Biostratigraphy and microfacies of the pelagic carbonate formations in the Yavorets section (Tithonian–Berriasian), Western Balkan Mts, Bulgaria

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Abstract. Calpionellid study has provided new evidence of early and late Tithonian age of the top of the Gintsi Formation, and of late Tithonian and early Berriasian age of the Glozhene Formation in the Yavorets section (Western Balkan Mts, Bulgaria). The calpionellid *Chitinoidea*, *Praetintinnopsella*, *Crassicollaria*, and *Calpionella* zones have been documented in successive order. Three calcareous dinocyst zones – *Colomisphaera tenuis*, *Colomisphaera fortis* and *Stomiosphaerina proxima*, have been determined in this lower Tithonian to lower Berriasian interval. From the base upwards, the following microfacies have been recognized: *Saccocoma* (Gintsi Formation, lower and upper Tithonian), *Globochaete alpina*, and calpionellid (Glozhene Formation, upper Tithonian and lower Berriasian). The base of the Berriasian has been traced at the explosion of the uniformly shaped spherical variety of *Calpionella alpina*. Evolutionary lineages of species of the genus *Calpionella* are discussed, as well as the vertical distributions and abundance peaks of crassicollarians. The calpionellid zones described herein are correlated with coeval zonations from the Western, Central and Eastern Tethyan domains. The regional correlation with previously studied sections of Tithonian/Berriasian pelagic carbonates in the Western Balkan Mts revealed a transition to hemipelagic deposition of the limestone-marl succession of the Salash Formation and/or sandstone accumulation during the middle to late Berriasian (*Elliptica* and *Simplex* calpionellid subzones) due to unstable conditions of the sedimentary environment. From the west to the east in the Western Balkan Unit (*i.e.*, from the Rosomač section in eastern Serbia to the Sarbenitsa, Bov and Yavorets sections in the Iskar River Valley area), there is a trend of slight progressive deepening of the basin. This is manifested in the occurrence of redeposited shallow-carbonate-platform microfossils in the west to greater thicknesses of the Gintsi and Glozhene formations and occurrence of sandstone channel deposits in the east.

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INTRODUCTION

The outcrops of the Yavorets, Gintsi and Glozhene formations around Yavorets Peak in the Yavorets syncline represent the easternmost ones in the West Balkan Mts (Fig. 1). To the west, the sections of Gintsi, Komshtitsa, Barlya, and the one in Rosomač in eastern Serbia have remained better studied for decades in terms of ammonite, calpionellid and calcareous dinocyst biostratigraphy, and carbonate

microfacies. The biostratigraphic and microfacies results yielded in this study are continuation of previous researches.

The purpose of this study is to erect calpionellid and calcareous dinocyst biostratigraphy and recognize microfacies of the top of the Gintsi Formation and the Glozhene Formation, and to correlate the results with the westerly-located sections at Gintsi and Barlya. The whole section of pelagic limestones on the western slope of Yavorets Peak reveals a

Fig. 1. Location of the studied section: a) Tectonic subdivision of Bulgaria (after Dabovski and Zagorchev, 2009; modified); b) Geographic position of the section (the map is a satellite image taken from Google Earth); c) Geological map of the studied area and position of the section (after Angelov *et al.*, 1992; simplified).

continuous succession of the Yavorets, Gintsi, Glozhene and Salash formations and covers the time interval from the Callovian–Oxfordian to the late Berriasian. Its detailed description, calpionellid and calcareous dinocyst biostratigraphy, carbonate microfacies, and extensive illustration will be a subject of another publication.

LITHOSTRATIGRAPHY AND PREVIOUS STUDIES

Nikolov and Sapunov (1970) introduced three formations of pelagic limestones, which are largely represented in the Western Balkan Mts, namely the Yavorets, Gintsi, and Glozhene formations in ascending stratigraphic order. All three are included in the Western Balkan Carbonate Group. These formations build up the western slope of Yavorets Peak, which is the location of this study. Sapunov (1976) described this section, mention-

ing its lithologic features, the ammonite finds, and thicknesses.

Gintsi Formation

Sapunov (1977a, b) recognized the *Hybonoticer* *beckeri* (uppermost Kimmeridgian) and *Hybonoticer* *hybonotum* (lowermost Tithonian) ammonite zones in the Gintsi Formation, in the uppermost packages 6 and 7, respectively, beneath Yavorets Peak. These levels occur below the strata with the first chitinoideids, which are described herein.

From a section at Bov Village, situated ~2 km to the west of the studied profile at Yavorets Peak, Metodiev and Sapunov (2008) reported new ammonite finds in the Gintsi Formation. Thus, the chronostratigraphic extent of this formation in the area has previously been documented as ranging from the lower Kimmeridgian [*Ataxioceras* (*Parataxioceras*) *desmoides* Zone] to the lower Tithonian [*Hybonoticer* *hybonotum* Zone].

Glozhene Formation

Mandov (1972) cited earlier finds of the brachiopod *Pygope janitor* (Pictet, 1868) and of the calpionellid species *Calpionella alpina* Lorenz, 1902 and *Calpionella elliptica* Cadisch, 1932 from the sediments of Glozhene Formation in the Yavorets syncline. He also placed the Jurassic/Cretaceous boundary at the top of the formation. Petrova (2010) revised these data and referred the upper part of the formation to the upper Berriasian, i.e., Jurassic/Cretaceous boundary passes down-section in the Glozhene Formation.

MATERIAL AND METHOD

A total of 30 samples were collected throughout the 77.5-m thick interval of the Yavorets section. Sampling density depends on exposure, the average intervals being from 2 m (samples Ya 23–Ya 32) to 1.5–5 m (samples Ya 33–Ya 52). The taxonomic identification of calpionellids and calcareous dinocysts was performed in the Geological Institute, Sofia, using Jenaval (for calpionellids) and Amplival (for calcareous dinoflagellate cysts) transmitting light-microscopes. The limestones were classified, using the textural scheme of Dunham (1962). Microfacies were determined based on the predominant microfossil content, in accordance with the paleontological microfacies of Reháková *et al.* (2011). In addition, one of the microfacies is correlated with the Standard Microfacies Types (SMF) of Flügel (2004). Thin-sections are hosted in the Department of Paleontology, Stratigraphy and Sedimentology of the Geological Institute “Str. Dimitrov” (Sofia, Bulgaria).

DESCRIPTION OF THE YAVORETS SECTION

The Yavorets section is located to the east of the right bank of the Iskar River, east of the village of Bov (Sofia District), on the western slope of Yavorets Peak (Fig. 1b; 43°02'08.29" N; 23°24'01.05" E). The section covers a part of the pelagic carbonates of the Yavorets syncline (Western Balkan Mts) (Fig. 1a–c). Sampling for the micropaleontological and microfacies studies follows the descriptions of the Yavorets, Gintsi and Glozhene formations of Sapunov (1976). Our investigation covers the topmost package of the Gintsi Formation and the whole Glozhene Formation. The section is herein described from the base upwards.

The Gintsi Formation (11 m thick) is represented by an alternation of light gray to pale rose-colored

thin-bedded or medium-bedded intraclastic limestones with medium-bedded nodular limestones and single layers of light gray thin-bedded micritic limestones (Fig. 2a, b).

