A. Uchman. 2011. The Global Stratotype Section and Point (GSSP) for the base of the Lutetian Stage at the Gorrondatxe section, Spain. – *Episodes* 34, 86-108.
- Monechi, S., E. Angori, K. von Salis. 2000. Calcareous nannofossil turnover around the Paleocene/Eocene transition at Alamedilla (southern Spain). – *Bull. Soc. Geol. France* 171, 4, 477-489.
- Müller, C. 1976. Tertiary and Quaternary calcareous nannoplankton in the Norwegian-Greenland Sea, DSDP, Leg 38. – *Init. Rep. DSDP* 38, 823-841.
- Müller, C. 1979. Calcareous nannofossils from the North Atlantic (Leg 48). – *Init. Rep. DSDP* 48, 589-639.
- Müller, C. 1982. Nannoplankton der Schweizer Molasse. – *Docum. Lab. Geol. Lyon* 7, 35-38.
- Müller, C., P. Brönnimann. 1974. Eine neue Art der Gattung *Helicosphaera* Kamptner aus dem Pazifischen Ozean. – *Eclogae geol. Helv.* 67, 3, 661-662.
- Mutterlose, J., C. Linnert, R. Norris. 2007. Calcareous nannofossils from the Paleocene-Eocene Thermal Maximum of the equatorial Atlantic (ODP Site 1260B): Evidence for tropical warming. – *Mar. Micropal.* 65, 1-2, 13-31.
- Nachev, I. 1993. Late Cretaceous paleogeodynamics of Bulgaria. – *Geologica Balc.* 23, 4, 3-23.
- Nachev, I., E. Dimitrova. 1995a. Upper Cretaceous stratigraphy of the Eastern Sredna Gora Zone. – *Geologica Balc.* 25, 3-4, 3-26.
- Nachev, I., E. Dimitrova. 1995b. Upper Cretaceous stratigraphy of the Eastern Balkan Mountains. – *Geologica Balc.* 25, 5-6, 43-74.
- Nachev, I., C. Nachev. 2001. „*Pobiti kamani*“ – bacterial-algal colonies. S., Artik, 130 pp. (in Bulgarian)
- Nikolov, T. 1987. *The Mediterranean Lower Cretaceous. Geologica Balc. Ser. oper. sing.*, 2, 269 pp.
- Nikolov, T. 1995. Current state and perspectives of the stratigraphy. – *Rev. Bulg. Geol. Soc.* 56, 1, 1-30. (in Bulgarian)
- Nikolov, T., B. Peybernès, K. Stoykova, R. Ciszac, M. Ivanov, M.-J. Fondécave-Wallez. 1998. About the age of the white limestones at the Village of Drenta, Elena District (East Fore-Balkan). – *Rev. Bulg. Geol. Soc.* 59, 1, 33-40. (in Bulgarian)
- Okada, H., D. Bukry. 1980. Supplementary modification and introduction of code numbers to the low-latitude coccolith biostratigraphic zonation (Bukry 1973, 1975). – *Mar. Micropal.* 5, 321-325.
- Orue-Etxebarria, X., G. Bernaola, J. Baceta, E. Angori, F. Caballero, S. Monechi, V. Pujalte, J. Dinarès-Turell, E. Apellaniz, A. Payros. 2004. New constraints on the evolution of planktic foraminifers and calcareous nannofossils across the Paleocene-Eocene boundary interval: the Zumaya section revisited. – *N. Jb. Geol. Palaont. Abh.* 234, 1-3, 223-259.
- Orue-Etxebarria, X., A. Payros, G. Bernaola, J. Dinarès-Turell, J. Tosquella, E. Apellaniz, F. Caballero. 2006. The Ypresian/Lutetian boundary at the Gorrondatxe beach section (Basque Country, W Pyrenees). *Field Excursion Guidebook, Climate & Biota of the Early Paleogene*. 33 pp.
- Oszczypko-Clowes, M. 2001. The nannofossil biostratigraphy of the youngest deposits of the Magura Nappe (East of the Skawa River, Polish Flysch Carpathians) and their palaeoenvironmental conditions. – *Ann. Soc. Geol. Pol.* 71, 139-188.
- Paskalev, M. 1983. Paleotectonic setting during the Upper Cretaceous in the area of the Vratnik Pass from the Balkan Mountains. – *Geotect., Tectonophys., Geodynam.* 15, 31-39. (in Bulgarian)
- Pavsich, J. 1977. Nannoplankton v zgornjekrednih in paleocenskih plasteh na Goriskem. – *Geologija* 20, 33-83.
- Pavsich, J., A. Horvat. 1988. The Cretaceous/Tertiary boundary interval in the flysch of Slovenia. – *Razprave Slov. Akad. znan. umetn.* 29, 5, 129-146.
- Payros, A., G. Bernaola, X. Orue-Etxebarria, J. Dinarès-Turell, J. Tosquella, E. Apellaniz. 2007. Reassessment of the Early-Middle Eocene biomagnetochronology based on evidence from the Gorrondatxe section (Basque Country, western Pyrenees). – *Lethaia* 40, 183-195.
- Perch-Nielsen, K. 1969. Die Coccolithen einiger danischer Maastrichtien und Danien lokalitäten. – *Medd. Dansk. Geol. For.* 19, 51-69.
- Perch-Nielsen, K. 1971. Einige neue Coccolithen aus dem Paleozan der Bucht von Biskaya. – *Bull. geol. Soc. Denmark* 20, 347-361.
- Perch-Nielsen, K. 1972a. Les nannofossiles calcaires de la limite Cretace-Tertiaire. – *Mem. BRGM* 77, 181-188.
- Perch-Nielsen, K. 1972b. Remarks on Late Cretaceous to Pleistocene coccoliths from the North Atlantic. – In: Laughton, A. S., W. A. Berggren et al. *Init. Rep. DSDP* 12, 1003-1069.
- Perch-Nielsen, K. 1979. Calcareous nannofossil zonation at the Cretaceous/Tertiary boundary in Denmark. – In: Birkelund, T., R. G. Bromley. *Cretaceous/Tertiary boundary event-symposium. I. The Maastrichtian and Danian of Denmark*, Copenhagen, 115-135.
- Perch-Nielsen, K. 1981a. Nouvelles observations sur les nannofossiles calcaires a la limite Crétacé-Tertiaire près de El Kef (Tunisie). – *Cahiers de Micropaléontol.* 3, 25-37.
- Perch-Nielsen, K. 1981b. New Maastrichtian and Paleocene calcareous nannofossils from Africa, Denmark, the USA and the Atlantic, and some Paleocene lineages. – *Eclogae geol. Helv.* 74, 3, 831-863.
- Perch-Nielsen, K. 1985a. Mesozoic calcareous nannofossils. Cenozoic calcareous nannofossils. – In: Bolli, H. M., J. B. Saunders, K. Perch-Nielsen, (Eds.). *Plankton stratigraphy*. Cambridge University Press, Cambridge, pp. 329-426, 427-554.
- Perch-Nielsen, K. 1985b. Calcareous nannofossils at the C/T boundary near Beloc, Haiti. – *INA Newsletter* 7,

