UPPER CRETACEOUS DEPOSITIONAL AND BIOTICAL CHANGES IN THE GOSAU-TYPE BASINS OF THE GETIC DEPRESSION

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Abstract. This paper is focussed on the Upper Cretaceous successions that crop out in the central part of the Getic Depression (the Foreland of the Southern Carpathians). We have studied various aspects related to the litho- and biostratigraphy (based on calcareous nannofossils analysis) of outcrops situated in the Codricului, Olt, and Muereasca valleys. The identified rich and diversified nannofossil assemblages allow pointing out the biozones covering several intervals of the Upper Cretaceous (upwards the Coniacian stage). A progressive deepening of depositional basin belonging to the Getic Depression was observed from the Coniacian, constitutes of shallow-marine deposits, towards the end of the Maastrichtian, composed of a deep-marine facies. These features allow recognizing the Lower Gosau and Upper Gosau Subgroups in the studied area. Based on the observed changes, we advance hypotheses about the regional sea-level fluctuation that probably mirror the tectonics of those times.

Key words: sedimentology, biostratigraphy, Coniacian-Maastrichtian interval; Lower Gosau and Upper Gosau Subgroups

1. INTRODUCTION

The Getic Depression, described as the Foreland of the Southern Carpathians, is situated north to the Moesian Platform and refers to a sedimentary basin that developed in parallel to the Southern Carpathians (Săndulescu, 1984; Mutihac, 1990; Schmid *et al.*, 1998; Maţenco *et al.*, 2017). During Cretaceous times, the evolution of the Getic Depression probably mirrored the influence of the W-E oriented dextral transtensional tectonics that produced the initial accommodation space and drove subsidence (i.e., Berza *et al.*, 1994; Răbăgia *et al.*, 2011; Krézsek *et al.*, 2013).

The Getic Depression, a foredeep region, is delimited to the north by the Intra-Moesian Fault, which separates it from the units of the Southern Carpathians (Fig. 1). Its southern margin is defined by the Pericarpathian Fault, which marks the transition towards the relatively undeformed Moesian Platform. In the northern region, the basement underlying the depression comprises a complex tectonic architecture, consisting of a system of nappes that contain four main tectonic units: Danubian, Severin, Getic, and Supragetic (Murgoci, 1905; Codarcea, 1940; Motaş, 1983; Săndulescu, 1984; Mutihac, 1990; Mutihac *et al.*, 2004; Maţenco *et al.*, 1997, 2007; Tărăpoancă *et al.*, 2007; Schmid *et al.*, 2008).

The Getic Depression is an important petroleum province with thousands of wells drilled and several fields discovered, as the exploration for oil and gas in the Getic Depression drew attention for over a hundred years (Ştefănescu, 1897; Murgeanu, 1941; Iorgulescu, 1953; Popescu, 1954; Popescu *et al.*, 1977; Jipa, 1982; Dicea, 1996, among many others). To date the sedimentary successions encountered in drillings and in outcrops, several palaeontological investigations have been carried out, mainly based on macro- and microfaunal analysis (i.e., Tătărâm, 1964; Popescu *et al.*, 1976; Szasz, 1976a and 1976b; Bombiţă *et al.*, 1980; Schleder *et al.*, 2023).

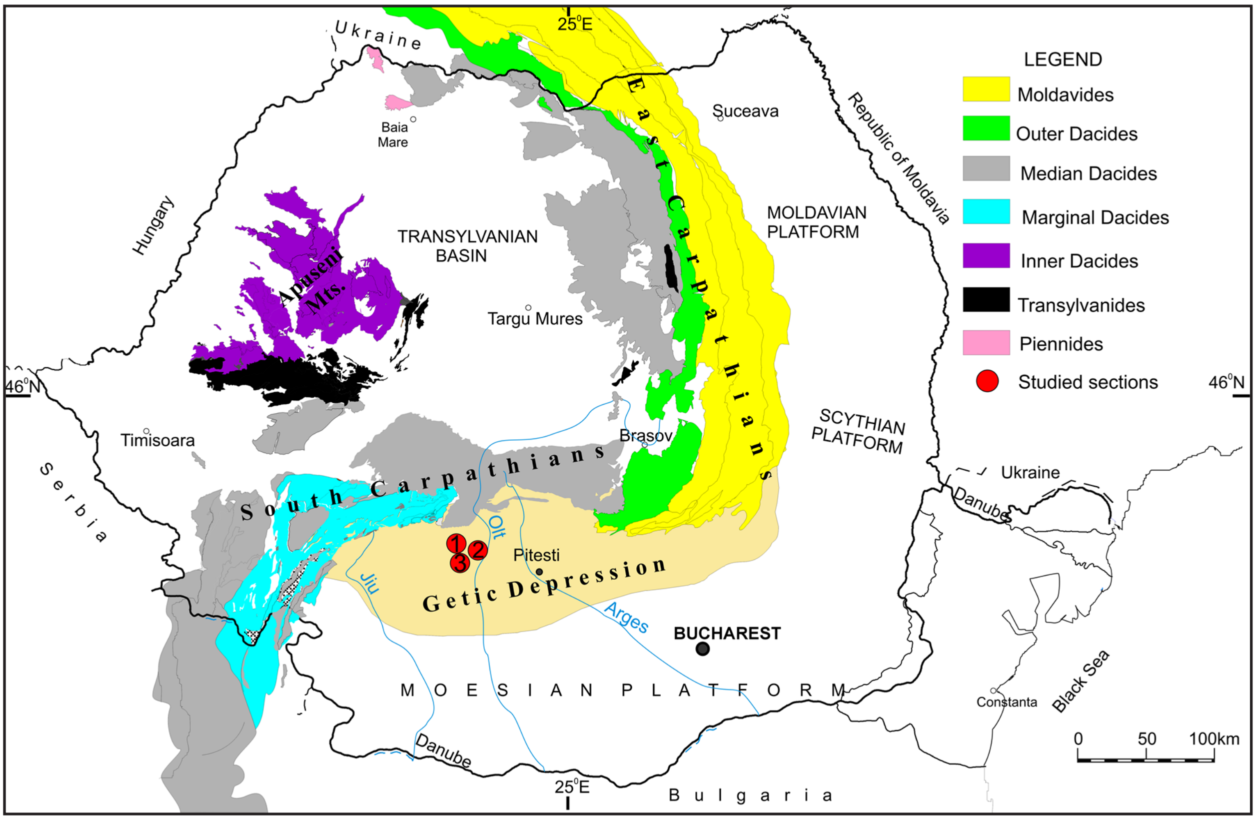

Fig. 1. Tectonic map of Romania showing the location of the samples (modified after Săndulescu, 1984; Răbăgia and Maţenco, 1999; Tărăpoancă *et al.*, 2007).