The overlying Glozhene Formation (66.5 m thick) is characterized by an alternation of gray thin- to medium-bedded intraclastic limestones with gray medium-bedded nodular limestones in the lower part (Fig. 2c, d) and an alternation of dark gray thin- to medium-bedded micritic limestones with gray thin- to medium-bedded clayey limestones in the upper part (Fig. 2e, f).

CALPIONELLID BIOSTRATIGRAPHY

A continuous succession of the calpionellid *Chitinoidea*, *Praetintinnopsella*, *Crassicollaria* zones and the lower part of the *Calpionella* Zone is herein described (Fig. 3). The definitions of the chitinoideid and calpionellid zones and subzones follow those of Remane *et al.* (1986), Reháková (1995), Reháková and Michalík (1997), Pop (1994b, 1997b), and Lakova and Petrova (2013).

A thorough review of interregional correlation of these zones and their subzones can be found in the work of Lakova and Petrova (2013). Only recently published zonations in Tunisia, Slovakia, Argentina, and elsewhere are included in this paper for correlation purpose (e.g., Boughdiri *et al.*, 2009; Michalík *et al.*, 2016; Kietzmann, 2017).

Chitinoidea Zone

The zone is defined at the first occurrence (FO) of microgranular-walled chitinoideids. It became evident that chitinoideids are absent from most of the Gintsi Formation and that they have their FO in sample Ya 24 in the upper package of the Gintsi Formation.

Chitinoideids in the Yavorets section are remarkably diverse in species as those from the South Carpathians in Romania (Pop, 1997a, 1998a, b), Tunisia (Boughdiri *et al.*, 2009; Sallouhi *et al.*, 2011), and Morocco (Benzaggagh *et al.*, 2010).

Chitinoideids have been largely observed in the topmost package of the Gintsi Formation and at the base of the Glozhene Formation. The abundance is as great as at the Gintsi and Barlya sections (see Lakova and Petrova, 2013) and is much greater than in coeval Tithonian strata of the Western Carpathians in Slovakia (D. Reháková, pers. comm.). A total of 21 chitinoideid species have been identified (Figs 3–5). The *Chitinoidea* Zone was divided into the *Longicollaria dobeni* and *Chitinoidea boneti* subzones (Fig. 3), the

Fig. 2. Views from the Yavorets section with sample numbers: a) Alternation of light gray thin-bedded intraclastic limestones with medium-bedded nodular limestones and single layers of light gray thin-bedded micritic limestones of the Gintsi Fm. (lower Tithonian); b) Gray medium-bedded intraclastic limestones of the Gintsi Fm. (upper Tithonian); c) Alternation of gray thin- to medium-bedded intraclastic limestones with gray medium-bedded nodular limestones from the lower part of the Glozhene Fm. (upper Tithonian); d) Medium-bedded gray nodular limestones from the lower part of the Glozhene Fm. (upper Tithonian); e) Alternation of dark gray thin- to medium-bedded micritic limestones with gray thin- to medium-bedded clayey limestones of the Glozhene Fm. (lower Berriasian); f) Medium-bedded gray micritic limestones from the top of the Glozhene Fm. (lower Berriasian).

base of the *Boneti* Subzone being accepted as the base of the upper Tithonian (see Benzaggagh *et al.*, 2010). Many chitinoideid species also occur

upwards in the *Praetintinnopsella* Zone and in the *Remanei* Subzone of the *Crassicollaria* Zone (Fig. 3).

[illegible]

Longicollaria dobeni Subzone

rumanica, *Borziella slovenica*, *Dobeniella colomi*, *Dobeniella tithonica*, and *Dobeniella* sp. (Figs 3, 4). The *Dobeni* Subzone was documented in samples Ya 24, Ya 25, and Ya 26. Its thickness is ~6 m. Down-section, no chitinoideidellids were observed. This subzone correlates well with the homonymous subzone in the Western Carpathians in Slovakia (Reháková, 1995), South Carpathians in Romania (Pop, 1997b), and Tunisia (Boughdiri *et al.*, 2009).

Fig. 4. Chitinoideids from the Yavorets section: 1–4) *Longicollaria dobeni*, sample Ya 25 (1–2), sample Ya 24 (3), sample Ya 26 (4); 5–8) *Borziella slovenica*, sample Ya 24 (5, 8), sample Ya 25 (6, 7); 9–12) *Daciella almajica*, sample Ya 26 (9), sample Ya 24 (10–12); 13–16) *Daciella banatica*, sample Ya 24; 17–20) *Daciella danubica*, sample Ya 24; 21–24) *Daciella svinitsensis*, sample Ya 24; 25–28) *Dobeniella colomi*, sample Ya 25 (25), sample Ya 24 (26–28); 29) *Dobeniella tithonica*, sample Ya 25; 30) *Carpathella rumanica*, sample Ya 29; 31–33) *Daciella* sp., sample Ya 26 (31), sample Ya 30 (32–33); 34–36) *Longicollaria insueta*, sample Ya 28 (34, 35), sample Ya 31 (36); 37–38) *Popiella oblongata*, sample Ya 28 (37), sample Ya 30 (38); 39–42) *Chitinoidea boneti*, sample Ya 29 (39–41), sample Ya 31 (42). The scale bar is 50 µm.

Chitinoidea boneti Subzone

This subzone occupies the uppermost part of the Gintsi Formation and a transitional package of gray nodular and intraclastic limestones between the typical Gintsi and Glozhene formations (samples Ya 27, Ya 28, and Ya 29) and its thickness could be assessed to about 6 m. The index-species *Chitinoidea boneti* co-occurs with *Chitinoidea elongata*, *Almajella cristobalensis*, *Dobeniella bermudezi*, *Dobeniella cubensis*, *Popiella oblongata*, *Longicollaria insueta*, *Chitinoidea popi*, *Chitinoidea hegarati*, *Chitinoidea carthagensis*, and *Dobeniella lubimovae* (Figs 3, 5). Besides, all species from the *Dobeni* Subzone continue ranging in the *Boneti* Subzone, too. This diverse association suggests a reliable correlation with the *Boneti* Subzone from Slovakia, Romania and Tunisia.

Praetintinnopsella Zone

The *Praetintinnopsella* Zone normally coincides with the fast transition between the Gintsi and Glozhene formations, which is lithologically manifested in predominance of micritic and intraclastic limestones and rapid decrease and disappearing of clayey nodular limestones (Lakova *et al.*, 2007; Lakova and Petrova, 2013). In the Yavorets section, the zone occupies the base of the Glozhene Formation (sample Ya 30) (Fig. 3). Its thickness is about 1.5–2 m. The base is defined at the first occurrence of the index-species *Praetintinnopsella andrusovi*, which is very abundant. Other species, ranging up from the *Boneti* Subzone, are *Chitinoidea boneti*, *Dobeniella cubensis*, *Dobeniella bermudezi*, *Popiella oblongata*, *Longicollaria insueta*, *Chitinoidea popi*, *Chitinoidea hegarati*, and *Chitinoidea carthagensis*. There are also rare representatives of the *Dobeni* Subzone, e.g., *Daciella banatica*, *Borziella slovenica*, and *Daciella* sp. (Figs 4, 5).