- Perch-Nielsen, K. 1985c. Early Paleocene calcareous nanofossils from Dakar, Senegal. – *INA Newsletter* 7, 83-84.
- Perch-Nielsen, K., J. M. Hansen. 1981. Selandian. – *Bull. D'Information Géol. Bassin Paris* 2, 219-230.
- Perch-Nielsen, K., J. McKenzie, Q. He. 1982. Biostratigraphy and isotope stratigraphy and the 'catastrophic' extinction of calcareous nannoplankton at the Cretaceous/Tertiary boundary. – *Geol. Soc. of America* 190, 353-371.
- Petrizzo, M. R. 2005. An Early Late Paleocene Event on Shatsky Rise, northwestern Pacific Ocean (ODP Leg 198): Evidence from Planktonic Foraminiferal Assemblages. – In: Bralower, T. J., I. Premoli Silva, M. J. Malone, (Eds.). *Proceedings of the Ocean Drilling Program, Scientific Results* 198, 1-30.
- Peybernès, B., M.-J. Fondécave-Wallez, K. Stoykova, M. Ivanov, T. Nikolov. 2004. Détermination de la limite Crétacé-Tertiaire en Bulgarie par les Foraminifères planctoniques. – *Geobios* 37, 6, 755-769.
- Pimpirev, C., Stoykova, K., Ivanov, M., Dimov, D. 2006. The sedimentary sequences of Hurd Peninsula, Livingston Island, South Shetland Islands: part of the late Jurassic – Cretaceous depositional history of the Antarctic Peninsula. – In: Futterer, D. K., D. Damaske, G. Kleinschmidt, F. Tessensohn (Eds.). *Antarctica: Contribution to global earth sciences*. Springer-Verlag, Berlin Heidelberg New York, 2006, 6, 247-252.
- Pollak, A. 1932. Das Eocän am Nordfuss des Ostbalkans. – *Zbl. Mineral., Geol. u. Paläontol., Abt. B* 10, 491-498.
- Pollak, A. 1933. Geologische Untersuchungen über das Endstück Ostbalkans. – *Abh. Math.-phys. Kl., Sachs. Acad. Wiss.* 41, 7, 1-60.
- Pospichal, J. J. 1991. Calcareous nanofossils across Cretaceous/Tertiary boundary at Site 752, Eastern Indian Ocean. – In: Weissel, J., J. Peirce, E. Taylor, J. Alt., et al. *Proc. ODP, Sci. Results* 121, 395-413.
- Pospichal, J. J., T. J. Bralower. 1992. Calcareous nanofossils across the Cretaceous/Tertiary boundary, Site 761, Northwest Australian Margin. – In: von Rad, U., B. U. Haq, *Proc. ODP, Sci. Results* 122, 735-751.
- Pospichal, J. J., B. T. Huber. 1992. The Cretaceous/Tertiary Boundary in the Southern Indian Ocean: Results from the Coring Operations of the Ocean Drilling Program. *Synth. Res. Sci. Drill. in Ind. Ocean. – Geophys. Monogr.* 70, 275-294.
- Pospichal, J. J., S. W. Wise. 1990a. Paleocene to Middle Eocene calcareous nanofossils of ODP Sites 689 and 690, Maud Rise, Weddell Sea. – In: Barker, P. F., J. P. Kennett et al. *Proc. ODP, Sci. Results* 113, 613-638.
- Pospichal, J. J., S. W. Wise. 1990b. Calcareous nanofossils across the K/T boundary, ODP Hole 690C, Maud Rise, Weddell Sea. – In: Barker, F.P., J. P. Kennett et al. *Proc. ODP, Sci. Results* 113, 515-532.
- Pospichal, J. J., S. W. Wise. 1990c. Maestrichtian Calcareous nanofossil biostratigraphy of Maud Rise ODP Leg 113 Sites 689 and 690, Weddell Sea. – In: Barker, F.P., J. P. Kennett, et al. *Proc. ODP, Sci. Results* 113, 465-487.
- Pospichal, J. J., S. W. Wise. 1992. Southern high latitude K/T boundary calcareous nanofossils. – In: Monechi, S., F. Proto-Decima, D. Rio (Eds.). *Proceedings of the INA Conf., Firenze, 1989. Memorie di Scienze Geologiche* 43, 133-147.
- Pospichal, J. J., W. Wei, S. W. Wise. 1991. Data Report: Indian Ocean Oligocene Strontium Isotope stratigraphy, Legs 119-121, Kerguelen Plateau and Ninetyeast Ridge. – In: Weissel, J., J. Peirce, E. Taylor, J. Alt, et al. *Proc. ODP, Sci. Results* 121, 921-930.
- Pospichal, J. J., W. Wei, S. W. Wise. 1992. Probing the limits of nanofossil stratigraphic resolution in the southern high latitudes. – *Mem. Sci. Geol.* 43, 115-132.
- Pospichal, J. J., J. Dehn, N. W. Driscoll, A. J. M. van Eijden, J. W. Farrell, E. Fourtanier, P. Gamson, J. Gee, T. R. Janecek, D. G. Jenkins, C. Klootwijk, R. Nomura, R. M. Owen, D. K. Rea, P. Resiwati, J. Smit, G. Smith. 1991a. Cretaceous-Paleogene biomagnetostratigraphy of Sites 752-755, Broken Ridge: A Synthesis. – In: Weissel, J., J. Peirce, E. Taylor, J. Alt, et al. *Proc. ODP, Sci. Results* 121, 721-741.
- Preisinger, A. 1994. Cyclostratigraphy of the K/T boundary section on the coast of the Black Sea near Bjala (Bulgaria). – In: *New developments regarding the K/T event and other catastrophes in Earth history*. LPI, Contribution, Lunar and Planetary Institute, Houston, 825, 90 p.
- Preisinger, A., S. Aslanian, K. Stoykova, F. Grass, H. J. Mauritsch, R. Scholger. 1993a. Cretaceous/Tertiary boundary sections on the coast of the Black Sea near Bjala (Bulgaria). – *Paleogeogr., Paleoclim., Paleoecol.* 104, 219-228.
- Preisinger, A., S. Aslanian, K. Stoykova, F. Grass, H. J. Mauritsch, R. Scholger. 1993b. Cretaceous/Tertiary boundary sections in the East Balkan area, Bulgaria. – *Geologica Balc.* 23, 5, 3-13.
- Preisinger, A., S. Aslanian, F. Brandstätter, F. Grass, H. Stradner, H. Summesberger. 2002. Cretaceous-Tertiary profile, rhythmic deposition, and geomagnetic polarity reversals of marine sediments near Bjala, Bulgaria. – In: Koeberl, C., MacLeod, K. G. (Eds.) *Catastrophic events and mass extinctions: impact and beyond*. Boulder, Colorado, *Geol. Soc. America Spec. Pap.* 356, 213-229.
- Preisinger, A., E. Zobetz, A. J. Gratz, R. Lahodynsky, M. Becke, H. J. Mauritsch, G. Eder, F. Grass, F. Rögl, H. Stradner, R. Surelian. 1986. The Cretaceous/Tertiary boundary in the Gosau Basin, Austria. – *Nature* 322, 6082, 794-799.
- Quillévéré, F., R. Norris, D. Kroon, P. Wilson. 2008. Transient ocean warming and shifts in carbon reservoirs during the early Danian. – *Earth Planet. Sci. Letters* 265, 3-4, 600-615.
- Raffi, I., J. Backmann, H. Pälike. 2005. Evolutionary trends of tropical calcareous nanofossil assemblage across the Paleocene/Eocene transition from the paleo-equatorial Pacific Ocean. – *Paleogeogr., Paleoclimatol. Paleoecol.* 226, 93-126.
- Raup, D. M., J. J. Sepkoski. 1986. Periodic extinction of the families and genera. – *Science* 231, 833-836.
- Renevier, E. 1874. Tableau des terrains sédimentaires for-

