Calpionellid biostratigraphy and microfacies analysis of a Tithonian–Berriasian carbonate succession in the Western Srednogorie (Bulgaria)

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Abstract. In the eastern part of the Western Srednogorie Unit, around Dragovishtitsa Village, a specific succession of the Gintsi and Glozhene–Slivnitsa formations has provided micropalaeontological evidence for late Tithonian (*Chitinoidea*, *Praetintinnopsella* and the base of *Crassicollaria* zones) and mid-Berriasian (the *Elliptica* Subzone of the *Calpionella* Zone) age on the basis of 45 chitinoideid and calpionellid species. A significant stratigraphic hiatus is documented within the Glozhene–Slivnitsa Formation, since a part of the *Crassicollaria* Zone, as well as the *Alpina*+*Remaniella* subzones of the *Calpionella* Zone, is absent from the Dragovishtitsa 1 section. The conformably overlying Salash Formation is of mid-Berriasian age (*Elliptica* Subzone) and is locally characterized by the presence of calcareous sandstones (Dragovishtitsa 2 section). The Salash–Cherni Osam Formation, as well as the clayey limestone unit covering the Slivnitsa Formation, is also of mid-Berriasian age (*Elliptica* Subzone). The Slivnitsa and Glozhene–Slivnitsa formations, which underlie the Salash–Cherni Osam Formation in the Dragovishtitsa East section, correspond to the *Crassicollaria* Zone and the *Alpina* Subzone, respectively. Reworking of calpionellids from the *Crassicollaria* Zone is documented in the *Alpina* and *Elliptica* subzones in all three studied sections. Eight microfacies types are distinguished, which suggests that the carbonate sediments were deposited in a carbonate platform rather than in a pelagic basin environment, although the upper part of the studied sections reveals an upward-deepening trend. The Slivnitsa Formation is covered by highly diachronous sediments from more distal settings: from mid-Berriasian around Dragovishtitsa Village to the Berriasian/Valanginian transition at the Tri Ushi section to late Valanginian in the Dragoman and Kalotina sections. This fact, together with the significant stratigraphic hiatus within the Glozhene–Slivnitsa Formation, is interpreted here as tectonically controlled. The presence of transitional depositional settings from carbonate platform to deeper-marine environments caused deposition of specific lithostratigraphic units not always corresponding to the diagnostic features of the Glozhene, Salash and Cherni Osam formations.

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INTRODUCTION

The Western Srednogorie Unit is a part of the Srednogorie Zone, which belongs to the Alpine orogen. The Upper Jurassic–Lower Cretaceous deposits are poorly studied in its eastern part (Sapunov *et al.*, 1985; Sapunov and Tchoumatchenco, 1995; Nikolov, 1995), un-

like the western one, where a number of studies have been conducted over the last 50 years (Mandov, 1967, 1970, 1976; Nikolov and Tzankov, 1998; Ivanova *et al.*, 2000, 2008; Mandov and Nikolov, 2001; Ivanova and Koleva-Rekalova, 2004; Petrova *et al.*, 2010, 2011). During the last geological mapping of the area in scale 1:50 000, it became evident that the Upper

Jurassic–Lower Cretaceous successions do not correspond to the conventional lithostratigraphic scheme that is currently in use. Apart from the data presented by Sapunov *et al.* (1985), no other biostratigraphic evidence has been published so far and the overall succession has remained without precise age assessment. Moreover, at many levels, these rocks need to be addressed in more details in terms of their lithology.

The eastern part of the Western Srednogorie attracted the interest of the present authors for the following reasons: 1) occurrence of unique carbonate development with pelagic microfossils (calpionellids); 2) lack of previous study on carbonate microfacies; 3) scarcity of palaeontological data for age determination of strata younger than Kimmeridgian; 4) new results gained during the last geological mapping of the area in scale 1:50 000.

This paper presents description of Tithonian and Berriasian carbonate sections in the Western Srednogorie, north of Dragovishtitsa Village (Fig. 1a–c), including calpionellid distribution and precise dating, regional stratigraphical implications, microfacies analysis and basin development inference for the end of the Jurassic and beginning of the Cretaceous in the study region.

Contributions to this study are as follows: Silviya Petrova (calpionellid taxonomy and biostratigraphy); Daniela Reháková (calpionellid biostratigraphy and foraminifera identification); Polina Andreeva and Jozef Michalík (microfacies analysis and basin development); Lubomir Metodiev (lithostratigraphy, regional geology and geological mapping), and Iskra Lakova (regional stratigraphy).

GEOLOGICAL SETTING

The Upper Jurassic and Lower Cretaceous carbonate rocks in the Western Srednogorie tectonic unit are mainly represented by the massive biogenic limestones of the Slivnitsa Formation deposited under conditions of a long-lived carbonate platform. These are of Callovian to Valanginian age (Ivanova, 1999; Ivanova and Koleva-Rekalova, 2004). In the westernmost part of this tectonic unit (in Dragoman area), the Slivnitsa Formation is unconformably covered by the hemipelagic limestones and marlstones of the Salash Formation of Valanginian and Hauterivian age (Mandov, 1967, 1970, 1976; Nikolov and Tzankov, 1998; Ivanova *et al.*, 2000, 2008; Mandov and Nikolov, 2001; Petrova *et al.*, 2010). Eastwards, this development rapidly becomes different, including poorly defined successions of platform, pelagic and hemipelagic carbonates, commonly containing intermediate lithologies in which both allochthonous and autochthonous components occur. It is only in the eastern part of the Western Srednogorie Unit that the “pelagic” Upper Jurassic and Lower Cretaceous formations have been described (Sapunov *et al.*, 1985).

Three sections were studied: Dragovishtitsa 1 section (GPS: 42°51'45" N; 23°13'30" E); Dragovishtitsa 2 section (GPS: 42°51'45" N; 23°13'31" E) and Dragovishtitsa East section (see Fig. 1a) situated NNE of Dragovishtitsa Village (Sofia District). The former two sections are located on the southeastern slope of the Mezhdina Summit and represent a natural extension of one another but with a quite different lithology. Section Dragovishtitsa East is a previously sampled section that actually is located on the territory of the active Balsha Quarry. The subject of this study are the Gintsi and Glozhene–Slivnitsa formations in the Dragovishtitsa 1 section, the Glozhene–Slivnitsa and the Salash formations in the Dragovishtitsa 2 section, as well as the Slivnitsa, Glozhene–Slivnitsa and the rhythmic alternation attributed to the Salash–Cherni Osam Formation in the Dragovishtitsa East section (Fig. 1b, c).

MATERIAL AND METHODS

A total of 59 thin-sections (15 from the Dragovishtitsa 1 section, 28 from the Dragovishtitsa 2 section, 14 from the Dragovishtitsa East section and two from the clayey limestone unit at the top of the Mezhdina Summit) were studied for chitinoideids and calpionellids with a Jenaval transmitting light-microscope. Microfacies analysis is based on detailed microscopic study of 52 thin-sections (15 from the Dragovishtitsa 1 section, 23 from the Dragovishtitsa 2 section, and 14 from the Dragovishtitsa East section), viewed on a standard petrographic microscope. The Dragovishtitsa East section was sampled in 1995 by I. Lakova. Sampling density in all three sections depends on exposure. The average sampling density is one sample/metre. Samples for thin-sections were taken preferentially from limestones. Microfacies types have been identified, following the textural classification proposed by Dunham (1962) and the diagnostic microfacies criteria of Flügel (2004). The field observations, calpionellid biostratigraphy and depositional setting interpretations were made jointly with Daniela Reháková and Jozef Michalík. The interpretation of resedimented chitinoideid and calpionellid species was based on their occurrence in younger strata and/or in transported intraclasts. The examined materials are hosted at the Geological Institute of the Bulgarian Academy of Sciences (Sofia).

LITHOSTRATIGRAPHY

The work of Sapunov *et al.* (1985) on the lithostratigraphy, biostratigraphy and regional distribution of the Upper Jurassic carbonate rocks in the area north of Dragovishtitsa Village was the first and still is the most comprehensive study. Those authors described two sections on the southern slope of the Mezhdina Summit. The lithostratigraphic succession recognized from base to top was as follows: Polaten, Yavorets,

Fig. 1. Location of the studied sections: *a*) Tectonic subdivision of Bulgaria (Dabovski and Zagorchev, 2009; modified); *b*) Geographic position of the sections (the map is a satellite image provided by Google Earth); *c*) Geological map of the studied area and position of the sections.