Crassicollaria Zone

In the Western Balkan Mts, this zone is characteristic for the lower part of the Glozhene Formation

at the Barlya, Komshtitsa, and Gintsi sections (Lakova, 1994; Lakova *et al.*, 2007; Lakova and Petrova, 2013). This was also confirmed in the Yavorets section. The thickness of the *Crassicollaria* Zone, however, reaches ~24 m (samples Ya 31–Ya 40), which suggests a greater rate of sedimentation in comparison to the sections mentioned above and located more westerly. The base of the *Crassicollaria* Zone is defined at the FO of hyaline-walled calpionellids (normally, the FO of *Tintinnopsella carpathica*). The vertical distribution of calpionellid species within this zone confirmed that the recent subdivision into three subzones, namely *Remanei*, *Intermedia*, and *Colomi* (Fig. 3), which was introduced by Pop (1994b) and applied in the Western Carpathians and France (e.g., Reháková *in*: Wimbledon *et al.*, 2013), fits better to the succession of bioevents than all previously used subzonal divisions.

Tintinnopsella remanei Subzone

This subzone occurs in the lower but not the lowermost part of the Glozhene Formation, its thickness being about 10.0 m (samples Ya 31–Ya 35) (Fig. 3). Its base is defined at the first occurrence of *Tintinnopsella carpathica* and, as a whole, at the appearance of hyaline-walled calpionellids. Within the subzone, *Crassicollaria intermedia*, *Crassicollaria brevis*, *Crassicollaria massutiniana*, and *Crassicollaria parvula* also make their FOs. *Praetintinnopsella andrusovi* and all representatives of *Dobeni* and *Boneti* subzones disappeared (Figs 3, 6–8). A specific feature of the *Tintinnopsella remanei* Subzone in the Yavorets section is an earlier occurrence of calpionellid species that generally make their FOs above the top of this subzone (e.g., *Crassicollaria parvula*, *Crassicollaria brevis*, and *Calpionella alpina*). Indeed, these three species are represented by single to rare, atypical specimens.

Crassicollaria intermedia Subzone

Crassicollaria intermedia Subzone was herein used to embrace the middle part of the latest

Fig. 5. Chitinoideids and semichitinoideids from the Yavorets section: 1–4) *Chitinoideella boneti*, sample Ya 31 (1), sample Ya 32 (2), sample Ya 31 (3, 4); 5–8) *Chitinoideella elongata*, sample Ya 31 (5, 7, 8), sample Ya 28 (6); 9–11) *Dobeniella bermudezi*, sample Ya 29 (9), sample Ya 30 (10), sample Ya 28 (11); 12) *Dobeniella lubimovae*, sample Ya 29; 13–16) *Dobeniella cubensis*, sample Ya 29 (13, 15), sample Ya 28 (14), sample Ya 31 (16); 17–20) *Almajella cristobalensis*, sample Ya 28 (17), sample Ya 29 (18, 19), sample Ya 31 (20); 21–24) *Chitinoideella popi*, sample Ya 28 (21), sample Ya 31 (22–24); 25–30) *Chitinoideella carthagensis*, sample Ya 31 (25, 26, 28, 29), sample Ya 32 (27), sample Ya 30 (30); 31–36) *Chitinoideella hegarati*, sample Ya 29 (31–34), sample Ya 31 (35), sample Ya 30 (36); 37–42) *Praetintinnopsella andrusovi*, sample Ya 30 (37–39), sample Ya 31 (40–42). The scale bar is 50 μm .

Tithonian *Crassicollaria* Zone. It confines strata between the FOs of *Calpionella grandalpina* and *Crassicollaria colomi* (see Pop, 1994b). Its thickness is 5.5 m (samples Ya 36–Ya 37) (Fig. 3). In the studied section, *Crassicollaria brevis* shows a well-pronounced level of abundance in the middle and upper parts of the *Crassicollaria* Zone (*Intermedia*+*Colomi* subzones). The *Crassicollaria intermedia* Subzone, as a whole, is characterized by diversity and abundance of crassicollarians (*Crassicollaria intermedia*, *Crassicollaria massutiniana*, *Crassicollaria brevis*, and *Crassicollaria parvula*) (Fig. 7). The base is defined by the FO of the large variety of *Calpionella alpina* (see Remane *et al.*, 1986; Pop, 1994b), widely known and accepted as a distinct species, i.e., *Calpionella grandalpina* (see Nagy, 1986; Houša, 1987; Reháková, 1995; Reháková and Michalík, 1997; Lakova *et al.*, 1999; Michalík and Reháková, 2011; Benzagagh *et al.*, 2012; Petrova *et al.*, 2012; Lakova and Petrova, 2013; Wimbledon *et al.*, 2013; Michalík *et al.*, 2016, 2019; Atasoy *et al.*, 2018; Košťák *et al.*, 2018; Kowal-Kasprzyk and Reháková, 2019; Svobodová *et al.*, 2019) (Figs 3, 6). *Calpionella alpina* (the small spherical form), which makes its FO just below the base of the *Intermedia* Subzone, progressively increases in abundance so that, at the top of the *Crassicollaria* Zone, it is as abundant as *Calpionella grandalpina* and, at the base of the *Calpionella* Zone, *Calpionella alpina* practically dominates the association.

Crassicollaria colomi Subzone

The base is defined at the FO of *Crassicollaria colomi*. The subzone represents the topmost Tithonian, its thickness here being 8.5 m (samples Ya 38–Ya 40) (Fig. 3). The association is rich in crassicollarians, such as *Crassicollaria intermedia*, *Crassicollaria brevis*, and *Crassicollaria massutiniana*, ranging from the underlying subzones. *Calpionella grandalpina* and *Calpionella alpina* are, however, also common. At the top of the subzone, a characteristic form with a highly elongated lorica, which has commonly been reported as “*Calpionella elliptalpina*” or as “homeomorph of *Calpionella ellipt-*

tica” in older publications, manifests a short range just below the *Crassicollaria/Calpionella* zonal boundary (Figs 3, 6).

Calpionella Zone

The *Calpionella* Zone (*Alpina* and *Remaniella* subzones) corresponds to a ~38.5-m thick interval of the Glozhene Formation at the Yavorets section (samples Ya 41–Ya 52, see Fig. 3). The lower boundary of the zone is placed at the explosion of the uniformly shaped spherical variety of *Calpionella alpina*. This is the primary marker for fixing the J/K boundary (see Wimbledon, 2017). The *Crassicollaria/Calpionella* zonal boundary, respectively the J/K boundary, is traced at about 28 m above the base of the Glozhene Formation.

Calpionella alpina Subzone

The base of the *Calpionella alpina* Subzone is defined, and is herein documented by, the sudden increase of *Calpionella alpina*, and the abrupt decline of *Calpionella grandalpina* and all crassicollarians except for the longer-ranging *Crassicollaria parvula*. The elongated elliptical form *Calpionella* “*elliptalpina*” never occurs above the top of the *Crassicollaria* Zone. The last rare to single specimens of *Crassicollaria massutiniana*, *Crassicollaria brevis*, *Crassicollaria intermedia* and *Calpionella grandalpina* were observed within the *Calpionella alpina* Subzone (above sample Ya 41). Normally, *Tintinnopsella carpathica*, *Crassicollaria parvula*, and *Calpionella alpina* occur throughout the subzone, and *Crassicollaria colomi* disappears in the mid-upper part. Three subsidiary bioevents have been registered in the lower-middle *Alpina* Subzone, namely the FOs of *Calpionella minuta*, *Tintinnopsella doliphormis*, and *Calpionella* sp. A. The subzone is of significant thickness, estimated to 35 m, samples Ya 41–Ya 50 (Figs 3, 6–8).