- més pendant les époques de la phase organique du globe terrestre. – *Bulletin de la Société Vaudoise des Sciences Naturelles* 13, 218-252.
- Rögl, F., K. von Salis, A. Preisinger, S. Aslanian, H. Summesberger. 1996. Stratigraphy across the Cretaceous/Paleogene boundary near Bjala, Bulgaria. – In: Jardine, S., Klasz, J., Delenay, J.-P. (Eds.) *Geologie de l'Afrique et de l'Atlantique sud: Act. Colloq. Angers*, 1994, Elf Aquitaine edition, Angers, 673-683.
- Röhl, U., T. J. Bralower, R. D. Norris, G. Wefer. 2000. A new chronology for the Late Paleocene Thermal Maximum and its environmental implications. – *Geology* 28, 10, 927-930.
- Röhl, U., T. Westerhold, S. Monechi, E. Thomas, J. C. Zachos, B. Donner. 2005. The third and final early Eocene thermal maximum: characteristics, timing, and mechanisms of the "X" event. – *Geological Society of America Annual Meeting, Abstr.* 37, 264.
- Röhl, U., T. Westerhold, T. J. Bralower, J. C. Zachos. 2007. On the duration of the Paleocene-Eocene Thermal Maximum (PETM). – *Geochemistry, Geophysics, Geosystems* 8, 12, Q12002. doi:10.1029/2007GC001784.
- Romein, A. J. T. 1979. Lineages in Early Paleogene calcareous nannoplankton. *Utrecht Micropaleontol. Bull.* 22, 231 pp.
- Rosenkrantz, A. 1924. De københavnske Grønsandslag og deres Placering i den danske Lagrække. – *Meddelelser fra Dansk Geologisk Forening* 6, 1-39.
- Roth, P. H. 1973. Calcareous nannofossils – Leg 17, Deep Sea Drilling Project. – In: Winterer, E. L., J. L. Ewing, et al. *Init. Rept. DSDP 17*, 695-795.
- Roth, P. H., J. L. Bowlder. 1979. Evolution of the calcareous nannofossil genus *Micula* in the Late Cretaceous. – *Micropaleont.* 25, 3, 272-280.
- Salvador, A. E. 1994. *International Stratigraphic Guide: A Guide to Stratigraphic Classification, Terminology and Procedure*. Boulder, Colorado, Geol. Soc. of America, 214 pp.
- Sapoundjieva, V. 1964. *Les Fossiles de Bulgarie, VIIb, Paleogene Echinoidea*. S., Academie des Sciences de Bulgarie, 64 p., 24 pl.
- Savov, S., M. Kehayova, Y. Kamenova, E. Dinkov, V. Kostadinov, D. Minev. 1956 f. Report on the geological explorations in the Aytos part of Eastern Stara Planina Mountain, carried out in 1955. *Geofund Committee of Geology, IV-42*. (in Bulgarian)
- Schaub, H. 1981. Nummulites et Assilines de la Tethys paléogène. Taxonomie, phylogénèse et biostratigraphie. – *Mémoires de la Société Paléontologique Suisse / Abhandlungen der schweizerischen paläontologischen Gesellschaft* 104, 1-236; 105: pl. 1-48; 106: pl. 49-97.
- Schimper, W. P. 1874. *Traité de Paléontologie végétale ou la flore du monde primitif dans ses rapports avec les formations géologiques et la flore du monde actuel. Tome troisième*. Paris, Baillière J.B. et Fils ed., 896 pp.
- Schmitz B., V. Pujalte, E. Molina, S. Monechi, X. Orue-Etxebarria, R. P. Speijer, L. Alegret, E. Apellaniz, I. Arenillas, M.-P. Aubry, J. I. Baceta, W. A. Berggren, G. Bernaola, F. Caballero, A. Clemmensen, J. Dinarès-Turell, C. Dupuis, C. Heilmann-Clausen, A. Hilario Orús, R. Knox, M. Martín-Rubio, S. Ortiz, A. Payros, M.-R. Petrizzo, K. von Salis, J. Sprong, E. Steurbaut, E. Thomsen. 2011. The Global Stratotype Sections and Points for the bases of the Selandian (Middle Paleocene) and Thanetian (Upper Paleocene) stages at Zumaiia, Spain. – *Episodes* 34, 220-243.
- Schulte, P., L. Alegret, I. Arenillas, J. A. Arz, P. J. Barton, P. R. Bown, T. J. Bralower, G. L. Christeson, P. Claeys, C. S. Cockell, G. S. Collins, A. Deutsch, T. J. Goldin, K. Goto, J. M. Grajales-Nishimura, R. A. F. Grieve, S. P. S. Gulick, K. R. Johnson, W. Kiessling, C. Koeberl, D. A. Kring, K. G. MacLeod, T. Matsui, J. Melosh, A. Montanari, J. V. Morgan, C. R. Neal, D. J. Nichols, R. D. Norris, E. Pierazzo, G. Ravizza, M. Rebolledo-Vieyra, W. U. Reimold, E. Robin, T. Salge, R. P. Speijer, A. R. Sweet, J. Urrutia-Fucugauchi, V. Vajda, M. T. Whalen, P. S. Willumsen. 2010. The Chicxulub Asteroid Impact and Mass Extinction at the Cretaceous-Paleogene Boundary. – *Science* 327, 5970, 1214-1218.
- Self-Trail, J. 2001. Biostratigraphic subdivision and correlation of upper Maastrichtian sediments from the Atlantic coastal plain and Blake Nose, western Atlantic. – In: Kroon, D. et al. (Eds.). *Western North Atlantic Paleogene and Cretaceous Paleogeography*. – *Geol. Soc. London Spec. Publ.* 183, 93-110.
- Self-Trail, J. 2002. Trends in late Maastrichtian calcareous nannofossils distribution patterns, Western North Atlantic margin. – *Micropaleont.* 48, 1, 31-52.
- Self-Trail, J., E. Seefelt. 2005. Rapid dissolution of calcareous nannofossils: a case study from freshly cored sediments of the south-eastern Atlantic Coastal Plain. – *J. Nannopl. Res.* 27, 2, 149-157.
- Self-Trail, J. M., D. S. Powars, D. K. Watkins, G. A. Wandless. 2012. Calcareous nannofossil assemblage changes across the Paleocene-Eocene Thermal Maximum: Evidence from a shelf setting. – *Mar. Micropal.* 92-93, 61-80.
- Shopov, V. L. 1989. Holocene coccolith from the deep Black sea carbonate sediments. – *Rev. Bulg. Geol. Soc.* 50, 1, 46-51. (in Bulgarian)
- Sinclair, H. D., S. G. Juranov, G. Georgiev, P. Byrne, N. P. Mountney. 1997. The Balkan Thrust Wedge and Foreland Basin of Eastern Bulgaria: Structural and Stratigraphic Development. – In: Robinson, A. G., (Ed.) *Regional and petroleum geology of the Black Sea and surrounding region*. – *AAPG Memoir* 68, 91-114.
- Sinnyovsky, D. 1988. Upper Cretaceous nannoplankton zonation in North Bulgaria. – *Geologica Balc.* 18, 6, 59-78.
- Sinnyovsky, D. 1990. Biostratigraphy of the Upper Cretaceous and Palaeocene in Bulgaria by calcareous nannoplankton. – In: Nikolov, T. (Ed.). *Microfossils in Bulgarian stratigraphy*. S., 43-46. (in Russian)
- Sinnyovsky, D. 1992. Calcareous nannoplankton from the Maastrichtian and Palaeocene in Devnya region. – *Rev. Bulg. Geol. Soc.* 53, 1, 101-104. (in Bulgarian)
- Sinnyovsky, D. 1993a. Maastrichtian-Paleocene age for the

