THE HAUTERIVIAN-BARREMIAN BOUNDARY INTERVAL IN THE SOUTHERN CARPATHIANS (BRAŞOV AREA, ROMANIA)

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Abstract. We have studied two successions that crops out around the Braşov town, situated in the Getic Nappe, Southern Carpathians. The studied sections belong to the Braşov Formation, mainly composed of marls, which are rich in macro-, microfauna and calcareous nannofossils. The micropalaeontologic studies reveal that the investigated successions are Early Cretaceous in age, covering the upper Hauterivian to lower Barremian interval.

Key words: Lower Cretaceous; Braşov unit; lithostratigraphy; biostratigraphy; correlation

1. INTRODUCTION

Lower Cretaceous deposits occur on large areas in the Romanian Carpathians. These sediments display a variety of facies, mainly a turbiditic one in the Eastern Carpathians, predominant pelagic and hemipelagic in the Southern Carpathians, while in the Apuseni Mountains both turbidites and hemipelagites occur (i.e., Patrulius *et al.*, 1977; Ianovici *et al.*, 1976; Jipa, 1980; Săndulescu, 1984, 1994; Ştefănescu and Melinte, 1996; Bădescu, 1997, 2005; Melinte-Dobrinescu and Jipa, 2008; Melinte-Dobrinescu *et al.*, 2009; Jipa *et al.*, 2020).

During the Late Jurassic–Early Cretaceous interval, the Southern Carpathians, placed those times at the northern passive margin of the Neo-Tethys, between 19º and 24ºN palaeolatitude (Panaiotu, 1998; Roban *et al.*, 2020), were characterized by the deposition of a carbonate platform, described as the Getic Carbonate Platform (Patrulius, 1969). Its sediments display complete Lower Cretaceous successions in various regions of the Southern Carpathian belt, starting from the Berriasian and ending in the lower Aptian, when siliciclastic deposits occurred and carbonate deposition ended (i.e., Dumitrescu *et al.*, 1962; Patrulius, 1969; Lupu and Zacher, 1996; Barragán and Melinte, 2006), coincident with the initiation of the meso-Cretaceous tectonics.

This work is focused on the Lower Cretaceous deposits that crop out in the eastern part of the Southern Carpathians, around the Braşov town (Fig 1). We studied a pelagic succession, namely the Braşov Formation, known for its macrofaunas (ammonites) and microfaunas (foraminifers).

We performed a detailed sampling and made calcareous nannofossils analyses, to accurately date this unit. Our findings allow the correlation of the studied Lower Cretaceous sediments with other deposits of the same age cropping out in the Carpathian area and with similar successions from the Tethyan Realm.

2. GEOLOGICAL SETTING

The entire studied area around the Braşov town is included, tectonic point of view, within the Getic Nappe, a major structural element of the Southern Carpathians.