Remaniella ferasini Subzone

The *Remaniella ferasini* Subzone covers a 3.5-m thick interval of the Glozhene Formation (samples

Fig. 6. Calpionellids of the genus *Calpionella* of the Yavorets section: 1–5) *Calpionella grandalpina*, sample Ya 36; 6–10) *Calpionella elliptalpina*, sample Ya 39 (6–8), sample Ya 40 (9, 10); 11–18) *Calpionella alpina* (small variety), sample Ya 37 (11), sample Ya 36 (12), sample Ya 47 (13–16), sample 48 (17), sample Ya 51 (18); 19–24) *Calpionella alpina* (small spherical form), sample Ya 44 (19–21), sample Ya 46 (22–24); 25–33) *Calpionella alpina* (large variety), sample Ya 40 (25), sample Ya 44 (26), sample Ya 47 (28), sample Ya 48 (30), sample 51 (29, 31–33), sample 52 (27); 34–38) *Calpionella minuta*, sample Ya 45 (34), sample Ya 47 (35), sample Ya 51 (36–38); 39–42) *Calpionella* sp. A (transitional form between *Calpionella alpina* and *Calpionella elliptica*), sample Ya 45 (39), sample Ya 51 (40–42). The scale bar is 50 µm.

Ya 51 to Ya 52, top of the section; see Fig. 3). The lower boundary is defined by the first record of the index-species *Remaniella ferasini*. The FOs of *Remaniella duranddelgai* and *Remaniella colomi* were also recorded at the same level. The association of the subzone is complemented by *Tintinnopsella carpathica*, *Crassicollaria parvula*, *Calpionella alpina*, *Calpionella minuta*, *Calpionella* sp. A, as well as by rare specimens of *Tintinnopsella doliphormis* (Figs 6, 8).

NOTES ON CALCAREOUS DINOCYST BIOSTRATIGRAPHY

Calcareous dinocysts are of primary importance for the biostratigraphy of the lower part of the Yavorets section, which includes the top of the Yavorets Formation and the main body of the Gintsi Formation. This will be the subject of another publication. In the herein described stratigraphic interval, three calcareous dinocyst zones have been determined, namely the *Colomisphaera tenuis*, *Colomisphaera fortis* and *Stomiosphaerina proxima* zones (Fig. 3). Definitions of the zones follow that of Ivanova (in: Lakova *et al.*, 1999).

Colomisphaera tenuis Zone

The lower boundary is defined at the FO of the index-species, which coincides with the appearance of chitinoideids (sample Ya 24). Two species are confined in the *Colomisphaera tenuis* Zone: *Colomisphaera cieszynica* and *Colomisphaera radiata*. *Crustocadosina semiradiata semiradiata* makes its FO at the base of this zone.

Longer-ranging calcareous dinocysts from the Oxfordian and Kimmeridgian continue occurring in this zone, *e.g.*, *Colomisphaera lapidosa*, *Colomisphaera carpathica*, *Colomisphaera nagy*, *Colomisphaera pieniniensis*, *Committosphaera sublapidosa*, and *Cadosina fusca fusca* (Figs 3, 9). Two of them, *Colomisphaera nagy* and *Colomisphaera pieniniensis*, disappear in the upper part of the zone. Of interest is mentioning the presence of *Cadosina fusca fusca* and *Crustocadosina semiradiata* semi-

radiata as auxiliary criteria for tracing the base of this zone.

The *Colomisphaera tenuis* Zone in this section corresponds to the topmost Gintsi Formation and the basal strata of the Glozhene Formation. Its thickness is 13.5–14 m (from samples Ya 23 to Ya 30). The zone correlates directly with the *Chitinoideida* and *Praetintinnopsella* zones, *i.e.*, the lower/upper Tithonian boundary is to be traced above the FO of *Colomisphaera tenuis* (Fig. 3).

Colomisphaera fortis Zone

The FO of *Colomisphaera fortis* marks the lower boundary of this zone. With small exceptions, the calcareous dinocyst association is the same as that of the *Colomisphaera tenuis* Zone (see Figs 3, 9). The last occurrence (LO) of *Colomisphaera tenuis* is at the top of the *Colomisphaera fortis* Zone. The thickness is ~4.0 m (samples Ya 31–Ya 33). In terms of calpionellid biostratigraphy, the *Colomisphaera fortis* Zone directly correlates with the lower half of the *Tintinnopsella remanei* Subzone and is thus a reliable evidence of the early late Tithonian.

Stomiosphaerina proxima Zone

The Tithonian/Berriasian boundary corresponds to the lower part of the *Stomiosphaerina proxima* Zone. The FO of the index-species marks the lower boundary at the level of sample Ya 34 (Fig. 3). Besides the calcareous dinocyst associations mentioned in the *Colomisphaera tenuis* Zone, additional species which occur in the *Stomiosphaerina proxima* Zone are *Colomisphaera fortis*, *Stomiosphaera misolensis*, *Stomiosphaera acculeata*, *Cadosina fusca cieszynica*, and *Colomisphaera lucida* (Fig. 9). Actually, the latter three species are rather characteristic for the Berriasian. The upper boundary of *Stomiosphaerina proxima* Zone has not been determined in the section studied. Normally, it is characterized by the FO of *Stomiosphaera wanneri* Borza, 1969 in the upper Berriasian, *e.g.*, in the Barlya section (see Grabowski *et al.*, 2016).

Fig. 7. Calpionellids of the genus *Crassicollaria* from the Yavorets section: 1–6) *Crassicollaria brevis*, sample Ya 37 (1, 2), sample Ya 38 (3), sample Ya 35 (4, 5), sample Ya 45 (6); 7–12) *Crassicollaria intermedia*, sample Ya 36 (7–10), sample Ya 33 (11), sample Ya 35 (12); 13–18) *Crassicollaria massutiniana*, sample Ya 36 (13, 14), sample Ya 39 (15, 16), sample Ya 35 (17), sample Ya 44 (18); 19–24) *Crassicollaria colomi*, sample Ya38 (19), sample Ya 39 (20), sample Ya 40 (21), sample Ya 43 (22), sample Ya 44 (23), sample Ya 45 (24); 25–30) *Crassicollaria parvula*, sample Ya 37 (25, 26), sample Ya 36 (27), sample Ya 45 (28), sample Ya 44 (29), sample Ya 52 (30). The scale bar is 50 μm .

CARBONATE MICROFACIES

Description

A set of successive microfacies (MF) has been identified through the studied section, based on the predominant microfossil constituents. They correspond to the so-called paleontological microfacies of Re-

háková *et al.* (2011). From the base upwards, these are: *Saccocoma* MF (Gintsi Formation, lower and upper Tithonian); *Globochaete alpina* MF (Glozhene Formation, upper Tithonian), and calpionellid MF (Glozhene Formation, upper Tithonian and lower Berriasian).