- Mezdra Formation in Mezdra region (Western Fore-Balkan). – *C. R. de l'Acad. Bulg. Sci.* 46, 2, 83-86.
- Sinnyovsky, D. 1993b. Upper Cretaceous nannofossil zones in the West Srednogie. – *Ann. Univ. of Mining and Geology* 39, 1, 11-14. (in Bulgarian)
- Sinnyovsky, D. 1996. New data on the age of Emine, Dvoinitsa and Obzor Formations, East Balkan. – In: *News in the geology of Bulgaria, VI Congress of BGS*, 24-26 October, S., 90-91. (in Bulgarian)
- Sinnyovsky, D. 1999. High resolution stratigraphy of the Upper Cretaceous-Paleocene rocks in Mezdra region. – *Ann. Univ. of Mining and Geology* 42, 1, 7-19. (in Bulgarian)
- Sinnyovsky, D. 2001a. Periodites from the Cretaceous-Tertiary boundary interval in several sections from East Bulgaria. – *C. R. de l'Acad. Bulg. Sci.* 54, 4, 65-73.
- Sinnyovsky, D. 2001b. Detailed nanofossil biostratigraphy of the allochthonous Lyutidol Formation and the underlying autochthonous sediments in the typical area near the village of Lyuti Dol, south of Mezdra. – *Ann. Univ. of Mining and Geology* 43-44, 1, 11-20. (in Bulgarian)
- Sinnyovsky, D. 2001c. Charles Lyell and his "Principles of geology" or how long an idea could be alive. – *Ann. of the Univ. of Mining and Geol.* 43-44, 1, 121-126.
- Sinnyovsky, D. 2003. Five protected outcrops of the Cretaceous/Tertiary boundary in Bulgaria. – *Ann. Univ. of Mining and Geology* 46, 1, 177-183. (in Bulgarian)
- Sinnyovsky, D. 2004a. Nannofossil subdivision and stratigraphic range of the Emine Flysch Formation in East Balkan, East Bulgaria. – *Ann. Univ. of Mining and Geology* 47, 1, 131-137.
- Sinnyovsky, D. 2004b. Calcareous nannoplankton biostratigraphy of the Carpathian type Upper Cretaceous-Paleocene deposits near Kladorub Village, Vidin District. – *Ann. Univ. of Mining and Geology* 47, 1, 139-145.
- Sinnyovsky, D. 2006a. Nanofossil biostratigraphy of Upper Cretaceous sediments in the Eastern Fore-Balkans between the Dodelen and Armera rivers, south of the villages of Grozdyovo and Goren Chiflik, Varna region. – *Ann. Univ. of Mining and Geology* 49, 1, 51-56. (in Bulgarian)
- Sinnyovsky, D. 2006b. New data on the stratigraphical range of Byala Formation around Byala, Varna District. – *Ann. Univ. of Mining and Geology* 49, 1, 57-62. (in Bulgarian)
- Sinnyovsky, D. 2007. *Upper Cretaceous calcareous nannofossil biostratigraphy*. Resume of Dr Sci Thesis, S., 53 pp. (in Bulgarian)
- Sinnyovsky, D. 2013. *Upper Cretaceous calcareous nannoplankton biostratigraphy in Bulgaria*. S., Publishing house "St. Ivan Rilski", 80 pp., 19 pl.
- Sinnyovsky, D., D. Sinnyovska. 1988. New data on the age of volcano-sedimentary complex in East Srednogie. – *Ann. Univ. of Min. Geol.* 34, 1, 41-47. (in Bulgarian)
- Sinnyovsky, D., D. Christova-Sinnyovska. 1993. A new concept about the geological structure of a part of west Fore-Balkan, south of Mezdra. – *Rev. Bulg. Geol. Soc.* 54, 3, 26-40. (in Bulgarian)
- Sinnyovsky, D., L. Petrov. 1991. Calcareous nannofossils from the Cenomanian near the village of Sanadinovo, Pleven District. – *Palaeontol., Strat., Lithol.* 29, 15-24. (in Bulgarian)
- Sinnyovsky, D., G. Petrov. 2000. Nannofossil evidences for Maastrichtian-Paleocene age of Kladorub Formation in North-West Bulgaria. – *C. R. de l'Acad. Bulg. Sci.* 53, 11, 41-44.
- Sinnyovsky, D., S. Shumenko. 1988. Calcareous nannoplankton zonation of the Cenomanian Stage in Central North Bulgaria. – *Geologica Balc.* 18, 4, 47-53.
- Sinnyovsky, D., Stoykova, K. 1995. Cretaceous/Tertiary boundary in the Emine Flysch Formation, East Balkan (Bulgaria). – *C. R. de l'Acad. Bulg. Sci.* 48, 3, 45-48.
- Sinnyovsky, D., A. T. Sultanov. 1990. New data on the lithology and biostratigraphy of the Upper Cretaceous from the section near the village of Venchan, Varna region. – *Palaeontol., Strat., Lithol.* 28, 41-52. (in Bulgarian)
- Sinnyovsky, D., A. Sultanov. 1994. Biostratigraphy and sedimentology of the Emine Flysch Formation in the near-shore part of the East Balkan. – *C. R. Acad. Bulg. Sci.* 47, 1, 73-76.
- Sinnyovsky, D., D. Vangelov. 1997. Biostratigraphy and relationships between Dvoinitsa and Tepe-tarla Formations in the East Balkan, Eastern Bulgaria. – *C. R. de l'Acad. Bulg. Sci.* 50, 5, 63-66.
- Sinnyovsky, D., D. Vangelov. 2007. Stratigraphy of the Upper Cretaceous-Paleocene sediments along the southern edge of the Provadia plateau in the Golyama Kamchia River defile. – *Rev. Bulg. Geol. Soc.* 68, 1-3, 23-35. (in Bulgarian)
- Sinnyovsky, D., V. Zhelev. 1989. Biostratigraphy of the Upper Cretaceous from the Kondel Ridge, Dragoman region. – *Ann. Univ. of Mining and Geology* 35, 1, 199-202. (in Bulgarian)
- Sinnyovsky, D., E. Dimitrova, S. Juranov. 1990. Upper Cretaceous microfossils from the core of the Lutidol Syncline. – *Ann. Univ. of Mining and Geology* 36, 1, 199-203. (in Bulgarian)
- Sinnyovsky, D., B. Valchev, D. Sinnyovska. 2002. Cretaceous/Tertiary boundary in the Carpathian type Upper Cretaceous near the village of Kladorub, Vidin District. – *Ann. Univ. of Mining and Geology* 45, 1, 1-5.
- Sinnyovsky, D., M. Antonov, V. Zhelev, G. Ajdanlijsky, D. Vangelov, K. Stoykova. 2004. Route III. Ljutibrod – Chelopek. – In: Sinnyovsky, D. (Ed.) *Geological routes in the Northern part of the Iskar Gorge. Guide of field geological training*. S., MES, V. Nedkov Publishing house, 43-52.
- Smit, J., W. G. H. Z. ten Kate. 1982. Trace element patterns at the Cretaceous-Tertiary boundary – consequences of a large impact. – *Cretaceous Res.* 3, 3, 307-332.
- Smit, J., A. J. T. Romein. 1985. A sequence of events across the Cretaceous-Tertiary boundary. – *Earth Planet. Sci. Letters*, 74, 155-170.
- Soultanov, A., D. Sinnyovsky. 1987. The chalk of North Bulgaria – composition, structure and genesis. – *Ann. Univ. of Mining and Geology* 33, 2, 57-66.
- Stancheva, M. 1959. Eocene foraminifera from Pleven

