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Rezumat: **Calcareous nannofossils from Oligocene to middle Miocene deposits of the Albanian-Thessalian Basin (Albania)**

Keywords: Albania, Albanian-Thessalian Basin, Biostratigraphy, Palaeocology, Calcareous nannofossil, Statistics, Palaeoevironment

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INTRODUCTION

The present study on "*Calcareous nannofossils from Oligocene to middle Miocene deposits from the Albanian-Thessalian Basin (Albania)*" is focused on the biostratigraphic and palaeoecologic characters of calcareous nannofossils from several transects of Oligocene – middle Miocene age from Albania.

This research comes with new and original contributions on the calcareous nannofossils and also completes and supports the existing poor biostratigraphical and micropalaeontological data and give a better picture on the palaeoecology and palaeoenvironmental implications of this microfossil group in Albania.

The first step in achieving the proposed goals was the detailed biostratigraphical comparison of the present results to the several standard zonation schemes with global and regional applicability, including here a comparison to the existing data from. It is worth to mention the support of the selected quantitative investigations for the biostratigraphical age assignment of the Langhian transects, to the regional scheme from the Mediterranean area. A broader discussion and comparison were done for biostratigraphy and the evolutionary trends of selected species, to the well-known global and/or regional bioevents. This study points out certain similarities in calcareous nannofossil content, but also differences in regards to some aspects connected to the exiting stratigraphical range of some taxa, which are widely detailed herein.

Within the context of this work, quantitative analysis and statistical methods were applied to support the palaeoecological characterization of the existing nannofossil assemblages, pointing out the abundance patterns of the dominant species and the palaeoenvironment according to their abundance fluctuations. For a better understanding of the depositional conditions and the existing palaeoenvironment, the statistics proved to be a useful tool in identification of various calcareous nannofossil combinations, suggesting different marine conditions, characterized by fluctuations of different palaeoenvironmental parameters, such as: terrigenous nutrient supply, bottom nutrient upwelling, wind-driven mixing, changes in sea-surface temperatures and salinity, and changes in water depth.

The valuable potential of calcareous nannofossil applicability in regional and local biostratigraphy in more restricted settings, in palaeoecological and palaeoenvironmental studies is well documented within this study.

The objectives of this thesis are:

- To determine and identify the calcareous nannofossil taxa and to give a detailed information regarding the biostratigraphy of this microfossil group for the investigated area;
- To compare the nannofossil biostratigraphy to various local, regional and global standard zonation schemes and data;
- To point out the palaeoecological preferences of the most abundant species and assemblage combinations;
- To compare the calcareous nannofossils palaeoecology from different areas and geological settings;
- To apply statistical methods in calcareous nannofossil investigation;
- To assess the changes in palaeoenvironment as indicated by calcareous nannofossil palaeoecology.

These aims were supported by the micropalaeontological investigation performed on calcareous nannofossils, partially on foraminifera and molluscs. The additional support for mollusc' and foraminifera' analyses were given by several other collaborators.

Results of this work have been published in two papers (Kallanxhi et al., 2016, Kallanxhi & Young, in press), while one is under preparation.

GEOLOGICAL SETTING

The Albanian territory includes a part of the Dinarides sensu lato (s.l.) orogenic system (Suess, 1883), which extends from the Southern Alps, along the Adriatic and Ionian coasts, and further to the Aegean Sea up to Taurus Mountains. The Dinarides s.l. (Kober, 1929) include the Dinarides sensu stricto (s.s.), the Hellenides and the Aegean chain. The connection between the Dinarides s.s. and the Hellenides is made on the Albanian territory, through the Shkodër-Pejë fault (S-P fault; Cvijič, 1901). Based on their location in regards to the S-P fault, the northern Albanian units (Cukali, Albanian Alps and Gashi) are parts of the Dinarides s.s. (Kober, 1929) and continue to Montenegro, while below the S-P fault, the southern units (Sazani, Ionian, Kruja, Krasta, Mirdita and Korabi zone), are part of the Hellenides and continue to the south-east on the Greek territory.

The Dinarides s.s. and the Hellenides, as part of the Mediterranean Alpine system, follow the contour of the eastern part of Adria plate (Giese & Reuter, 1978). Due to the fact that the Albanian territory comprises the largest part of the Hellenides, the orogenic structures in Albania were named "Albanides" (Peza, 1967), and from the east to west, are organized into two structural zones: internal, located in the eastern part of Albania (Mirdita, Korabi and Gashi zones) and external one to the west (Albanian Alps, Krasta - Cukali, Kruja, Ionian, and Sazani zones). The internal units overthrust the external ones and continue into the Greek territory where form the Hellenides.

The stratigraphic record of the intramontane Albanian-Thessalian Basin (ATHB; Bourcart, 1922) overlies transgressivelly the Mirdita and Krasta – Cukali zones. The ATHB represents the continuation on the Albanian territory of the Mesohellenic Trough (Brunn, 1956; Figure 1) from Greece, which is the largest molassic-type basin of the Hellenides. The ATHB – Mesohellenic Basin (MHB) is around 300 km long and 30-40 km wide, from which around 85 km are on the Albanian territory. It extends from the southern Albania through Greece, down to Thessaly plain. The MHB – ATHB structural evolution is related to the Alpine orogenesis, following the same direction as the Hellenides structures, located between the Apulian Microplate (part of External Hellenides, non-metamorphic) and the Pelagonian Nappe (Internal Hellenides, metamorphic). Kilias et al. (2015) considered the MHB as a NNW – SSE oriented strike-slip and piggy-back basin, which evolved from the middle Eocene to Quaternary as a succession of overlapping basins (Ferrière et al., 1998).

The sedimentary fill of the ATHB (Biçoku et al., 1967; Pashko et al., 1973; Pashko, 1996, 2018) was separated into three depositional cycles: I –Eocene (Lutetian – Priabonian); II

– Oligocene to Aquitanian; III – Burdigalian to Langhian. Several sedimentation areas (Morava, Gora – Mokra, Voskopoja and Pogradec) were separated within the ATHB, which display some particular aspects in lithology and faunal content (Pashko et al., 1973).

The lithostratigraphy of the second and third sedimentary cycles (Oligocene to middle Miocene) from the main sedimentation area of Morava will be presented following the work of Papa & Pashko (1962, 1965, 1966), Pashko et al. (1973), Pashko (1977a, 1981), and Xhomo et al. (2002).

The Oligocene stratigraphy

The Oligocene sedimentary sequences overlie transgressivelly the ultramafic rocks and older Lutetian formations. They comprise several Rupelian and Chattian units (Figure 2), well developed in the eastern and south-eastern part of Morava and adjacent basins to the west, north, and north-east. Some of these sediments from Morava area contain rich Rupelian and Chattian macro- and microfauna, which can be correlated with deposits from Italy and Greece (Pashko, 2018). The stratigraphic units cannot be always clearly separated in north and west (Voskopoja, Gora, Mokra and Pogradec), therefore the earlier studies considered these units as undivided Oligocene (Pashko et al., 1973), while others made correlations only based on lithological similarities to the Morava area (Dimo et al., 1982; Pashko, 1996; Kumati et al., 1997). The fluctuating fossil content and the lack of index fossils make the assignment to either Rupelian and/or Chattian rather difficult.