Since the late 90's, the successions of the Getic Depression, especially the Paleogene-Miocene ones, have been detailed studied for their calcareous nannofossil content, for providing accurate age of various lithostratigraphic units (Roban and Melinte, 2005; Ghiţă and Şindilar, 2021; Ghiţă and Melinte-Dobrinescu, 2005). Meantime, the Cretaceous successions largely occurring in the Getic Depression almost lack micropaleontological studies, as only macrofaunal assemblages have reported (Popescu and Patrulius, 1968; Szasz, 1976a and 1976b; Lupu *et al.*, 1978: Ion and Szasz, 1994).

We present in this paper several Upper Cretaceous successions cropping out in the Getic Depression, exposed between the Brezoi Basin towards west and the Olt River to the east. The main aim was to decipher the factors that control the lithological and sedimentological changes, which took place in the study area, and to accurately date the investigated sections based on calcareous nannofossil biostratigraphy. A possible link between modifications in the palaeosetting and tectonics is also discussed herein.

2. GEOLOGICAL SETTING

The Getic Depression sedimentation is characterized by three successive cycles: (i) Upper Cretaceous to Paleogene, (ii) Lower Miocene to Upper Miocene and, (iii) uppermost Miocene to Upper Pliocene (i.e., Săndulescu, 1984, 1988; Ryer, 1998; Răbăgia and Maţenco, 1999; Roban and Melinte, 2005; Maţenco *et al.*, 2007; Schmid *et al.*, 2008). The eastern part of the Getic Depression is viewed as the extension of the Eastern Carpathians, while its western part corresponds to a Paleogene to Early Miocene strike-slip basin (i.e. the Getic Basin), extended on the contact zone between the Carpathians and Moesia and thrusted over Moesia within the Middle Miocene times (i.e., Săndulescu, 1984, 1988; Ryer, 1998; Răbăgia and Maţenco, 1999; Roban and Melinte, 2005; Maţenco *et al.*, 2007; Schmid *et al.*, 2008).

The oldest depositional cycle, i.e., Upper Cretaceous to Paleogene, is mainly characterized by the deposition of shallow-water marine deposits. The second cycle, Lower Miocene to Upper Miocene, is dominated by siliciclastic successions, most probably sourced from the uplifted Carpathian chain. The third sedimentation cycle, extending from the uppermost Miocene to the Upper Pliocene, represents the final stage of basin infilling (Săndulescu, 1984; Mutihac, 1990; Maţenco *et al.*, 1997b; Mutihac *et al.*, 2004; Roban and Melinte, 2005; Melinte-Dobrinescu and Roban, 2016).

Notably, the two older sedimentary cycles were subjected to significant post-depositional deformation, including compressive folding and faulting. Probably, this pattern represents a consequence of major tectonic events during the Burdigalian-Sarmatian interval.

3. MATERIAL AND METHODS

Several Upper Cretaceous successions that crop out in the central part of the Getic Depression have been investigated. We have studied three sections exposed on Codricului, Olt and Muereasca valleys (Fig. 2).

Previous studies of these successions indicate that all of them are Late Cretaceous in age, based on their macrofaunal content, i.e., ammonites and inoceramids, according to Szasz (1976a; 1986), Ion and Szasz (1994), Ion *et al.* (1997); similar results were given by preliminary investigation of the calcareous nannofossils (Melinte-Dobrinescu and Roban, 2016).

The nannofossil analysis have been carried out with Olympus polarized microscope, with x1200 magnification. The smear-slides were simply prepared, the samples being not subject of ultrasounds or other procedures. Taxonomic identification and biostratigraphy follow Burnett (1998).

4. RESULTS

4.1. Codricului Valley

The sediments cropping out on the left bank of the Codricului Valley (right tributary of the Cheia Valley), downstream the Iezer Hermitage, are represented by a succession of cm-thick grey calcareous sandstones and grey-greenish claystones (Fig. 3), which belong to the Vasilatu Formation (*sensu* Szasz, 1976a), having a known areal occurrence between the Cheia and Olt valleys and their tributaries. The above-mentioned author described the Vasilatu Formation as having a transgressive lower boundary in contact with the crystalline series of Sebeş-Lotru, while its upper is marked by the basal conglomerates of the Brezoi Formation. Based on its macrofauna, the whole Vasilatu unit has been dated as Coniacian–lower Campanian (Szasz, 1976a and 1986; Ion and Szasz, 1994; Ion *et al.*, 1997).

The study succession has a stratigraphical thickness of 27.8 m and contains (according to Szasz, 1976a; 1986) macrofaunas, i.e., *Forresteria petrocoriensis*, *F. nicklesi*, and *Yabeiceras costatum* (Fig. 3), which characterized the Coniacian stage. The lower part of the studied section contains an assemblage with *Lithastrinus septenarius* (species that occur at the base of the UC9 biozone of Burnett, 1998), along with other nannofossils, such as *Eiffellithus turriseiffelii*, *Eprolithus floralis*, *Tranolithus orionatus*, and *Cribrosphaerella ehrenbergii* (Fig. 4); all of them are distributed in the whole Upper Cretaceous interval. *Watznaueria barnesiae*, indicator of dissolution processes, when occurs over 40% of total nannofossil assemblages (according to Roth and Krumbach, 1986), represents around 30% in the studied samples.