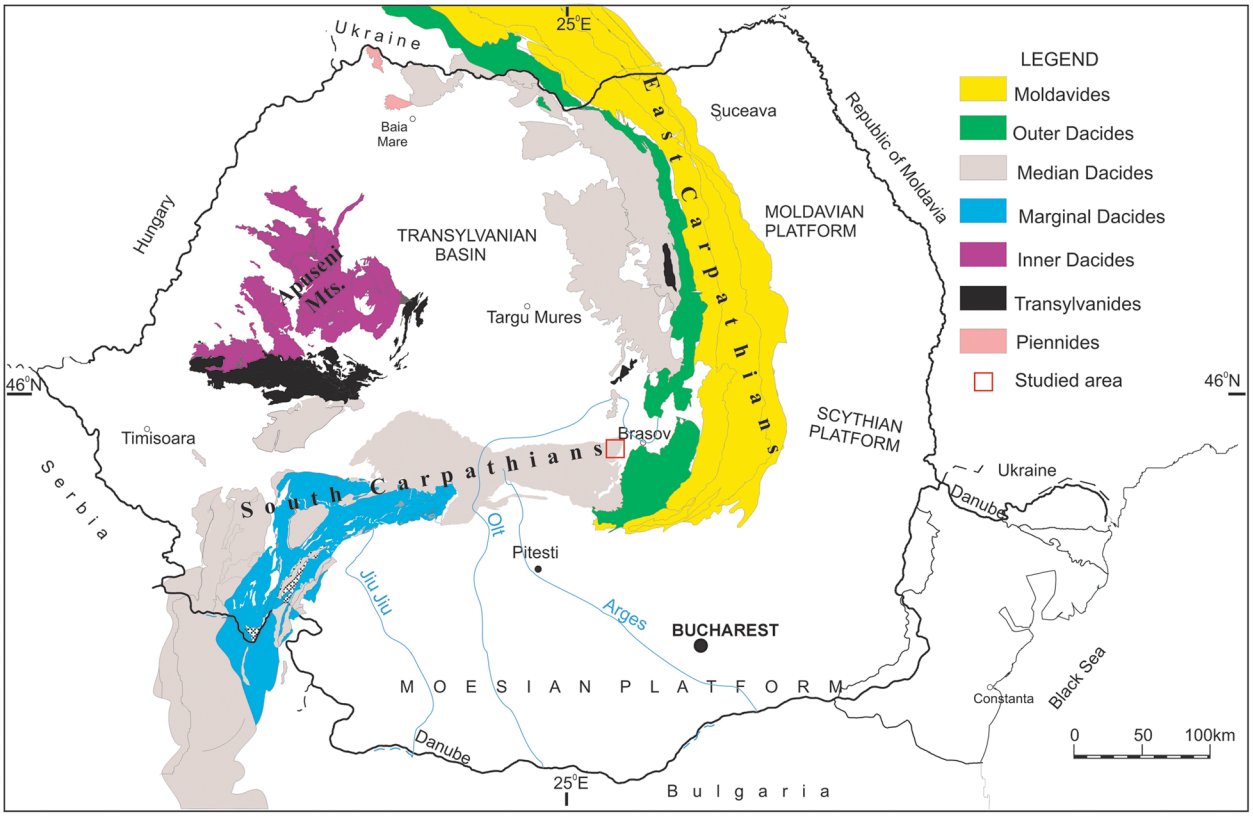

Fig. 1. Tectonic map of Romania showing the location of the samples (modified after Săndulescu, 1984; Bădescu, 2005).

The formation namely "The Braşov Marls" was firstly described as "Neocommergel der Serie von Braşov" (Jekelius, 1938), while later the lithological unit was mentioned as "Deposits of the Dîmbovicioara Series" (Patrulius, 1963; Patrulius *et al.*, 1967a and 1967b); "Braşov Marls" (Săndulescu, 1966) and "Dîmbovicioara Formation" (Patrulius and Avram, in Patrulius *et al.* 1977). The formal name of this unit, i.e., the Braşov Formation, was introduced by Avram and Grădinaru (1993).

The Braşov Formation has a limited areal occurrence, around the Braşov town, including in the SW part of the Tâmpa Hill and in the Scheii Braşovului, nearby the Saint Nicholas Church, as well as in the Poiana Braşov resort (i.e., Sticlăria Valley), and around the Codlea town, in the Piatra Mare Quarry (Săndulescu *et al.*, 1972a and 1972b). Most outcrops of the Braşov Formation are no longer preserved, due the expansion of the buildings in the above-mentioned areas during the last decades.

The Braşov unit discordantly covers older Jurassic (i.e., Bathonian to Kimmeridgian) hemipelagic deposits, such as limestones and calcarenites, and are transgressively overlayed by upper Lower Cretaceous sediments, i.e., Albian conglomerates, sandstones, and breccia The Braşov Formation is in general thin, up to 8-10m stratigraphical thickness. The base of the Braşov Formation is exposed in Valea Lată (eastern area of Măgura Codlei), where compact, grey, and yellowish calcareous marls discordantly cover Middle to Upper limestones and breccia (Săndulescu, 1966). In the Postăvaru Mts., the succession begins with glauconitic limestones (Dracului Brook), while in Căldării Brook (in Poiana Braşov) a 0.5m-thick glauconitic limestone is located towards the middle of the Braşov Marls (Săndulescu, 1964).

Previous studies (Avram and Grădinaru, 2001) indicated that a complete succession of the Braşov Formation, adequate to be selected as type section of this unit, does not appear at present in its spreading area. Except the exposures of the Piatra Mare Quarry (SW of Codlea Town), where the basal part of the formation, around 4 m-thick crops out, all the other exposures preserve stressed successions, composed of dm-thick marls, limestones, and cm-thick calcarenites.

The age of the Braşov Formation was attributed, based on its, macro- and microfaunas, to the Valanginian-Barremian interval, according to data from several outcrops exposed in the Postăvaru Mts., Braşov town, and Poiana Braşov (Patrulius, 1963, 1969; Săndulescu, 1964, 1966; Patrulius *et al.*, 1977; Săndulescu-Ion, 1970; Avram, 1983; Avram and Grădinaru, 1993). The base of the marls belonging to the Braşov unit, is placed in the Verrucosum ammonite zone, late Valanginian in age, while the top is placed in the lower Barremian (Avram and Grădinaru, 2001).