The Gintsi Formation is generally characterized by nodular limestones. Its equivalents are the “am-

Fig. 8. Calpionellids of the genera *Tintinnopsella* and *Remaniella* from the Yavorets section: 1–6) *Tintinnopsella remanei*, sample Ya 33 (1), sample Ya 34 (2–5), sample Ya 35 (6); 7–17) *Tintinnopsella carpathica* (different varieties), sample Ya 31 (7), sample Ya 35 (8), sample Ya 33 (9), sample Ya 44 (10), sample Ya 47 (11, 17), sample Ya 43 (13), sample Ya 49 (16), sample Ya 39 (14), sample Ya 37 (15), sample Ya 52 (12); 18–21) *Tintinnopsella doliphormis*, sample Ya 44 (18), sample Ya 47 (19), sample Ya 48 (20), sample Ya 51 (21); 22–24) *Remaniella ferasini*, sample Ya 52 (22, 23), sample Ya 51 (24); 25–28) *Remaniella duranddelgai*, sample Ya 51; 29, 30) *Remaniella colomi*, sample Ya 51. The scale bar is 50 μ m.

monitico rosso superiore”-type pelagic limestones. The indicative microfossil for them is the pelagic crinoid *Saccocoma* that defines the *Saccocoma* MF. It is represented by radiolarian-*Saccocoma* wackestone (Ya 23, Ya 24 and Ya 27); radiolarian-*Globochaete-Saccocoma* wackestone (Ya 25 and Ya 26), and radiolarian-*Globochaete-Saccocoma*

wackestone with intraclasts (Ya 28) (Figs 3, 10). It is worth mentioning that the interval from samples Ya 24 to Ya 28, around the lower/upper Tithonian boundary, contains diverse chitinoideids, although their quantity could not be used to characterize a certain microfacies because the radiolarians, globochaetids and *Saccocoma* considerably prevail over

Fig. 9. Calcareous dinoflagellate cysts from the Yavorets section: 1, 2) *Colomisphaera tenuis*, sample Ya 24 (1), sample Ya 32 (2); 3) *Colomisphaera radiata*, sample Ya 24; 4) *Colomisphaera lapidosa*, sample Ya 25; 5) *Colomisphaera pieniniensis*, sample Ya 25; 6) *Colomisphaera nagy*, sample Ya 25; 7, 8) *Colomisphaera cieszynica*, sample Ya 24 (7), sample Ya 33 (8); 9, 10) *Committosphaera sublapidosa*, sample Ya 24 (9), sample Ya 29 (10); 11–13) *Colomisphaera fortis*, sample Ya 41 (11), sample Ya 35 (12), sample Ya 44 (13); 14, 15) *Colomisphaera carpathica*, sample Ya 24 (14), sample Ya 47 (15); 16, 17) *Stomiosphaerina proxima*, sample Ya 34 (16), sample Ya 37 (17); 18, 19) *Colomisphaera lucida*, sample Ya 46 (18), sample Ya 48 (19); 20) *Stomiosphaera misolensis*, sample Ya 48; 21, 22) *Crustocadosina semiradiata semiradiata*, sample Ya 50 (21), sample Ya 30 (22); 23–26) *Crustocadosina semiradiata olzae*, sample Ya 35; 27–29) *Cadosina fusca fusca*, sample Ya 25 (27), sample Ya 29 (28), sample Ya 52 (29); 30) *Cadosina fusca cieszynica*, sample Ya 43. The scale bar is 50 μ m.

Fig. 10. Microphotographs of *Saccocoma* (a, b), *Globochaete* (c, d) and Calpionellid (e, f) microfacies from the Yavorets section: a) Radiolarian-Saccocoma-Globochaete wackestone – predominantly calcified radiolarians (R), sponge spicules (SS), *Globochaete alpina* (GA) and rare *Saccocoma* remains (S), foraminifera (F), single dolomite rhombohedra (D), single micritic intraclasts (MI) in micrite matrix. Sample Ya 28, Gintsi Fm.; b) Radiolarian-Globochaete-Saccocoma wackestone – boundary between a part of a nodule (N) containing rare calcified radiolarians (R), sponge spicules (SS), *Globochaete alpina* (GA), ostracod test (O) and groundmass enriched predominantly in *Saccocoma* fragments (S), *Globochaete alpina* (GA) and rare calcareous dinocysts (Cd), and chitinoideids (Ch). Sample Ya 25, Gintsi Fm.; c) Radiolarian-Saccocoma-Globochaete wackestone – mainly calcified radiolarians (R), sponge spicules (SS), *Globochaete alpina* (GA) and single quartz grains (Q) and rare calcareous dinocysts (Cd), micritic intraclasts (MI). Sample Ya 29, Glozhene Fm.; d) Radiolarian-Globochaete wackestone – small micrite intraclasts (MI) and single sponge spicules (SS), *Globochaete alpina* (GA) and rare remains of holothurian sclerites (Hs). Sample Ya 33, Glozhene Fm.; e) Calpionellid wackestone – predominantly calpionellids (Ca), rare *Globochaete alpina* (GA), tiny dolomite rhombohedra (D) and single quartz grains (Q) in micrite matrix. Sample Ya 42, Glozhene Fm.; f) Calpionellid wackestone – predominantly calpionellids (Ca) and rare *Globochaete alpina* (GA) in micrite matrix. Sample Ya 52, Glozhene Formation. Note: All images are in plane-polarized light.

the chitinoideids. The pelagic crinoid oscicles still occur over the *Saccocoma* MF, although in considerably reduced amount.

The Glozhene Formation, similarly to all corresponding Biancone-type pelagic limestones in the Tethyan Domain, is rich in *Globochaete alpina* Lombard, 1945 and calpionellids. Consequently, the dominating microfacies are *Globochaete alpina* MF (the base of the Glozhene Formation) and the calpionellid MF (Glozhene Formation, without its first 14 m) (see Figs 3, 10). It is only at the basal part of the formation (Ya 29 to Ya 35), where the calpionellids of the *Praetintinnopsella* Zone and the *Remanei* Subzone are still scarce, that the *Globochaete alpina* wackestone and radiolarian-spicule wackestone were determined, respectively. The calpionellid MF is mainly represented by calpionellid wackestone to mudstone (from Ya 36 to Ya 52). This microfacies corresponds to SMT 3-Calp. (deep basinal facies, Facial zone 1) of Flügel (2004).

Interpretation of the depositional environment

The nodular limestones of the Gintsi Formation were formed on a submarine rise (structural high or pelagic platform), as can be seen from many examples from the Tethyan Domain (Flügel, 2004, and references therein). Nodularization of the original sediments is a diagenetic process well described by Clari and Martire (1996). Two types of nodular limestone were recognized in the studied section: incipient nodular and nodular. Some nodule boundaries in the incipient nodular limestones are sharp but most commonly diffuse, with a gradual transition to the matrix. The matrix of the nodular limestones (rich in *Saccocoma* fragments) possesses pale rose color and nodules are surrounded by it.

The micritic limestones of the Glozhene Formation contain calpionellids, *Globochaete alpina*, radiolarians, and sponge spicules and, most probably, were formed in a deep-water basinal environment (SMT 3, FZ 1, see Flügel, 2004) after drowning of the pelagic platform. These limestones are also very characteristic of the Tethyan Domain as Biancone (Majolica) facies. The sediments were deposited above the calcite compensation depth (CCD) and below the aragonite compensation depth (ACD). This depth range is herein indicated by the presence of calcite skeletons (aptychi, calcareous nannofossils, sometimes brachiopods) and the lack of aragonite ones (Wieczorek, 1988).

The most widely accepted concept is that the nodular limestones were accumulated on a submarine structural high (pelagic swell, pelagic platform) (see Jenkyns, 1974; Jach, 2007). On the other hand,

Flügel (2004) refers limestones with calpionellids to SMT 3-Calp. (deep basinal facies, Facial zone 1).