Towards the base of the studied section exposing the Vasilatu Formation, the first occurrence (FO) of *Micula staurophora*, the first species of genus *Micula* occurring in the stratigraphic scale, was identified, marking the base of the UC10 biozone of Burnett (1998). The FO is known to be a global bioevent of the Coniacian (i.e., Manivit, 1989; Varol, 1992; Lees and Bown, 2005). High abundance of this nannofossil is indicative for a nearshore marine facies (Lamolda *et al.*, 2005; Püttmann and Mutterlose, 2019).

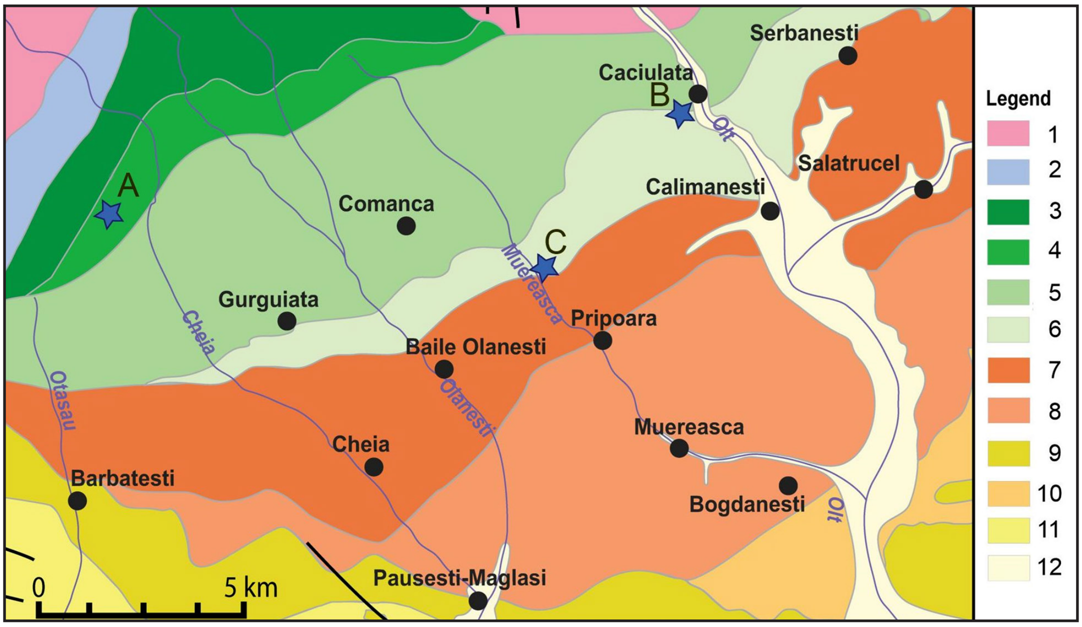

Fig. 2. Geological map of the NE Getic Depression scale 1:50,000 (modified after Popescu *et al.*, 1976, 1977), published by the Geological Institute of Romania. **A**, **B**, **C** – studied successions; **A** – Codricului Valley, **B** – Olt Valley, **C** – Muereasca Valley. *Lithological legend*: **1** – Precambrian (Proterozoic); **2** – Upper Jurassic; **3** – Lower Cretaceous (Albian); **4** – Upper Cretaceous (Coniacian); **5** – Upper Cretaceous (Santonian); **6** – uppermost Cretaceous (Maastrichtian); **7 –** Eocene (Ypresian-Lutetian); **8** – Lower Oligocene - lowermost Miocene (Rupelian-Aquitanian); **9** – Lower Miocene (Burdigalian); **10** – Middle Miocene (Badenian); **11** – Upper Miocene (Sarmatian); **12** – Quaternary.