The oldest Oligocene deposits outcropping in the area were assigned to the middle – late Rupelian (Bourcart, 1922; Nowack, 1929; Adrianova et al., 1961; Biçoku et al., 1967; Pashko et al., 1973; Pashko, 1977a, 1977b, 1981, 2018; Xhomo et al., 2002) and have a thickness of around 800 m. The succession starts with the **Mborja – Dishnica Formation** consiting of conglomerates with clasts of ultrabasic rocks and limestones, intercalated with coarse-grained massive and bedded sandstones, locally siltstones, silty greenish concretions, and andesitic tuffs.

The coal-bearing **Drenova Formation** is well developed in the western part of Morava Mt. area. The succession is made of grey indured marlstones, with dark grey coaly claystones and siltstones, dolomite concretions, and several brown coal beds. It contains typical Rupelian well – preserved molluscs (Bourcart, 1922; Nowack, 1929; Pashko et al., 1973; Pashko, 1977a, 1977b, 1981, 2018) and poorly preserved foraminifera.

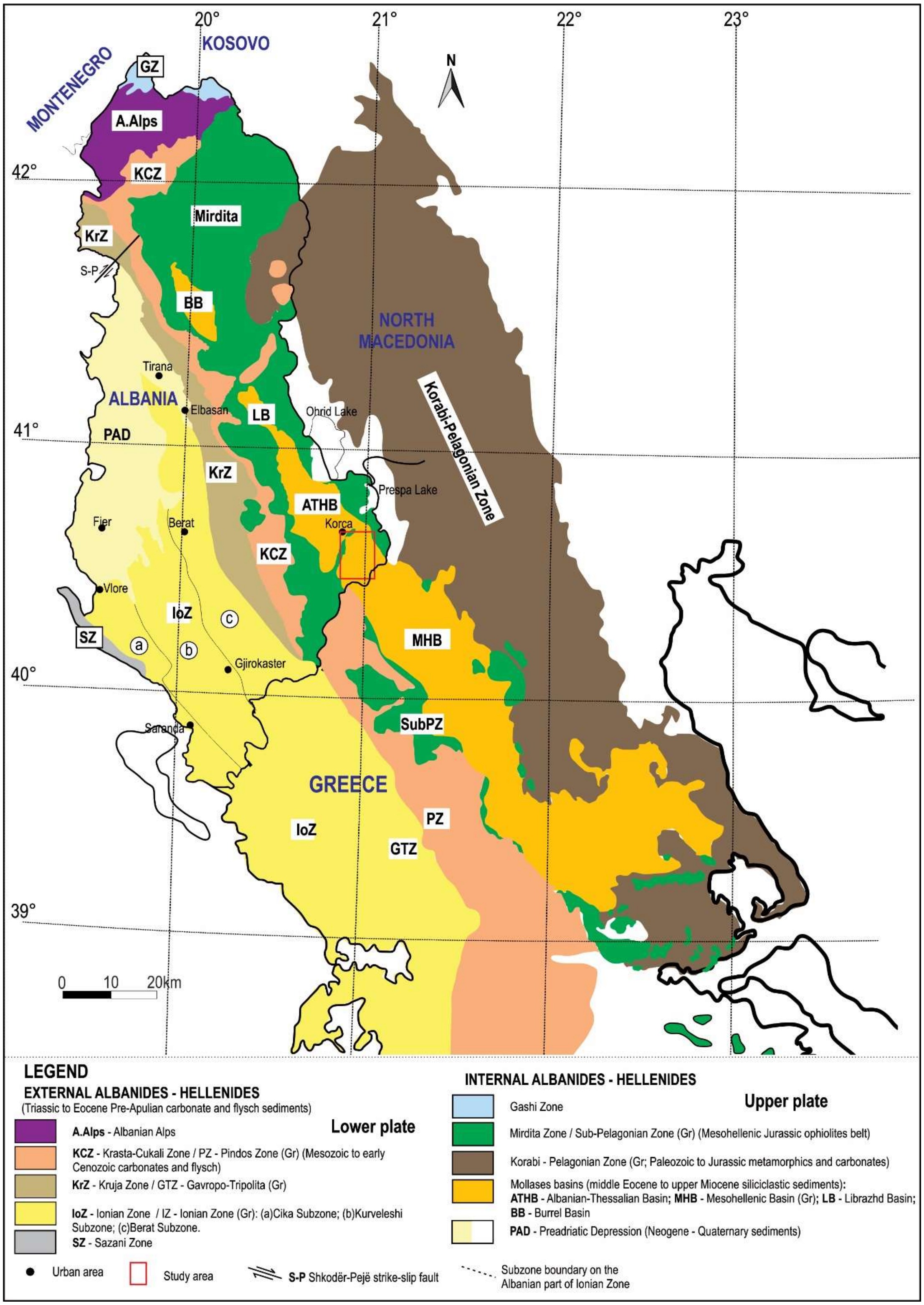

Figure 1. Simplified map showing the location of the ATHB – MHB on the Albanian and Greek territories, and of the studied area within the ATHB (sketch modified after Robertson & Mountrakis, 2006; Xhomo et al., 2002 and Aliaj, 2012).

The upper Rupelian is represented by the **Drenica Formation**, which consists of massive medium- to coarse-grained sandstones, intercalated with clast-supported well-rounded conglomerates, mainly made of limestones and ultrabasic elements.

The base of the Chattian can be easily distinguished in Morava Mt., where the deposits of the **"*Chama* Marls Formation"** overlay gradually the Rupelian sediments (Bourcart, 1922; Pashko et al., 1973; Pashko, 1977a, 1981, 2018; Xhomo et al., 2002). It is mainly characterized by a pack of grey-bluish succession of marlstones and siltstones, with thin fine-grained sandstones in the uppermost part.

The overlaying **Plasa Formation** has flysch appearancetype and sandy character, with fossil plants in all the succession (Pashko et al., 1973). The fossil content includes Oligocene molluscs (Pashko et al., 1973; Pashko, 1977a, 2018) resembling the formations below, while the benthonic foraminifera are rare and less diverse (Papa & Pashko, 1962; Pashko et al., 1973).

Lower to middle Miocene stratigraphy

The Neogene sediments have a wider development in the area compared to the Paleogene.

The Aquitanian formations represent a long narrow strip on the eastern part of Morava Mt. (Figure 2). In general, there is a gradual transition from the Plasa Formation to the lower Aquitanian **Bozdovec Formation** (Pashko et al., 1973). It consists of a thick sequence of grey-bluish marlstones, yellowish claystones and siltstones, with rare fine- to medium-grained sandstones in the first part, fine turbidites in the middle part and silty marlstones with very rare sandstones to the top. All sections contain rich foraminifera and molluscs' assemblages (Pashko et al., 1973; Pashko, 2018). The overlaying is the **Guri i Capit Formation** and is composed mainly of conglomerates. Based on the molluscs' assemblages and similarities to the northern Italy basins, the sediments of both Bozdovec and Guri i Capit formations can be assigned to the Aquitanian (Pashko et al., 1973; Pashko, 2018).