Gintsi, Glozhene, Slivnitsa and Salash formations. Calpionellid data by D. Bakalova (*in*: Sapunov *et al.*, 1985) suggested the presence of the *Alpina* and *Elliptica* subzones in the Salash Formation. On the northern slope of Mezhdina Summit, Sapunov *et al.* (1985) described a succession consisting of the Polaten, Slivnitsa and Salash formations. The authors pointed out the unique nature of the Dragovishtitsa area, where sediments of various depositional settings are in close

proximity to each other. The geological mapping of the area in scale 1:100 000 revealed the presence of another lithostratigraphic unit, the Salash–Cherni Osam Formation (Nikolov, 1995), as well as a direct contact between the Slivnitsa and Salash formations (Sapunov and Tchoumatchenco, 1995). Recent geological mapping of the area in scale 1:50 000 has contributed with additional information on the lithostratigraphy, distribution and relationships between the formations

(see Fig. 1c). A small, isolated and strongly tectonized outcrop south of Dragovishtitsa Village was assigned to the Salash–Cherni Osam Formation.

In the herein studied eastern part of the Western Srednogorie Unit, the Polaten Formation underlies all carbonate Callovian and Upper Jurassic rocks. Starting from the Callovian–Oxfordian, the sediments of the Polaten Formation (mainly grey allochemic sandy limestones of Bathonian age) are unconformably covered by formations of two differentiated facies types: the carbonate-platform massive biogenic limestones of the Slivnitsa Formation to the north and to the west, and the “pelagic” limestones of the West Balkan Carbonate Group (Yavorets+Gintsi+Glozhene formations, see Nikolov and Sapunov, 1970) to the south-southeast. The Glozhene Formation is covered by an alternation of clayey limestones and calcareous sandstones. This alternation was described and referred to the Salash Formation by Sapunov *et al.* (1985). The occurrence of sandstones, which increase in abundance upwards, is, however, quite atypical of the Salash Formation (Nikolov and Zankov, 1971). Therefore, this alternation should be regarded in different manner, from lithostratigraphic point of view. Two solutions seem possible: to retain it as the Salash Formation, but paying attention to the sandstone component, or to attribute it to the Salash–Cherni Osam Formation of Nikolov (1995). The latter bears resemblance to both the Salash and the Cherni Osam formations by having an intermediate hemipelagic–turbidity character of the sediments. Recent field observations across the area containing the sections of this study did not reveal the presence of turbidity deposits. The appearance of sandstones in our sections does not seem sufficient to attribute these intervals to the Salash–Cherni Osam Formation. On the other hand, the former studies of the area have shown that a mixed hemipelagic–turbidity development really existed, but now it cannot be confirmed, as outcrops have disappeared due to the active expansion of the Balsha Quarry. The only outcrop that resembles the lithology of the Salash–Cherni Osam Formation is that to the south of Dragovishtitsa Village, but it is so deformed that it is impossible to restore the original stratification of the rocks. Therefore, the name Salash–Cherni Osam Formation is used in this study conditionally.

Yavorets Formation

This unit covers unconformably the Polaten Formation. The boundary between the two formations is sharp, associated with submarine break in sedimentation (Sapunov *et al.*, 1985). The Yavorets Formation consists of hard, grey, medium-bedded micritic limestones, with an approximate total thickness of 20 m to 40 m. It was considered as middle Callovian to early late Oxfordian in age by Sapunov *et al.* (1985). Micro-palaeontological evidence from calcareous dinocysts and foraminifera determined by D. Ivanova (*in*: Petro-

va *et al.*, 2014), indicated that the exposures of the Yavorets Formation to the southeast of Dragovishtitsa Village are of middle Callovian to Oxfordian age.

Gintsi Formation

The unit consists of grey to pinkish-grey, medium-bedded nodular limestones. The measured thickness is 26 m. The age determined based on ammonites (Sapunov *et al.* 1985) is late Oxfordian to early Kimmeridgian. The uppermost part of the Dragovishtitsa 1 section is proven herein to be of earliest late Tithonian age, based on calpionellids (the *Boneti* Subzone of the *Chitinoidella* Zone).

Slivnitsa Formation

In its typical development, this unit crops out largely in the south and west parts of the area around Dragovishtitsa Village. The Slivnitsa Formation is composed of light grey, thick-bedded to massive, intraclastic and bioclastic limestones. It covers with short lithological transition the Glozhene Formation. The age of the Slivnitsa Formation is coeval with the upper parts of the Gintsi Formation and the Glozhene Formation, and locally these formations may interfinger. Sapunov *et al.* (1985) considered it as late Tithonian to early Berriasian in age. The age indicated by calpionellids in the Dragovishtitsa East section is late Tithonian (*Crassicollaria* Zone, *Massutiniana* Subzone).

Glozhene–Slivnitsa Formation

The bulk of exposures in the Dragovishtitsa area show lithological features similar to the Glozhene Formation, but they differ in lithology from the typical pelagic deposits in the Western Balkan region. Commonly, the grey micritic limestones are medium- to thick-bedded, intraclastic to bioclastic, with chert nodules or platy chert interlayers. In some cases, it is difficult to attribute these rocks to either the Glozhene or the Slivnitsa Formation. The microfossil content includes pelagic elements (chitinoidellids, calpionellids, calcareous dinocysts, saccocomids, globochaetids as basic constituents), which are mixed with bryozoans, foraminifera, calcareous green algae, *Lithocodium–Bacinella*, pelecypods, gastropods and coral fragments of shallow-water depositional settings. Regarding both the field appearance and spatial relationships with the underlying Gintsi Formation and the short lateral transitions to the typical Slivnitsa Formation, we assign this part of the carbonate succession to the Glozhene–Slivnitsa Formation. It corresponds to parts of the upper Tithonian and the lower Berriasian. Noteworthy is a newly discovered stratigraphic hiatus covering the Tithonian–Berriasian boundary interval (*i.e.*, the absence of the greatest part of the *Crassicollaria* Zone and *Alpina+Remaniella* subzones of the *Calpionella* Zone) in the Dragovishtitsa 1 section. Early Berriasian

age (the *Alpina* Subzone of the *Calpionella* Zone), is established for the formation in the Dragovishtitsa East section.

Salash Formation

This unit represents an irregular alternation of thin-bedded, grey, clayey limestones, marlstones and rare siltstones, with thin interbeds of yellowish calcareous sandstones. The sandstones increase in abundance up-section. The measured thickness is 26 m. The age is determined here as late early Berriasian (the *Elliptica* Subzone of the *Calpionella* Zone).

Clayey limestone unit

Sapunov *et al.* (1985) considered the Salash Formation to be a lithostratigraphic unit of dark grey, medium-bedded, micritic, clayey and intraclastic limestones that cover directly the Slivnitsa Formation. However, this succession lacks the diagnostic features of the Salash Formation, *i.e.*, alternation of micritic and clayey limestones or of clayey limestones and marlstones (Nikolov and Zankov, 1971). It differs from the Salash Formations at the Dragovishtitsa 2 section, too. For these reasons, we designate it informally as clayey limestone unit. The age indicated by calpionellids is latest early Berriasian (the *Elliptica* Subzone of the *Calpionella* Zone).

Salash–Cherni Osam Formation

Nikolov (1995) used this formal name for a three-component alternation of sandstones, marlstones and clayey to micritic limestones that overlie the Glozhene Formation and are laterally replaced to the north-west by the Salash Formation. The Salash–Cherni Osam Formation corresponds to the uppermost lower Berriasian, as documented here (the *Elliptica* Subzone of the *Calpionella* Zone) in the Dragovishtitsa East section.

BIOSTRATIGRAPHY

Calpionellid zones and subzones follow the definitions and zonal schemes of Pop (1997a), Reháková and Michalík (1997) and Lakova and Petrova (2013). The Tithonian *Chitinoidella* and *Praetintinnopsella* zones, along with the base of the *Crassicollaria* (*Remanei* Subzone), and the lower Berriasian *Elliptica* Subzone of the *Calpionella* Zone have been documented in Dragovishtitsa 1 section. It is noteworthy that a large portion of the uppermost Tithonian *Crassicollaria* Zone (almost the entire *Remanei* Subzone, without its base, and the *Massutiniana* Subzone) and the lower Berriasian *Alpina* and *Remaniella* subzones of the *Calpionella* Zone are absent in this section. The *Elliptica* Subzone has been recorded in the Dragovishtitsa 2 section and in Dragovishtitsa East section, in the latter

section together with the *Crassicollaria* Zone (upper parts of the *Massutiniana* Subzone) and the *Alpina* Subzone of the *Calpionella* Zone. Previous record of the chitinoidellids in other parts of the Alpine–Carpathian region has been taken into account, *e.g.*, in the Carpathians of Slovakia (Borza, 1969; Reháková, 2000), and Romania (Pop, 1997b), as well as in more distant areas, such as Tunisia (Sallouhi *et al.*, 2011) and Argentina (Kietzmann, 2017).