3. MATERIAL AND METHODS

We have studied two successions of the Brașov Formation: Section 1 is placed in the Brașov town (on the path that goes up the Tâmpa Hill) and Section 2 in the Sticlăria Valley and its right tributary, Căldării Brook, located west of Poiana Brașov (Fig. 2). Section 1 yielded a very few occurrences, up to 1 m thick, most of them covered by vegetation. In this succession, the occurrence of the Brașov Formation is due to the tectonics of the area (Săndulescu *et al.*, 1972b), i.e., faulted Upper Jurassic (Kimmeridgian-Tithonian) limestones, on top of them being placed the Lower Cretaceous marls (Fig. 2). In this area, south of the Tâmpa Hill, in the 19th Century, Herbich (1872) and later, Avram and Gradinaru (1993) collected from outcrops a rich fauna of ammonites (hosted in the collections of the Department of Geology of the Faculty of Biology and Geology, Babeș-Bolyai University, Cluj-Napoca), which contain, among other species: *Phyllopachyceras hurqui* (COLLIGNON), *Lytoceras* cf. *subfimbriatum* (d'ORBIGNY), *Crioceratites* cf. *nolani* (KIL.), *C.* cf. *villersianum* (d'ORBIGNY), *Pseudothurmannia* sp., *Acanthodiscus* aff. *radiatus* (BRUG.), *Paraspinoceras jourdani* (ASTIER), *Bochianites* cf. *renevieri* (OOSTER), and *Haploceras grasianum* (d'ORBIGNY), assemblage indicative for the Hauterivian stage, interval covered by the Radiatus up to the Angulicostata Amonite Zones.

Section 2 exposed 8.2m of grey marls, including the outcrop of the Sticlăriei Valley and Căldării Brook (right tributary).