The basal Burdigalian is recognized by the presence of limestones with rhodophyte algae (*Lithothamnium*) of the **Morava Formation**, extended in the whole area (Bourcart, 1922; Sanxhak, 1957; Pashko et al., 1973; Xhomo et al., 2002). The formation gradually overlies the Guri i Capit Formation, while to the south (Dardha section) covers the Dardha "Schlier". The limestone is associated with medium-grained sandstones and conglomerates lenses with molluscs, echinoids, and large foraminifera (*Lepidocyclina elephantina*).

The overlaying sediments belong to **Bradvica Formation** and consists of massive fine- to medium-grained sandstones, fossiliferous grainstones, siltstones and marlstones (Pashko et al., 1973; Pashko, 2018). In the upper part, the conglomerates are more frequent, while the topmost is mainly siltic, with plant remains and fine-grained sandstones. Rare and poorly preserved molluscs and abundant foraminifera assemblages were identified (Pashko et al., 1973; Pashko, 2018).

The Bradvica Formation is gradually overlain by the sediments of the **Sinica Formation**, which represents a thick sedimentary sequence (>1000m) composed of grey-bluish marlstones, siltstones and fine-grained sandstones with fossils (*Flabellipecten* cf. *burdigaliensis*), followed by medium-grained massive sandstones, sandy limestones with pectinids and *Lithothamnium*. All the investigated sections contain rich and well-preserved foraminifera assemblages (Pashko et al., 1973).

The **Miras Formation** outcrops in the south – eastern part of the Devoll Basin where it reaches its maximum thickness (750 m), overlays gradually the Sinica Formation (Pashko et al., 1973; Pashko, 1996, 2018; Xhomo et al., 2002). The main feature of this formation is the thick massive sandstone beds with sandy concretions, with intercalations of grey-bluish siltstones and marlstones.

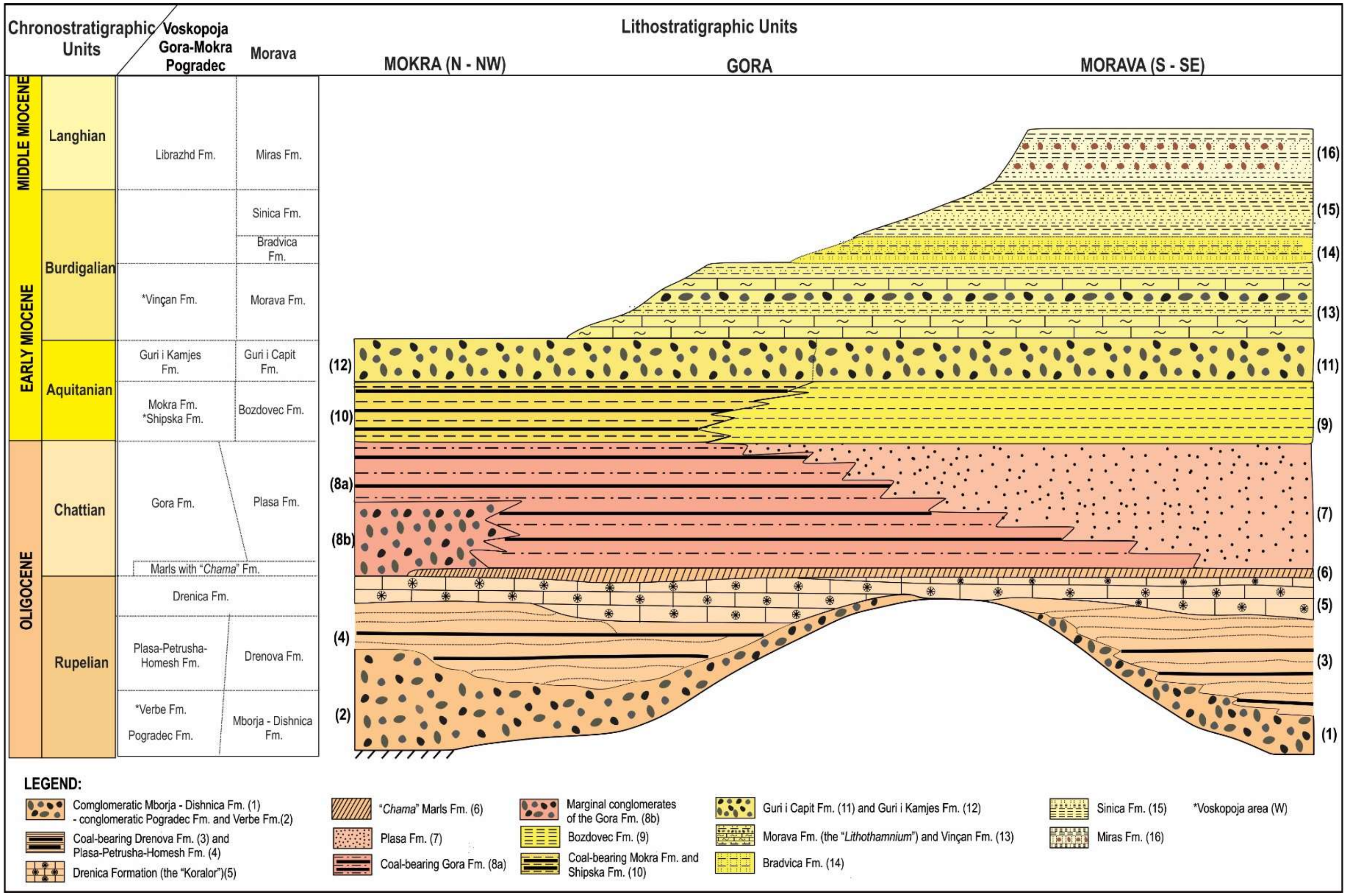

Figure 2. Lithostratigraphy of the Oligocene to middle Miocene sequences of the Albanian-Thessalian Basin from the main sedimentation areas (modified after Dimo et al., 1982, 1989).

HISTORICAL BACKGROUND

The first biostratigraphical studies from Albania based on calcareous nannofossils and their applicability in biostratigraphy dates back to 1982. The most studies were performed in the framework of the oil research conducted by the Oil & Gas Institute (Fier, Albania), and are mainly known from the Pre-Adriatic Depression (PAD), Ionian Zone (IoZ), Kruja Zone (KrZ), Sazani Zone (SZ) and less from the Albanian – Thessalian Basin (ATHB).

The calcareous nannofossil applicability in oil and gas industry is mentioned for the first time by Kiçi (1974), who gave only a general information on the subject, without specific research data. The first researchers who studied this microfossil group were Islami (1982) and Islami & Prençi (1983). They investigated the Miocene sediments from the Pre-Adriatic Basin and assigned these deposits to the "Helvetian" to Tortonian. In general, the works are concentrated on Oligocene and Miocene sediments from the Pre-Adriatic Basin and Ionian Zone (Islami & Çobo,1984, 1985; Çobo, 1986; Çobo,1989; Dalipi & Çobo, 1989; Çobo, 1992).