Dragovishtitsa 1 section

This section includes the Gintsi and Glozhene–Slivnitsa formations. Vertical distribution of the chitinoidellid and calpionellid species is shown in Fig. 2, and chitinoidellids are documented in Figs 3 and 4.

The *Chitinoidella* Zone (samples K 01–K 06a, see Fig. 2) corresponds to the upper part of the Gintsi Formation (10 m) and the basal 3 m of the Glozhene–Slivnitsa Formation. The *Dobeni* Subzone (*pars.*) has been recorded in the Gintsi Formation (sample K 01). The association is scarce and consists of only four species: *Longicollaria dobeni*, *Borziella slovenica*, *Daciella banatica* and *Dobeniella colomi*. The *Boneti* Subzone (samples K 02–K 06a) covers the top of the Gintsi Formation and the base of the Glozhene–Slivnitsa Formation, being 5–6 m thick. The chitinoidellid association is diverse. Characteristic representatives of the *Dobeni* Subzone (*e.g.*, *Daciella almajica*, *Daciella danubica*, *Daciella svinitsensis* and *Dobeniella tithonica*) occur, along with species typical for the *Boneti* Subzone: *Dobeniella bermudezi*, *Dobeniella cubensis*, *Longicollaria insueta*, *Chitinoidella* sp. and *Popiella oblongata*. The first occurrence (FO) of *Almajiella cristobalensis*, *Carpathella rumanica* and *Chitinoidella elongata* is marked in the top of the subzone. Preservation is moderate to poor, and it is not rare for some species to occur only as single specimens.

According to the recent chronostratigraphic scale of the Tithonian (Ogg and Hinnov, 2012), the upper Tithonian includes the *Microcanthoceras microcanthum* and *Durangites ammonite* zones. Direct correlations of ammonites and calpionellids have shown that the base of the *Boneti* Subzone coincides precisely with the base of the *Microcanthoceras microcanthum* Zone in Spain, France, Morocco and Tunisia (Enay and Geyssant, 1975; Cecca *et al.*, 1989; Boughdiri *et al.*, 2009; Benzaggagh *et al.*, 2010). Thus, the base of the *Boneti* Subzone is a reliable indicator for the base of the upper Tithonian.

The *Praetintinnopsella* Zone (1.5 m thick, samples K 06b–K 06c) is represented by its index-species accompanied with certain chitinoidellid species from the *Dobeni* and *Boneti* subzones in the mid of the Glozhene–Slivnitsa Formation (see Fig. 2). *Dobeniella pinarensis*, *Chitinoidella carthagensis*, *Chitinoidella hegarrati* and *Chitinoidella popi* were also recorded. The last occurrences (LOs) of *Dobeniella bermudezi* and *Dobeniella cubensis* were recorded at the top of the zone.

Fig. 2. Dragovishtitsa 1 section – litho- and biostratigraphy, range-chart of the calpionellid species, microfacies types and interpretation of the depositional environment.

Fig. 3. Chitinoideids of the Dragovishtitsa 1 section: 1–3 *Longicollaria dobeni*, sample K 05 (1), sample K 06 (2), sample K 06a (3); 4, 5 *Borziella slovenica*, sample K 03 (4), sample K 06a (5); 6–8 *Daciella almajica*, sample K 03 (6), sample K 04 (7), sample K 06b (8); 9, 10 *Daciella banatica*, sample K 03 (9), sample K 05 (10); 11, 12 *Daciella danubica*, sample K 04 (11), sample K 06c (12); 13–15 *Daciella svinitsensis*, sample K 03 (13), sample K 04 (14), sample K 06a (15); 16, 17 *Dobeniella colomi*, sample K 04 (16), sample K 06 (17); 18, 19 *Dobeniella tithonica*, sample K 04 (18), sample K 06a (19); 20, 21 *Carpathella rumantica*, sample K 06b (20), sample K 06c (21); 22–24 *Chitinoideella boneti*, sample K 06a (22, 23), sample K 06b (24); 25, 26 *Chitinoideella elongata*, sample K 06a (25), sample K 06c (26); 27, 28 *Popiella oblongata*, sample K 06 (27), sample K 06a (28); 29, 30 *Daciella* sp., sample K 04 (29), sample K 06a (30).

The *Crassicollaria* Zone (*Remanei* Subzone) is indicated in one sample only (K 06d, see Fig. 2). The assemblage is characterized by the presence of the index-species of the *Remanei* Subzone, *Tintinnopsella* cf. *remanei*, as well as *Crassicollaria* cf. *intermedia*, *Praetintinnopsella andrusovi* and some representatives of chitinoideids.

The *Calpionella* Zone (*Elliptica* Subzone) corresponds to a ~7 m thick interval of the top of the Glozhene–Slivnitsa Formation at the Dragovishtitsa

1 section (samples K 06e–K 07c, see Fig. 2). The calpionellid assemblage includes *Calpionella alpina*, *Calpionella minuta*, *Calpionella elliptica*, *Calpionella* sp. A (transitional form between *Calpionella alpina* and *Calpionella elliptica*), *Tintinnopsella carpathica*, *Tintinnopsella doliphormis*, *Crassicollaria parvula*, *Remaniella ferasini*. Apart from the calpionellids, abundant fragments of bryozoans, benthic foraminifera, green calcareous algae and *Lithocodium*–*Bacinnella* that are characteristic of the shallow-marine settings

Fig. 4. Chitinoideids and semichitinoideids of the Dragovishtitsa 1 section: 1, 2) *Chitinoideella* sp., sample K 06a (1), sample K 06c (2); 3) *Chitinoideella carthagensis*, sample K 06b; 4) *Chitinoideella popi*, sample K 06b; 5, 6) *Chitinoideella hegarati*, sample K 06c; 7–9) *Dobeniella bermudezi*, sample K 04 (7), sample K 06 (8), sample K 06b (9); 10, 11) *Dobeniella cubensis*, sample K 04 (10), sample K 06d (11); 12, 13) *Almajella cristobalensis*, sample K 06 (12), sample K 06c (13); 14, 15) *Dobeniella pinarensis*, sample K 06b (14), sample K 06c (15); 16, 17) *Longicollaria insueta*, sample K 06 (16), sample K 06a (17); 18–20) *Praetintinnopsella andrusovi*, sample K 06b (18), sample K 06c (19, 20).

Fig. 5. Dragovishtitsa 2 section – litho- and biostratigraphy, range-chart of the calpionellid species, microfacies types and interpretation of the depositional environment.

occur. Resedimented calpionellids were recorded in the *Elliptica* Subzone at the Dragovishtitsa 1 section, such as *Borziella slovenica*, *Daciella banatica*, *Daciella almajica*, *Chitinoidea boneti* and *Chitinoidea elongata* from the *Chitinoidea* Zone, as well as *Crassicollaria* cf. *brevis*, *Crassicollaria massutiniana*, *Crassicollaria* cf. *intermedia*, *Tintinnopsella* cf. *remanei* and *Calpionella grandalpina*. The latter forms are from the missing part of the *Crassicollaria* Zone and suggest a post-depositional washout of adjacent older strata.

The stratigraphic hiatus recorded here corresponds to part of the upper Tithonian (the greatest part of *Crassicollaria* Zone) and the lower Berriasian (*Alpina* and *Remaniella* subzones of the *Calpionella* Zone). This result is somewhat surprising, as in all pelagic sections previously studied in the West Balkan and West Fore-Balkan in Bulgaria (Lakova *et al.*, 1999; Lakova and Petrova, 2013) there is a complete record of sedimentation across the Tithonian/Berriasian boundary. Here, the considerable hiatus reflects most probably dynamic conditions on the shelf where sediments had been destroyed and reworked. This is evidenced by the resedimentation of chitinoideids and crassicollarians in younger strata. Similar palaeoenvironmental conditions were described by Michalík *et al.* (2012) from the Manín Unit of the Western Carpathians.

Dragovishtitsa 2 section

The Glozhene–Slivnitsa Formation (7.5 m thick) and the Salash Formation (19 m thick) crop out in this section. Vertical distribution of the calpionellid species is shown in Fig. 5, and the calpionellids themselves are illustrated in Fig. 6.