DISCUSSION

Morphological diversity of the genus *Calpionella*

The genus *Calpionella* is characterized by a considerable variety and changes in the size and shape of the lorica in time. Its evolutionary lineage began during the late Tithonian and terminated during the early Valanginian. The “bloom” of the genus *Calpionella* corresponds to the upper Tithonian (*Crassicollaria* Zone) and lower Berriasian (*Calpionella* Zone).

The first representatives of the genus appear at the top of the *Remanei* Subzone of the *Crassicollaria* Zone. These are the first *Calpionella alpina*. The specimens are small to medium in size, with a less-pronounced collar or without collar (see Figs 3, 6.11, 6.12). The lower boundary of the overlying *Intermedia* Subzone is accepted to be placed at the FO of *Calpionella grandalpina*, or “large, somewhat elongated variety” in the sense of Remane *et al.* (1986). This is a big-size form, having a large, almost isometric lorica with maximum width at the shoulder, and a straight collar (see Figs 3, 6.1–6.5). Together with *Calpionella grandalpina*, *Calpionella alpina* with a well-visible collar also occurs in the *Intermedia* Subzone (Fig. 6.25).

The FO and LO of the short-living form *Calpionella “elliptalpina”* is marked in the *Colomi* Subzone (uppermost part of the *Crassicollaria* Zone). This form is characterized by a big size and elongated lorica (Figs 3, 6.6–6.10). The species has often been described in the past as a homeomorph of the “*Calpionella elliptica*” or has been confused with the real *Calpionella elliptica* Cadisch, 1932. Lakova (1994) offered the extinction of the species as an additional criterion for the Jurassic/Cretaceous boundary. Kowal-Kasprzyk and Reháková (2019) made a thorough morphometric analysis of loricae of *Calpionella alpina* (small spherical form), *Calpionella grandalpina*, and *Calpionella elliptalpina*.

The main criterion for tracing the base of the Berriasian is the “explosion” of the small spherical form of *Calpionella alpina* (Wimbledon, 2017) (Figs 3, 6.19–6.24). This form is dominant in the lower part of the *Alpina* Subzone of the *Calpionella* Zone. It co-occurs with other small- to medium-sized, more or less isometric or elliptical varieties of *Calpionella alpina* (see Remane, 1963, and Fig. 6.13–6.18, 6.26–6.33), the latter being represented in very small quantities. Their number significantly

increases at the expense of the spherical-shaped form in the upper part of the *Alpina* Subzone.

A successive event in the evolution of the genus *Calpionella* is the appearance of *Calpionella minuta* in the middle of the *Alpina* Subzone (Fig. 3). Representatives of this species are of small size, have thin-walled lorica, and are moderately elongated (Fig. 6.34–6.38). The next event in the evolution the genus *Calpionella* registered in the Yavorets section is the FO of *Calpionella* sp. A., also in the middle of the *Alpina* Subzone, shortly after the appearance of the *Calpionella minuta* (Fig. 3). Remane (1963) called this variety *Calpionella* sp. This potentially new species is an intermediate form between *Calpionella alpina* and the real *Calpionella elliptica* (Fig. 6.39–6.42). Very often, such specimens have been described as *Calpionella elliptica*, but the former's loricae are shorter, with somewhat convex walls and not as straight as in the typical *Calpionella elliptica*. The LO of *Calpionella* sp. A is in the lower part of the *Elliptica* Subzone of the *Calpionella* Zone (Grabowski *et al.*, 2016).

Stratigraphical distribution of the genus *Crassicollaria*

In contrast to the genus *Calpionella*, all species of the genus *Crassicollaria* appear almost simultaneously or within a small time interval in the *Crassicollaria* Zone. Their peak of abundance and diversity is also related to the *Crassicollaria* Zone. They gradually disappear within the lower part of the *Calpionella* Zone. Only one species, *Crassicollaria parvula*, survived until the late Berriasian (*Calpionellopsis* Zone, *Oblonga* Subzone) (Grabowski *et al.*, 2016).

The main problem with representatives of the genus *Crassicollaria* is their first appearance, their disappearance and the presence or absence of blooming levels of some species. In the past, it has been assumed that the first crassicollarians appear in the *Remanei* Subzone and they belong to the species *Crassicollaria intermedia* and *Crassicollaria massutiniana*. The FOs of the other species, such as *Crassicollaria parvula*, *Crassicollaria brevis*, and *Crassicollaria colomi*, were assumed as characteristic of the *Intermedia* Subzone or its equivalents (see Remane, 1963; Remane *et al.*, 1986; Reháková, 1995; Reháková and Michalík, 1997; Lakova *et al.*, 1999; Lakova and Petrova, 2013). However, the accumulated data in recent years (Andreini *et al.*, 2007; Reháková *et al.*, 2011; Elbra *et al.*, 2018; Košťák *et al.*, 2018; Svobodová *et al.*, 2019) confirm Pop's (1998b) data from the South Carpathians that, in the *Remanei* Subzone, there are almost si-

multaneous appearances of *Crassicollaria parvula*, *Crassicollaria intermedia*, *Crassicollaria massutiniana*, and *Crassicollaria brevis*. Our data from the Yavorets section (Figs 3, 7), as well as from the Barlya section (unpublished data), prove it once more. Pop (1998b) also proposed a newly defined *Parvula* Subzone as an equivalent of the *Remanei* Subzone, whose lower boundary is defined by the first occurrence of the index-species. The FO of *Crassicollaria colomi* has been documented in the upper part of the *Crassicollaria* Zone in different localities in the Tethyan region, which gave Pop (1994b) reason to define the *Colomi* Subzone as the third subzone of the *Crassicollaria* Zone. In the present paper, we use this subzone for the first time, its lower boundary being placed at the FO of *Crassicollaria colomi* in the Yavorets section (Fig. 3).

Regarding the extinction of species of the genus *Crassicollaria*, in the past, it has been claimed that *Crassicollaria intermedia*, *Crassicollaria massutiniana*, and *Crassicollaria brevis* disappear at the very top of the *Crassicollaria* Zone, and only single specimens can be seen at the base of the *Calpionella* Zone (see Remane, 1963; Remane *et al.*, 1986; Reháková, 1995; Reháková and Michalík, 1997; Lakova *et al.*, 1999; Lakova and Petrova, 2013). The data from Yavorets show that these crassicollarians crossed the Jurassic/Cretaceous boundary, being represented, however, in significantly reduced numbers, then gradually decreasing and disappearing to the middle and upper parts of the *Alpina* Subzone together with *Crassicollaria colomi* (Figs 3, 7). This has also been confirmed by Grabowski *et al.*, (2010) in Hungary, by Reháková *et al.* (2011) in the Pieniny Klippen Belt and the Carpathians in Western Ukraine, and by Skupien and Doupovcová (2019) in the Outer Western Carpathians (Czech Republic).