The Oligocene to Miocene flysch deposits of the Ionian Zone were investigated by Vathi (1085, 1987, 1989, 1993, 1998a, 1998b), Vathi & Budri (1086, 1990) and Vathi et al. (1994), who revealed several calcareous nannofossil zones and emended some of them.

In the Sazani Zone (Kepi e Gjuhezës), the late Oligocene NP25 – *Sphenolithus ciperoensis* Zone was mentioned by Vathi (1995, in Xhomo et al. 2002).

The sediments belonging to the Firza Flysch were dated for the first time as late Tithonian to late Valanginian by Gardin et al. (1996).

The sediments of the ATHB were studied by Kumati et al. (1995; in Pashko, 2018; NN4 to NN5). Kumati et al. (1997) investigated calcareous nannofossils, palinomorphs and foraminifera from this area and assigned the sediments to the Rupelian (NP24 Zone) up to Langhian (NN5) interval. Middle Eocene and Burdigalian sediments from the western coast of Ohrid Lake (northeastern ATHB) were investigated by Vathi & Kumati (1997).

Danelian et al. (2007) assigned the sediments from the Sopoti Section in the Ionian Zone to the late Barremian to early Cenomanian (the NC6 to NC10 zones).

Latest studies on calcareous nannofossils from Albania are part of this study and deal with the ATHB molasses deposits (Kallanxhi et al., 2016; Kallanxhi & Young, in press; Kallanxhi et al., in preparation).

Oligocene to middle Miocene sequences of the ATHB

The first information on the palaeontology and stratigraphy of the deposits surrounding the Korça city area was given by Dreger (1892), who mentioned for the first time the Oligocene molluscs from the Morava area, while information on Paleogene deposits of this region is given by Hilber (1894). During his expeditions in the northern Greece, Philippson (in Phillipson & Oppenheim, 1894) came into contact with the Oligocene deposits from the southern part of the Albanian territory (the Korça and Devoll regions). The fossil material collected by him was studied by Oppenheim (in Phillipson & Oppenheim, 1894). Another publication on the Morava's molluscs collected by Hilber was done by Penecke (1897). The upper Aquitanian (the conglomerates of Guri i Capit Formation) were mentioned for the first time by Welters (1906; in Pashko et al., 1973) as overlaying the Oligocene in the area.

Several broader studies on the Oligocene and Miocene deposits from the Morava area were carried out by Bourcart (1919, 1920, 1922) and Bourcart & Cossmann (1921). The molluscs from the "grey-bluish marls" was initially assigned to the Priabonian, but later investigations of Nowack (1929), Papa & Pashko (1962, 1966) considered it as Rupelian (the Drenica Formation).

The Paleogene and Neogene succession of the Mirdita area was detailed by Nowack (1929) in the first Albanian Geological map (1:200000). Stankejev (1950) included all the Oligocene deposits of Morava in the "clayey schist of Oligocene – Aquitanian age".

Similar findings are mentioned also by the Baçalldin (1951) who comprised all the previously considered Oligocene, Aquitanian and partially Burdigalian sediments in the Aquitanian.

Several reports of Mishunina (1951 and 1955) and Mishunina & Ivanovna (1957) did not mention any Paleogene deposits in the area. The only stages mentioned were the Burdigalian, the "Helvetian" and the Tortonian.

Sanxhak (1957) assigned the coal-bearing deposits of the Mborja – Drenova mines to the Miocene. The Aquitanian included the formerly described Oligocene basal conglomerates, the coal-bearing Drenova Formation, partially the sandstones and conglomerates of the Drenica Formation, the Aquitanian of the Bozdovec and Guri i Capit formations, the Burdigalian Morava, Bradvica and the Sinica formations, while to the Helvetian only the Miras Formation.

In a stratigraphical study of the Mborja site, Adrianova et al. (1961) separated the following units: the Oligocene breccia, conglomerates, sandstone and siltstones of the "Latorfian" and Rupelian; Aquitanian - including the former Chattian; Burdigalian - including all the former Aquitanian and the Burdigalian. In the "Helvetian" was included only the Sinica Formation.

In their study on the early Miocene in Albania, Papa & Pashko (1962) investigated also the stratigraphical succession of Mborja site and of Mokra basin. They mentioned in the Morava area the "Latorfian" with conglomerates, breccias, claystones and siltstones intercalations, the Rupelian Drenova Formation and the lower part of the Drenica Formation. The Aquitanian, Burdigalian, and lower "Helvetian" record is given in detail.

The monographic work on Albanian Geology of Biçoku et al. (1967) assigning the Oligocene, Aquitanian, Burdigalian and early Helvetian ages is based on previous studies of Papa & Pashko (1962, 1965 and 1966).

Based on previous studies, Petro & Lavdari (1971) separated a first cycle of Oligocene to early Miocene age, including all the molasses of the Morava area (Oligocene, Aquitanian, Burdigalian, and "Helvetian" sediments), and a second one of Miocene to Pliocene age which fills the Devoll Basin.

Petro & Hyseni (1972) detailed the basal units of the Morava Mt. identifying three depositional facieses: the Dishnica – Mborja conglomerates, the lagoonal coal – bearing series (Drenova Formation) and the upper marine Drenica Formation. Petro & Dodona (1976) point out the importance of the coral horizon from the Drenica Formation and its extension within the ATHB.

The first full correlation and description of the area belongs to Pashko et al. (1973), who gave a complete overview regarding the stratigraphy and paleontology of the Albanian-Thessalian Basin. They also made a correlation with the previous studies, pointing out many errors in age assignments. Later studies (Pashko 1977a, 1981 and 1996; Xhomo et al., 2002) continued on the same trend regarding the formations' definitions and descriptions. Pashko (2018) assigned the Langhian age to the Sinica Formation and the Serravallian age to the Miras Formation (previously considered as Langhian).

MATERIAL AND METHODS

The investigated material was collected from thirteen transects (Table 1; Figure 3), from marlstones, claystones and siltstones of Oligocene to middle Miocene sediments. In total, 550 samples were analyzed for calcareous nannofossils.

Table 1. Summary of the transects with their GPS position and the number of samples collected. The age is based on the results of this study and partially on existing literature (*).