Starting with the top of the Glozhene–Slivnitsa Formation, the whole section corresponds to the *Elliptica* Subzone of the *Calpionella* Zone. The calpionellid assemblage is quite rich in species (see Figs 5, 6). The occurrence of *Remaniella cadischiana*, *Tintinnopsella subacuta*, *Borziella atava* and *Tintinnopsella longa* suggests that the upper 17 m of the section belong to the uppermost *Elliptica* Subzone. Similar calpionellid succession has recently been reported from the

Barlya section (Grabowski *et al.*, 2016), where in the mid-*Elliptica* Subzone *Remaniella borzai*, *Lorenziella hungarica* have their FOs and the large variety of *Tintinnopsella carpathica* becomes abundant. Additional members of the assemblage are *Calpionella alpina*, *Calpionella minuta*, *Calpionella* sp. A, *Crassicollaria parvula*, *Tintinnopsella doliphormis*, and more common species of the genus *Remaniella*, such as *Remaniella catalanoi*, *Remaniella ferasini* and *Remaniella colomi*. Interestingly, the diversity and the abundance of calpionellids in this section did not differ from pelagic environments. As a whole, calpionellids show greater diversity and abundance in the Western Balkan Unit and the Western Srednogorie Unit compared to those in the Western Carpathians in Slovakia (D. Reháková, unpublished data). Resedimented species from the *Crassicollaria* Zone were observed again. These are *Crassicollaria* cf. *brevis*, *Crassicollaria massutiniana*, *Crassicollaria* cf. *intermedia* and *Tintinnopsella* cf. *remanei*.

Dragovishtitsa East section

This section is located in the active Balsha Quarry (Fig. 1b). Above the bioclastic limestones of the Slivnitsa (6 m thick) and then of the Glozhene–Slivnitsa Formation (4 m thick), a triple alternation of calcareous sandstones, marlstones and clayey to micritic limestones occur (Salash–Cherni Osam Formation, 16 m thick) (Fig. 7). This section was mentioned by Nikolov (1995). The three formations here studied are separated by unexposed intervals. The vertical distribution of calpionellid species recorded in this section is shown in Fig. 7. The calpionellids are presented in Fig. 8. The Slivnitsa Formation is dated as late Tithonian (the *Massutiniana* Subzone of the *Crassicollaria* Zone, samples 401–405), and the Glozhene–Slivnitsa Formation as earliest Berriasian (the *Alpina* Subzone of the *Calpionella* Zone, samples 406–407). The rhythmic alternation of sandstones, marlstones and clayey/micritic limestones of the Salash–Cherni Osam Formation corresponds to the mid-Berriasian *Elliptica* Subzone of the *Calpionella* Zone (samples 408–414).

Fig. 6. Calpionellids of the Dragovishtitsa 2 section: 1–3) *Calpionella alpina*, sample K 09 (1, 2), sample K 19a (3); 4, 5) *Calpionella* sp. A (transitional form between *Calpionella alpina* and *Calpionella elliptica*), sample K 08 (4), sample K 20 (5); 6, 7) *Calpionella elliptica*, sample L 4 (6), sample K 23 (7); 8, 9) *Calpionella minuta*, sample K 19a (8), sample K 24 (9); 10, 11) *Crassicollaria parvula*, sample K 12 (10), sample K 19a (11); 12, 13) *Lorenziella hungarica*, sample K 18 (12), sample K 23 (13); 14, 15) *Tintinnopsella carpathica* (small forms), sample K 15 (14), sample K 24 (15); 16, 17) *Tintinnopsella carpathica* (large forms), sample K 15; 18, 19) *Tintinnopsella doliphormis*, sample K 19a (18), sample K 24 (19); 20, 21) *Tintinnopsella subacuta*, sample K 22; 22, 23) *Tintinnopsella longa*, sample K 22 (22), sample K 17 (23); 24, 25) *Remaniella cadischiana*, sample K 19 (24), sample K 18 (25); 26) *Remaniella catalanoi*, sample K 19; 27) *Remaniella borzai*, sample K 14; 28) *Remaniella colomi*, sample K 08; 29) *Remaniella ferasini*, sample K 21; 30) *Borziella atava*, sample 24.

The *Crassicollaria* Zone in this section is represented by its upper subzone, the *Massutiniana* Subzone. The calpionellids are rare and poorly preserved, and some of them are resedimented. The as-

semblage of the subzone includes *Crassicollaria* cf. *brevis*, *Crassicollaria* cf. *intermedia*, *Crassicollaria massutiniana*, *Crassicollaria parvula*, *Tintinnopsella carpathica*, *Calpionella alpina*, *Calpionella grandal-*

Fig. 7. Dragovishtitsa East section – litho- and biostratigraphy, range-chart of the calpionellid species, microfacies types and interpretation of the depositional environment.

pina and *Crassicollaria colomi*, also resedimented *Tintinnopsella* cf. *remanei* and *Daciella almajica*. The presence of *Crassicollaria colomi* indicates the upper parts of the subzone.

The *Calpionella* Zone is represented by two of its three subzones: *Alpina* and *Elliptica*. The *Alpina* Subzone is characterized by the presence of *Calpionella alpina*, *Crassicollaria parvula* and *Tintinnopsella carpathica*. The assemblage also includes resedimented representatives of *Crassicollaria* cf. *brevis*, *Crassicollaria* cf. *intermedia*, *Crassicollaria massutiniana* and *Tintinnopsella* cf. *remanei*. All calpionellids in this subzone are poorly preserved. The absence of diagnostic species, such as *Crassicollaria colomi*, *Tintinnopsella doliphormis* and *Calpionella minuta*, suggests that these are middle parts of the *Alpina* Subzone. The *Elliptica* Subzone has almost the same assemblage as the one noted in the Dragovishtitsa 2 section. The whole interval, between samples 408 and 414, seems to represent the top of the *Elliptica* Subzone since *Tintinnopsella longa* and *Tintinnopsella subacuta* occur in sample 408 (see Fig. 7).

Clayey limestone unit at the Mezhdina Summit

Both the Slivnitsa Formation to the northwest and the Salash Formation in the Dragovishtitsa 2 section are covered by a largely cropping out lithological body consisting of dark grey medium-bedded clayey and intraclastic limestones. Our interest in its micropalaeontological content and age has been provoked by the chance to elucidate the problem of westward rejuvenation of the top of the Slivnitsa Formation and its immediate cover and the timing of drowning of the carbonate platform.

Samples K1 and K2 collected from the clayey limestone unit are characterized by the following calpionellid species: *Calpionella alpina*, *Calpionella minuta*, *Calpionella elliptica*, *Crassicollaria parvula*, *Tintinnopsella carpathica* (both small and large forms), *Tintinnopsella subacuta*, *Tintinnopsella longa*, *Lorenziella hungarica* and *Remaniella cadischiana*. Thus, the unit is of latest early Berriasian age (i.e., the *Elliptica* Subzone of the *Calpionella* Zone). Berriasian age of the top of the Slivnitsa Formation and its cover in the neighbouring Beledie Han section was assumed by Sapunov *et al.* (1985) and Nikolov and Tzankov (1998) on the basis of the calcareous algal species *Cayeuxia kurdistanensis* Elliott, 1956 that is a longer-ranging microfossil (Berriasian to Albian; see Omaña *et al.*, 2016). Our present calpionellid results provide a more precise age determination.

Tectonically altered Salash–Cherni Osam Formation

During the geological mapping of the area in scale 1:50 000, L. Metodiev described a body of alternating shales, marlstones and clayey limestones affected

by tectonic alteration. This body was attributed by Metodiev to the Salash–Cherni Osam Formarion. It crops out along the eastern cutting of the Golyanovtsi–Dragovishtitsa road. Under the microscope, the samples (F1, F2, F3) taken for thin-sections revealed recrystallization of the primary carbonate matrix and almost complete lack of determinable microfossils. Due to the alteration, it was impossible to acquire data for age determination and microfacies identification for interpretation of the depositional environment.

MICROFACIES ANALYSIS

A detailed sedimentological study was performed on 52 thin-sections collected through the Tithonian–Berriasian sections north of Dragovishtitsa Village (sections Dragovishtitsa 1, Dragovishtitsa 2 and Dragovishtitsa East). Eight microfacies types (MFT 1–MFT 8) have been identified. Some of them are compared to the Wilson's Standard Microfacies Scheme expanded by Flügel (2004). Two groups of microfacies are described below: Tithonian (MFT 1–MFT 3) and Berriasian (MFT 4–MFT 8).

Tithonian microfacies

In this study, three deep-water to shallow-marine microfacies types (MFT 1–MFT 3) have been recognized within the lower to upper Tithonian deposits of the Gintsi, Glozhene–Slivnitsa and Slivnitsa formations. The Gintsi Formation consists of grey to pinkish-grey mostly medium-bedded and commonly nodular limestones (Fig. 9a). The Tithonian part of the Glozhene–Slivnitsa Formation consists of grey, thin- to medium-bedded limestones (Fig. 9b).

MFT 1 Bioclastic wackestone/packstone

Description: This microfacies is characterized by the presence of various bioclasts (Fig. 10a, b) including calpionellids, calcified radiolarians, whole juvenile ammonites, aptychi, calcified sponge spicules, echinoid spines, *Globochaete alpina* Lombard, 1945, commonly broken *Saccocoma* crinoids, thin-shelled ostracods, calcareous dinoflagellate cysts, brachiopods and scarce benthic foraminifera. Peloids also occur but are only locally abundant. The rock matrix is micritic or recrystallized to microsparite. Sometimes, it appears mottled due to burrowing. MFT 1 is commonly represented in the Gintsi and Glozhene–Slivnitsa formations only in the Dragovishtitsa 1 section.