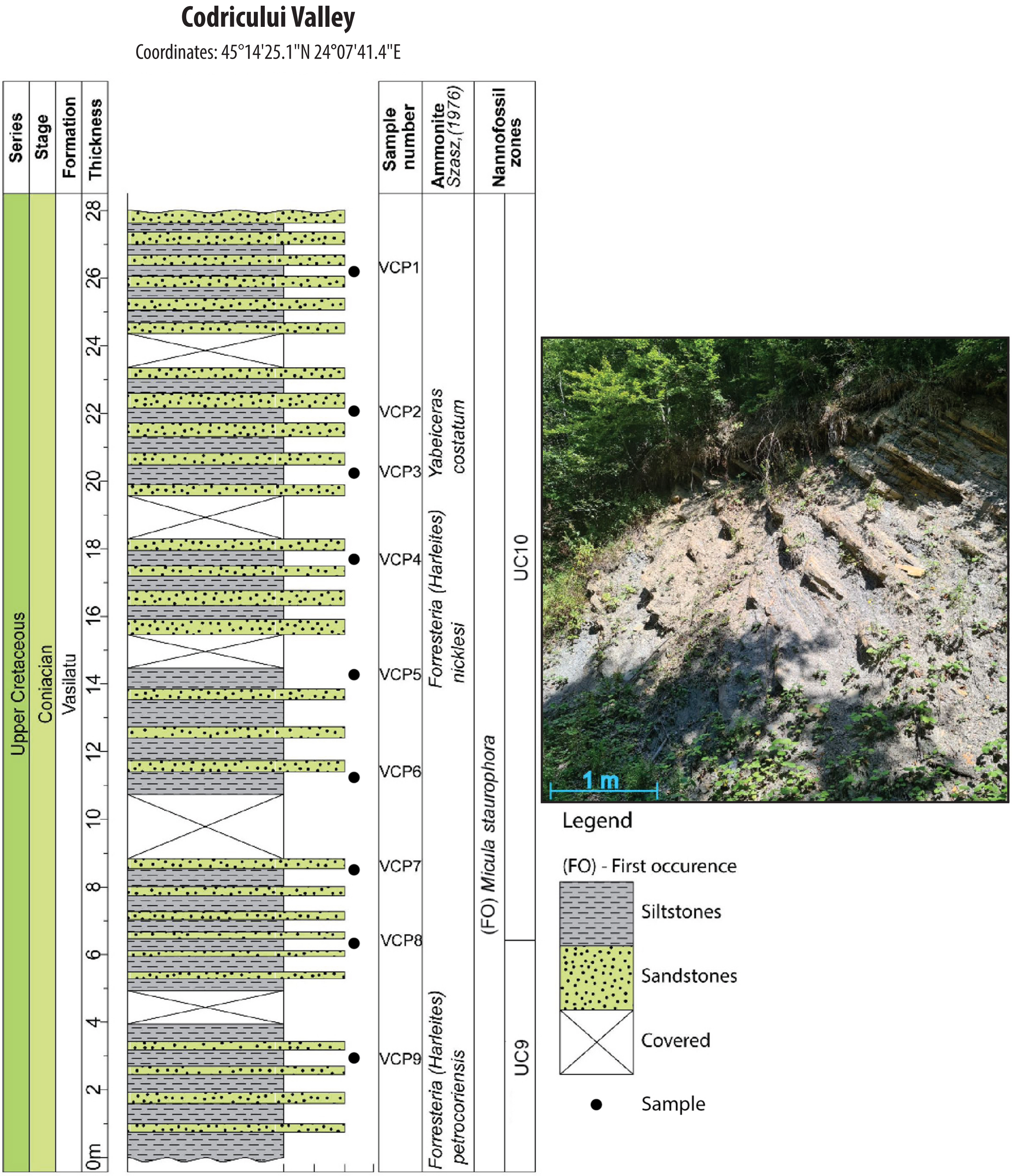

Fig. 3. Litho- and biostratigraphy of the Vasilatu Formation in the Codricului Valley.

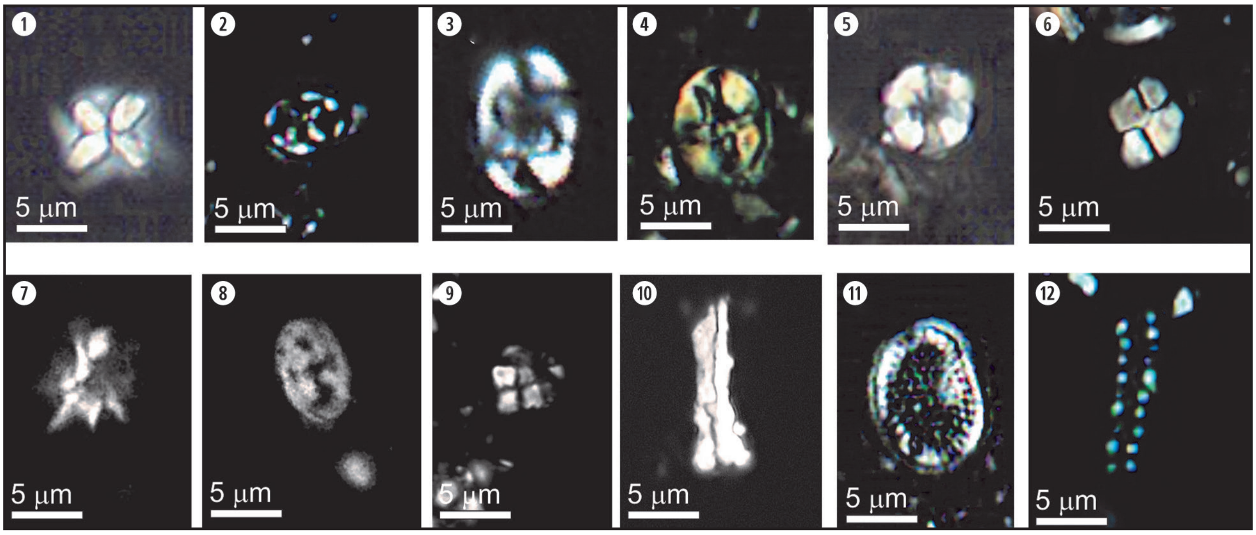

Fig. 4. Microphotographs of the calcareous nannofossil species encountered in the Codricului Valley taken at LM (light microscope), N+(crossed-nicols). (**1**) *Micula staurophora* (Gardet, 1955) Stradner, 1963; Sample VCP8; (**2**) *Prediscophaera cretacea* (Arkhangelsky, 1912) Gartner, 1968; Sample VCP1; (**3**) *Eiffellithus turriseiffelii* (Deflandre *in* Deflandre and Fert, 1954) Reinhardt, 1965; Sample VCP9; (**4**) *Eiffellithus eximius* (Stover, 1966) Perch-Nielsen, 1968; Sample VCP5; (**5**) *Eprolithus floralis* (Stradner, 1962) Stover, 1966; Sample VCP9; (**6**) *Calculites ovalis* (Stradner, 1963) Prins and Sissingh in Sissingh, 1977; Sample VCP1; (**7**) *Lithastrinus septenarius* Forchheimer, 1972; Sample VCP9; (**8**) *Tranolithus orionatus* (Reinhardt, 1966a) Reinhardt, 1966b; Sample VCP2; (**9**) *Quadrum gartneri* Prins and Perch-Nielsen *in* Manivit *et al.*, 1977; Sample VCP4; (**10**) *Lucianorhabdus maleformis* Reinhardt, 1966; Sample VCP5; (**11**) *Cribrosphaerella ehrenbergii* (Arkhangelsky, 1912) Deflandre in Piveteau, 1952; Sample VCP9; (**12**) *Microrhabdulus belgicus* Hay and Towe, 1963; Sample VCP9.

The calcareous nannofossil assemblages of the Codricului section are dominated by the species of the Polycyclolithaceae Family, belonging to the taxa *Micula*, *Eprolithus*, *Lithastrinus*, *Calculites* and *Quadrum* (Fig. 4).

4.2. Olt Valley

The succession of the Vasilatu Formation exposed in Cheia basin (including the Codricului Valley), continues from the Coniacian (as described above) up to Santonian (Szasz, 1986; Ştefănescu *et al.*, 1982; Melinte, 1997), and grade up into a younger hemipelagic succession in the Olt Valley, mainly made by grey marlstones and siltstones, from which we have studied a 11.8-m thick succession (Fig. 5). Previously, from this succession macrofaunas (mainly inoceramids) and microfaunas (foraminifer species of the *Globotruncana* genus) were reported (Szasz, 1976; Ion and Szasz, 1994), indicating in general a Campanian age.