- area. – *Work Geol. Bulg. Ser. Palaeontol.*, 1 (in Bulgarian)
- Stancheva, M. 1961. Foraminifera from the Kozichino series. – *Work Geol. Bulg. Ser. Palaeontol.* 3, 257-267. (in Bulgarian)
- Stinnesbeck, W. 1996. Ammonite extinctions and environmental changes across the Cretaceous-Tertiary Boundary in Central Chile. – In: MacLeod, N., G. Keller, (Eds.): *The Cretaceous-Tertiary Boundary Mass Extinction: Biotic and Environmental Events*. Norton Press, New York, 289-302.
- Stoll, H., N. Shimizu, D. Archer, P. Ziveri. 2007. Coccolithophore productivity response to greenhouse event of the Paleocene-Eocene Thermal Maximum. – *Earth Planet. Sci. Letters* 258, 1-2, 192-206.
- Stoykova, K. 1990. Stratigraphy of Paleocene-Eocene sediments in Pleven district (Central North Bulgaria) by calcareous nannoplankton. – *C. R. de l'Acad. bulg. Sci.* 43, 1, 95-97.
- Stoykova, K. 1994. Nannofossil biostratigraphy of the wells in the Black Sea offshore around the villages of Samotino and Shkorpilovtsi. – *Rev. Bulg. Geol. Soc.* 55, 69-82 (in Bulgarian).
- Stoykova, K. 1996a. Changes in the marine calcareous nannoflora at the boundary between the Mesozoic and Cenozoic. – *Fitogenofond – evolution, biological diversity and ecology*. S., BAS, 51-52. (in Bulgarian)
- Stoykova, K. 1996b. Calcareous nannoplankton recovery from the Cretaceous/Tertiary mass-extinction event in Bjala section, East Bulgaria. – *VINAPC and 150 years Smithsonian Institution, Washington DC, Abstracts*, p. 18.
- Stoykova, K., M. Ivanov. 1992. An uninterrupted section across the Cretaceous/Tertiary boundary at the town of Bjala, Black Sea coast (Bulgaria). – *C. R. de l'Acad. Bulg. Sci.* 45, 1, 61-64.
- Stoykova, K., M. Ivanov. 2002a. The Cretaceous/Tertiary transition in Bulgaria: palaeoenvironmental interpretation from calcareous nannofossils, macrofauna and lithology. – *J. Nannopl. Res.* 24, 2, 164-165.
- Stoykova, K., M. Ivanov. 2002b. Event and sequence stratigraphy of the Maastrichtian and Danian in Bulgaria. – *Geologica Balc.* 32, 2-4, 55-61.
- Stoykova, K., M. Ivanov. 2004a. Calcareous nannofossils and sequence stratigraphy of the Cretaceous/Tertiary transition in Bulgaria. – *J. Nannopl. Res.* 26, 1, 47-61.
- Stoykova, K., M. Ivanov. 2004b. New data on stratigraphy of the Paleogene in Central North Bulgaria. – *C. R. de l'Acad. bulg. Sci.* 57, 12, 75-82.
- Stoykova, K., M. Ivanov. 2004c. Errata: Calcareous nannofossils and sequence stratigraphy of the Cretaceous/Tertiary transition in Bulgaria. – *J. Nannopl. Res.* 27, 1, 99-106.
- Stoykova, K., M. Ivanov. 2005. First data on the presence of the Paleocene-Eocene Thermal Maximum in Bulgaria. – *C. R. de l'Acad. bulg. Sci.* 58, 3, 297-302.
- Stoykova, K., M. Ivanov. 2006a. Middle and Upper Paleocene Stratigraphy of Bjala region (Black sea coast, Bulgaria). – *C. R. de l'Acad. bulg. Sci.* 59, 11, 1171-1176.
- Stoykova, K., M. Ivanov. 2006b. A complete section of the Paleocene Series near Bjala, East Bulgaria – nannofossil data. – *Proc. Conf. Geosciences 2006*, 37-40. (in Bulgarian)
- Stoykova, K., M. Ivanov. 2021. New data on the age of the Emine Formation (East Balkan, Bulgaria). – *Rev. Bulg. Geol. Soc.* 82, 3, 126-128.
- Stoykova, K., D. Ivanova. 2000. Upper Jurassic-Lower Cretaceous calcareous nannofossil and calcareous dinocyst occurrences and their relationship to the sea-level changes: an example from the West Balkan Mountains, Bulgaria. – *J. Nannopl. Res.* 22, 2, 143-144.
- Stoykova, K., D. Ivanova. 2001. Calcareous nannofossils and dinocyst occurrence related to the sea-level changes in the Upper Jurassic-Lower Cretaceous sediments of the West Balkan Mountains, Bulgaria. – *C. R. de l'Acad. Bulg. Sci.* 54, 1, 61-64.
- Stoykova, K., D. Vangelov. 1997. Nannofossil stratigraphy of the lower Palaeocene sediments in Varna region (NE Bulgaria). – *Rev. Bulg. Geol. Soc.* 58, 3, 179-187. (in Bulgarian)
- Stoykova, K., J. Dinarès-Turell, M. Ivanov. 2006. Calcareous nannofossils record along the Paleocene-Eocene transition at Kladorub and Riben sections, Bulgaria. – In: *Climate and Biota of the Early Paleogene 2006*. Abstract book, p. 133.
- Stoykova, K., S. Juranov, M. Ivanov. 2004. New locality of the K/T boundary in Bjala Fm. near Goritsa, E Bulgaria. – *Proc. Ann. Sci. Conf. Bulg. Geol. Soc.*, "Geology-2004", Abstracts, 83-85.
- Stoykova, K., S. Juranov, M. Ivanov. 2005a. Calibration of calcareous nannofossils and planktonic foraminifers' zonation in the Lower and Middle Paleocene of Bulgaria. – *Geologica Balc.* 35, 1-2, 3-8.
- Stoykova, K., M. Ivanov, J. Dinarès-Turell, M. Sprovieri. 2005b. Paleocene-Eocene Thermal Maximum – biostratigraphic and stable isotope data in Bulgarian sections. – *Bulg. Geol. Society, 80-th Anniversary, Ann. Conf.*, ISBN 954-91606-2-9; 21-23.
- Stoykova, K., C. Pimpirev, D. Dimov. 2002. Calcareous nannofossils from the Miers Bluff Formation (Livingston Island, South Shetland Island, Antarctica): first evidence for a Late Cretaceous Age. – *J. Nannopl. Res.* 24, 2, Cambridge Univ. Press, 166-167.
- Stoykova, K., J. Dinarès-Turell, V. Pujalte, J. Elorza. 2013. Integrated high-resolution nannofossil biostratigraphy and cyclo-magnetostratigraphy of the Upper Maastrichtian: correlation between the Bjala (Bulgaria) and Sopelana (Spain) sections. – *J. Nannopl. Res., Spec. Issue 33, INA 14 abstracts*, 33, p. 113.
- Stoykova, K., M. Ivanov, V. Belivanova, R. Kostov, R. Tzankarska, T. Ilieva. 2000. Integrated stratigraphical, sedimentological and mineralogical-geochemical studies of the Cretaceous/Tertiary boundary in Bulgaria. – *Rev. Bulg. Geol. Soc.* 61, 1-3, 61-75. (in Bulgarian)
- Stradner, H. 1963. New contributions to Mesozoic stratigraphy by mean of nannofossils. – *Proc. 6th WPC*, 1963, 1-16.
- Stradner, H., J. Steinmetz, L. Svabenicka. 1984. Cretaceous calcareous nannofossils from the Angola Basin, Deep