Transects	*Details*	*Latitude*	*Longitude*	*Age*	*Samples*
Mborja (Mb)	Detail A	40°35'47.52"	20°48'50.89"	Rupelian	5
	Detail B	40°35'44.01"	20°48'58.53"	Rupelian	9
	Detail C	40°35'43.66"	20°48'58.77"	Rupelian	10
Dardha Road 2 (RD-2)		40°32'28.49"	20°47'24.96"	Rupelian	8
Dardha Road 1 (RD-1)		40°32'3.93"	20°47'28.36"	Rupelian	56
Morava-5 (Mo-5)	Detail A	40°36'57.61"	20°49'26.05"	Unclear (Rupelian*)	7
	Detail B	40°36'57.96"	20°49'27.79"	Rupelian-Chattian?	21
	Detail C	40°36'57.31"	20°49'30.65"	Rupelian-Chattian?	7
	Detail D	40°36'57.31"	20°49'32.16"	Unclear (Chattian*)	19
Bozdovec (BD		40°34'48.37"	20°50'9.65"	Chattian	103
Dardha (Da)		40°31'14.04"	20°49'54.16"	early Burdigalian	97
Dardha 1 (Da-1)		40°31’11”	20°51’23” 20°51’24” 20°51’26”	early Burdigalian	26
Kodra Partizani (KP)		40°37’05.21”	20°47'54.36”	early Burdigalian	18
Miras-3 (Mi-3)	Detail A	40°30’10.3”	20°53’31.7”	middle Burdigalian	36
	Detail B	40°30’10.1”	20°53’30.2”	middle Burdigalian	6
Miras-4 (Mi-4)		40°30’8.1’"	20°53’37.1”	middle Burdigalian	24
Miras-1 (Mi-1)		40°30’17.9”	20°54”32.2	early Langhian	33
Çetë (Ct)	Detail A	40°29’51.72”	20°55’14.11”	Langhian	18
	Detail B	40°29’57.79”	20°55’20.39”	Langhian	24
Miras-2 (Mi-2)		40°30’21.2”	20°55’02.6”	Langhian	23

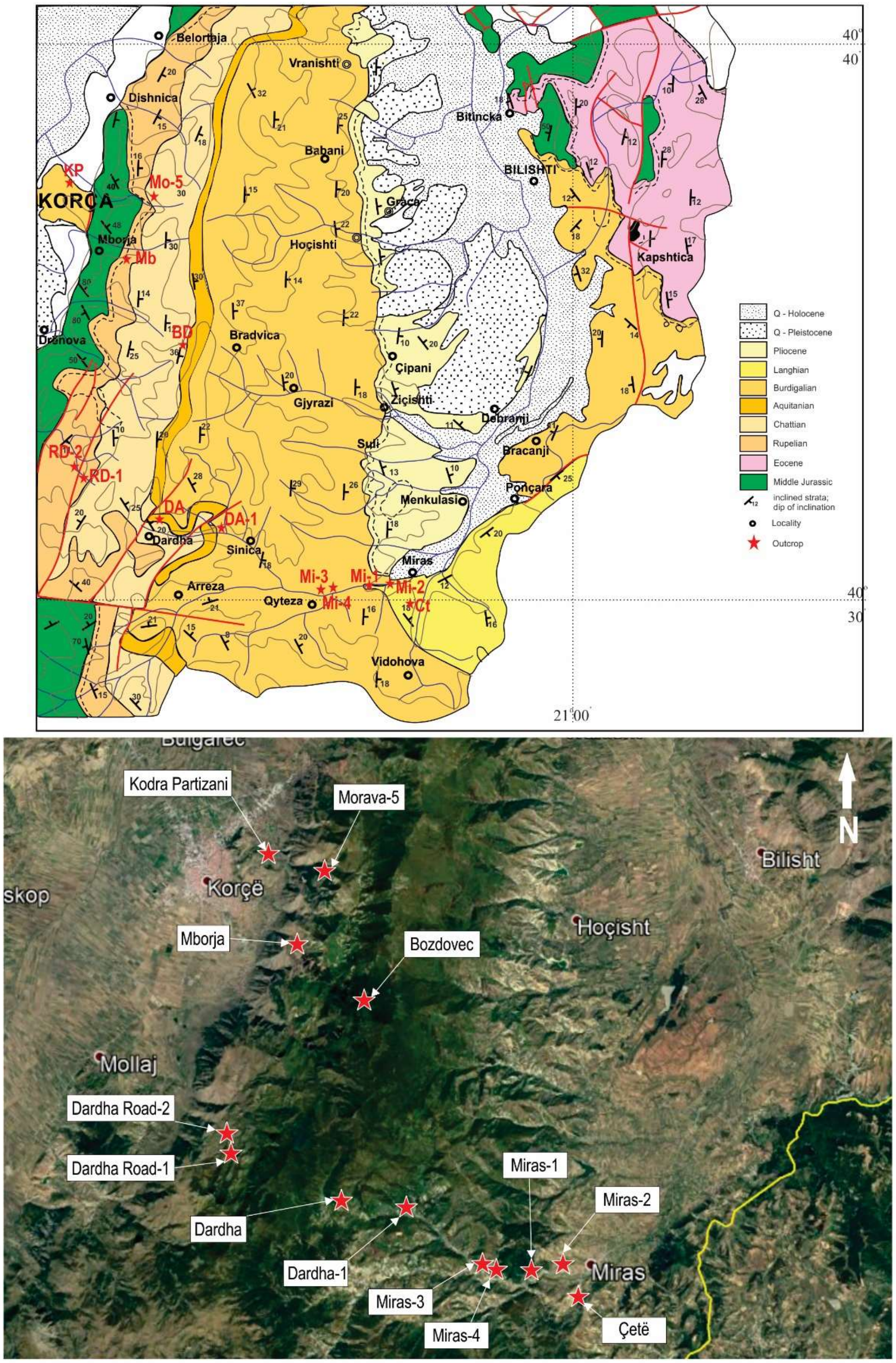

Figure 3. Location of the investigated transects on geological map (after Xhomo et al. 2002; 1:200000) and on satellite image (Google Earth).

Investigation techniques

The standard smear slide technique adapted after Bown & Young (1998) was used for the preparation of all collected samples. All samples were investigated under transmitted light microscope using an oil-immersion objective (100x) (at a magnification of at least 1000x) in cross – polarized light (XPL), in bright field (BF), under gypsum plate (GP) and phase contrast (PC).

Quantitative data collection was done with the light microscope using for most abundant samples, while for those with very poor content, only qualitative observations were made (presence/absence data). 49 samples resulted to be barren in calcareous nannofossils. The small reticulofenestrids with closed central area were grouped and counted as *Reticulofenestra* gr. 3-5 µm and conventionally two species, namely *Reticulofenestra producta* and *R. antarctica*, were added to the lists of taxa.

Extended counting and biometric measurements were performed on specimens belonging to species *Helicosphaera minima* (Kallanxhi & Young, in press).

The overall calcareous nannofossil abundance was assessed at the first look into the light microscope (LM; all specimens in one FOV – field of view), no matter the existing species. Blooms were considered when more than 90 % of the counted assemblage, contain only one species. Additionally, 300 – 500 FOV were investigated for rarer taxa and added to the species table.

Standard biostratigraphy

The calcareous nannofossils standard biostratigraphy generally used worldwide and applied herein also, follows the concepts of Martini (1971) and Okada & Bukry (1980). Additional, for the late Oligocene – middle Miocene interval was taken into consideration the Mediterranean zonation (Fornaciari & Rio, 1996; Fornaciari et al., 1996; Di Stefano et al., 2008). The standard zonations for low to middle latitudes areas of Agnini et al. (2014) for Oligocene and of Backman et al. (2012) for Miocene are used for comparison, while for the early to middle Miocene interval at middle and high latitudes, additional data are provided according to Young (1998). Other biostratigraphical schemes from the Mediterranean area and Albanian territory used for comparison are Theodoridis (1984), Vathi (1989) and Vathi & Budri (1986).