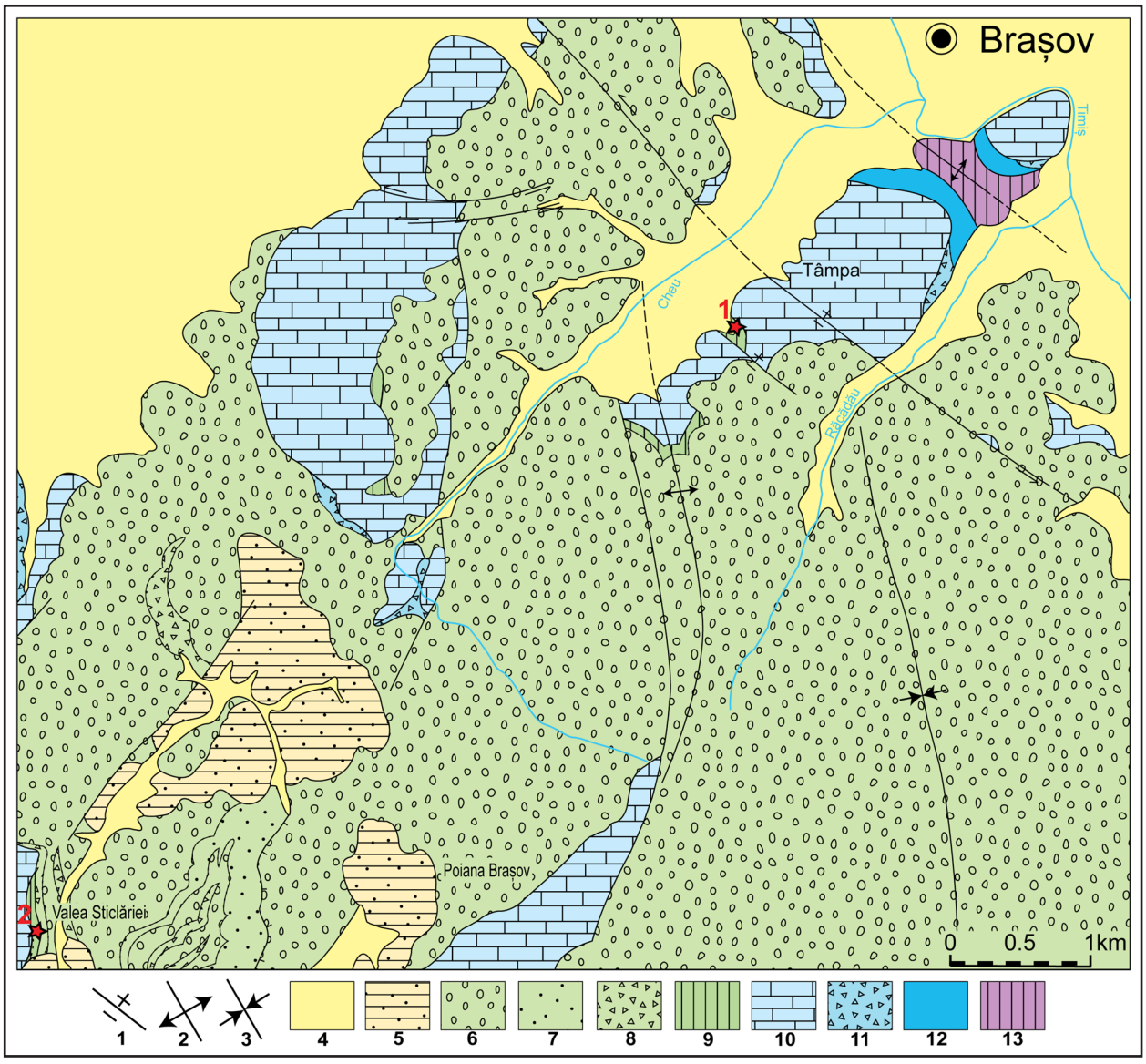

Fig. 2. Map of the studied area around Brașov town, modified after Săndulescu (1964 and 1966) and Săndulescu *et al.* (1972b). *Legend*: **1** - Fault; **2** - Anticline; **3** - Syncline; **4** - Quaternary; **5** - Quaternary-Neogene; **6** - Albian conglomerates; **7**- Albian sandstones; **8** - Albian breccias; **9** - Lower Cretaceous marls; **10** - Upper Jurassic limestones; **11**- Jurassic breccia; **12** - Middle Jurassic limestones.; **13** - Triassic limestones. Studied sections (red stars): **1** - Brașov town (Tâmpa Hill); **2** - Sticlăria Valley.

The marls of the Braşov unit discordantly cover the Upper Jurassic limestones, while on the top they are overlaid by Albian breccia and conglomerates, according to Săndulescu *et al.*, 1972b (Fig. 2). We studied *in situ* and performed a detailed sampled of this section in the years 1996-2000. Unfortunately, the exposures are not constantly visible, as in Poiana Braşov, where Section 2 is placed, as new building were erected and the main part of the outcrops is now covered.

From the marls of the Braşov unit, exposed on the right bank of the Sticlăriei Valley and the right tributary Căldării Brook near the "Aviatorilor" chalet, a rich fauna of ammonites (presently hosted in the Geological Museum of the Geological Institute of Romania, Bucharest) was reported by Săndulescu-Ion (1970) and Avram and Gradinaru (2001), enclosing: *Pseudovaldedorsella*? sp., *Pseudobelus brevis* (PAQUIER), and *Crioceratites* ex. gr. *duvali* LEV. Some 80 m upstream on the same tributary, the macrofaunas contains *Holcophylloceras*? cf. *tethys* (d'ORB.), *Phyllopachyceras* ex. gr. *infundibulum* (d'ORB.), *Pseudothurmannia mortilleti* (PICT. & LOR.), *Hibolites jaculum* (PHILL.), *Duvalia dilatata* (BL.), *Crioceratites duvali* LEV., *C. nolani*, *Euptychoceras* cf. *cuvilieri* THIEULOY, *Haploceras* (*Neolissoceras*) *grasianum* (d'ORBIGNY), and *Duvalia dilatata binervioides* STYOY ANOV A-VERGILOV A. This assemblage indicates a Hauterivian age.

We studied the lithology of the above-mentioned sections and we sampled them in detail for calcareous nannofossil analysis. A total of 31 samples were taken from the two studied successions, 8 from the Braşov town (Tâmpa Hill) and 24 from the Sticlăria Valley. Smear slides were prepared using the standard smear slide method of Bown and Young (1998). The slides were examined under a Light Microscope (LM) Olympus, in crossed nicols and polarized-light. Specific and generic determination of nannofossils follows Perch-Nielsen (1985), Bralower *et al.* (1989), Bown *et al.* (1998), and Bown (2005).

4. RESULTS

Both studied sections are represented, lithologically point of view, by grey marls, exposed in cm-thick beds. In the composite section Sticlăria Valley - Căldării Brook (from Poiana Braşov), two glauconitic limestones, up to 70cm-thick were identified in the lower and towards the upper parts of the succession (Fig. 3).