- Sea Drilling Project Site 530. – In: Hay, W. W., J. C. Sibuet, et al. *Init. Rept. DSDP 75*, 565-649.
- Sugarman, P. J., K. G. Miller, D. Bukry, M. D. Feigenson. 1995. Uppermost Campanian-Maastrichtian strontium isotopic, biostratigraphic and sequence stratigraphic framework of the New Jersey Coastal Plain. – *Bull. GSA* 107, 19-37.
- Svabenicka, L. 1990. Calcareous nannoplankton in flysch sediments of the Bile Karpaty Unit (the West Carpathians). – *Sbor. geol. Ved., Paleont.* 31, 9-65.
- Svabenicka, L. 1992. Upper Cretaceous nannofossils from the Klement Formation. – In: Hamrsmid, B., J. Young (Eds.): *J. Nannopl. Res., Proc. 4th INA Conf., 1991*, Knihov. ZPN, 14a, 1, 189-205.
- Svabenicka, L. 1995. The stratigraphical correlation of the Campanian Low- and High-Latitude calcareous nannofossils in Southern Moravia (Western Carpathians). – *Geologica Carpath.* 46, 5, 297-302.
- Thierstein, H. R. 1981. Late Cretaceous nannoplankton and the change at the Cretaceous-Tertiary boundary. – *SEPM Spec. Publ.* 32, 355-394.
- Thierstein, H. R., H. Okada. 1979. The Cretaceous/Tertiary boundary event in the North Atlantic. – In: Tucholke, B. E., P. R. Vogt et al., *Init. Repts. DSDP 43*, 601-616.
- Thierstein, H. R., F. Azaro, W. U. Ehrmann, B. Huber, H. Michel, H. Sakai, B. Schmitz. 1991. The Cretaceous/Tertiary boundary at Site 738, Southern Kerguelen Plateau. – In: Barron, J., B. Larsen, et al. *Proc. ODP, Sci. Results* 119, 849-867.
- Toula, F. 1892. Geologische Untersuchungen im Östlichen Balkan und in anderen Theilen von Bulgarien und Östrumelien. – *Denkschr. Math.-Naturwiss. Classe, Akad. Wiss., Wien* 59, 2, 409-478.
- Tremolada, F., T. J. Bralower. 2004. Nannofossil assemblage fluctuations during the Paleocene – Eocene Thermal Maximum at Sites 213 (Indian Ocean) and 401 (North Atlantic Ocean): palaeoceanographic implications. – *Mar. Micropal.* 52, 107-116.
- Tremolada, F., B. de Bernardi, E. Erba. 2008. Size variations of the calcareous nannofossil taxon *Discoaster multiradiatus* (Incertae sedis) across the Paleocene-Eocene thermal maximum in Ocean Drilling Program Holes 690B and 1209B. – *Mar. Micropal.* 67, 3, 239-254.
- Trifonova, E. 1959. On the presence of Palaeocene in east Bulgaria. – *Ann. Dir. Geol. Res., A* 10, 155-164. (in Bulgarian)
- Trifonova, E. 1960. South Senonian foraminifera species from the Maastrichtian near Byala, Varna area. – *Bull. Geol. Inst. BAS* 8, 347-359. (in Bulgarian)
- Tsaneva, P. 1963. Stratigraphy of the Palaeogene in C-11 Oryahovo. – *Rev. Bulg. Geol. Soc.* 24, 3, 316-320. (in Bulgarian)
- Tsaneva, P. 1964. Stratigraphy of the Palaeogene in central North and NW Bulgaria by microfossil data. – *Ann. Dir. Geol., A* 15, 163-186. (in Bulgarian)
- Tsaneva, P. 1971a. Some planktonic foraminifers from the Palaeogene of North Bulgaria. – *Bull. Geol. Inst. Ser. Palaeontol.* 20, 23-42. (in Bulgarian)
- Tsaneva, P. 1971b. Phylogeny of the genus *Globorotalia* from the Palaeogene of North Bulgaria. – *Rev. Bulg. Geol. Soc.* 32, 2, 209-219. (in Bulgarian)