Our studies, based on calcareous nannofossil analyses, indicate an early Campanian stage, respectively, the UC14 biozone. The identified assemblages contain significant biostratigraphic taxa (Wise, 1983; Burnett, 1998; Melinte and Odin, 2001; Püttmann and Mutterlose, 2019), such as (Fig. 6): *Ceratolithoides verbeekii* (which has the total range in the Campanian, with the FO – first occurrence in the early Campanian), *Arkhangelskiella cymbiformis* (known distribution late Santonian-late Maastrichtian), *Eiffellithus eximius* (with the LO - last occurrence at the base of the Maastrichtian), *Cribrocorona gallica* (ranging in the Coniacian-Maastrichtian interval), and *Petrarhabdus copulatus* (FO at the base of the Campanian). Other taxa commonly encountered are subspecies of the species *Broinsonia parca*, i.e., *Broinsonia parca* subsp. *expansa, Broinsonia parca* subsp. *parca,* and *Broinsonia parca* subsp. *constricta*. The last mentioned nannofossil first occurred in the early Campanian. To note that *Ceratolithoides aculeus*, which appeared in the late Campanian, was not encountered in the studied samples.

4.3. Muereasca Valley

The studied section exposed the Căciulata Formation, which outcrops on both sides of the Muereasca Valley, in the vicinity of the Muereasca Monastery. This lithological unit was first described as the Căciulata Marls (Popescu *et al.*, 1976), along the Căciulata Valley, a tributary of the Olt River. The formation is divided into two distinct successions, delineated by the Olt River. The lower part of the unit, exposed on the left bank of the Olt River and in the Olănești Valley, is characterised by metric-scale conglomerates with dm-thick siltstones interbedded. The upper part of the Căciulata Formation, which largely crops out on the right bank of the Olt River, consists of alternating beds of greyish to blackish, silty, and argillaceous marls, with intercalated strata of quartz sandstones with a calcitic cement (Popescu *et al.*, 1976). Popescu and Patrulius (1968) further describe the formation as being dominated by greyish marls and sandy-silty clays with a high mica content, interbedded with dm-thick sandstones. The Căciulata Formation was previously assigned to the late Campanian-Maastrichtian interval (Patrulius, 1968), based on both macrofaunas (inoceramids) and nannofossils.

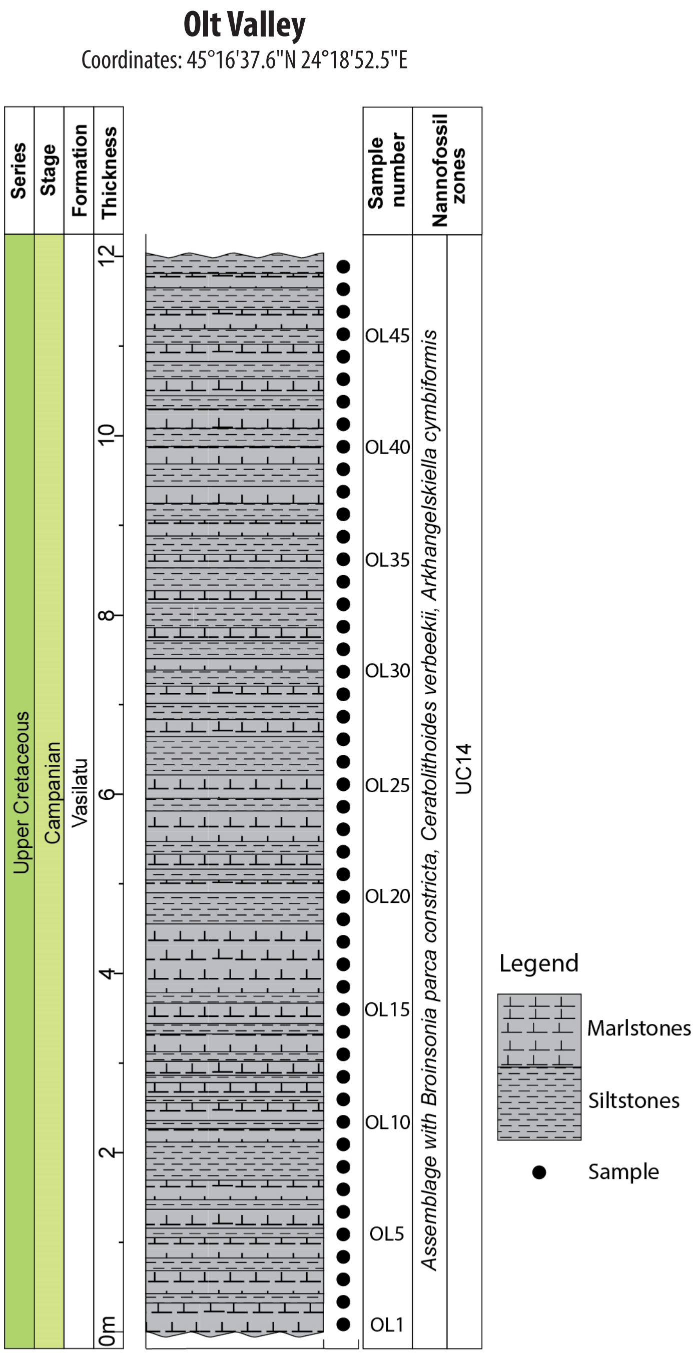

Fig. 5. Litho- and biostratigraphy of the Vasilatu Formation in the Olt Valley.