The standard taxonomy follows the concepts of Perch-Nielsen (1985), Young et al. (1991), Young (1998) and Nannotax3 website (http://www.mikrotax.org/Nannotax3).

The species counts and percentages were treated using the Microsoft Excel application and the PAST program (Hammer et al., 2001) was used for statistics.

The species *Helicosphaera minima* underwent special counting and measurement of length and width, and based on this, statistical charts of length vs. width variation were drawn (Kallanxhi & Young, in press).

Multivariate Hierarchical Clustering using Ward's method and Principal Component Analysis were applied for statistical interpretation for each identified nannofossil zone.

RESULTS AND DISCUSSIONS

This section represents the main contribution of this study and gives a detailed description of the investigated transects, their lithology, detailed information on calcareous nannofossil assemblages, the existing markers, biostratigraphical age assignment and abundance patterns of dominant taxa. It deals with all biostratigraphical aspects, species evolutionary trends during the Oligocene to middle Miocene as indicated by literature records, pointing out similarities and differences of various aspects on this thematic. Another sub-section deals with the autochthonous assemblages' diversity, describes the palaeoecology of the most abundant species and/or taxonomical groups, deals with multivariate statistics' and interpretation of depositional palaeoenvironment.

Calcareous nannofossils biostratigraphy

The Oligocene through middle Miocene calcareous nannofossil biostratigraphy is based on evolutionary trends (species appearance, extinctions, turnovers) and ranges of some species belonging to *Sphenolithus* genus, with additional primary and/or secondary biostratigraphical events provided by species belonging to *Helicosphaera*, *Discoaster*, *Triquetrorhabdulus* and *Reticulofenestra* genera (Martini, 1971; Okada & Bukry, 1980; Perch-Nielsen, 1985; Rio et al., 1990; Fornaciari et al., 1990; Fornaciari & Rio, 1996; Di Stefano et al., 2008; Backman et al., 2012; Agnini et al., 2014). For the present study, the main reference standard biozonations used herein are according to Martini (1971) and Okada & Bukry (1980).

The sampled Oligocene transects (Dardha Road-2, Mborja, Morava-5, Dardha Road-1 and Bozdovec) fall within the middle Rupelian – Chattian, and were assigned to three standard biozones, namely top of *Sphenolithus predistentus* Zone (NP23), *Sphenolithus distentus* Zone

(NP24) and *Sphenolithus ciperoensis* Zone (NP25) of Martini (1971). These three zones correspond to *Sphenolithus predistentus* Zone (CP17), *Cyclicargolithus floridanus* Subzone (CP19a) and *Reticulofenestra bisecta* Subzone (CP19b) of Okada & Bukry (1980), partially to the uppermost *Dictyococcites bisectus* PRZ (CNO3), to *Sphenolithus distentus/S. predistentus* CRZ (CNO4) and *Sphenolithus ciperoensis* TZ (CNO5) of Agnini et al. (2014), to the *Sphenolithus predistentus* Zone, *Sphenolithus distentus* Zone and *Sphenolithus ciperoensis* Zone of (Vathi, 1989), and to the *Sphenolithus ciperoensis* PRZ (MNP25a) of Fornaciari & Rio (1996) (Figure 4).

The sampled Miocene transects (Dardha, Dardha-1, Kodra Partizani, Miras-3, Miras-4, Miras-1, Çetë and Miras-2) fall within the early Burdigalian to Langhian interval, being assigned to four standard biozones (Martini, 1971), their age assignment being supported by the presence of successive species appearance belonging to *Sphenolithus* and *Helicosphaera* genera.

NP23 – *Sphenolithus predistentus* Zone

The presence of *Sphenolithus predistentus*, and the absence of *Sphenolithus distentus* with the FO at the base of Zone CP18 and of *Sphenolithus ciperoensis* with the FO at the base of zones NP24/CP19a, indicate the oldest age for the Dardha Road-2, among all investigated transects. Vathi (1989) and Vathi & Budri (1990) described assemblages with *S. predistentus* from the Ionian Zone (Albania) assigning them to their *Sphenolithus predistentus* Zone.

NP24 – *Sphenolithus distentus* Zone

The attribution of Mborja, Dardha Road-1 and Morava-5 transects to the NP24 – *Sphenolithus distentus* Zone (Martini, 1971), respectively to CP19a – *Cyclicargolithus floridanus* Subzone (Okada & Bukry, 1980) is supported by the co-occurrence of several marker species (*Sphenolithus predistentus*, *Sphenolithus distentus*, *Sphenolithus ciperoensis*, *Pontosphaera* cf. *enormis* and *Triquetrorhabdulus carinatus*). Similar assemblages are mentioned by Vathi (1989) and Vathi & Budri (1990) from Ionian Zone in Albania.

NP25 – *Sphenolithus ciperoensis* Zone

The age assignment of Bozdovec transect to the *Sphenolithus ciperoensis* Zone (NP25; Kallanxhi et al., 2016) is supported by the absence of the marker species *Sphenolithus distentus* and *S. predistentus.* In terms of the Mediterranean Zonation, according to Fornaciari & Rio (1996), the studied interval would fall within *Sphenolithus ciperoensis* PRZ (MNP25a), defined by the LO of *Sphenolithus distentus* at the base and LO of *Sphenolithus ciperoensis* at the top.

The continuous presence of the marker species *Sphenolithus ciperoensis* along the transect, allowed correlation also with the *Sphenolithus ciperoensis* TZ (CNO5) of Agnini et al. (2014), defined by the Top of *Sphenolithus predistentus* at the base and Top of *Sphenolithus ciperoensis* at the top. The co-occurrence of *S. ciperoensis* with *S.* cf. *delphix* in Bozdovec is similar to the data documented from Ionian Zone by Vathi (1989) and Vathi & Budri (1990). According to these records the studied transect can be assigned to *Sphenolithus ciperoensis* Zone as per above mentioned authors, defined at the base by the LO of *Sphenolithus distentus* and at the top by the LO of *Sphenolithus ciperoensis*.

NN2 – *Discoaster druggii* Zone

The transects Dardha, Dardha-1 and Kodra Partizani were assigned to the middle – upper part of long ranging *Discoaster druggii* Zone (NN2; Martini, 1971) of early Miocene age (early Burdigalian) and to the *Discoaster druggii* Subzone of Okada & Bukry (Subzone CN1c; 1980). A further subdivision and refinement of the Zone NN2/CN1c is supported by well-dated successive bioevents which allowed a clearer age assignment to the *Helicosphaera ampliaperta* PRZ (MNN2b; Fornaciari & Rio, 1996) in the Mediterranean, and to the *Helicosphaera carteri* PRZ biozone of Backman et al. (CNM4; 2012).

NN3 – *Sphenolithus belemnos* Zone

The transects Miras-3 and Miras-4 were assigned to the short-range *Sphenolithus belemnos* Zone (NN3; Martini, 1971) and to the *Sphenolithus belemnos* Zone (CN2; Okada & Bukry, 1980) of middle Burdigalian age. According to the Mediterranean and low- to middle latitudes standard zonations of Fornaciari & Rio (1996) and Backman et al. (2012), the material is attributed to the MNN3a – *Sphenolithus belemnos* TRZ and to CNM5 – *Sphenolithus belemnos* BZ. The continuous presence of index species *Sphenolithus belemnos*, co-occurring together with *Sphenolithus disbelemnos* and overlapping with *S. pseudoheteromorphus* point out to a middle Burdigalian age.