Interpretation: The skeletal association (radiolarians, calpionellids, ammonites, sponge spicules, *Globochaete alpina*, calcareous dinoflagellate cysts) indicates an open-marine, deep-water environment. Benthic foraminifera and some of the broken skeletal grains (*Saccocoma* crinoids, brachiopod shells, etc.) were probably transported from other parts of the

Fig. 8. Calpionellids of the Dragovishtitsa East section: 1) *Tintinnopsella* cf. *remanei*, sample 408, (the specimen is resedimented); 2, 3) *Crassicollaria* cf. *intermedia*, sample 402; 4) *Crassicollaria* cf. *brevis*, sample 408, (the specimen is resedimented); 5) *Crassicollaria massutiniana*, sample 402 (the specimen is resedimented); 6, 7) *Crassicollaria colomi*, sample 404; 8, 9) *Crassicollaria parvula*, sample 408; 10) *Calpionella grandalpina*, sample 402 (the specimen is resedimented); 11–13) *Calpionella alpina*, sample 406 (11), sample 408 (12, 13); 14, 15) *Calpionella minuta*, sample 408; 16) *Calpionella* sp. A, sample 411; 17, 18) *Calpionella elliptica*, sample 411 (17), sample 413 (18); 19, 20) *Tintinnopsella subacuta*, sample 408; 21) *Tintinnopsella longa*, sample 408; 22, 23) *Tintinnopsella carpathica* (small forms), sample 408 (22), sample 409 (23); 24, 25) *Tintinnopsella carpathica* (large forms), sample 408 (24), sample 414 (25); 26) *Remaniella borzai*, sample 414; 27) *Remaniella ferasini*, sample 410; 28) *Remaniella colomi*, sample 414; 29, 30) *Remaniella cadischiana*, sample 414.

basin during periods of stronger storm activity. The micritic matrix and bioturbation fabrics characterize a setting with low sedimentation rates and predominant low-energy hydrodynamic conditions. The carbonate deposits of MFT 1 are interpreted as formed below the storm wave base.

MFT 2 Bioclastic wackestone intercalated with intraclastic-bioclastic grainstone layers

Description: MFT 2 consists of bioclastic wackestones containing irregular layers and lenses of bioclastic grainstones (Fig. 10c, d). The wackestones are composed of the same skeletal grains as in MFT 1, which are scattered within dark brown micritic matrix. The grainstone layers are represented by strongly micritized bioclasts (crinoids, brachiopods, calcareous green algae, *Crescentiella morronensis* (Crescenti, 1969) (formerly *Tubiphytes morronensis crescenti*), benthic foraminifera, ostracods and echinoid spines). Micritic intraclasts with elongate or irregular shapes and size between 0.02 mm and 1.00 mm are locally abundant. Peloids and single ooids also occur. The rock groundmass is represented by blocky and drusy calcite cements. Syntaxial calcite overgrowths are observed around some echinoderm fragments. Rounded and abraded skeletal grains also occur. The sediments of MFT 2 are only scarcely documented in close association with MFT 1 in the Gintsi and Glozhene–Slivnitsa formations from the Dragovishtitsa 1 section.

Interpretation: The bioclastic wackestones are regarded as products of open-marine and low-energy deep-water sedimentation. On the other hand, the winnowed limestone texture, micritic intraclasts and fossil association (calcareous green algae, benthic foraminifera, ostracods, crinoids, brachiopods, echinoids) of the grainstone layers characterize a high-energy shallow-marine environment with normal salinity and open circulation. They are interpreted as allochthonous shallow-marine components, which were redeposited in a deeper-water marine setting. The sediments of MFT 2 are interpreted as formed below the storm wave base.

MFT 3 Peloid-ooid packstone and grainstone

Description: This MFT is composed of common peloids and micritic ooids (Fig. 10e–h) associated with rare bioclasts (benthic foraminifera, calcareous green algae, calcareous dinoflagellate cysts, ostracods, calcified radiolarians, ammonites, echinoderms) and micritic intraclasts. Ammonite shells (Fig. 10f) are filled with bioclastic wackestones of MFT 1. Well-rounded micritic intraclasts (bioclastic wackestones and mudstones with calpionellids) are also locally observed. The ooids are characterized by mostly sphaerical shapes and range in size between 0.10 mm and 0.60 mm. The ooid cortexes are strongly micritized and locally display poorly preserved concentric laminae (Fig. 10g). The nuclei consist of calpionellids, *Globochaete alpina*, shell detritus and micritic intraclasts. The rock groundmass is represented by drusy sparitic cement. Bladed marine-phreatic cement locally forms isopachous rims around some ooids (Fig. 10e), and syntaxial calcite overgrowths are observed around echinoderm fragments. Allochems are moderately to poorly sorted. This microfacies is commonly reported from the Slivnitsa Formation in the Dragovishtitsa East section.

Interpretation: The abundant ooids, well-rounded micritic intraclasts and winnowed grainstone textures characterize a shallow-marine environment with predominant high-energy conditions. A part of the skeletal grains (e.g., ammonites, calcareous dinoflagellate cysts, radiolarians, calpionellids, *Globochaete alpina*) were probably transported from deeper parts of the basin and redeposited in the agitated shallow-marine environment during storm events. The sediments of MFT 3 are interpreted as deposited near or above the fair-weather wave base. This MFT can be compared to SMF 15 “Oolite” (Flügel, 2004).

Lower Berriasian microfacies

Berriasian microfacies from the Dragovishtitsa 1, Dragovishtitsa 2 and Dragovishtitsa East sections are sub-

Fig. 9. Views from the Dragovishtitsa 1 and Dragovishtitsa 2 sections: *a*) Dark grey thin- to medium-bedded limestones of the Gintsi Fm. (upper Tithonian), Dragovishtitsa 1 section; *b*) Dark grey thin-bedded limestones of the Glozhene–Slivnitsa Fm. (upper Tithonian), Dragovishtitsa 1 section; *c*) Light grey medium- to thick-bedded limestones from the lower parts of the Glozhene–Slivnitsa Fm. (lower Berriasian), Dragovishtitsa 1 section; *d*) Thin-bedded grey limestones from the uppermost part of the Glozhene–Slivnitsa Fm. (lower Berriasian), Dragovishtitsa 2 section; *e*) the carbonate sediments around the boundary between the Glozhene–Slivnitsa Fm. and the Salash Fm. (lower Berriasian), Dragovishtitsa 2 section.

divided into two groups: 1) microfacies deposited between the fair-weather wave base and the storm wave base; and 2) microfacies types deposited below the storm wave base.

Microfacies types from the first group occur in the Glozhene–Slivnitsa Formation (Figs 9c–e, 11a–c) and are interpreted as a result of storm-influenced sedimentation. These tempestites are characterized by erosive lower bed surfaces, variable bed thicknesses and locally represented oscillation symmetrical ripples (Fig. 11a–c). Under the microscope, they are composed of bioclastic packstones and rudstones with large benthic foraminifera and *Lithocodium–Bacinella* (MFT 4), intraclastic-bioclastic packstone/grainstones (MFT 5) and peloid-bioclastic wackestones and wackestones/packstones (MFT 6).

The second microfacies group (deposited below the storm wave base) is represented only in the Salash Formation (Fig. 9e), which consists of thin-bedded limestones (MFT 7 and MFT 8) locally interbedded with marlstones, siltstones and sandstones.

MFT 4 Bioclastic packstone and rudstone with large benthic foraminifera and *Lithocodium–Bacinella*

Description: MFT 4 consists of large benthic foraminifera [mainly trocholinids, such as *Andersenolina alpina* (Leupold, 1935) and *Protopeneroplis ultragranulata* (Gorbatchik, 1971) – Fig. 12a; *Andersenolina delphinensis* (Arnaud-Vanneau, Boisseau and Darsac, 1988) – Fig. 13b; and litiolids, e.g., *Pseudocyclammina lituus* (Yokohama, 1890) with complex inner structures – Fig. 12b)] and *Lithocodium–Bacinella* (Figs 12c, d, 13a, b), plus subordinately represented crinoids (Fig. 12f), small benthic foraminifera, brachiopods, pelecypods, gastropods (Fig. 12e), rare calcareous green algae, echinoid spines, *Crescentiella morronensis*, bryozoans, scarce calpionellids and calcified radiolarians. Most of the skeletal grains are strongly micritized or have variable in thickness micritic coatings. Peloids are locally common and well-rounded micritic intraclasts (Fig. 12g) are also observed. The groundmass is represented by micritic/microsparitic matrix or rare sparitic cement. Some echinoderm fragments display syntaxial calcite overgrowths. MFT 4 occurs in the Glozhene–Slivnitsa Formation in Dragovishtitsa 1, Dragovishtitsa 2 and in the Dragovishtitsa East section.