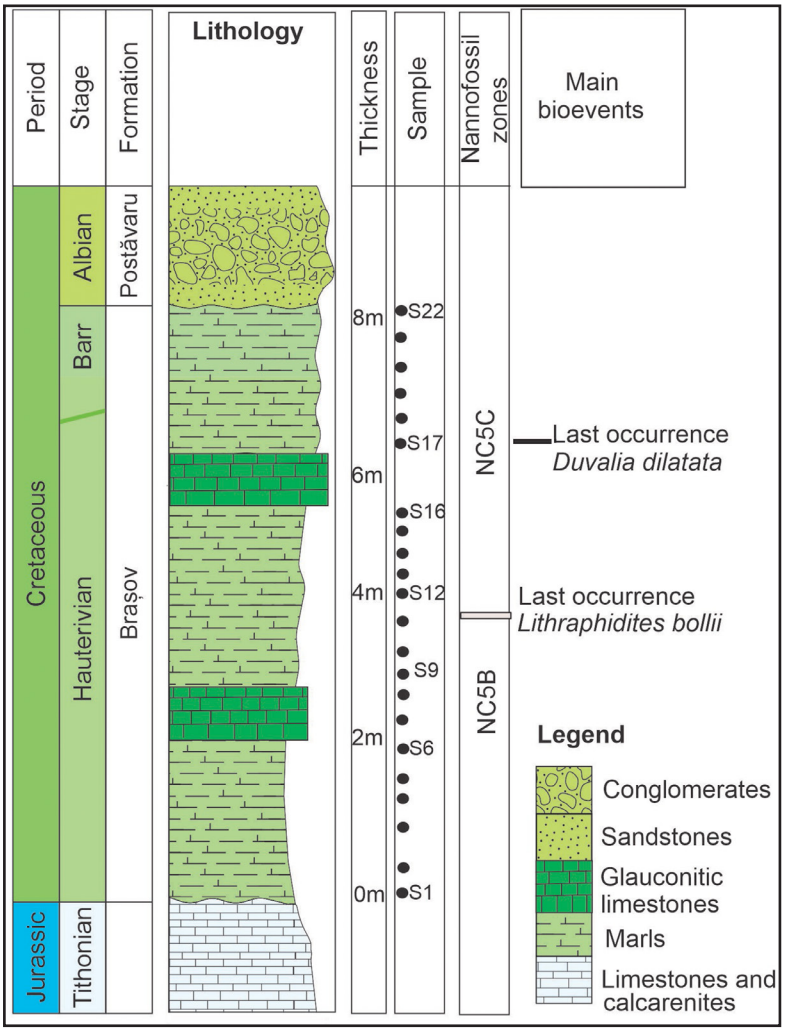

Fig. 3. Litho- and biostratigraphy based on the calcareous nannofossils of the composite section Sticlăria Valley - Căldării Brook (Poiana Braşov).

All the observed nannofossil assemblages belong to the NC5 biozone of Bralower *et al.* (1995), as *Hayesites irregularis*, which the FO (first occurrence) marks the base on NC6, was not recorded in the studied samples (Table 1). The presence of *Lithraphidites bollii* in the lower part of the investigated succession is indicative for the NC5B of Bralower *et al.* (1995). This species is rare, but consistently present in the lower part of the successions. Based on the LO (last occurrence) of *Lithraphidites bollii* (Fig. 3 and Table 1), we have pointed out the base of NC5C of Bralower *et al.* (1995).

In all, 47 nannofossil taxa were identified, the assemblages being dominated by Tethyan taxa, especially by the nannoconids, both wide canal nannoconid group (*Nannoconus bucheri*, *N. circularis*, *N. dislocatus, N. globulus*, *N. grandis*, *N. kamptneri*, and *N. wassallii*) and narrow canal nannoconid group (*Nannoconus bermudezii* and *N. steinmannii steinmannii*). The nannoconids represent up to 45% of total assemblages. Other Tethyan taxa, present in the recorded assemblages, are *Conusphaera rothii* and *Calcicalathina oblongata* (Fig. 4 and Table 1). *Watznaueria barnesiae* is present in all analyzed samples, but its abundance never exceeded 27%. Other species of the genus *Watznaueria*, i.e., *W. britannica* and *W. ovata*, are also present. Nannofossils commonly encountered in the studied successions are also species of the genus *Micrantholithus* (*M. hoschulzii* and *M. obtusus*), as well as species of the *Zeugrhabdotus* genus (Table 1).