NN4 – *Helicosphaera ampliaperta* Zone

The transect Miras-1 was assigned to the upper part of *Helicosphaera ampliaperta* (NN4; Martini, 1971) and to the upper *Helicosphaera ampliaperta* zones (CN3; Okada & Bukry, 1980), correlating partially to the *Discoaster signus* CRZ (CNM7) of Backman et al. (2012). According to the Mediterranean zonation (Di Stefano et al., 2008; Turco et al., 2011) the sampled transects falls within the *Coronocyclus nitescens* IS (MNN4c Subzone; MNN4 – *Helicosphaera ampliaperta* IZ) of early Langhian age.

NN5 – *Sphenolithus heteromorphus* Zone

The transects Çetë and Miras-2 were assigned to the lower *Sphenolithus heteromorphus* (NN5; Martini, 1971), lower *Sphenolithus heteromorphus* zones (CN4; Okada & Bukry, 1980), these correlating to the *Discoaster signus* CRZ (CNM7) of Backman et al. (2012). According to the Mediterranean zonation (Di Stefano et al., 2008; Turco et al., 2011) the sampled transects falls within the MNN5 – *Sphenolithus heteromorphus* IZ.

Palaeoecology and palaeoenvironment

This section gives detailed information about the calcareous nannofossil abundance, the palaeoecological preferences of the most abundant species and taxonomical groups identified in the studied transects, when referring to the temperature, salinity, nutrient influx and availability, taking into account also the co-existence with various other taxa, and their preference to different geological settings. The various nannofossil combinations reflect specific palaeoecological preferences and characterize different palaeoenvironments. This section is supported by multivariate statistics performed on counted assemblages.

Calcareous nannofossil abundance

For the investigated time interval (Oligocene to middle Miocene) the most important taxa and taxonomical groups for palaeoecological interpretation were: the reticulofenestrids (*Reticulofenestra minuta*, *Reticulofenestra* gr. 3-5 µm, *R. dictyoda*, *R. pseudoumbilicus*, *R. gelida*, *R. haqii*, *R. bisecta*, *R. stavensis* and *Cyclicargolithus floridanus*), *Coccolithus pelagicus*, *Helicosphaera* spp., *Sphenolithus* spp., *Umbilicosphaera jafari* and *Discoaster* spp.

The dominant species are the long-ranging taxa *Reticulofenestra minuta*, *Cyclicargolithus floridanus* and *Coccolithus pelagicus.*

Cyclicargolithus floridanus is continuously distributed along the sampled interval, reaching the highest percentages in the Oligocene, while for the early Miocene a drastic decrease has been noticed, starting from the Kodra Partizani transect upward.

Reticulofenestra minuta is the most abundant within the investigated material, having a continuous distribution in all transects, reaching the highest percentage in Miras-1 (upper NN4/CN3; MNN4c zones; early Langhian), where accounts > 90 % of the total assemblage.

Another long-ranging taxa is *Coccolithus pelagicus* (Danian to recent; Varol, 1989), which reaches distinct peaks in NP25 (late Oligocene), NN2, NN3 (early Miocene) and NN5 biozones (middle Miocene).

The small reticulofenestrids with closed central area assigned to *Reticulofenestra* gr. 3-5 µm, display higher proportions in NP24 biozone (Oligocene) and NN2 biozone (early Miocene; early Burdigalian), while a drastic decrease can be noticed in NN4 and NN5 biozones (middle Miocene).

The small reticulofenestrids with size 3 to 5 µm and with an opened central area were assigned to two species, namely *Reticulofenestra dictyoda* in the Oligocene (NP24 and NP25) and *Reticulofenestra haqii* in early to middle Miocene transects (NN2, NN3, NN4 and NN5 Zones). This group is more abundant within the Miocene.

The Oligocene *Reticulofenestra bisecta* is not abundant, reaching its maximum amount in Dardha Road-1 transect (Zone NP24) and less in the rest of the Oligocene transects.

Medium- to large sized reticulofenestrids (>5 µm) with an opened central area were assigned to *Reticulofenestra dictyoda* (Oligocene) and to *Reticulofenestra pseudoumbilicus* (Miocene), and display low abundance in NP24, NP25, NN2 and NN5 biozones, and increased percentages in the zones NN2 and NN3.

During the early – middle Miocene, the species *Reticulofenestra gelida* accounts higher percentages within NN2 and NN3 biozones and lower in NN4 and NN5 biozones.

The taxa *Umbilicosphaera jafari* although it's present in all Oligocene (zones NP24 and NP25) and Miocene transects, exhibits higher quantities in the NN5 biozone (middle Miocene).

Sphenolithus spp. is present in all transects, but its composition is changing according to the specific time interval. The most abundant species is the long-ranging *Sphenolithus moriformis* (Selandian – Zanclean). Within NN5 biozone (middle Miocene) the marker species *S. heteromorphus* displays increased amounts. In general, excepting *S. heteromorphus*, the rest of the index species for Oligocene and Miocene do not exceed 2 %.

The helicoliths display low amounts in NP24 and NP25 biozones (Oligocene). Some increase is noticed within Zone NN2 (early Miocene), while highest amounts were recorded within NN3 (early Miocene) and NN5 biozones (middle Miocene).

The *Discoaster* genus is very rare in general, some of the transects lack totally this genus. Only in the NN5 biozone (middle Miocene) it is noticed a slight increase in quantity, but this is discontinuous along the same transect.

Palaeoenvironmental evolution of the ATHB

During the early Oligocene (mid-late Rupelian), the palaeogeographical configuration and climate in the Mediterranean area influenced the content and evolution of existing marine microfossils. In terms of calcareous nannofossils, the records from around the Mediterranean realm point out the prevailing of a southern subtropical palaeoenvironment (Popov et al., 2002) as suggested by the dominance of warm-water *Discoaster*, *Sphenolithus*, *Helicosphaera* and *Reticulofenestra* genera. Within the ATHB the middle – late Rupelian interval (upper NP23 and NP24 zones) is characterized by the dominance of shallow lagoonal coal-bearing deposits with poor diversity and low abundance of species (10 species), and shallow near-shore dynamic palaeoenvironment to calmer neritic regime, with moderate to high diverse assemblages (between 31 and 47 species) with dominant *Reticulofenestra* spp. (mainly *R. minuta*, *Cy. floridanus* and small reticulofenestrids with closed central area), *C. pelagicus*, and less abundant *Sphenolithus* spp. and *Helicosphaera* spp. The calcareous nannofossil composition and abundance fluctuations are connected to the increased nutrient supply from the continent, to rich nutrient upwelling and water column mixing, wind-driven turbulence and a general warm to temperate climate with seasonal oscillations. Similarities in species composition between the ATHB and other Mediterranean sites (Mesopotamian Basin, Müller, 1971; Oligocene from Trinidad Island, Bramlette & Wilcoxon, 1967 and Popov et al., 2002; NP24-NP25 zones from Pindos – Gavrovo zones in Greece, Stoykova et al., 2003; Vakalas et al., 2004; NP24-NP25 zones from Diapondia Islands, External Ionian Zone – Greece, Makrodimitras et al., 2010) are acknowledged, but there are also some differences which are probably connected to local basinal conditions.