In the Yavorets section, an acme of *Crassicollaria brevis* was documented in the upper part of the *Crassicollaria* Zone (see Fig. 3, samples Ya 37 and Ya 38, *Intermedia*+*Colomi* subzones). The same phenomenon has also been noted by Pop (1974) in the South Carpathians in Romania. Based on it, Pop (1974) introduced the *Crassicollaria brevis-parvula* Subzone. Later on, Pop (1994b) wrote that this event is not always clear enough and constant to be used as a criterion for defining a subzone, but where it exists it can help recognizing the upper part of the *Crassicollaria* Zone. Another abundance event is the acme of *Crassicollaria parvula* in the lower part of the *Calpionella* Zone (see Lakova and Petrova, 2013). Unlike the other sections in the Western Balkan Mts, in the Yavorets section it is not so well expressed. So far, there is evidence of acme of *Crassicollaria parvula* in other areas of the Tethyan

region, e.g., Spain (Pruner *et al.*, 2010), the Western Carpathians of Slovakia (Michalík and Reháková, 2011), and the Trans-Danubian Range (Grabowski *et al.*, 2010). Probably, these bloom levels depend on conditions of the depositional environment.

Regional and interregional correlations of the calpionellid zonation

Regional correlations – Western Balkan Mts

The determination of the *Chitinoidea*, *Praetintinnopsella*, *Crassicollaria*, and *Calpionella* zones with their subzones in the Yavorets section offers a more complete litho-/biostratigraphic correlation of the upper Tithonian and lower Berriasian parts of the Gintsi and Glozhene formations, when compared with previous biostratigraphic results from the westerly located sections at Gintsi, Komshtitsa and Barlya (see Lakova, 1994; Lakova *et al.*, 1999, 2007; Lakova and Petrova, 2013). As a whole, the Gintsi/Glozhene Formation boundary is related to the *Chitinoidea* Zone. The base of the Berriasian, i.e., the base of the *Alpina* Subzone, is traced in the lower third of the Glozhene Formation. The boundary of the Glozhene Formation with the overlying Salash Formation marks the end of a long-lasting carbonate pelagic cycle (Oxfordian to Berriasian, see Lakova *et al.*, 2007) and corresponds to the *Elliptica* Subzone of the *Calpionella* Zone in the sections at Barlya and Komshtitsa. There is a stratigraphic hiatus between the Glozhene and Salash formations in sections Gintsi 1 and Gintsi 2 (Lakova and Petrova, 2013). The *Simplex* and *Oblonga* subzones of the *Calpionellopsis* Zone are missing. It suggests unstable conditions of the sedimentary environment, which predetermines the onset of hemipelagic sedimentation.

In the area of the Iskar River Valley, sandstones have been observed in the interval of the lithological transition between the Glozhene and Salash formations (Mandov, 1972). Later on, Petrova (2010) provided calpionellid data on the age of this event; it corresponds to the *Simplex* or *Simplex/Oblonga* subzonal boundary in the sections at Sarbenitsa and Bov, respectively. The herein studied Yavorets section is located only some 2 km to the east of the Bov section; however, the lithologic boundary between the Glozhene and Salash formations does not crop out. Nevertheless, test sampling from sandy-calcareous siltstones in the area beneath Yavorets Peak yielded a diverse calpionellid association of the lower part of the *Oblonga* Subzone. It may be concluded, therefore, that the present study gives evidence of the introduction of somewhat terrig-

enous sedimentation at the same stratigraphic level as in the Bov section of Petrova (2010).

On the territory of eastern Serbia, in the westernmost end of this band of Tithonian and Berriasian pelagic carbonate sediments, the section of Rosomač shows significant similarity with the Barlya section (see Petrova *et al.*, 2012). There is difference in the allochemic content of the correlatives of the Gintsi and Glozhene formations, namely the Pokrovenik and Rosomač limestones, expressed in the presence of allochthonous microfossils redeposited from a neighboring shallow carbonate platform. Recently, confirmation of such a suggestion has come from the study of Carević *et al.* (2018) of the upper Tithonian pelagic carbonates of the Carpatho-Balkanides in northeastern Serbia. There, in the section of Jelenska Stena, a mixed foraminifer-calpionellid microfossil association has suggested a connection with the northerly situated Getic carbonate platform.

Interregional Tethyan correlations

A thorough review of interregional correlation of the calpionellid zones and subzones herein described can be seen in Lakova and Petrova (2013). Only recently published zonations in Slovakia, Tunisia and Argentina and elsewhere are included in this paper for correlation purposes (e.g., Michalík *et al.*, 2016; Boughdiri *et al.*, 2009; Kietzmann, 2017). Recent chitinoideid and calpionellid finds have been published from three main domains: Central Tethyan (Europe, Turkey and North Africa), Eastern Tethyan (Iran and Oman), and Western Tethyan (Cuba, Mexico). Chitinoideids, calpionellids and calcareous dinocysts from Argentina are the first ones from such a remote area as the Pacific Region.

Extensive publications of calpionellid zonations integrated with nannofossil biostratigraphy and magnetostratigraphy from the Carpathian region are characteristic for the present decade. Michalík *et al.* (2016) presented the *Chitinoidea*, *Crassicollaria* and *Calpionella* zones and their subzones from the Strapková section in the Western Carpathian of Slovakia. In that area, the regional development of ammonitico rosso is the Czorsztyn Formation (with the *Malmica* calcareous dinocyst Zone overlain by the *Dobeni* and *Boneti* subzones), and the Biancone facies is referred to the Pieniny Limestone Formation with the *Crassicollaria* and *Calpionella* zones detected. Elbra *et al.* (2018) and Svobodová *et al.* (2019) published integrated microfossil zonation, magnetostratigraphy and isotope geochemistry of the Kurovice section in the Czech Republic. The calcareous dinocyst *Colomisphaera tenuis* Zone, di-

rectly overlain by the *Crassicollaria* and *Calpionella* zones, was recorded. Very recently, integrated stratigraphy of the Snežnica section of the Western Carpathians in Slovakia has been erected (Michalík *et al.*, 2019), where the top of the Czorsztyn Limestone Formation has been assigned to the upper Tithonian (*Chitinoidea*, *Praetintinnopsella*, and *Crassicollaria* zones), and the Pieniny Limestone Formation – to the top *Crassicollaria* and *Calpionella* zones. Kowal-Kasprzyk (2014, 2018) reported on chitinoideids of five genera mainly from the *Boneti* Zone, found in the exotic limestones of the Silesian Nappe in the Polish Outer Carpathians. In the Tatra Mts (Central Western Carpathians in Poland and Slovakia), Jach *et al.* (2012) reported on the presence of the *Dobeni* and *Boneti* subzones in the Tithonian gray nodular limestones of the Lejowa Valley section, the two subzones being only indicated by scarce chitinoideid associations and overlying the *Parastomiosphaera malmica* dinocyst Zone. It is worth mentioning the relative rarity of chitinoideid species, especially those from the lower *Dobeni* Subzone, throughout the Carpathian sections compared to our Western Balkan sections and to the legacy of Grigore Pop from the South Carpathians. Partly, the reason might be the presence of radiolarian cherts or shallow carbonate platforms at the lower/upper Tithonian boundary interval, *e.g.*, in the Snežnica, Kurovice, and Lejowa Valley sections, as well as in Turkey (Atasoy *et al.*, 2018) and Oman (Celestino *et al.*, 2017).