5. DISCUSSION

In both studied sections, we identified rich and diversified nannofossil assemblages, which have a moderate to good preservation. The nannofossil total abundance observed in the studied samples of both sections varies from 7.4 nannofossils/FOV (field of view) up to 8.3 nannofossils/FOV.

Assemblages are composed mainly of wide- and narrow canals *Nannoconus* spp., warm water taxa of the Tethyan Realm (Busson and Noël, 1991; Erba and Tremolada, 2004); along them, other Tethyan taxa (Busson and Noël, 1991; Street and Bown, 2000; Bown, 2005), such as *Calcicalathina oblongata, Conusphaera rothii,* and *Lithraphidites bollii* occur, but with a lower frequency comparing with the nannoconids.

Watznaueria barnesiae, a cosmopolitan nannofossil that dominates the Lower and Upper Cretaceous assemblages both in the Tethyan and Boreal realms (i.e., Perch-Nilsen, 1985; Mutterlose *et al.*, 2005) does not exceed 27% of total assemblages. According to Roth and Krumbach (1986), nannofossil assemblages that contain over 40% specimens of *Watznaueria barnesiae* are heavily altered by diagenetic processes, which is not the case in the successions studied by us. Other cosmopolitan nannofossils (Erba, 2004; Lees *et al.*, 2005), which yielded a consistent occurrence throughout the studied successions, are species of the genera *Micrantholithus* and *Zeugrhabdotus*.

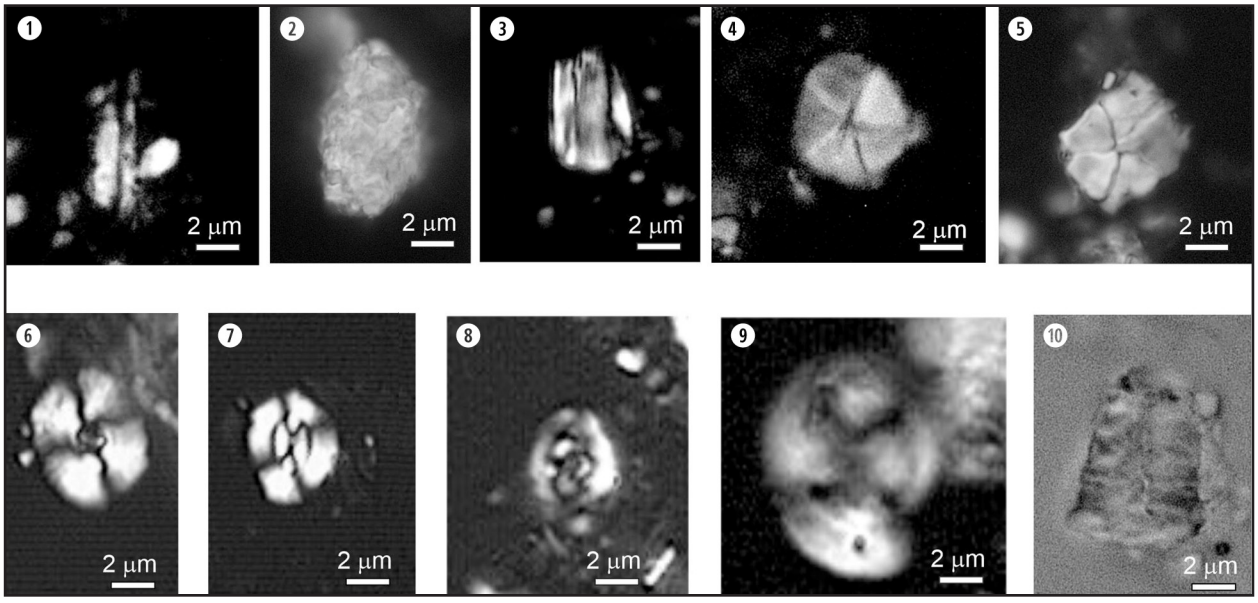

Fig. 4. Microphotographs taken at LM (light microscope), of the calcareous nannofossils identified in the studied successions; NII – crossed nicols 1-9, polarized light 10. Scale bar in microns. **1** - *Lithraphidites bollii* (Thierstein, 1971) Thierstein, 1973; Sample S11. **2** - *Calcicalathina oblongata* (Worsley, 1971) Thierstein, 1971; Sample S21. **3** - *Conusphaera rothii* (Thierstein, 1971) Jakubowski, 1986; Sample S3. **4** - *Micrantholithus hoschulzii* (Reinhardt, 1966) Thierstein, 1971; Sample S16. **5** - *Micrantholithus obtusus* Stradner, 1963; Sample S17. **6** - *Watznaueria britannica* (Stradner, 1963) Reinhardt, 1964; Sample S19. **7** - *Watznaueria barnesiae* (Black *in* Black & Barnes, 1959) Perch-Nielsen, 1968; Sample S21. **8** - *Helenea chiastia* Worsley, 1971; Sample S18. **9** - *Haqius circumradiatus* (Stover, 1966) Roth, 1978**;** Sample S20; **10** - *Nannoconus steinmannii* Kamptner, *1931*; Sample S19.