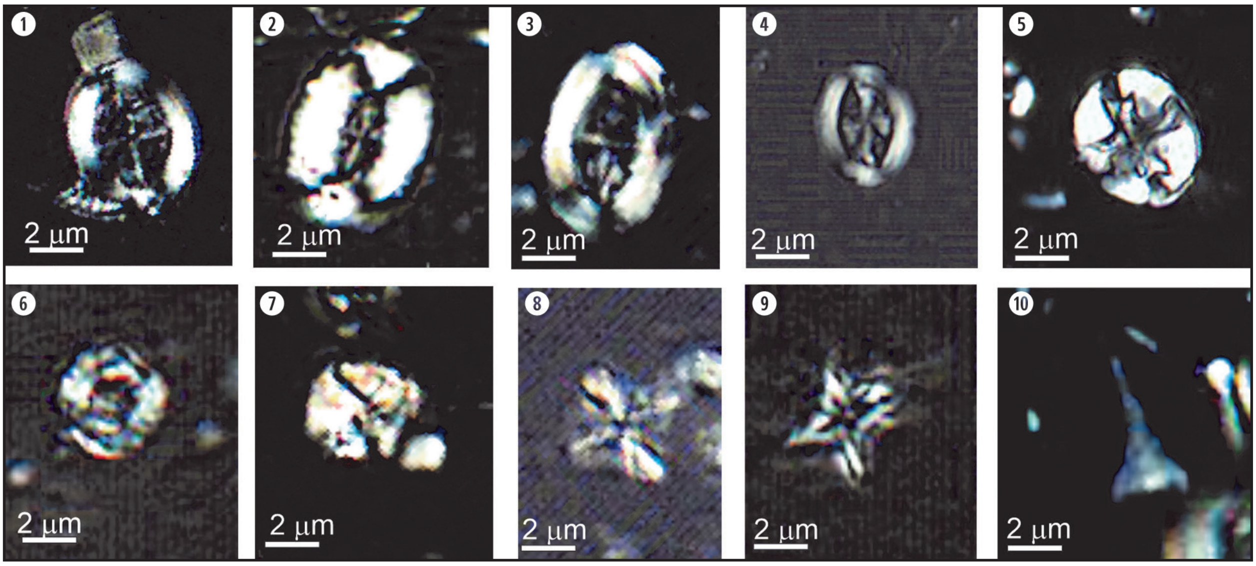

Fig. 6. Microphotographs of the calcareous nannofossil species encountered in the Olt Valley taken at LM (light microscope), N+(crossed-nicols). (**1**) *Broinsonia parca* subsp. *expansa* Wise and Watkins in Wise, 1983, Sample 39; (**2**) *Broinsonia parca* subsp. *constricta* Hattner *et al.*, 1980, Sample OL1; (**3**) *Broinsonia parca* subsp. *parca* (Stradner, 1963) Bukry, 1969, Sample OL45; (**4**) *Broinsonia enormis* (Shumenko, 1968) Manivit, 1971, Sample; (**5**) *Eiffellithus eximius* (Stover, 1966) Perch-Nielsen, 1968, Sample 22; (**6**) *Cribrocorona gallica* (Stradner, 1963) Perch-Nielsen, 1973, Sample OL17; (**7**) *Petrarhabdus copulatus* (Deflandre, 1959) Wind and Wise *in* Wise, 1983, Sample 14; (**8**) *Micula staurophora* (Gardet, 1955) Stradner, 196, Sample OL9; (**9**) *Micula concava* (Stradner *in* Martini and Stradner, 1960) Verbeek, 1976, Sample OL9; (**10)** *Ceratolithoides verbeekii* Perch-Nielsen, 1979, Sample OL1.

In the Muereasca Valley, the analysed section reaches a thickness of 22 m (Fig. 7) and is composed of thick packages of marls intercalated with clays. The marls are grey, slightly friable, and rich in mica. This succession is unconformably covered by conglomerates and breccias. These contain clasts composed predominantly of crystalline schists and Lower Cretaceous limestones and are supposed to be, taken in account their stratigraphic position, Paleocene in age (Popescu *et al.*, 1976, 1977; Bombiţă *et al.*, 1980; Ştefănescu *et al.*, 1982).

The samples collected from the Muereasca section contain rich and diversified calcareous nannofossil assemblages, dominated by the taxa of the *Micula* genus, among them, *Micula murus*, which has its FO in the upper Maastrichtian (subzone UC20b -Burnett, 1998), along with *Micula staurophora*, and *Micula concava* are commonly encountered (Fig. 8). The age of the studied succession is uppermost Maastrichtian; the presence of *Ceratolithoides kamptneri* is indicative for the base of the UC20c subzone (Figs. 7 and 8).

5. DISCUSSION

Following the Austroalpine definition (i.e., Wagreich and Faupl, 1994), the studied Upper Cretaceous deposits of the Southern Carpathians may be grouped in the Lower Gosau Subgroup (shallow marine facies) and the Upper Gosau Subgroup (deep marine facies). The above-mentioned authors show that, in the Alpine area of Austria, the Lower Gosau Subgroup (upper Turonian-Campanian) is characterized by terrestrial to shallow-marine facies associations, while the Upper Gosau Subgroup (upper Santonian-Eocene) encloses deep-water hemipelagic and turbidite sediments. Both the Lower Gosau Subgroup and Upper Gosau Subgroup constitute a geological stratigraphic group of lithological units that crop out in Austria, Germany, Slovakia, Hungary, and Romania, which extends in the Late Cretaceous to the Eocene interval (i.e., Wagreich and Faupl, 1994; Schmid *et al.*, 2004; Wagreich *et al.*, 2008; McCann, 2008). The features of the Cretaceous Gosau-type basins were recognized in the Southern Carpathians, especially in the western part, within the Haţeg basin and also in the Apuseni Mountains (Lupu, 1970; Lupu and Lupu, 1983; Willingshofer *et al.*, 1999; Schuller *et al.*, 2009; Melinte-Dobrinescu and Roban, 2016).