- Tsaneva, P., Y. Vaptsarova. 1961. Stratigraphy of the Upper Cretaceous and Paleogene near the village of Dalgodeltsi, Lom region, according to microfaunistic data. – *Rev. Bulg. Geol. Soc.* 12, 2, 117-122. (in Bulgarian)
- Tzankov, T. 1964. Ammonites from the Masatrichtian near the village of Kladorub, Belogradchik region (North-western Bulgaria). – *Work Geol. Bulg. Ser. Palaeontol.* 6, 143-187. (in Bulgarian)
- Tzankov, T. 1972. Jungalpidsche Deformationen im Krajna-Gebeit (NW der VR Bulgarien). – *Geologie* 21, 24-60.
- Tzankov, T. (Ed.). 1994. *Explanatory note to the geological map of Bulgaria in scale 1:100 000. Map sheet Cherven Bryag. S., 75 pp.* (in Bulgarian)
- Tzankov, T. (Ed.). 1995a. *Explanatory note to the geological map of Bulgaria in scale 1:100 000. Map sheet Gabrovo. S., ET "Avers", 90 pp.* (in Bulgarian)
- Tzankov, T. (Ed.). 1995b. *Explanatory note to the geological map of Bulgaria in scale 1:100 000. Map sheet Vratsa. S., ET "Avers", 102 pp.* (in Bulgarian)
- Tzankov, V. 1936. Eocene stratigraphy in northeastern Bulgaria north of the Kamchia River. – *Geology of the Balkans II*, 1, 49-67. (in Bulgarian)
- Tzankov, V. 1943. Geology of the Provadia plateau and the salt deposit in its eastern part. – *Rev. Bulg. Geol. Soc.* 14, 2, 83-118. (in Bulgarian)
- Tzankov, V. 1946. Biostratigraphic and paleoecological study of geological formations in Bulgaria. – In: Cohen, E. (Ed). *Fundamentals of geology of Bulgaria. – Ann. Dir. Geol. Mining Res. A* 4, 239-273. (in Bulgarian)
- Tzankov, V. 1951. Sur la presence du couches Daniennes dans le Balkan Oriental. – *Bull. Geol., Geogr. Chem. Inst.* 1, 95-102.
- Tzankov, V., R. Beregov. 1940. Geology of the Varna plateau. – *Rev. Bulg. Geol. Soc.* 12, 2, 119-148. (in Bulgarian)
- Tzankov, V., E. Cohen. 1941. Geology of the Avren (Mominio) plateau. – *Ann. Dir. Nat. resources A* 1, 9-32. (in Bulgarian)
- Tzankov, V., B. Strashimirov, N. Dimitrova. 1952. Stratigraphic and paleontological characteristics of the Cretaceous and Lutetian in the Provadia region. – *Ann. Dir. Geol. Mining Res. A* 3, 59-86. (in Bulgarian)
- Tzankov, V., P. Tsaneva, Y. Vaptsarova. 1961. On the stratigraphy of the Upper Cretaceous and Paleogene in Central Northern Bulgaria. – *Ann. Sofia Univ., Fac. Biol. Geol. Geogr.* 54, 2, 223-255. (in Bulgarian)
- Tzankov, V., B. Strashimirov, N. Dimitrova, B. Vrablyanski. 1960. Stratigraphic studies of the Jurassic and the Cretaceous in Northwestern Bulgaria. – *Work Geol. Bulg. Ser. Strat. Tect.* 1, 203-247. (in Bulgarian)
- Valchev, B. 2006. Representatives of family Ammosphaeroidinidae Cushman, 1927 to family Globotextulariidae Cushman, 1927 from the Paleocene of the coastal part of East Stara Planina. – *Rev. Bulg. Geol. Soc.* 67, 1-3, 5-11.
- Vangelov, D. 2000. *Stratigraphical aspects of the basin analysis*. PhD thesis Summary, 40 pp. (in Bulgarian)
- Vangelov, D., D. Sinnyovsky. 2000. New data on the stratigraphy of the Upper Cretaceous-Paleogene rocks and