The late Oligocene (Chattian; Zone NP25) within the ATHB is dominated by abundant and highly diverse assemblages (55 species) with *R. minuta*, *Cy. floridanus*, small reticulofenestrids with closed central area, *C. pelagicus*, *S. moriformis*, *S. ciperoensis*, *S.* cf. *delphix*, less helicoliths and *Zygrhablithus bijugatus.* These associations point out to warm neritic and more stable marine settings, with local influence of seasonal in-land nutrient input, wind-driven nutrient upwelling and sea-surface water turbulence.

The late Oligocene to Aquitanian transition (NN1 to lower NN2) corresponds to the opening of a new seaway connection from the Indian Ocean to Mediterranean and further to the Paratethys (Rögl, 1998). Warm water ingress and microfaunal exchange was possible during this slice time, being associated with the widespread deposition of larger foraminifera all around the Mediterranean and Paratethys. The warm climate and similar marine conditions prevailed during the early Burdigalian in the Mediterranean area (upper NN2 – lower NN3 Zones; Rögl, 1998; Popov et al., 2004). In the ATHB the calcareous nannofossils assemblages' characteristic for this time interval (zones NN2 – NN3) point out to the existence of a neritic eutrophic palaeoenvironment, humid and warm climate, fluctuations in terrigenous material supply, increased coastal current activity probably due to local palaeogeographical conditions. Moderate diverse assemblages (22 to 31 species) were recorded in the upper part of Zone NN2 (early Burdigalian) and during middle Burdigalian a slight increase of species diversity is documented in Zone NN3 (from 31 to 34 species).

The palaeogeographical configuration changed during the middle Burdigalian, in the time slice between upper NN3 and lower NN4, due to the collision of the Arabian Plate with the Anatolian Plate, which resulted in the closing of the seaway between the Mediterranean and Indian Ocean (Rögl, 1998). The late Burdigalian corresponds partially to the long-ranging Zone NN4, during which important tectonic changes took place, expressed by the strong compression and overthrusting in the Hellenides, which ended the marine sedimentation in the ATHB – MHB (Rögl, 1998). The base and middle part of Zone NN4 of middle to late Burdigalian age were not identified within the studied transects.

The Middle Miocene (Langhian) represents a crucial time interval for the geodynamic and climatic evolution of the Mediterranean. The global sea-level rise associated with the base of the Langhian (Haq et al., 1988, Rögl 1998, 1999), and the wide transgression affected the Mediterranean area and further to the north the Paratethyan domain. This transgression is connected to the re-opening of the sea gateway between Anatolia and the Arabian plates, which allowed the re-connection to the Indo-Pacific realm, and influx of warm water tropical fauna to the area (Haq, 1980). Another important event during the early middle Miocene (early Langhian) is the worldwide warming phase known as the Middle Miocene Climatic Optimum (MMCO) which according to Zachos et al. (2001) represents the warmest period in the last 23 Ma.

During this time interval a seaway connection between the Mediterranean and Central Paratethys existed through the Venetian Basin along the Trans-Tethyan-Trench-Corridor in Slovenia (Rögl, 1998). The seaway connections from the Northern Mediterranean to the Central Paratethys, through the ATHB - MHB as suggested by Studencka et al. (1995) was inexistent.

These palaeogeographical changes and the prevailing of tropical climate during early middle Miocene (Haq et al., 1977; Haq, 1980; Böhme, 2003; Rögl, 1998, 1999; Prista et al., 2015) are reflected also in the investigated area, by the enrichment in calcareous nannofossil composition and increased diversity (31 species in Miras-1, 41 in Çetë and 36 in Miras-2) during Langhian, with ingression of warm water oligotrophic elements (*Sphenolithus heteromorphus*, *Umbilicosphaera jafari* and *Discoaster* spp.), some of them being characteristic for more open-marine palaeoenvironments and increased water depth. The blooms of *Reticulofenestra minuta* in Miras-1 transect might be connected to the transgression event during early Langhian (Holcová, 2013) coupled with seasonal material runoff from the continent, while the higher diversity from Çetë transect where the intervals with discoasters, sphenoliths and *U. jafari* are recorded, point out to deeper stratified palaeoenvironment, oligotrophic conditions and normal to hypersaline sea-surface waters.

Seasonal fluctuations in the precipitation amount and implicit in the continental material input, short periods of higher eutrophy and productivity, rich nutrient upwelling and wind-driven water turbulence and mixing are supposed to have happened during the deposition of the Miras-2, as indicated by the calcareous nannofossil combinations and abundance fluctuations.

CONCLUSIONS

Calcareous nannofossils from the Oligocene to middle Miocene formations of the Albanian-Thessalian Basin (Albania) were studied in order to reveal their biostratigraphic and palaeoecologic potential. Beside direct observations and qualitative approach, statistical quantitative methods were applied for the first time on this group.

The biostratigraphic assignment relied on the presence of primary and secondary marker species, characteristic for different time intervals. Based on the occurrences of the main marker species of global, regional and local importance, and on the documented abundances for other species along the sampled transects, seven biozones (Martini, 1971) characteristic for the Oligocene to middle Miocene interval were documented as follows:

Similarities between the described calcareous nannofossil assemblages and previously published assemblages from Albania were documented.

A very rare helicoliths taxon, namely *Helicosphaera minima*, was rediscovered in the Oligocene sediments of Morava area (ATHB, Albania), making this the second occurrence in the world.

The quantitative investigations based on calcareous nannofossil abundance, correlated with specific palaeoecological preferences of the most abundant taxa and according to the statistical treatment (Multivariate Clustering and Principal Component Analysis), allowed the palaeoenvironmental reconstruction of each documented biozone and the general evolution of the sedimentary basin in the Oligocene – middle Miocene interval:

The present study offers a detailed overview on the spatial and temporal distribution of calcareous nannofossil assemblages, pointing out similarities and differences in their correlations to various global and regional standard schemes. From biostratigraphically point of view this study supports the age assignment for parts of various formations and offers a clearer stratigraphical position on several stages of the International Chronostratigraphic Chart. As per this study, the Zone NP23 is mentioned for the first time in Drenova Formation (Dardha Road-2), and a new age is assigned to Dardha transect (previously considered late Aquitanian), namely early Burdigalian. New data and clarifications regarding the age of parts from Sinica Formation (Miras-3 and Miras-4 transects) and from Miras Formation are highlighted, assigning these sediments to the middle Burdigalian (Zone NN3), respectively to the early – middle Langhian (upper NN4 – lower NN5). This study contributes to a better understanding of the palaeoecology of various calcareous nannofossil species and associations in marginal settings and semi-enclosed basins, and highlights the palaeoenvironmental evolution of the area during the Oligocene to middle Miocene.

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