Interpretation: Most of the skeletal grains (*Lithocodium–Bacinella*, trocholinids, crinoids, brachiopods, pelecypods, gastropods, etc.) are indicative of shallow-marine setting with normal salinity and open water circulation. The abundant *Lithocodium aggregatum* Elliott, 1956 and *Bacinella irregularis* Radoičić, 1959 occupied a wide range of tropical and sub-tropical settings including supratidal algae mats and subtidal reefs (Rameil *et al.*, 2010). The scarce calpionellids and radiolarians are interpreted as transported and redepos-

ited from deeper parts of the basin by stronger storms and currents. The packstone and rudstone textures, as well as the locally represented well-rounded micritic intraclasts, characterize high-energy conditions.

MFT 5 Intraclastic-bioclastic packstone/grainstone

Description: MFT 5 consists of packstones/grainstones with common intraclasts (Fig. 13c, d) and various skeletal grains. The latter are micritized to various degrees and include *Lithocodium–Bacinella*, brachiopod shells, crinoids (Fig. 13c), small and large benthic foraminifera, mainly trocholinids, echinoid spines, pelecypods and bryozoans, plus rare calpionellids and calcified radiolarians. The intraclasts are mostly sub-rounded, varying in size (from 0.02 mm to 1.00 cm) and were derived mostly from bioclastic wackestones of MFT 8. The groundmass is represented by micritic matrix and drusy calcite cements. Syntaxial calcite overgrowths are also observed around some echinoderm bioclasts. The allochems are poorly sorted. MFT 5 occurs only in the Glozhene–Slivnitsa Formation in the Dragovishtitsa 2 section.

Interpretation: The grain-supported texture, fossil association (*Lithocodium–Bacinella*, crinoids, large benthic foraminifera and mollusk shells) and the commonly represented subrounded intraclasts suggest deposition in a high-energy shallow-marine setting with normal salinity and open water circulation. This MFT is interpreted as lag deposits represented in the lowermost parts of the tempestite successions (Fig. 10a, b).

MFT 6 Peloid-bioclastic wackestone and wackestone/packstone

Description: The deposits of MFT 6 consist of wackestones and wackestones/packstones with skeletal grains and variable amount of peloids (Figs 12h, 13e–h). The fossil association is represented by calpionellids, calcified radiolarians (Fig. 13h), *Globochaete alpina* and calcified sponge spicules, as well as echinoderms, *Crescentiella morronensis* (Fig. 13f), thin-shelled ostracods, brachiopod bioclasts, calcareous dinoflagellate cysts, rare small and large benthic foraminifera (mainly trocholinids *Andersenolina alpina* and *Andersenolina delphinensis* – Fig. 13f), bryozoans (Fig. 13g), sparse corals (Fig. 13e), *Lithocodium–Bacinella* and micritized calcareous green algae. Various amounts of clastic quartz and feldspar angular grains of silt and sand size also occur. The allochems are poorly sorted. Some calcified sponge spicules display parallel alignment (Fig. 13h). MFT 6 commonly occurs in the Glozhene–Slivnitsa Formation in the Dragovishtitsa 1 and Dragovishtitsa 2 sections.

Interpretation: The micritic matrix indicates non-agitated environment. The fossil association is represented by a mixture of skeletal grains that occupied

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Fig. 10. Tithonian microfacies from the Gintsi, Glozhene–Slivnitsa and Slivnitsa formations: *a, b*) Bioclastic wackestone/packstone (MFT 1) containing whole ammonite shells (white arrow), calcified sponge spicules (yellow arrow) and calcified radiolarians (black arrow). Sample K 01, Gintsi Fm., Dragovishtitsa 1 section; *c, d*) MFT 2, Bioclastic wackestone intercalated with intraclastic-bioclastic grainstone layers (white arrows). Sample K 06b, Glozhene–Slivnitsa Fm., Dragovishtitsa 1 section; *e*) Ooid-peloidal grainstone (MFT 3) displaying relic bladed isopachous cement (black arrow). Sample 403, Slivnitsa Fm., Dragovishtitsa East section; *f*) MFT 3, redeposited ammonite shell (yellow arrow) filled with bioclastic wackestones of MFT 1. Sample 403, Slivnitsa Fm., Dragovishtitsa East section; *g*) Ooids with strongly micritized cortex, locally displaying poorly preserved concentric laminae (MFT 3). Some ooid nuclei consist of calpionellids (*Calpionella grandalpina*) (white arrow). Sample 404, Slivnitsa Fm., Dragovishtitsa East section; *h*) MFT 3, micritized calcareous algae bioclast (yellow arrow). Sample 404, Slivnitsa Fm., Dragovishtitsa East section. Note: All images in plane-polarized light.

Fig. 11. Views of the base of the Dragovishtitsa 2 section: *a*) Carbonate tempestite sequence from the Glozhene–Slivnitsa Fm. that are characterized by erosive lower bed surfaces, constantly variable bed thickness and locally presented oscillation symmetrical ripples. Distinguished microfacies types (MFT 4–MFT 6) are also noted; *b*) Close view of erosive lower bed surface (white arrow); *c*) Close view of oscillation symmetrical ripples (white arrows).

Fig. 12. Lower Berriasian microfacies from the Glozhene–Slivnitsa Formation: *a*) MFT 4, large benthic trocholinid foraminifera – *Andersenolina alpina* (Leupold) (black arrow), *Protopenneroplis ultragranulata* (Gorbachik) (yellow arrow) and *Lithocodium* bioclast (white arrow). Sample K 06e, Glozhene–Slivnitsa Fm., Dragovishtitsa 1 section; *b*) MFT 4, large benthic lituolid foraminifera with complex inner structures [*Pseudocyclamina lituus* (Yokohama)]. Sample K 06e, Glozhene–Slivnitsa Fm., Dragovishtitsa 1 section; *c, d*) MFT 4, *Lithocodium–Bacinella* bioclasts (black arrows). Samples K 06e and K 07, Glozhene–Slivnitsa Fm., Dragovishtitsa 1 section; *e*) MFT 4, micritized gastropod shell (white arrow). Sample K 06e, Glozhene–Slivnitsa Fm., Dragovishtitsa 1 section; *f*) MFT 4, Crinoid bioclast with irregular in thickness micritic coating (white arrow). Sample K 07, Glozhene–Slivnitsa Fm., Dragovishtitsa 1 section; *g*) MFT 4, well-rounded micritic intraclast (black arrow). Sample K 06e, Glozhene–Slivnitsa Fm., Dragovishtitsa 1 section; *h*) MFT 4, large benthic trocholinid foraminifera (white arrow) and bryozoan bioclast (black arrow). Sample 406, Glozhene–Slivnitsa Fm., Dragovishtitsa East section. Note: All images in plane-polarized light.

various shallow-marine (e.g., *Lithocodium–Bacinella*, trocholinids, bryozoans, micritized calcareous green algae) to deep-marine (calpionellids, *Globochaete alpina*, radiolarians, etc.) settings. The locally represented calcified sponge spicules displaying parallel alignment suggest the influence of storm-generated currents. The deposits of MFT 6 resulted from predominant calm-water sedimentation that was locally interrupted by storm-generated waves and currents.

MFT 7 Fine-grained bioclastic-peloidal packstone/grainstone

Description: MFT 7 (Fig. 14*a, b*) consists of very fine-grained packstones/grainstones containing abundant peloids, small bioclasts and micritic intraclasts. Skeletal grains are represented by calcified siliceous sponge spicules, plus benthic foraminifera, rare calpionellids, calcified radiolarians, calcareous dinoflagellate cysts, thin-shelled ostracods, crinoids and echinoid spines. This MFT occurs rarely only in the lowermost part of the Salash Formation in the Dragovishtitsa 2 section. Clastic grains include sand-sized angular quartz and feldspar grains, as well as sporadic lithic fragments. The groundmass is composed of micritic matrix and sparitic cements. Syntaxial calcite overgrowths are observed around some echinoderm bioclasts.

Interpretation: The fossil association (calcified siliceous sponge spicules, calpionellids, radiolarians, calcareous dinoflagellate cysts, thin-shelled ostracods, etc.) indicates a relatively deep-water marine setting (Flügel, 2004). Packstones and grainstones consisting of peloids and small lithoclasts and bioclasts commonly occur in deeper basins, open-marine shelf and are abundantly represented in outer ramp settings (Flügel, 2004). This MFT is very similar to SMF 2: “Microbioclastic peloidal calcisiltite”.