In the Velykyi Kamianets section in the Ukraine Carpathians, the *Chitinoidea* and *Praetintinnopsella* zones have been detected in the Czorsztyn Limestone Formation (an equivalent of the upper nodular limestones), and the *Crassicollaria* and *Calpionella* zones – in the *Calpionella*-bearing Dursztyn Limestone Formation (Grabowski *et al.*, 2019). The *Boneti* Subzone is represented by a diverse association, whereas the *Dobeni* Subzone is only indicated by its index-species as in many other Carpathian sections. Grabowski *et al.* (2019) presented a correlation between calpionellid zonation and magnetostratigraphy across the Tithonian/Berriasian boundary in several sections of the Trans-Danubian and Carpathian regions. This direct correlation has revealed that the base of the *Boneti* Subzone approximates the base of M20r magnetic chron, the top of the *Remanei* Subzone – the base of M19r magnetic chron, and the base of the *Ferasini* Subzone correlates well with the M18r chron.

Calpionellid biostratigraphy across the Jurassic/Cretaceous boundary in Morocco and Tunisia is famous for the direct correlation with ammonite successions and zonation that enhances the chrono-

stratigraphic value of the calpionellid zones and subzones. Boughdiri *et al.* (2009), Benzaggagh *et al.* (2010), and Sallouhi *et al.* (2011) documented the position of the base of the *Boneti* Subzone exactly at the *Ponti/Microcanthum* boundary in terms of ammonites, thus implying that the base of the *Boneti* Subzone may be used to trace the lower/upper Tithonian boundary.

Although not as comprehensive as in the Central Tethyan Domain, first records of chitinoideids and calpionellids in the Eastern Tethyan enlarge the geographical distribution and correlation potential of these microfossils, *e.g.*, in Iran (Benzaggagh *et al.*, 2012) and Oman (Celestino *et al.*, 2017).

In the Western Tethyan Domain, recent studies have reported on the presence of the *Crassicollaria* and *Calpionella* zones in Mexico and Cuba (see Pszczółkowski, 2013, and references therein). It is also worth mentioning the discovery of chitinoideids, calpionellids and calcareous dinocysts in the Tithonian/Berriasian boundary strata of the Pacific Region in Argentina (Kietzmann, 2017; Kietzmann *et al.*, 2018).

CONCLUSIONS

Four calpionellid zones and seven subzones and three calcareous dinocyst zones were documented in the upper part of the Yavorets section.

Chitinoideids and calpionellids provided new evidence for the early–late Tithonian age of the Gintsi Formation, as well as for the late Tithonian to earliest Berriasian age of the Glozhene Formation, together with calcareous dinocyst biostratigraphy.

The Jurassic/Cretaceous boundary was drawn in the lower part of the Glozhene Formation, based on the last occurrence of *Calpionella elliptalpinia* and the “explosion” of the spherical form of *Calpionella alpina* (the *Crassicollaria colomi*)/*Calpionella alpina* subzonal boundary). It falls into the lower part of the calcareous dinocyst *Stomiosphaerina proxima* Zone.

A set of three successive microfacies were identified: *Saccocoma* MF (Gintsi Formation, lower–upper Tithonian); *Globochaete alpina* MF (Glozhene Formation, upper Tithonian); and calpionellid MF (Glozhene Formation, upper Tithonian–lower Berriasian).

Considering the microfossil constituents and carbonate textures, it can be inferred that the sediments of the Gintsi Formation were accumulated on a structural high of the basin floor, whereas those of the Glozhene Formation were deposited into a deeper-water basin environment.

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APPENDIX. TAXONOMIC LIST

Alphabetic list of all chitinoideid, calpionellid and calcareous dinocyst taxa mentioned in the text and figures is given below. See Furrázola Bermúdez (1965), Borza (1969), Furrázola Bermúdez and Kreisel (1973), Pop (1994a, b, 1996, 1997a, b, 1998a, b), Reháková (1998, 2002), Sallouhi *et al.* (2011) for chitinoideids and calpionellids, and Vogler (1941) and Ivanova and Kietzmann (2017, and references therein) for calcareous dinocysts for full taxonomic descriptions with authorship.

Chitinoideids, semichitinoideids, and calpionellids

Almajella Pop, 1998

Almajella cristobalensis (Furrázola Bermúdez, 1965)

Borziella Pop, 1997

Borziella slovenica (Borza, 1969)

Carpathella Pop, 1998

Carpathella rumanica Pop, 1998

Chitinoideella Doben, 1963

Chitinoideella boneti Doben, 1963

Chitinoideella carthagensis Sallouhi, Boughdiri and Cordey, 2011

Chitinoideella elongata Pop, 1997

Chitinoideella hegarati Sallouhi, Boughdiri and Cordey, 2011

Chitinoideella popi Sallouhi, Boughdiri and Cordey, 2011

Daciella Pop, 1998

Daciella almajica Pop, 1998

Daciella banatica Pop, 1998

Daciella danubica Pop, 1998

Daciella svinitensis Pop, 1998

Daciella sp.

Dobeniella Pop, 1997

Dobeniella bermudezi (Furrázola Bermúdez, 1965)

Dobeniella colomi (Borza, 1966)

Dobeniella cubensis (Furrázola Bermúdez, 1965)

Dobeniella lubimovae (Furrázola Bermúdez and Kreisel, 1973)

Dobeniella tithonica (Borza, 1969)

Longicollaria Pop, 1997

Longicollaria dobeni (Borza, 1966)

Longicollaria insueta (Řehánek, 1986)

Popiella Reháková, 2002

Popiella oblongata Reháková, 2002

Praetintinnopsella Borza, 1969

Praetintinnopsella andrusovi Borza, 1969

Calpionella Lorenz, 1902

Calpionella alpina Lorenz, 1902

Calpionella elliptalpina Nagy, 1986

Calpionella grandalpina Nagy, 1986

Calpionella minuta Houša, 1990

Calpionella sp. A

Crassicollaria Remane, 1962

Crassicollaria brevis Remane, 1962

Crassicollaria colomi Doben, 1963

Crassicollaria intermedia (Durand Delga, 1957)

Crassicollaria massutiniana (Colom, 1948)

Crassicollaria parvula Remane, 1962

Remaniella Catalano, 1965

Remaniella colomi Pop, 1996

Remaniella duranddelgai Pop, 1996

Remaniella ferasini (Catalano, 1965)

Tintinnopsella Colom, 1948

Tintinnopsella carpathica (Murgeanu and Filipescu, 1933)

Tintinnopsella doliphormis (Colom, 1939)

Tintinnopsella remanei Borza, 1969

Calcareous dinocysts

Cadosina Wanner, 1940

Cadosina fusca cieszynica Nowak, 1968

Cadosina fusca fusca Wanner, 1940

Colomisphaera Nowak, 1968

Colomisphaera carpathica (Borza, 1964)

Colomisphaera cieszynica Nowak, 1968

Colomisphaera fortis Řehánek, 1982

Colomisphaera lapidosa (Vogler, 1941)

Colomisphaera lucida Borza, 1986

Colomisphaera nagy Borza, 1969

Colomisphaera pieniniensis (Borza, 1969)

Colomisphaera radiata (Vogler, 1941)

Colomisphaera tenuis (Nagy, 1966)

Committosphaera Řehánek, 1985

Committosphaera sublapidosa (Vogler, 1941)

Crustocadosina Řehánek, 1985

Crustocadosina semiradiata semiradiata (Wanner, 1940)

Crustocadosina semiradiata olzae (Nowak, 1966)

Stomiosphaera Wanner, 1940

Stomiosphaera acculeata Vogler, 1941
Stomiosphaera misolensis (Vogler, 1941)

Stomiosphaerina Nowak, 1974
Stomiosphaerina proxima Řehánek, 1987

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