- the development of the depositional settings in part of the Eastern Fore-Balkans. – *Ann. Univ. Sofia, Fac. of Geol. and Geogr.* 93, 1, 39-64. (in Bulgarian)
- Vangelov, D., D. Sinnyovsky. 2001. Depositional processes and facies interpretation of a part of the Emine basin, Eastern Balkanides. – *Ann. Univ. Sof., Fac. of Geol. and Geogr.* 94, 1, 41-62.
- Vangelov, D., D. Sinnyovsky. 2006a. Stratigraphy of the Upper Cretaceous and Paleogene sediments in a part of the Eastern Fore-Balkan between the rivers Luda Kamchia and Armera. – *Ann. Univ. Sofia, Fac. of Geol. and Geogr.* 98, 1, 31-51. (in Bulgarian)
- Vangelov, D., D. Sinnyovsky. 2006b. Characteristics, age and distribution of the Tepe-Tarla and Topolitsa Formations in the Aytos Balkan (East Balkans). – *Ann. Univ. Sofia, Fac. of Geol. and Geogr.* 98, 1, 17-29. (in Bulgarian)
- Vaptsarova, Y. 1963. On the presence of Danian near the villages Novo Selo and Koshava (Vidin District). – *Rev. Bulg. Geol. Soc.* 24, 1, 84-86. (in Bulgarian)
- Varol, O. 1989. Paleocene calcareous nannofossil biostratigraphy. – In: Crux, J., S. van Heck, (Eds.). *Nannofossils and their applications*. British Micropal. Soc. Ser., Ellis Horwood Ltd., Chichester, 267-310.
- Von Salis, K., S. Monechi, L. Bybell, J. Self-Trail, J. Young. 2000. Remarks on calcareous nannofossil genera *Rhomboaster* and *Tribrachiatus* around the Paleocene/Eocene boundary. – *GFF* 122, 138-140.
- Wagreich, M. 1992. A review of low-latitude "Tethyan" calcareous nannoplankton assemblages of the Cretaceous. – In: Kollmann, H. A., H. Zapfe (Eds.). *New Aspects on Tethyan Cretaceous Fossil Assemblages*. Wien, Springer, 45-55.
- Wagreich, M., T. Kuchler, H. Summesberger. 2003. Correlation of calcareous nannofossil zones to the local first occurrence of *Pachydiscus neubergicus* (von Hauer, 1858) (Ammonoidea) in European Upper Cretaceous sections. – *Netherl. J. Geosc. Geol. Mijnbouw* 82, 3, 283-288.
- Wei, W. 1998. New calcareous nannofossil species and stratigraphic markers from the Upper Paleocene. – *J. Nannopl. Res.* 20, 2, 107-115.
- Wei, W., J. J. Pospichal. 1991. Danian calcareous nannofossil succession at Site 738 in the Southern Indian Ocean. – In: Barron, J., B. Larsen, et al. *Proc. ODP, Sci. Results* 119, 495-512.
- Wei, W., H. R. Thierstein. 1991. Upper Cretaceous and Cenozoic calcareous nannofossils of the Kerguelen Plateau (southern Indian Ocean) and Prydz Bay (East Antarctica). – In: Barron, J., B. Larsen, et al. *Proc. ODP, Sci. Results* 119, 467-487.
- Wei, W., S. Zhong. 1996. Taxonomy and magnetobiochronology of *Tribrachiatus* and *Rhomboaster*, two genera of calcareous nannofossils. – *J. Paleontol.* 5, 70, 1, 7-22.
- Westerhold, T., U. Röhl, I. Raffi, E. Fornaciari, S. Monechi, V. Reale, J. Bowles, H. Evans. 2008. Astronomical calibration of the Paleocene time. – *Palaeogeogr., Palaeoclimatol., Palaeoecol.* 257, 4, 377-403.
- Wind, F. H., S. W. Wise. 1978. Mesozoic holococcoliths. – *Geology* 6, 140-142.
- Wise, S. W. 1983. Coccolith biostratigraphy of Deep Sea Drilling Project leg 71 cores. – In: *Antarctic Journal United States* 18, 5, 150-152.
- Wise, S. W., A. M. Gombos, J. P. Muza. 1985. Cenozoic evolution of polar water masses, southwest Atlantic Ocean. – In: Hsu, K. J., H. J. Weissert. *South Atlantic Paleooceanography*. Cambridge University Press, 283-324.
- Wolfe, J. 1991. Palaeobotanical evidence for a June 'impact winter' at the Cretaceous/Tertiary boundary. – *Nature* 352, 420-423.
- Worsley, T. 1970. Late Maastrichtian Nannoplankton Provinces. – *Nature* 225, 5239, 1242-1243.
- Young, J. R., P. R. Bown. 1991. An ontogenetic sequence of coccoliths from the Late Jurassic Kimmeridge Clay of England. – *Palaeontology* 34, 4, 843-850.
- Zachos, J. C., K. C. Lohmann, C. G. Walker, S. W. Wise. 1993. Abrupt climate change and transient climates during the Paleogene: a marine perspective. – *J. Geol.* 101, 191-213.
- Zachos, J. C., D. Kroon and others. 2004. Early Cenozoic extreme climates: The Walvis Ridge transect. *Proceedings, ODP, Leg 208* www.odp.tamu.edu/publications/208_IR/208ir.htm]
- Zagorchev, I., K. Stoykova, E. Dimitrova, I. Boyanov, A. Goranov. 2001. First data on a Late Maastrichtian – Danian age of the conglomeratic formation in the sole of the Central-Balkan granite thrust sheet. – *C. R. de l'Acad. Bulg. Sci.* 54, 8, 57-60.
- Zhelev, S. 1934. Geology of the vicinities of Plevna. – *Rev. Bulg. Geol. Soc.* 6, 2, 110-138. (in Bulgarian)
- Zhelev, S. 1936. The Eocene in Plevna region. – *Rev. Bulg. Geol. Soc.* 8, 2, 26-29. (in Bulgarian)
- Zhelev, S., P. Gochev. 1938. The Tertiary between the rivers Iskar and Osam. – *Rev. Bulg. Geol. Soc.* 10, 1, 39-83. (in Bulgarian)
- Zhelev, V., D. Sinnyovsky. 1989. On a paleogeographical problem in the Upper Cretaceous development of West Srednogorie. – *CBGA Abstracts*, 580-583.
- Zlatarski, G. 1884. Geological and palaeontological notes between Plevna and Troyan Balkan. – *Periodical Review* 10, 52-78. (in Bulgarian)
- Zlatarski, G. 1905. The Senonian formations in the eastern and partly central Balkans and to the South of this mountain. – *Periodical Review* 66. (in Bulgarian)
- Zlatarski, G. 1907. Senonian Stage in East Bulgaria north of the Balkan and its subdivision of lower (Emscherien) and upper (Aturien) Substage. – *Ann. Sofia Univ., Phys.-Math. Fac.* 2, 31-51. (in Bulgarian)
- Zlatarski, G. 1927. *Geology of Bulgaria*. S., University Library, 65, 268 pp. (in Bulgarian)

<https://www.mikrotax.org/Nannotax3/>

<https://www.paleogene.org>

**Nannofossil stratigraphy and global events
in the Paleocene and lower Eocene
of northern Bulgaria**

Kristalina Stoykova

Bulgarian
First edition 2022

Language editor Michael Sandy
Reviewers Ivan Zagorchev, Valeri Sachanski

Graphical design and layout Yankulov Ltd.



ISBN 978-619-245-125-7

© Stoykova, K.

Prof. Marin Drinov Publishing House of Bulgarian Academy of Sciences
Acad. Georgi Bonchev Str., Bl. 6, 1113 Sofia, Bulgaria
www.baspress.com