MFT 8 Bioturbated bioclastic wackestone and wackestone/packstone

Description: MFT 8 comprises wackestones and sporadic wackestones/packstones containing mainly fine-grained pelagic microfossils (Fig. 14*c–h*). They are

represented mostly by calpionellids (Fig. 14*d, f, h*) and calcified radiolarians (Fig. 14*f*), plus calcified sponge spicules (Fig. 14*c*), *Globochaete alpina*, echinoderm bioclasts, thin-shelled ostracods and rare calcareous dinoflagellate cysts, benthic foraminifera and brachiopod shell detritus. Whole ammonite shells and aptychi (Fig. 14*g, h*) are also observed. Peloids are scarce in some wackestones/packstones. Silt- to sand-sized clastic quartz and feldspar angular grains are variably represented (from <5% to up to 10%). Bioturbation fabrics are very common. Micritic matrix is characterized by inhomogeneous texture most probably due to burrowing (Fig. 14*e, f*). Variations in packing densities are often observed. MFT 8 is abundant in the Salash Formation in Dragovishtitsa 2 section and in the Salash–Cherni Osam Formation in the Dragovishtitsa East section.

Interpretation: The fossil assemblage, micritic matrix and common bioturbation suggest deposition in a deep-water, non-agitated setting with low sedimentation rate. MFT 8 can be correlated with SMF 1-Burrowed: “Burrowed bioclastic wackestone with abundant fine pelagic and benthic biodebris” that occurs in basin and open-marine shelf settings, as well as in outer ramp environments.

DISCUSSION

Calpionellid biostratigraphy

The identification of 45 chitinoideid and calpionellid species belonging to 15 genera of the three families (Chitinoideidae Trejo, 1975, Semichitinoideidae Nowak, 1978 and Calpionellidae Colom, 1948) in the three sections studied has allowed the recognition of the *Chitinoideella*, *Praetintinnopsella*, *Crassicol-laria* and *Calpionella* zones. In the Dragovishtitsa 1 section, the *Chitinoideella* Zone is represented by the top-*Dobeni* Subzone and the whole *Boneti* Subzone and covers the sediments of upper parts of the Gintsi Formation and the base of the Glozhene–Slivnitsa Formation. The *Praetintinnopsella* Zone has been recorded only in this section. The *Crassicol-laria* Zone (*Remanei* Subzone) is documented only in one

Fig. 13. Lower Berriasian microfacies from the Glozhene–Slivnitsa Formation: *a, b*) MFT 4, rudstone and packstone/grainstone containing common *Lithocodium–Bacinnella* bioclasts (black arrows) and locally presented trocholinid foraminifera – *Andersenolina delphinensis* (Arnaud-Vanneau, Boisseau and Darsac) (white arrow). Sample L 3, Glozhene–Slivnitsa Fm., Dragovishtitsa 2 section; *c, d*) MFT 5, grainstone with rounded intraclasts (yellow arrows), originating from bioclastic wackestones of MFT 6 and large crinoid bioclast (white arrow). Sample L 2, Glozhene–Slivnitsa Fm., Dragovishtitsa 2 section; *e*) Coral bioclast (white arrow) within bioclastic wackestone of MFT 6. Sample K 08, Glozhene–Slivnitsa Fm., Dragovishtitsa 2 section; *f*) MFT 6, bioclastic wackestone with *Crescentiella morronensis* (Crescenti) (yellow arrow), micritized large benthic trocholinid foraminifera (white arrows) – *Protopeneroplus ultragranulata* (Gorbatchik) in left lower corner and *Andersenolina alpina* (Leupold) in upper right corner, and echinoid spine (gray arrow). Sample K 08, Glozhene–Slivnitsa Fm., Dragovishtitsa 2 section; *g*) MFT 6, peloid-bioclastic wackestone/packstone with bryozoan bioclasts (white arrow) and calpionellids; *Calpionella alpina* dominates over *Calpionella elliptica* (yellow arrow). Sample K 6f, Glozhene–Slivnitsa Fm., Dragovishtitsa 1 section; *h*) MFT 6, bioclastic wackestone with calcified sponge spicules (white arrows), displaying parallel alignment. Sample L 5, Glozhene–Slivnitsa Fm., Dragovishtitsa 2 section. Note: All images in plane-polarized light.

sample, just below the stratigraphic hiatus within the Glozhene–Slivnitsa Formation. The upper parts of the *Crassicollaria* Zone (*Massutiniana* Subzone) are connected with the top of the Slivnitsa Formation in the Dragovishtitsa East section. The *Alpina* Subzone of the *Calpionella* Zone has been indicated in the Glozhene–Slivnitsa Formation in the Dragovishtitsa East section, without its lower and upper boundaries. The *Elliptica* Subzone of the *Calpionella* Zone deserves special attention since it has been recorded in each section, but in different lithostratigraphic units: the Glozhene–Slivnitsa Formation (Dragovishtitsa 1 section), the Glozhene–Slivnitsa and Salash formations (Dragovishtitsa 2 section) and the Salash–Cherni Osam Formation (Dragovishtitsa East section), as well as in the clayey limestone unit that covers the Slivnitsa Formation at the highest parts of the Mezhdina Summit. It means that, during the mid-Berriasian (equivalent to the chron of the *Elliptica* Subzone), several important events took place: the deposition of the Glozhene–Slivnitsa Formation above a large stratigraphic gap, the drowning of the carbonate platform (Slivnitsa Formation) and the start of siliciclastic-carbonate sedimentation (Salash and Salash–Cherni Osam formations).

Evolution of the Tithonian–Berriasian depositional environments

The studied Tithonian–Berriasian carbonate deposits north of Dragovishtitsa Village were formed in various shallow to deep-marine settings, under high- to low-energy conditions. Thus, during the early (the *Dobeni* Subzone of the *Chitinoidella* Zone) and late Tithonian (the *Boneti* Subzone of the *Chitinoidella* Zone, *Praetintinnopsella* Zone and the base of the *Crassicollaria* Zone), carbonate sedimentation in the Dragovishtitsa 1 section (*i.e.*, Gintsi and Glozhene–Slivnitsa formations) took place in a non-agitated deep-water and open-marine environment with low sedimentation rates (MFT 1). Most probably, this setting was located

below the storm wave base and was only sporadically affected by stronger storms and currents, when bioclastic wackestones with intraclastic-bioclastic grainstone layers of MFT 2 were formed. On the other hand, the upper Tithonian deposits (*Crassicollaria* Zone, *Massutiniana* Subzone) of the Slivnitsa Formation in the Dragovishtitsa East section, indicate an agitated shallow-marine setting, located near or above the fair-weather wave base, with deposition of packstones and grainstones with abundant ooids and peloids (MFT 3).

A deepening-upward trend is recognized within the Berriasian interval of the succession. Thus, mid-Berriasian (the *Elliptica* Subzone of the *Calpionella* Zone) deposition occurred under predominantly high-energy conditions and strong storm influence (MFT 4–MFT 6), when various in thickness tempestite successions were formed between the fair-weather wave base and the storm wave base in the Glozhene–Slivnitsa Formation (Dragovishtitsa 1, Dragovishtitsa 2 and Dragovishtitsa East sections).

Later on, in the upper part of the *Elliptica* Subzone (latest early Berriasian), a change of the depositional environment occurred, when the siliciclastic-carbonate succession of the Salash Formation (in Dragovishtitsa 2 section) and the Salash–Cherni Osam Formation (in Dragovishtitsa East section) were deposited in a deep-water marine setting (MFT 7 and MFT 8) below the storm wave base.

On the basis of the obtained sedimentological data, it can be assumed that the lower Berriasian succession was formed on a carbonate ramp, with well-distinguished storm-dominated mid-ramp zone (MFT 4–MFT 6 in the Glozhene–Slivnitsa Formation) and outer ramp zone (MFT 7 and MFT 8 in the Salash Formation) (*cf.* Burchette and Wright, 1992).