In the studied area, the central part of the Getic Depression, representing the Foreland of the Southern Carpathians, we recognize a shallow marine succession in the Coniacian-lower Campanian interval (Fig. 9), which may be assigned to the Lower Gosau Subgroup. Starting from the upper part of the lower Campanian up to the uppermost Maastrichtian, the hemipelagic deep marine sediments (Fig. 9) observed in the investigated area could be assigned to the Upper Gosau Subgroup. Taking into account our data, a progressive deepening of the central part of the Getic Depression basin from the Coniacian towards the Maastrichtian is observed, reflecting differences between the eurybathic (regional) sea-level curve and the eustatic (global) one (Fig. 9).

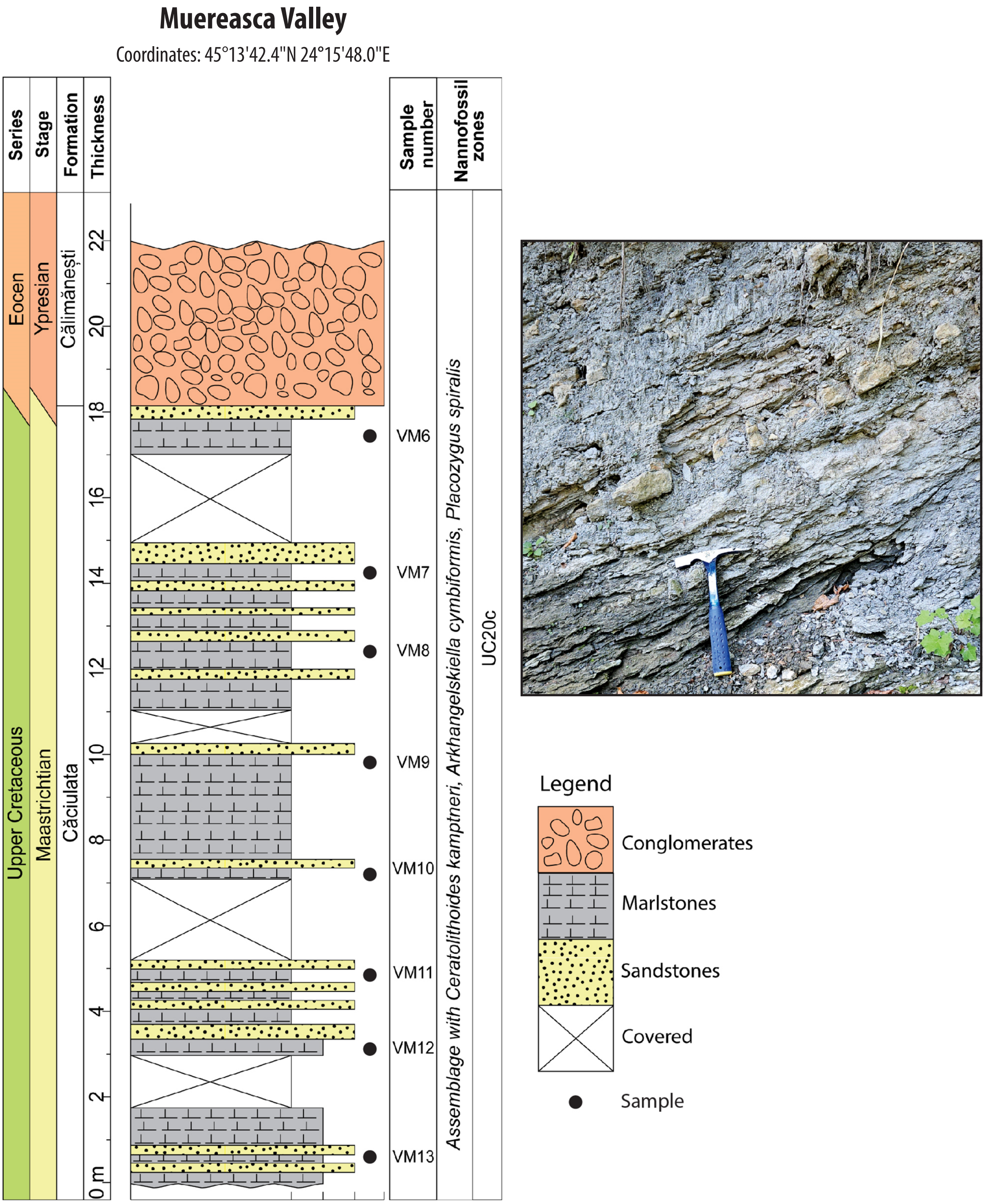

Fig. 7. Litho- and biostratigraphy of the Maastrichtian in the Muereasca Valley.