Table 1. Calcareous nannofossil distribution of the Braşov Formation exposed in the composite section Sticlăria Valley - Căldării Brook (Poiana Braşov).

STAGE	NO. SAMPLE	*Assipetra infracretacea*	*Axopodorhabdus dietzmanii*	*Biscutum* sp.	*Braarudosphaera primula*	*Calcicalathina oblongata*	*Conusphaera rothii*	*Cretarhabdus conicus*	*Cyclagelosphaera deflandrei*	*Cyclagelospjaera margerelii*	*Diazomatolithus lehmanii*	*Diloma galiciense*	*Discorhabdus ignotus*	*Hagius circumradiatus*	*Helenea chiastia*	*Helenea quadrata*	*Hemipodorhabdus gorkae*	*Lithrapidites bollii*	*Lithraphidites carniolensis*	*Manivitella pemmatoidea*	*Micrantholithus hoschulzii*	*Micrantholithus obtusus*	*Naannoconus bermudezii*	*Nannoconus bucheri*	*Nannoconus circularis*	*Nannoconus dislocatus*	*Nannoconus grandis*	*Nannoconus globulus*	*Nannoconus kamptneri*	*Nannoconus steinmannii*	*Nannoconus wassalii*	*Percivalia fenestrata*	*Rhagodiscus asper*	*Rhagodiscus infinitus*	*Retecapsa angustiforata*	*Retecapsa crenulata*	*Rotelapillus crenulatus*	*Rucinolithus* sp.	*Staurolithites mutterlosei*	*Staurolithites stradneri*	*Watznaueria barnesiae*	*Watznaueria britannica*	*Watznaueria ovata*	*Watznaueria manivitae*	*Zeugrhabdotus diplogrammus*	*Zeugrhabdotus embergeri*	*Zeugrhabdotus erectus*	*Zeugrhabdotus xenotus*	NANNOFOSSIL SUBZONES
BARREMIAN	S22		P	P		P	F		P					P	R		P		R	P	F			P				R	R						P	P					F	P				R			NC5C
	S21	P		P	P	P	P				P				F	P	R		R	P	F			P	R	R		R	R	P	P	R				R	F				F	P				F	R	R	
	S20						F	P		P			R	P			P		P	R	F	P			P	P		R	R	R			R		F		R				R	P				P	R		
	S19					P	P	R	P										R		P	P	P	R	R		P	R	R	P			P			P					F	P					R		
	S18	P		F	P	P		R							P		P				F			R		P	P	F	F		R				F	P	R	P	P		C					F		P	
	S17	P		F			R		P	P	P		R	P						P		P					P	F			P	P				P				P	F	P						R	
HAUTERIVIAN	S16						R		F		P			R					R		R		F				P	F							F		R	P			C	P			P		R	P	
	S15		P			P	R	P	P	P					F						P	P		F			P		R	R		P		P		R		F			F	R				P			
	S14			F			P				P		P				R				F								R	R			R			P	R	F			C	R			P				
	S13					R	P	P	R						R				P		F				R	P			R	R			P			R	R		P	P	C					F			
	S12		P							R	P		P		R	P				P	F		F	F	R	P			P				F		R	R		F			F						P		
	S11	R				F	P	P		F					R		R	R	R	R	F	R						F	R			F		P		R					F			P	R	R	P		NC5B
	S10	R		P		R	P						P		R			P			P			R				F		R	R							R		P	C		P	P		R			
	S9			F		R	P	P			R		P	P			R			R	P	F							F	R	P				R		F	R			C		P	P	R	P	P		
	S8	R	P		P	F				F					F		R	R		P		F						F		F		R		P			F			P	P	P		P		P			
	S7	P		F			P				R		P	P			P	P		P	F	P	R	P	P				P		R	R	R	P			F				P	P	P	P	P		P		
	S6		P			P	R	P		R								R				R			P					F	P					R		R	P		C	P	P	P		F		P	
	S5	R				P		P		R			P	P	R		R			P		R	R	R			F			C	P		R		F			P			P			R		F	P	P	
	S4	P		R		R	P		P				P	R		P		P	P	P	F	F		P			R	R		F		F				R		P		R	C			R		F	P		
	S3	P	P		P	F	R	P			P		P		R			R		R	F	F								F			R	P		P	P		P	R	R		P						
	S2	R	R				R		R	R	P		P		R			P	R	P	F	P	R	P			P	P	F	C			R			R	P			R	P	P		R		F			
	S1	P		R		F	R		R	R				F				R			F	F	P					P		F								R		R	C	P	R			F	P		