Regional lithostratigraphy

The area north of Dragovishtitsa Village provides large outcrops of the Slivnitsa Formation in the northern and western parts. There, the Slivnitsa Formation

Fig. 14. Lower Berriasian microfacies from the Salash and Salash–Cherni Osam formations: *a, b*) MFT 7, fine-grained bioclastic-peloidal packstone and grainstone, containing calcified sponge spicules (black arrows), echinoderm bioclasts (yellow arrow) and calcareous dinocysts (white arrow). Sample K 13, Salash Formation, Dragovishtitsa 2 section; *c*) MFT 8, bioclastic wackestone containing calcified sponge spicules (white arrow). Sample 412, Salash–Cherni Osam Formation, Dragovishtitsa East section; *d*) MFT 8, bioclastic wackestone with common calpionellids (yellow arrows). Sample K 22, Salash Formation, Dragovishtitsa 2 section; *e*) MFT 8, bioclastic wackestone with bioturbation fabric. Sample K 14, Salash Formation, Dragovishtitsa 2 section; *f*) MFT 8, bioturbated bioclastic wackestone with calpionellids *Calpionella alpina* and *Tintinnopsella carpathica* (yellow arrows) and calcified radiolarians (white arrow). Sample 413, Salash–Cherni Osam Formation, Dragovishtitsa East section; *g*) MFT 8, bioclastic wackestone containing aptychi (white arrow) and calpionellids, small and large forms of *Tintinnopsella carpathica* and *Calpionella alpina* (yellow arrows). Sample K 24, Salash Formation, Dragovishtitsa 2 section; *h*) MFT 8, part from ammonite shell (white arrow). Sample K 20, Salash Formation, Dragovishtitsa 2 section. Note: All images in plane-polarized light.

is covered by atypical Salash Formation (Sapunov *et al.*, 1985). In northeastern direction, the Slivnitsa Formation passes both vertically and laterally into the Glozhene–Slivnitsa Formation of late Tithonian and early Berriasian age. The overlying Salash Formation corresponds to the mid-Berriasian (the *Elliptica* Subzone of the *Calpionella* Zone) and is characterized by the presence of calcareous sandstones. Farther east, the Salash–Cherni Osam Formation in the Dragovishtitsa East section represents coeval and more distal equivalent of the Salash Formation. A small portion of the Slivnitsa Formation is here dated as late Tithonian; however, the chronostratigraphic range of this formation in the eastern part of the Western Srednogie [Beledie Han and Dragovishtitsa sections in Sapunov *et al.* (1985)] seems to be much larger. In any case, the top of the Slivnitsa Formation is not younger than mid-Berriasian. East of the study area, around Kremikovtsi Village, deposition of turbiditic sediments of the Neshkovtsi and Cherni Osam formations started earlier during the middle Kimmeridgian (Sapunov and Tchoumatchenco, 1995).

Westward rejuvenation of the cover and drowning of the carbonate platform

The shallow carbonate platform sediments of the Slivnitsa Formation in the western part of the Western Srednogie Unit have been thoroughly studied both in terms of foraminifer biostratigraphy and carbonate microfacies (Ivanova, 1999; Ivanova and Koleva-Rekalova, 2004; Ivanova *et al.*, 2008). These authors disclose the presence of a long-lived Callovian to Valanginian carbonate platform at the sites of Kalotina, Velinovo, Rebro and Lyalintsi. Additionally, it has been evidenced that in the Kalotina and Dragoman sections, the drowning of the carbonate platform occurred during the late Valanginian (Ivanova *et al.*, 2000; Petrova *et al.*, 2010). There, the Slivnitsa Formation is covered by hemipelagic limestone-marlstone rocks of the Salash Formation. Easterly, still in the western part of Western Srednogie, in the Tri Ushi section, the carbonate platform drowned earlier, at the very end

of the Berriasian (Ivanova *et al.*, 2000; Petrova *et al.*, 2010, 2011). In these three sections (Kalotina, Dragoman and Tri Ushi), the lithological boundary between the Slivnitsa and Salash formations is clearly marked by erosional surfaces, iron hydroxides and glaucony mineralization. It is only in the area of Dragovishtitsa Village, here studied, where the boundary between the Slivnitsa Formation and the clayey limestone unit represents an abrupt lithological contact, manifested in change of colour and bed thickness. The drowning of the carbonate platform is highly diachronous, from mid-Berriasian at Dragovishtitsa area to top Berriasian at Tri Ushi, to late Valanginian at Dragoman and Kalotina. Similar events have recently been described from the Getic carbonate platform of the Southern Carpathians in Romania (Grădinaru *et al.*, 2016). The tectonic control expressed by normal faults of the passive margin can best explain the diachroneity and the variability of the sediments overlying the drowning unconformity in the Western Srednogie of Bulgaria.

CONCLUSIONS

The main results of this study are as follows:

1) In the eastern part of the Western Srednogie Unit, around Dragovishtitsa Village, a specific succession of the Gintsi and Glozhene–Slivnitsa formations has provided micropalaeontological evidence of late Tithonian (*Chitinoidea*, *Praetintinnopsella* and *Crassicollaria* zones) and mid-Berriasian (the *Elliptica* Subzone of the *Calpionella* Zone) age on the basis of 45 chitinoideid and calpionellid species. A significant stratigraphic hiatus is documented within the Glozhene–Slivnitsa Formation, since the *Crassicollaria* Zone, as well as the *Alpina*+*Remaniella* subzones of the *Calpionella* Zone, is absent from the succession. The conformably overlying Salash Formation is of mid-Berriasian age (the *Elliptica* Subzone of the *Calpionella* Zone) and is locally characterized by the presence of calcareous sandstones.

2) The presence of specific transional depositional settings, from carbonate platform to deeper-marine environment, has led to deposition of specific lithostrati-

graphic units not always corresponding to the diagnostic features of the Glozhene, Salash and Cherni Osam formations.

3) The Salash–Cherni Osam Formation, as well as the clayey limestone unit that covers the Slivnitsa Formation, is mid-Berriasian in age [the *Elliptica* Subzone (*pars.*) of the *Calpionella* Zone]. The Slivnitsa and Glozhene–Slivnitsa formations that underlie the Salash–Cherni Osam Formation in the Dragovishtitsa East section correspond to the *Massutiniana* Subzone (*pars.*) of the *Crassicollaria* Zone and the *Alpina* Subzone (*pars.*) of the *Calpionella* Zone, respectively. Re-working of calpionellids from the *Crassicollaria* Zone is documented in the *Alpina* and *Elliptica* subzones in the Dragovishtitsa 1, Dragovishtitsa 2 and Dragovishtitsa East sections.

4) Eight microfacies have been distinguished, suggesting that the sediments were deposited under carbonate platform, rather than basin pelagic, conditions. The upper parts of the studied sections reveal an upward-deepening depositional trend.

5) The Slivnitsa Formation is covered by highly diachronous sediments of more distal settings:

from mid-Berriasian around Dragovishtitsa Village to the Berriasian/Valanginian transition in the Tri Ushi section to late Valanginian in the Dragoman and Kalotina sections. This fact, together with the significant stratigraphic hiatus within the Glozhene–Slivnitsa Formation, is considered as tectonically controlled.

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APPENDIX. TAXONOMIC LIST

An alphabetic list of all chitinoideid and calpionellid taxa mentioned in text and figures is given below. See Furrázola Bermúdez (1965), Borza (1969), Furrázola Bermúdez and Kreisel (1973), Pop (1994a, b, 1996, 1997b, 1998), Grün and Blau (1996), Reháková (1998, 2002), Sallouhi *et al.* (2011) and references therein for information concerning taxonomy and authorship.

Chitinoideids and semichitinoideids:

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
Chitinoideella sp.
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 pinarensis (Furrázola Bermúdez and Kreisel, 1973)
Dobeniella tithonica (Borza, 1969)
Longicollaria Pop, 1997
Longicollaria dobeni (Borza, 1966)
Longicollaria insueta (Rehánek, 1986)
Popiella Reháková, 2002
Popiella oblongata Reháková, 2002

Praetintinnopsella Borza, 1969
Praetintinnopsella andrusovi Borza, 1969

Calpionellids:

Borzaiella Grün and Blau, 1996
Borzaiella atava Grün and Blau, 1996
Calpionella Lorenz, 1902
Calpionella alpina Lorenz, 1902
Calpionella elliptica Cadisch, 1932
Calpionella grandalpina Nagy, 1986
Calpionella minuta Houša, 1990
Calpionella sp. A
Crassicollaria Remane, 1962

Crassicollaria cf. *brevis* Remane, 1962
Crassicollaria colomi Doben, 1963
Crassicollaria cf. *intermedia* (Durand Delga, 1957)
Crassicollaria massutiniana (Colom, 1948)
Crassicollaria parvula Remane, 1962
Lorenziella Knauer and Nagy, 1963
Lorenziella hungarica Knauer and Nagy, 1963
Remaniella Catalano, 1965
Remaniella borzai Pop, 1994
Remaniella cadischiana (Colom, 1948)

Remaniella catalanoi Pop, 1996
Remaniella colomi Pop, 1996
Remaniella ferasini (Catalano, 1965)
Tintinnopsella Colom, 1948
Tintinnopsella carpathica (Murgeanu and Filipescu, 1933)
Tintinnopsella doliphormis (Colom, 1939)
Tintinnopsella longa (Colom, 1939)
Tintinnopsella subacuta (Colom, 1948)
Tintinnopsella cf. *remanei* Borza, 1969

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