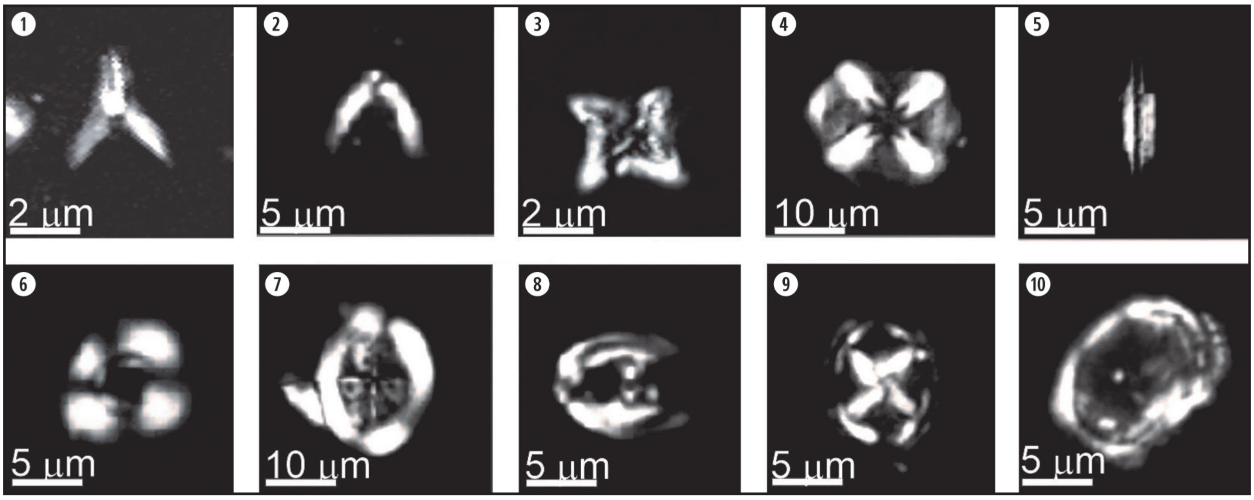

Fig. 8. Microphotographs of the calcareous nannofossil species encountered in the Olt Valley taken at LM (light microscope), N+(crossed-nicols). (**1**) *Ceratolithoides aculeus* (Stradner, 1961) Prins and Sissingh in Sissingh, 1977, Sample VM11; (**2**) *Ceratolithoides kamptneri* Bramlette and Martini, 1964, Sample VM9; (**3**) *Micula murus* (Martini, 1961) Bukry, 1973, Sample VM9; (**4**) *Micula staurophora* (Gardet, 1955) Stradner, 1969, Sample VM8; (**5**) *Lithraphidites quadratus* Bramlette and Martini, 1964**,** Sample VM11; (**6**) *Cylindralithus serratus* Bramlette and Martini, 1964, Sample VM7; (**7**) *Arkhangelskiella cymbiformis* Vekshina, 1959, Sample VM7; (**8**) *Placozygus fibuliformis* (Reinhardt, 1964) Hoffmann, 1970, Sample VM11; (**9**) *Prediscosphaera cretacea* (Arkhangelsky, 1912) Gartner, 1968; Sample VM11; (**10**) Kamptnerius magnificus Deflandre, 1959, Sample VM11.

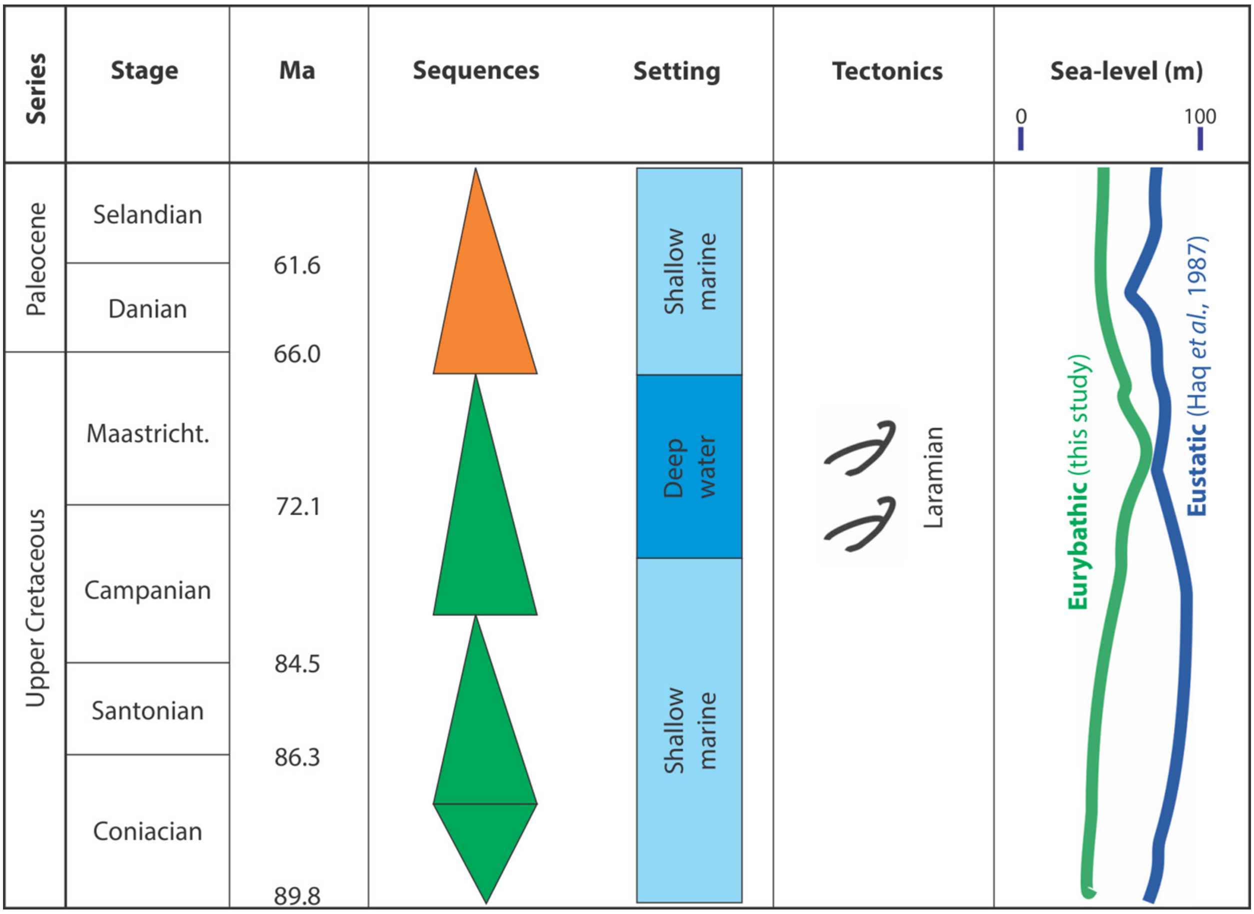

Fig. 9. Sequences in the Cretaceous of the Getic depression and sea-level fluctuations.

6. CONCLUSIONS

We have studied three Upper Cretaceous successions from the central part of the Getic Depression, west of the Olt River; their age is Coniacian, upper part of the lower Campanian, and upper Maastrichtian, as indicated by the calcareous nannofossil investigations. The identified palaeosetting points out changes from a shallow marine palaeoenvironment (Lower Gosau Subgroup) to an open marine one (Upper Gosau Subgroup).

Most probably, the changes in the palaeosetting reflect the Upper Cretaceous active tectonic in the Southern Carpathians, including the mid-Cretaceous movements (Aptian-Albian) and Laramian ones. Possibly, the sea-level fluctuations (eustatic and eurybatic) and climate modifications enhanced the effects of the tectonics.

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