Legend: P (present) = 1-3 specimens>5 FOVs (fields of view);
R (rare) = 1-2 specimens/5 FOVs;
F (few) = 3-5 specimens/5 FOVs;
C (common) = > 5 specimens/5 FOVs.

Biostratigraphical point of view, the investigated successions belong to the NC5 nannofossil zone of Bralower *et al.* (1995), argued by the absence of *Cruciellipsis cuvillieri*, which the LO (last occurrence) marks the boundary between the NC4 and NC5 zones. According to the above-mentioned authors, the top of the first subzone NC5a of NC5 is delineated by the FO of *Assipetra terebrodentarius*. This species occurs from the base of both studied successions from the Southern Carpathians.

Lithraphidites bollii, which has the FO (first occurrence) in the lower Hauterivian (Mutterlose *et al.*, 2021) is present from the investigated lowermost samples, allowing the assignment of the succession lower parts to the NC5B subzone of Bralower *et al.* (1995). Following the above-mentioned authors, the LO of *Lithraphidites bollii* marks the boundary between the NC5B and NC5C nannofossil subzones. This event was recorded in the studied section of Brașov town (Tâmpa Hill) and in the composite section Sticlăria Valley-Căldării Brook, towards the upper part, and marks the lower boundary of NC5C (Fig. 3).

At the GSSP (Global Boundary Stratotype Section and Point) of the Barremian stage, at Rio Argos, W of the Caravaca town, SE Spain, the boundary between the Hauterivian and Barremian stages is placed between the ammonite zones *Pseudothurmannia ohmi* (subzone *P. picteti*) and *Taveraidiscus hugii* (Company *et al.*, 2024). The above-mentioned authors indicate that the last representatives of the *Pseudothurmannia* genus occur towards the top of the Hauterivian.

In the composite section Sticlăriei Valley and Căldării Brook, herein presented, Avram and Grădinaru (2001) indicate the presence of *Pseudothurmannia* species, i.e., *P. mortilleti* and *P. ohmi*; they traced the boundary between the Hauterivian and Barremian stages at the disappearance of the genus *Pseudothurmannia* representatives.

Besides ammonites, in the studied successions, belemnites, such as *Duvalia dilatata* and *Duvalia pontica*, are present (Săndulescu-Ion, 1970 and this study). In the composite section Sticlăriei Valley-Căldării Brook, the belemnites became extinct in the levels containing the last *Pseudothurmannia* ammonite species.

In terms of nannofossils, the boundary between the Hauterivian and Barremian stages falls, at the GSSP of the Barremian, within the NC5C subzone. We identified the boundary between these two subzones towards the upper part of the studied sections; therefore, the main part of the studied successions is late Hauterivian in age and only their top belongs to the early Barremian.

6. CONCLUSIONS

We have studied two pelagic successions from the Southern Carpathians, located in the Brașov town area. Both sections contain rich and diversified nannofossil assemblages, including Tethyan and cosmopolitan taxa. Based on the nannofossil biostratigraphy, the study depositional interval extends in the upper Hauteriavin to the lower Barremian, covered by the NC5 nannofossil zones, including the NC5B and NC5C subzones of Bralower *et al.* (1995).

The boundary between the Hauterivian and Barremian is placed in the NC5C nannofossil zone, above the disappearance of the last representative of the ammonite genus *Pseudothurmannia* and the last occurrence of the belemnite *Duvalia dilatata*. We conclude that the top of the Brasov unit is situated in the lowermost Barremian.

The nannofossil assemblage composition found in the sections from the eastern Southern Carpathians are similar with those identified in other Tethyan areas within the Hauterivian-Barremian boundary interval, i.e., Italy (Umbria-Marche, Apennines, Central Italy and Venetian Alps, northeastern Italy, Coccioni *et al.*, 1998; Tremolada *et al.*, 2009), SE Spain – Subbetic (Aguado, 2012; Aguado *et al.*, 2014), and SE France (Baudin *et al.*, 1999), allowing good correlation of the main bioevents recorded in the investigated area with southern European regions.

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